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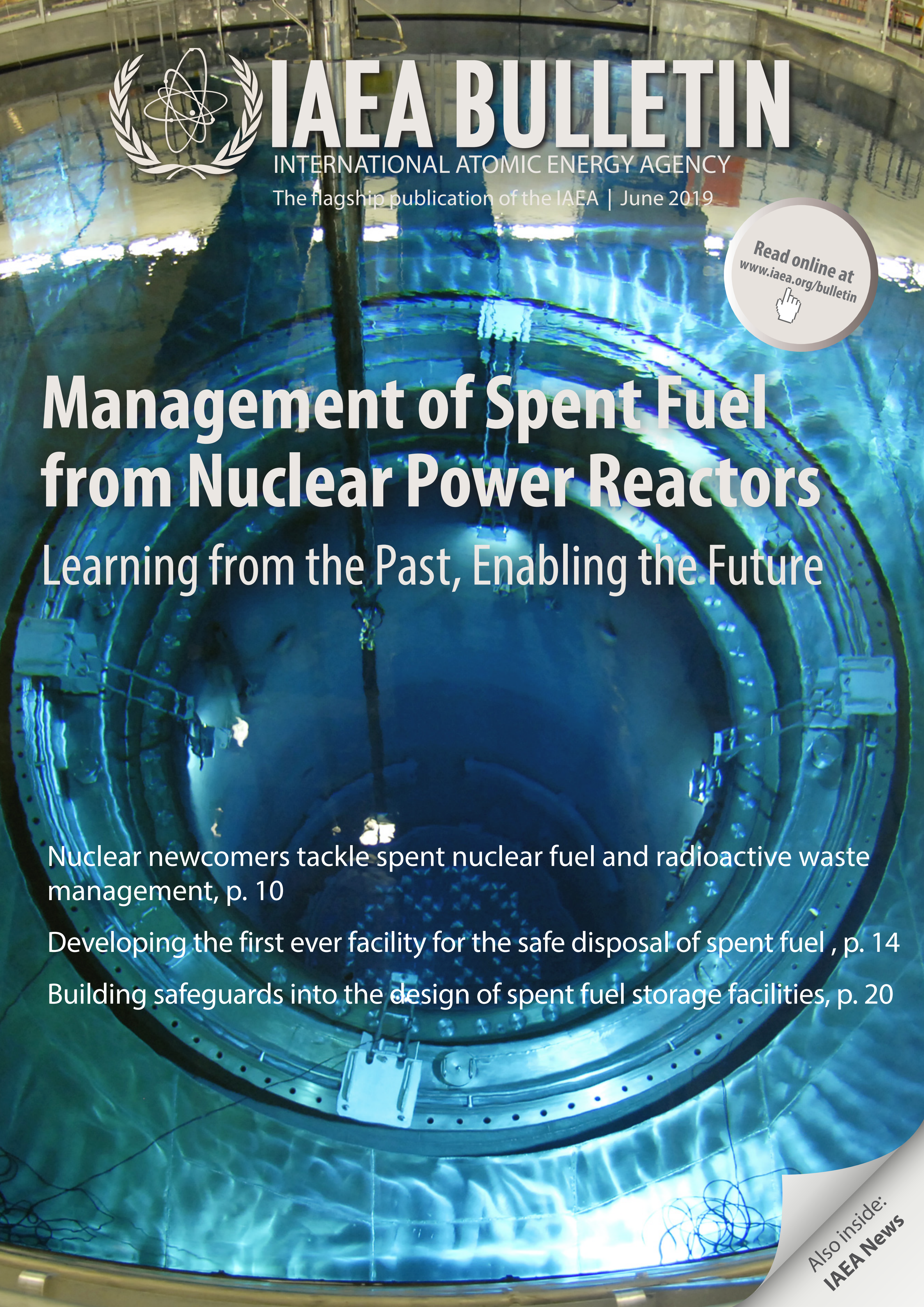
Management of Spent Fuel from Nuclear Power Reactors

Learning from the Past, Enabling the Future



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The view from within Olkiluoto 1
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IAEA

The International Atomic Energy Agency's mission is to prevent the spread of nuclear weapons and to help all countries — especially in the developing world — benefit from the peaceful, safe and secure use of nuclear science and technology.

Established as an autonomous organization under the United Nations in 1957, the IAEA is the only organization within the UN system with expertise in nuclear technologies. The IAEA's unique specialist laboratories help transfer knowledge and expertise to IAEA Member States in areas such as human health, food, water, industry and the environment.

The IAEA also serves as the global platform for strengthening nuclear security. The IAEA has established the Nuclear Security Series of international consensus guidance publications on nuclear security. The IAEA's work also focuses on helping to minimize the risk of nuclear and other radioactive material falling into the hands of terrorists and criminals, or of nuclear facilities being subjected to malicious acts.

The IAEA safety standards provide a system of fundamental safety principles and reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation. The IAEA safety standards have been developed for all types of nuclear facilities and activities that serve peaceful purposes, as well as for protective actions to reduce existing radiation risks.

The IAEA also verifies through its inspection system that Member States comply with their commitments under the Nuclear Non-Proliferation Treaty and other non-proliferation agreements to use nuclear material and facilities only for peaceful purposes.

The IAEA's work is multi-faceted and engages a wide variety of partners at the national, regional and international levels. IAEA programmes and budgets are set through decisions of its policymaking bodies — the 35-member Board of Governors and the General Conference of all Member States.

The IAEA is headquartered at the Vienna International Centre. Field and liaison offices are located in Geneva, New York, Tokyo and Toronto. The IAEA operates scientific laboratories in Monaco, Seibersdorf and Vienna. In addition, the IAEA supports and provides funding to the Abdus Salam International Centre for Theoretical Physics, in Trieste, Italy.

The importance of safe, secure and sustainable spent fuel management

By Yukiya Amano, Director General, IAEA

Nuclear power can help to address the twin challenges of ensuring reliable energy supplies and curbing greenhouse gas emissions. The 451 nuclear power reactors in operation in 30 countries today supply over 10% of the world's total electricity and a third of all low-carbon power. Nuclear power will continue to play a key role in the world's low-carbon energy mix for decades to come.

The safe, secure and sustainable management of spent fuel from nuclear power reactors is key to the future of nuclear energy.

This challenge is as much for policymakers as for engineers. In fact, technical solutions for the management of spent fuel exist, ranging from reprocessing and recycling, to conditioning spent fuel for disposal in deep underground repositories. Furthermore, research has established the feasibility of advanced processes, such as partitioning and transmutation, which have the potential to further reduce the impact of nuclear waste. The implementation of any selected strategy can take decades. Allocating the necessary resources to implement the strategy is often difficult.

The management of spent fuel involves a long-term commitment, and national strategies must be flexible enough to make it possible to integrate new technologies that will enhance and improve the efficiency, safety, security and sustainability of nuclear power.

In this edition of the *IAEA Bulletin*, we examine solutions from around the world. We explain Russia's integrated strategy to handle, at a single location, wet and dry storage, reprocessing, fuel fabrication and – eventually – high level waste disposal (p. 6). French experts tell us what makes their spent fuel management efficient (p. 8), while safe and secure transport is the focus of our article on spent fuel management in the United Kingdom (p. 12).

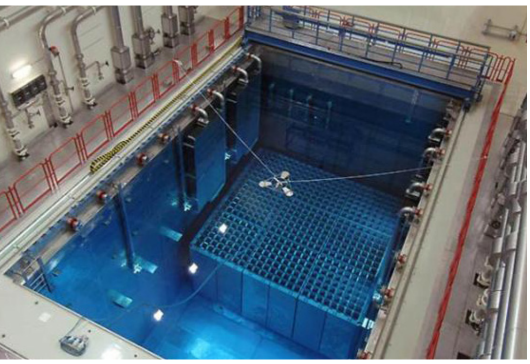
We profile joint research by Sweden and Finland into the development of underground repositories (p. 14). We consider how safeguards considerations can play a part in the design of spent fuel management facilities (p. 20), making life easier for both the operator and IAEA safeguards inspectors. We look into the future by discussing the approach countries new to nuclear power could take to spent fuel management (p. 10) and explore how the planned introduction of Small and Modular Reactors in some countries could affect spent fuel management (p. 11).

This year's IAEA International Conference on the Management of Spent Fuel from Nuclear Power Reactors: Learning from the Past, Enabling the Future is a follow-up to our previous conference on this subject in 2015. Back then, delegates emphasized the need for a more integrated approach to the fuel cycle, with more coordination between major players and decision-makers. This year, participants will focus, among other topics, on how the management of spent fuel can be affected by decisions taken at the front end of the nuclear fuel cycle and on sharing best practices and lessons learned in this area.

The IAEA will continue to assist Member States in the important field of spent fuel management by providing technical expertise and a platform for international exchange. I wish delegates a very successful conference.

"The safe, secure and sustainable management of spent fuel from nuclear power reactors is key to the future of nuclear energy."

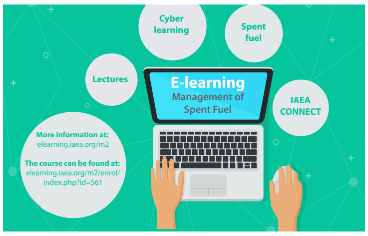
—Yukiya Amano, Director General, IAEA

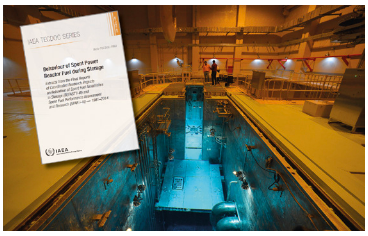


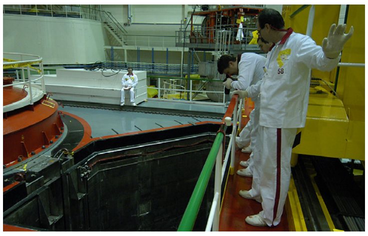
(Photo: Kernkraftwerk Gösgen-Däniken AG)

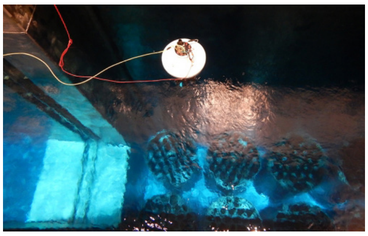
(Photo: Energy Solutions)

(Photo: Rosatom)









World View

IAEA Updates

Lifecycle of

The fuel that is used in most nuclear power reactors today is based on ceramic uranium oxide. The design of the fuel and its fissile content varies between different reactor types. The fuel in light water reactors, such as pressurized water reactors and boiling water reactors, and in modern gas cooled reactors, uses uranium enriched to increase its fissile uranium-235 content to up to 5 per cent, while CANDU and pressurized heavy water reactors mainly use slightly enriched or natural uranium, with a uranium-235 content of about 0.7 per cent.

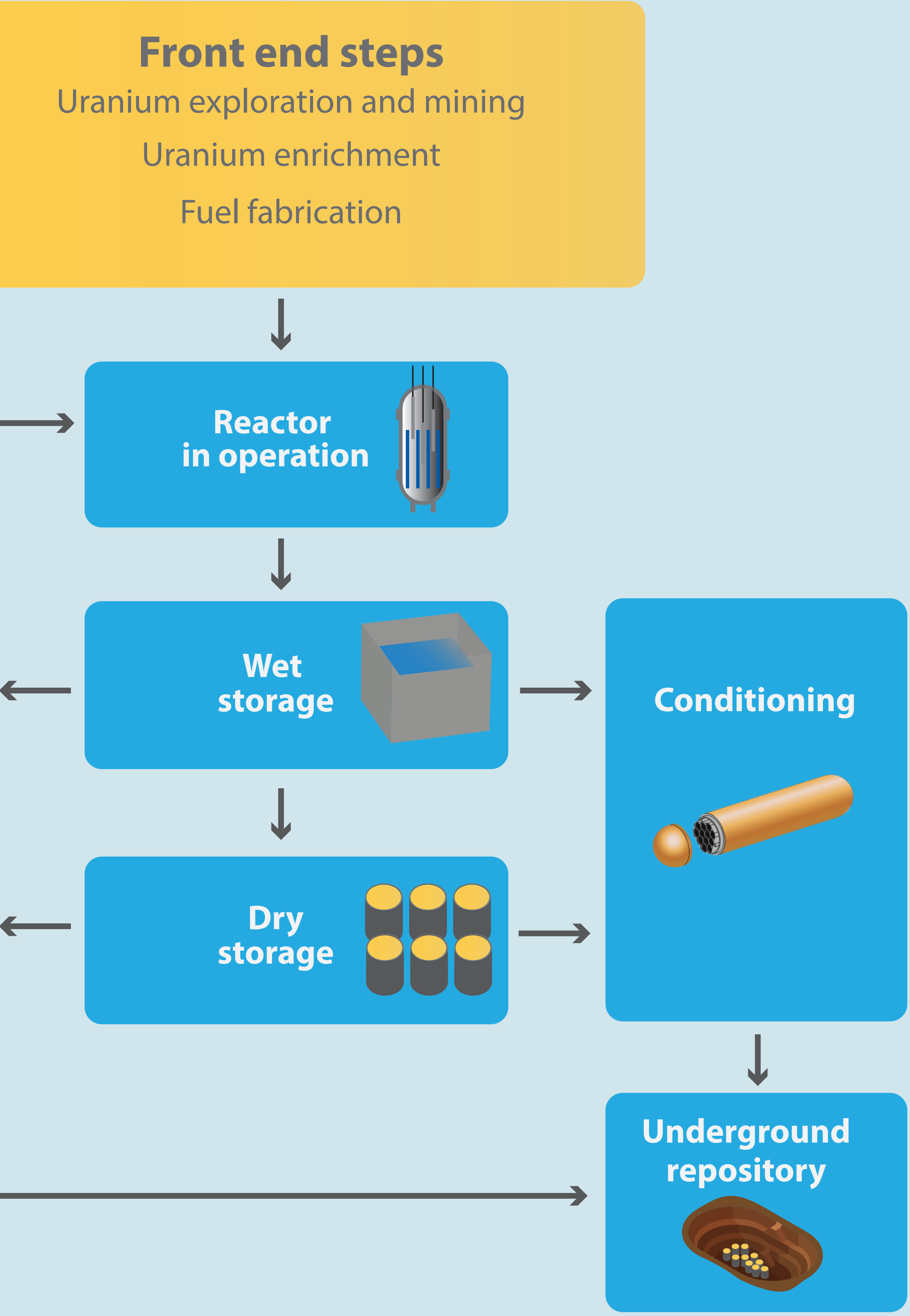
A 1000 megawatt electric pressurized water reactor core typically contains between 120 and 200 fuel assemblies. Each fuel assembly contains around 500 kg of uranium oxide and can generate about 200 million kilowatt hours of electricity over its lifetime in the core. A reactor of this size discharges about 40 spent fuel assemblies per year containing about a total of 20 tonnes of uranium oxide.

The nuclear fuel is considered spent when it no longer can sustain the fission reaction. In a pressurized water reactor, this takes about three to seven years, depending on the fuel and its location in the reactor core. When it is removed from the core, spent fuel looks similar to a fresh fuel assembly, but it is highly radioactive and hot and must be cooled and shielded. It is transferred to a storage pool since water is a good cooling and shielding material. After a period of cooling time, it can be transferred to a dry storage facility, if required.

Currently, after an adequate period of storage, spent fuel can either be:

- considered as waste to be conditioned and disposed of in a deep geological repository. This is called open fuel cycle; or
- reprocessed to recover remaining fissile material that can be recycled as new fuel in nuclear reactors, generating high-level waste that will be disposed of in a deep geological repository. This is referred to as closed fuel cycle.

Nuclear Fuel



Under one roof: Russia's integrated strategy for spent fuel management

By Nicole Jawerth

> **"The integrated complex will improve the efficiency and competitiveness of the Russian nuclear industry and make nuclear energy even safer and more environmentally friendly."**
>
> *—Petr Gavrilov, Director General, Mining and Chemical Complex (MCC), Russia*

A one-stop-shop for spent fuel management is one way to describe Russia's Mining and Chemical Complex (MCC) near Krasnoyarsk, Siberia. The complex is designed to handle spent fuel at its different stages, all at one site. In many countries, these activities — involving fuel that is no longer useful but still very radioactive — are performed at separate facilities that are, in some cases, up to hundreds of kilometers apart. By taking an integrated approach, Russia's national strategy for spent fuel management aims to improve efficiency, cut costs and optimize safety and security.

"Russia's nuclear power industry is continuing to develop and increase its contribution to the country's overall energy mix. So, we need to make sure that the management of spent nuclear fuel is reliable, sustainable, safe and secure," said Anzhelika Khaperskaya, a senior manager in the Spent Nuclear Fuel Management Project Office of Russia's State Atomic Energy Corporation (Rosatom), and one of the designers of the integrated approach. "The integrated complex will help us cut down on the need to transport nuclear materials or waste and allow us to focus safety and security measures in one place, which is also better from an economic point of view."

About 4000 kilometers east of Moscow, in central Siberia, the repurposing of the MCC under this integrated approach began in 2017. The site's existing personnel and facilities provided the necessary infrastructure to jump-start the integration.

Previously, Russia had primarily stored its spent fuel and partly processed this fuel at the RT-1 plant at the Mayak Production Association near Ekaterinburg, about 1600 kilometers east of Moscow, in western Siberia.

Unlike the RT-1 plant, which mainly handles reprocessing and has a small pilot fabrication facility, the MCC already has wet and dry spent fuel storage, as well as facilities for reprocessing and fabrication of new fuels for light water and fast reactors, and will eventually have an underground research laboratory for high-level waste disposal. The complex is expected to be fully integrated and operational by 2035.

Simplifying the process

Safety and security measures need to be taken at every step of the management process to protect people and the environment and to minimize the risk of attacks, thefts or misuse of nuclear material.

For example, spent fuel is typically transported several times, starting from where it was used, such as at a nuclear power plant, and then between facilities at different sites for storage, reprocessing, fabrication or disposal. The movement of nuclear material requires additional safety and security measures.

"Throughout the integrated strategy, we have taken steps to eliminate safety and security risks in order to protect people and the environment. One such step has been to bring several management processes, namely wet and dry storing, reprocessing and new fuel fabrication into one MCC site to minimize the transport of nuclear materials," said Petr Gavrilov, Director General of MCC, part of Rosatom.

Finding effective ways to reduce the number of processes was a key step in setting up the new approach. Experts from the MCC, leading industry institutions and the Russian Academy of Sciences worked together to select, test and, in some cases, develop new technologies, equipment and methods that adhere to IAEA safety standards and security guidance and can solve complex scientific and technical challenges.

For instance, the MCC will handle the reprocessing of a new type of uranium–plutonium fuel called REMIX. This fuel has been developed as part of the integrated approach to minimizing spent fuel storage times and reducing the amount of radioactive waste for disposal. Unlike other types of nuclear fuels for light water reactors, REMIX

A look inside an operator station at the MCC Complex. Staff supervise spent nuclear fuel assemblies automatically being reloaded from the wet storage facility to the dry storage facility.

(Photo: MCC-press)

can be recycled at today's nuclear power plants as many as seven times, which means it can provide enough nuclear fuel to cover the entire lifespan of a light water reactor at a power plant.

"We have been developing new and innovative reprocessing, recycling and partitioning technologies, as well as infrastructure related to the nuclear fuel cycle. We are essentially trying to shrink the impact of spent fuel management and support sustainable development in the future by recycling uranium and plutonium multiple times for thermal and fast reactors and reducing the radiotoxicity of radioactive waste," Khaperskaya said.

National strategies

In 2018, nuclear power accounted for 18.4% of the energy production in Russia. Every year, the country produces around 700 tonnes of spent nuclear fuel from its nuclear power plants, research reactors and submarines. With the country's plans to expand its nuclear industry, including the large-scale implementation of fast reactors, the MCC's integrated system is expected to help minimize the impact of that increase.

"The safe handling of spent nuclear fuel is a strategic direction of nuclear power development in Russia. It is necessary to provide safe and cost-effective storage of both lasting and newly-generated spent nuclear fuel for nuclear power needs," Gavrilov said. "The integrated complex will improve the efficiency and competitiveness of the Russian nuclear industry and make nuclear energy even safer and more environmentally friendly."

Russia's integrated approach is just one example of how a country can manage its spent nuclear fuel. All countries with nuclear power programmes have national spent fuel management policies and strategies.

A national strategy is tailored to the size and needs of a country's nuclear programme, ensuring it fits into the country's overall energy plan. While each strategy is different, most address the technical, political, socio-economic, and safety and security aspects of the different steps of spent fuel management, ensuring adherence to IAEA safety standards and security guidance.

Although countries are responsible for the safe and secure management of their spent nuclear fuel, the IAEA provides technical guidance and assists countries in exchanging information to develop well-informed strategies. It also provides expertise and training support for implementing these strategies. As spent nuclear fuel is a form of nuclear material, IAEA safeguards also play a key role in ensuring spent fuel is not misused or diverted from peaceful uses.

France's efficiency in the nuclear fuel cycle: what can *oui* learn?

By Shant Krikorian

With 58 nuclear power reactors producing nearly 72% of France's electricity in 2018, France is one of the countries with the highest share of nuclear power in its energy production. Along with this energy, however, France's nuclear fleet is also responsible for producing a significant amount of spent fuel and radioactive waste.

The strength of France's national spent fuel policy, in addition to tight legislation and a strong regulatory body, can be attributed to the standardization of its nuclear fleet and the policy of recycling its spent fuel, French experts have said. This leads to an efficient and secure supply and a reduced radioactive waste burden.

In France, all operating units are pressurized water reactors of just three standard types, all designed by Framatome: three-loop 900 MWe (34 reactors), four-loop 1300 MWe (20 reactors) and four-loop 1450 MWe (4 reactors). French nuclear power reactors, therefore, have the highest degree of standardization among countries with large nuclear fleets. This also translates into a standardized approach when dealing with the back end of the nuclear fuel cycle, which involves spent fuel and waste management, decommissioning, and environmental remediation.

"The recycling of spent fuel is a major element of the strategy of the French nuclear sector, which has more than 30 years of industrial experience."

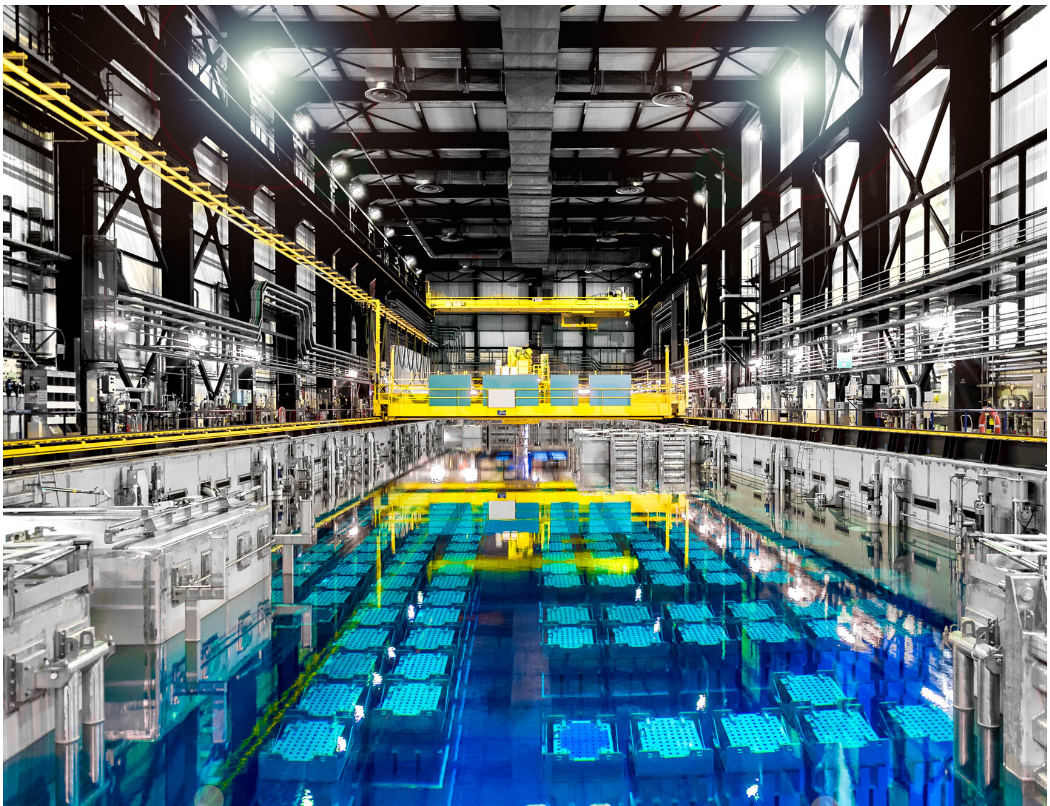
—Denis Lépée, Senior Vice President and Head, Nuclear Fuel Division, EDF

To manage the nearly 1150 tonnes of spent fuel it produces every year, France, like several other countries, decided early on to close its national nuclear fuel cycle by recycling or reprocessing spent fuel. In doing so, the French nuclear industry can recover uranium and plutonium from the used fuel for reuse, thereby also reducing the volume of high-level waste.

The nuclear fuel recycling process involves converting spent plutonium, formed in nuclear power reactors as a by-product of burning uranium fuel, and uranium into a "mixed oxide" (MOX) that can be reused in nuclear power plants to produce more electricity.

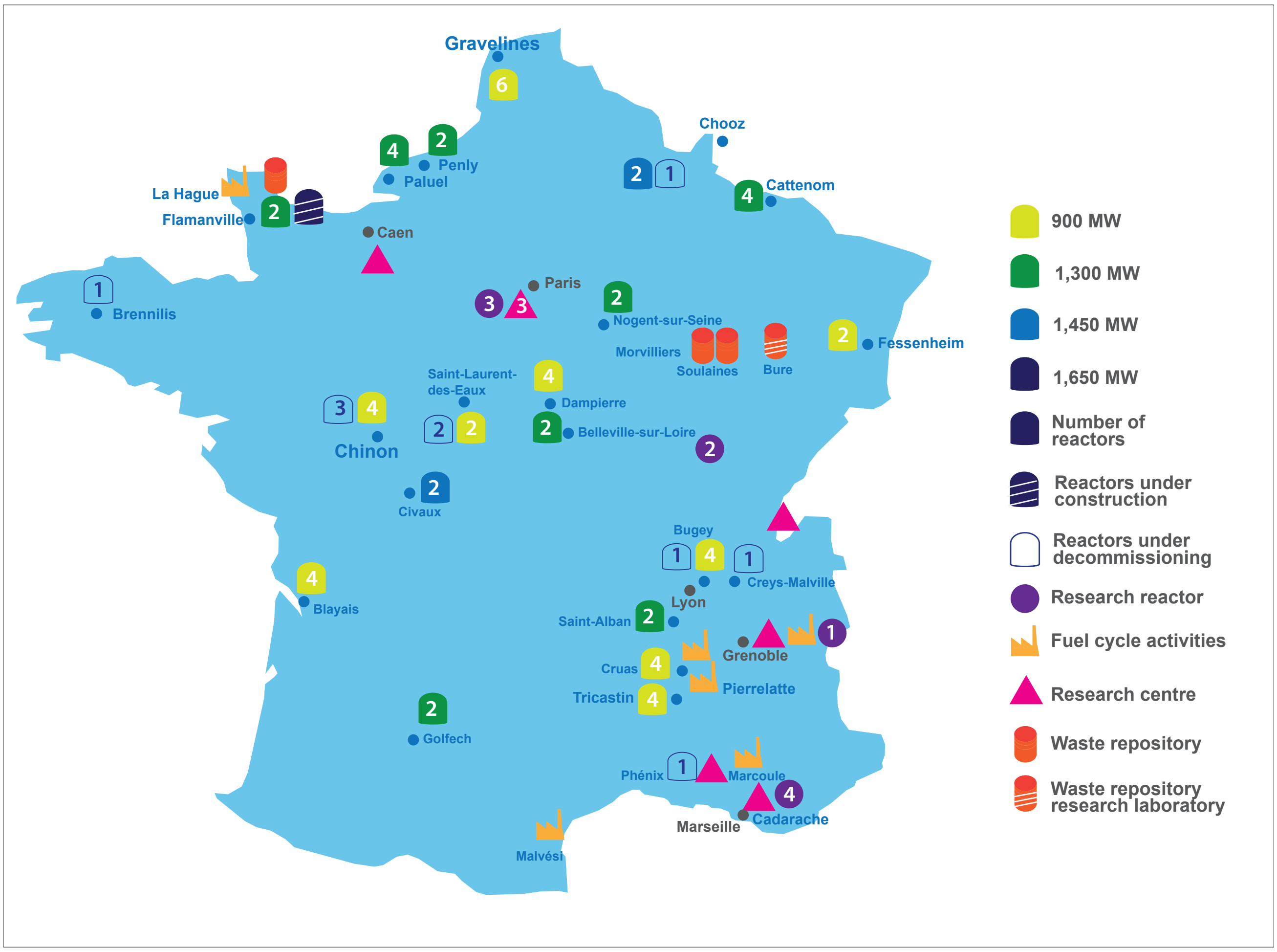
"The recycling of spent fuel is a major element of the strategy of the French nuclear sector, which has more than 30 years of industrial experience," says Denis Lépée, Senior Vice President and Head of the Nuclear Fuel Division at EDF, the French electric utility company that operates the country's nuclear power plants.

"This makes it possible to limit the volume of materials and to minimize waste, while conditioning it in a safe way. This strategy, which is an important pillar of France's overall nuclear electricity production, makes



The Orano La Hague reprocessing facility. More than 34,000 metric tons of used fuel has been treated here since the site's operation in 1976.

(Photo: Orano)



Map of French nuclear facilities

(Source: EDF, CEA)

a significant contribution to the country's energy independence."

Through recycling, up to 96% of the reusable material in spent fuel can be recovered. In its 6th National Report under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, France states that the national policy of recycling spent fuel has meant that it needs 17% less natural uranium to operate its plants than it would without recycling.

Orano, the French company in charge of nuclear fuel cycle activities that provides the fuel for and manages the waste from the country's nuclear power plants, has stated that its strategy is to reprocess spent fuel while optimizing the energy yield of nuclear fuel. Reprocessing is carried out at the La Hague reprocessing plant and at Marcoule MOX fuel manufacturing plant.

Since the start of operations in the mid-1960s, the La Hague plant has safely processed over 23 000 tonnes of spent fuel — enough to power France's nuclear fleet for 14 years.

Used fuel assemblies from various nuclear power plants are transported to La Hague, where they are kept in a storage pool. Components from the spent fuel are then separated and recyclable materials are recovered. At the Melox facility, plutonium is remixed with depleted uranium to produce MOX fuel.

This reprocessing–recycling strategy requires close and regular coordination between the various industrial actors, said John Czerwin, Senior Vice President of Marketing and Sales Support at Orano. These actors include those who manage reactors, fuel and disposal infrastructures, ensuring the coherence of the integrated industrial system.

"This confirms the benefits of this strategy: first, maintaining limited nuclear waste; second, saving uranium resources by enhancing the reuse of materials; and finally, preparing for the future in order to strengthen France's energy independence and guarantee the sustainability of nuclear energy," Czerwin adds.

The French Safety Authority (ASN) regularly assesses the safety impact of this approach.

Nuclear newcomers tackle spent nuclear fuel and radioactive waste management

By Shant Krikorian

Growing demand for large-scale, low carbon electricity has prompted many countries to consider nuclear power to meet their growing energy needs. With nine nuclear reactors under construction in four countries that are introducing nuclear power for the first time, demonstrating adherence to the international legal instruments, safety standards, security and nuclear energy guidelines and safeguards requirements is an important aspect of preparing for a nuclear energy programme. This also includes the management and disposal of spent fuel and radioactive waste.

For newcomer countries like Bangladesh, Belarus, Turkey and the United Arab Emirates, the issue of spent fuel and radioactive waste management should be addressed from the very beginning of a nuclear power programme and should not be neglected, since it influences both the economics and public acceptance of nuclear power, said Mikhail Chudakov, IAEA Deputy Director General and Head of the Department of Nuclear Energy.

The IAEA supports its Member States in establishing policies on spent nuclear fuel. This assistance is integrated into the IAEA's overall support for newcomer countries in the form of guidelines, Integrated Nuclear Infrastructure Review (INIR) missions, and regional, national and international workshops on issues related to infrastructure development.

IAEA Director General Yukiya Amano has repeatedly called for newcomer countries to join and ratify the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The principles of the Convention should be part of the national nuclear infrastructure throughout the development of a nuclear programme, he has said.

INIR missions are important tools for assessing the status of national nuclear infrastructure and provide recommendations and guidance for safe, secure and responsible development of nuclear power programmes.

"From the construction of a nuclear power plant to the final disposal of all the waste it produces can take well over several decades. That is why it is important that a credible strategy and technical plans, as well as methods for their financing, exist from the outset for carrying out all future actions in a manner that ensures safety, security and the necessary resources and competences at all times," underlined Milko Kovachev, Head of the Nuclear Infrastructure Development Section at the IAEA.

The key waste-related message given to newcomers is as follows: radioactive waste needs to be managed in such a way as to avoid imposing an undue burden on future generations.

For spent fuel management, the IAEA advises nuclear newcomers to:

- Ensure that spent fuel and radioactive waste management infrastructure is fully developed when implementing nuclear power programmes. This infrastructure is best built through the formulation of a national spent fuel and radioactive waste policy and related strategies.
- Take into account that the development and implementation of a national policy requires a systematic, staggered approach lasting several decades.
- Establish the waste management infrastructure in the early stages of planning nuclear power programmes.

Small modular reactors: a challenge for spent fuel management?

By Irena Chatzis

Small modular reactors (SMRs) have been the talk of scientists and researchers in the nuclear industry for many years — but to what extent will their debut, expected next year, create challenges in spent fuel management? It depends, say experts, on the particular SMR design and a country's existing spent fuel management practices.

SMRs are relatively small and flexible: they have a power capacity of up to 300 MW(e) and their output can fluctuate in line with demand. This makes them particularly attractive for remote regions with less developed grids, but also for use as a complement to renewables and for non-electric applications of nuclear power. SMRs can be manufactured and then shipped and installed on site, so they are expected to be more affordable to build.

Globally, there are about 50 SMR designs and concepts at different stages of development. Three SMR plants are in advanced stages of construction or commissioning in Argentina, China and Russia, which are all scheduled to start operation between 2019 and 2022.

Countries with established nuclear power programmes have been managing their spent fuel for decades. They have gained extensive experience and have proper infrastructure in place. For these countries, management of spent fuel arising from SMRs shouldn't pose a challenge if they opt to deploy SMRs based on current technologies, said Christophe Xerri, Director of the Division of Nuclear Fuel Cycle and Waste Technology at the IAEA.

"Since this type of small modular reactor will be using the same fuel as conventional, large nuclear power plants, its spent fuel can be managed in the same way as that of large reactors," Xerri said. Even for SMRs based on new technologies, such as high temperature gas cooled reactors, which will use fuel packed in graphite prismatic blocks or graphite pebbles, countries that have nuclear power plants will already have solutions in place for storing and managing spent fuel. "They can either use existing infrastructure or adjust it for the new radioactive waste streams," Xerri said.

Countries that are new to nuclear power should carefully consider spent fuel management and establish a relevant infrastructure as they work on introducing nuclear energy. They will need to do this even if they choose conventional nuclear power plants or SMRs based on current technologies. "They will face more challenges if they opt for first-of-a-kind or less-established technology, as there will be less experience and fewer benchmarks for managing the entire fuel cycle," Xerri said. "Solutions for managing spent fuel and radioactive waste arising from SMRs will be one of the most important factors to take into account when choosing a technology, along with the security of fuel supply."

Some SMR designs have features that could reduce the tasks associated with spent fuel management. Power plants based on these designs require less frequent refuelling, every 3 to 7 years, in comparison to between 1 and 2 years for conventional plants, and some are even designed to operate for up to 30 years without refuelling. Nevertheless, even in such cases, there will be some spent fuel left, which will have to be properly managed.

To address these issues and support newcomer countries, more research and development work is required on the fuel cycle for some SMR technologies. Engineers and designers have a unique opportunity to work on solutions for the improved management of spent fuel and radioactive waste for SMRs in the early stages of development, Xerri highlighted. "This approach will help address uncertainties related to the back end of the fuel cycle, reduce costs and enhance societal acceptance of nuclear power," he said. The IAEA is involved in several ongoing activities on SMRs and is intensifying its efforts to support Member States' research and development in this area.

Fostering the safe and secure transport of spent fuel in the United Kingdom

By Nathalie Mikhailova

Spent fuel is transported in casks specifically designed to protect people from the radioactive contents contained in them, as well as to survive severe transport accidents without significant leaks.
(Photo: International Nuclear Services)

Spent nuclear fuel is highly radioactive and during transport it can be a potential target of theft or sabotage. Therefore, its transport between facilities requires careful planning and the implementation of numerous safety and security measures.

In the United Kingdom, which has 15 nuclear power reactors, specialized companies have been safely and securely transporting spent fuel both within the country and from overseas over the past several decades, covering a total distance of more than 19 million kilometres. A strong regulatory framework and effective communication between stakeholders have been key to their success, industry players have said.

In the UK, spent fuel shipments take place regularly: a fuel shipment occurs somewhere in the country almost every week. Most of the spent fuel from power reactors has been, and continues to be, transported to the Sellafield facility in Cumbria, England. Much of the transport of spent fuel is provided by Direct Rail Services, which has been transporting nuclear material since 1995 without any incidents involving the release of radiation.

"We need to continue to transport in a compliant way and properly communicate what we are doing and why it is safe."

—John Mulkern, Secretary General, World Nuclear Transport Institute

"We have the capabilities and the infrastructure for the safe and secure transport of spent fuel and, above all, we have decades of experience," said John Mulkern, Secretary General at the World Nuclear Transport Institute (WNTI), a network organization representing the collective interests of the nuclear material transport sector. "This experience is particularly valuable in the context of countries initiating nuclear power programmes and therefore looking to develop the necessary transport systems."

Developing and upholding a sound framework for effective transport

The IAEA assists countries in the development and implementation of transport strategies in compliance with the relevant IAEA safety standards. The Specific Safety Requirements under Regulations for the Safe Transport of Radioactive Material (IAEA Safety Standards Series No. SSR-6 (Rev.1)) have been adopted by the International Civil Aviation Authority for transport by air, by the International Maritime Organization for shipment by sea and by national regulatory authorities for land transport — both road and rail.

The requirements of SSR-6 (Rev.1), published in 2018, include activity and classification of radioactive material, definition and permitted contents of package types, package design performance and testing criteria for each type. For each package type, it defines the requirements for design approval by national regulatory authorities before use and periodically thereafter; documentation, labelling and package marking; external surface temperature, radiation and contamination limits; consignment limits; and training.

In the case of packaging, requirements are based on the hazard level of the material to be contained. For high-hazard radioactive material, such as spent fuel, packaging needs to comply with prescribed design and performance requirements in order to withstand severe transport accidents that involve impact and fire without significant release of its contents. This is determined through rigorous testing of the material in various situations. British Nuclear Fuels Limited, for example, has conducted a series of public demonstrations simulating accidents of a train hitting a spent fuel cask at speeds of nearly 160 km/h. Little damage was done to the cask, demonstrating its safety (see the Science box).

“Another important aspect of transport is how we reassure the communities these materials travel through that they are safe and secure. When people see casks, they often have concerns,” said Mulkern. International Nuclear Services, a company involved in the management and transportation of nuclear fuel, for example, holds regular community and stakeholder meetings in Barrow-in-Furness, a port town in the north of England with direct rail links to the Sellafield site, to discuss what they are transporting through the county and worldwide, and how it is safe and secure.

The transport of hazardous materials also entails the prevention of potential acts of theft or sabotage, which requires appropriate physical protection not only through container design, but also through relevant security procedures. The IAEA assists countries, upon request, with the development and maintenance of physical protection regimes, including through support in drafting transport security regulations and transport security exercises. The purpose of such exercises is to identify any potential weaknesses in the transport security regime and make any necessary improvements.

Planning for the future

“Moving forward, it is important to continue to encourage younger people to be directly involved in the nuclear industry, particularly in the transport sector,” said Mulkern. “New power plants are being built all over the world, so we need to make sure that the existing experience and expertise is handed over in an appropriate way. People need to have not only the information, but also the experience of undertaking shipments, whether they involve spent fuel or decommissioning waste, as well as the confidence to transport them in the right way. We need to continue to transport in a compliant way and properly communicate what we are doing and why it is safe.”

THE SCIENCE

Transporting spent nuclear fuel

Package types and their performance criteria for transporting radioactive material are defined according to the hazard posed by their contents and the conditions under which the packages are expected to retain the containment and shielding of the radioactive material. So-called Type B packages are used to transport materials with higher levels of radioactivity, such as spent fuel. They are designed not only to withstand the heat generated by their radioactive contents, but also to survive severe transport accidents without significant leaks of the spent fuel contained within them.

Transport of nuclear material also entails specific requirements for the marking and labelling of packages and placarding of conveyances, as well as for documentation, external radiation and contamination limits, operational controls, quality assurance and notification, and approval of certain shipments and package types.

Developing the first ever facility for the safe disposal of spent fuel

By Nathalie Mikhailova

> **"Social acceptance relates to trust for the implementer, regulator and decision makers. This trust has to be built and maintained."**
>
> *— Jussi Heinonen, Director, Nuclear Waste Regulation and Safeguards Department, Finland's Radiation and Nuclear Safety Authority*

Following several decades of committed implementation of disposal strategies in Finland and Sweden, as well as cooperation in the development of a safe disposal solution based on a Swedish design, the first ever deep geological repository for spent fuel is being constructed in Olkiluoto, Finland. Sweden, along with other countries, is also working towards building such a facility.

After spent fuel is removed from nuclear power reactors, it continues to generate significant heat for several decades. It is therefore placed in water pools or in dry storage facilities to cool down. Storage pools and containers ensure that spent fuel maintains its integrity and no radiation or radioactive materials are released, thereby protecting people and the environment from exposure. However, spent fuel remains highly radioactive for several thousands of years and needs to be isolated for several hundred thousand years.

One way to dispose of spent fuel — when declared as waste — once the heat has decayed is to bury it in engineered facilities several hundred metres below ground level, in deep geological disposal facilities. The objective is to contain its radioactivity by encapsulating the spent fuel in robust and leak-tight containers and isolating it by burying it. Such facilities consist of a system of tunnels or chambers, built at a site geologically suitable for ensuring the long-term safety of the buried material (see the Science box).

The facility being built in Finland is based on the 'KBS-3' disposal concept, which was developed by the Swedish Nuclear Fuel and Waste Management Company (SKB), in close cooperation with Posiva, the Finnish company responsible for the disposal of spent nuclear fuel. The KBS-3 method consists of encapsulating spent fuel in corrosion-resistant copper canisters and embedding the canisters in swelling clay inside the repository's tunnels up to 500 metres below ground level.

"Not only are we both opting for the direct disposal of spent fuel, but Finland and Sweden also have similar reactors, which means that we have similar spent fuel. Expanding direct cooperation for various research and development activities made sense for both of us," said Magnus Westerlind, Senior Advisor at the SKB. "For example, we have done basically everything related to the copper cannisters as a joint development project."

In both countries, government decisions in the late 1970s and early 1980s led to the introduction of policies requiring the producers of nuclear waste to also be responsible for its management. In Finland, spent fuel from the Loviisa nuclear power plant was transported to the Soviet Union, and later Russia, for reprocessing until 1996. When the Finnish government issued the operating license for the Olkiluoto nuclear power plant in 1978, it requested that the licensee develop a waste management plan, including for spent nuclear fuel, which had to be disposed of in Finland.

In Sweden, power plant owners came together in the late 1970s to form the SKB with a view to jointly manage spent fuel. This initiated research and development activities for the development of a disposal concept, which ultimately led to the KBS-3 method. This concept was selected as an appropriate means of waste disposal in 1983 and has since been developed further. A site for the implementation of this concept has been selected and plans for construction are under way.

"An important element in actually implementing the disposal strategy in practice is the review process, which takes place every three years," said Westerlind. "As part of this process, numerous parties — universities, government agencies, non-governmental organizations and municipalities — are invited to comment on our strategy. This has made a significant contribution to not only the technical review of our programme, but also to making sure that the programme is in line with Swedish policies." Furthermore, extensive work has been done, and is ongoing, to gain and maintain public acceptance for siting and construction of the spent fuel disposal facility, he added.

Constructing the first ever disposal facility in Finland

Before construction of a disposal facility can begin, the company in charge of implementing the concept needs to obtain a construction licence. In Finland, the licence was issued in 2015, marking the first time a construction licence for a geological disposal facility was received anywhere in the world.

The site was chosen following several years of screening a number of potential sites. After surveying the country's land mass based on geological information, Posiva continued site characterization through site-specific studies, which included drilling, to find a geologically suitable environment. During this process, Posiva also started discussions with several municipalities about hosting a facility.

"Social acceptance and social factors play a crucial role in site selection," said Jussi Heinonen, Director of the Nuclear Waste Regulation and Safeguards Department at Finland's Radiation and Nuclear Safety Authority (STUK). "Social acceptance relates to trust for the implementer, regulator and decision makers. This trust has to be built and maintained."

Posiva is in the middle of the construction of the ONKALO disposal facility, at a depth of over 400 metres below ground level and is set to begin the excavation of the disposal tunnels soon. The disposal process is planned to start in 2024.

The Onkalo disposal facility for spent fuel being constructed in Olkiluoto, Finland, consists of an engineered system of tunnels. Onkalo is also used to characterize the host rock to support safety case development.

(Photo: Posiva Oy)

Progress in other countries

In 2011, the SKB submitted its licence application for the construction of a disposal facility in Forsmark, 150 kilometres north of Stockholm, which was reviewed by the Swedish Radiation Safety Authority (SSM) and the Land and Environmental Court. These authorities have since submitted their review statements to the government for a final decision on the licence.

Finland and Sweden are not the only countries making progress in this area. In France, the radioactive waste management agency Andra is currently preparing its licence application. In Canada and Switzerland, national waste management agencies are investigating appropriate sites through site characterization.

THE SCIENCE

Deep geological disposal facilities

Intensive research has identified the suitability of various rock types to host deep geological disposal facilities to isolate radioactive waste. These disposal facilities are constructed in suitable geological formations at a depth of several hundred metres and designed to contain high-level waste for hundreds of thousands of years.

A key characteristic of deep geological disposal facilities is that they provide passive safety, meaning that once the disposal facility has been closed, no further human action is required.

Building these disposal facilities several hundred metres below ground level, at a depth that effectively isolates waste from potential surface perturbations for hundreds of thousands of years, involves placing the waste in a non-dynamic environment, as opposed to a more dynamic, near-surface geological environment, where conditions tend to be less stable.

Coping with growth: China's spent fuel management strategy

With the start of a massive economic expansion in the early 1990s, authorities in China consider nuclear energy a key element in the country's security of energy supply and lower carbon footprint. China has launched an ambitious nuclear power programme, which has grown over the years.

Currently, China is operating 46 nuclear reactors with a total electric power capacity of 45 GWe, producing about 4% of the country's electricity. With 11 new reactors under construction or planning, 20% of the world's nuclear reactors under construction are in China. China's nuclear capacity is expected to reach 150 GWe in 2035 and 300 GWe in 2050, according to estimates of the Chinese Academy of Engineering.

With such an expansion, the amount of spent fuel to manage will proportionally increase as well. China is therefore making progress in advancing its nuclear fuel cycle strategy, expanding its spent fuel and radioactive waste management infrastructure.

China has opted for a closed nuclear fuel cycle policy, including spent fuel storage either at-reactor or away-from-reactor facilities, then transporting fuel for recycling and eventual use in fast reactors. Its first prototype, the Chinese Experimental Fast Reactor (CEFR) with 65 MWe was connected to the grid in 2011 and served as a basis for the development of a 600 MWe demonstration fast reactor which is currently under construction and is scheduled to be commissioned by 2023. Construction of the first commercial unit, with 1000 to 1200 MWe capacity, could start in December 2028 and start operation in around 2034. Fast reactor technology is expected to become predominant by mid-century, according to China's published nuclear power strategy.

In the meantime, the strategy is to reprocess spent fuel from existing pressurized water reactors (PWRs) and recycle them into mixed oxide fuel (MOX) to fuel PWRs. China already operates a pilot reprocessing plant in Gansu province with a capacity of 200 tonnes of Uranium per year (tU/y), and in January 2018, China and France signed an agreement for the construction of a reprocessing and recycling plant to produce MOX fuel for PWRs. In June 2018, Orano and the China National Nuclear Corporation launched the preparatory works for the spent fuel reprocessing plant, which will have a capacity of 800 tU/y.

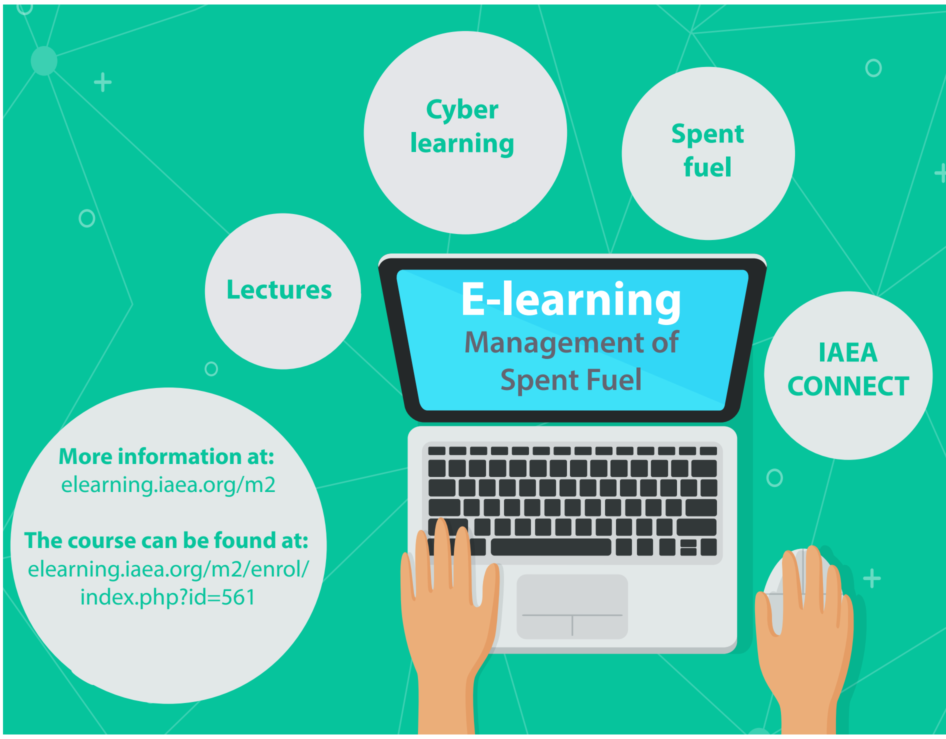
Completion of a geological repository for the disposal of high-level waste is planned by 2050. Selection of the site for an underground laboratory has been completed and is planned to be built by 2026.

Spent fuel storage at China's Qinshan Nuclear Power Plant. The spent fuel is planned to be stored on site in protected and ventilated containers until China's facility for the recycling and reprocessing of spent nuclear fuel is completed.
(Photo: M. Gaspar/IAEA)

New e-learning course on the management of spent fuel from nuclear power reactors

By Natalia Ivanova

The IAEA has designed an online e-learning course to provide an overview of the different strategies applied worldwide for managing spent fuel. The course is part of the spent fuel and radioactive waste management, decommissioning and environmental remediation curriculum, which includes several other modules.



The course, aimed at nuclear professionals, newcomers to the subject and engineering and science students, explains different options for managing spent fuel and the factors that may influence the selection of a particular management strategy for a country. It is the most detailed course developed by the IAEA on the subject to date.

Currently, 4 of the 13 lectures are available through the IAEA's Cyber Learning Platform for Network Education and Training, as well as via the IAEA CONNECT platform. The remaining lectures will be uploaded by early 2020. Besides English, they will be available in French, Japanese, Russian and Spanish.

Course content

The first two lectures, which provide an introduction to spent fuel management, cover all aspects of the management of spent fuel — from when it is discharged from a nuclear reactor core until it is considered waste and disposed of in a deep geological repository. These lectures provide an overview of different options for managing spent fuel, of factors influencing the choice of spent fuel strategy and of the ramifications of selecting the various options. Lectures 3 and 4, on spent fuel storage, explain the different options and technologies — wet and dry — for storing spent nuclear fuel, as well as general safety considerations for spent fuel storage to meet the fundamental safety objective of protecting people and the environment from the harmful effects of ionizing radiation.

"The rest of the lectures will cover spent fuel characteristics and transport, as well as spent fuel recycling technologies and innovative fuel cycles for Generation IV reactors," said Amparo González Espartero, Technical Lead for Spent Fuel Management at the IAEA.

"The technical content of these lectures has been developed by a group of experts from countries with different views and strategies on the management of their spent fuel. It is therefore very balanced and based on facts and figures," she said.

Lectures begin with a list and brief summary of e-learning objectives followed by more detailed explanations. Each lecture comprises several chapters to provide a deeper understanding of the material. At the end of each lecture, there is a short quiz to test users' knowledge, and audio summaries cover the key learning points. The modular structure ensures that users can go through the topics at their own pace. To illustrate the information and make it more accessible, the modules use different media formats, including videos and interactive exercises. The text of the narration, supplementary material and a glossary of terms are also available to improve users' understanding.

Spent fuel management: four decades of research

By Laura Gil

The nuclear power plant construction boom of the 1960s and 1970s held the promise of a new energy era and at the same time brought about a new challenge: dealing with the spent fuel discharged by the plants. Could this fuel be recycled? Could it be disposed of? Could it be stored and, if so, for how long and under what conditions?

"Each one of us can offer a different angle on the same shared issue."

—Ferenc Takáts, Managing Director, Enercon

Over the years, experts have developed answers to these questions. Almost four decades' worth of research on spent nuclear fuel management coordinated by the IAEA is now available in a new publication. *Behaviour of Spent Power Reactor Fuel during Storage* (IAEA-TECDOC-1862) is the title of an IAEA publication that compiles relevant data, observations and recommendations recorded by experts on this topic since 1981.

"When we started doing the research with the IAEA in the early 80s, we were aware that storing spent fuel, which is highly radioactive, had a series of technical and scientific implications," said Ferenc Takáts, Managing Director of TS Enercon, a Hungarian engineering consulting firm. "We were looking for basic information on these implications to build a general database of countries with experience, because there was no such thing back then."

In the early days of nuclear power, many countries had planned to recycle their spent fuel and, by doing so, maximize the utilization of their uranium. The first step of recycling is reprocessing, a chemical process that involves separating the fissile material, unused plutonium and uranium in the fuel for reuse in new mixed oxide (or MOX) fuels. France, Russia and the United Kingdom currently have commercial reprocessing facilities.

Several other countries have chosen to dispose of spent fuel instead of recycling it. These include Canada, Finland, Sweden and the United States. This alternative involves safely placing the spent fuel in a location deep in the ground, under conditions that do not allow for its retrieval.

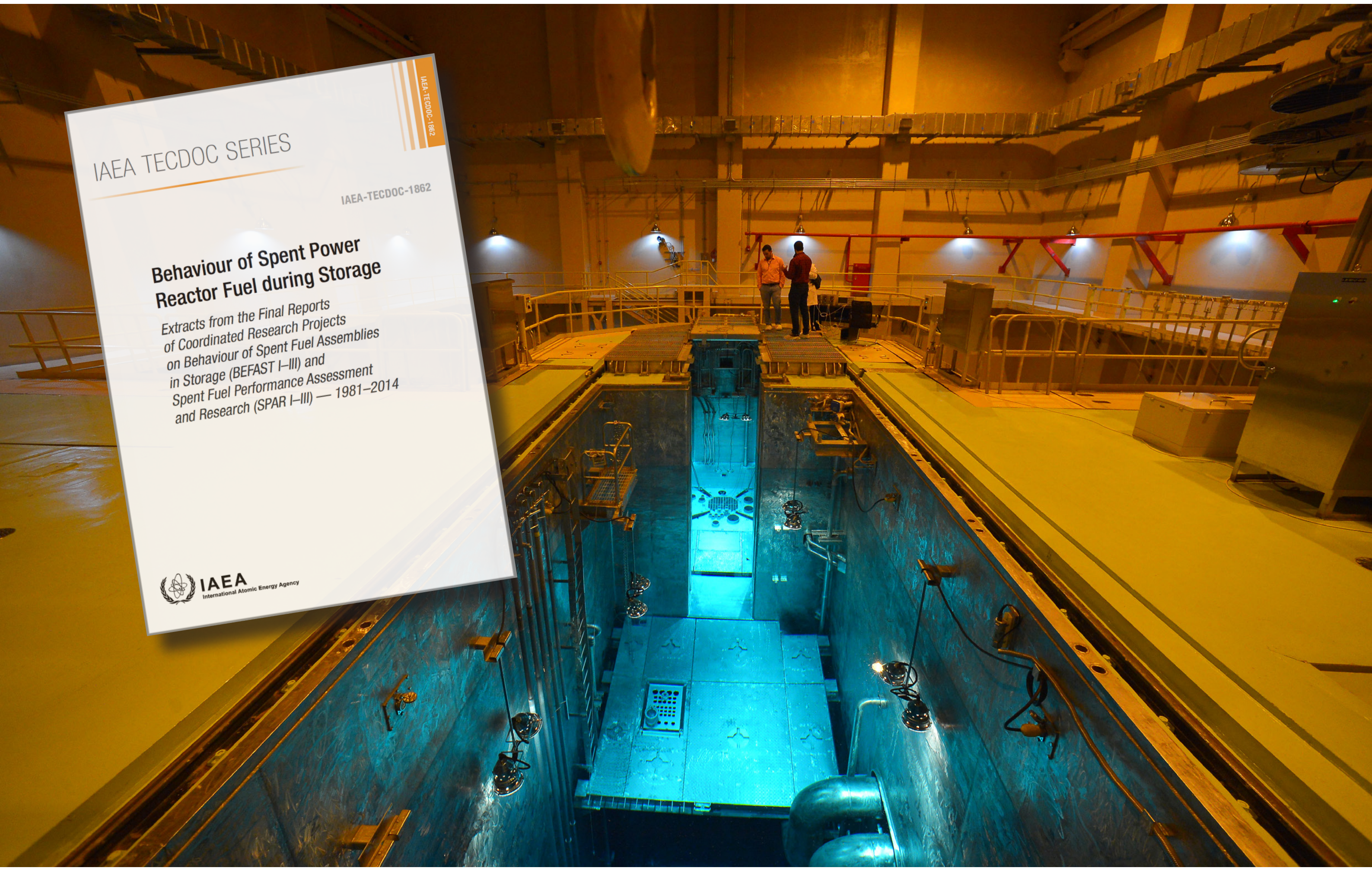
Initially, all countries had planned to reprocess their spent fuel, either in their own facilities or abroad. However, direct disposal became the favoured option in most countries in the 1980s and 1990s, as uranium prices remained low and environmental concerns related to reprocessing were raised. Then, in the early 2000s, the appeal of reprocessing again grew in light of the need for cheap, low-carbon electricity and concerns about the availability of uranium in the longer term.

While this debate was ongoing and views shifted, authorities often delayed their decision, and, eventually, spent fuel remained in temporary storage for longer than anticipated.

IAEA research project

It was in this context, and in response to the preferred option of 'interim storage', that a series of IAEA coordinated research projects, or CRPs, was launched, the first of which was initiated in 1981. Experts from 10 countries started to study and discuss the behaviour of spent fuel during storage (BEFAST), covering all activities related to the storage of the fuel until it was either reprocessed or sent for disposal. The participating countries contributed their research and development results regarding fundamental questions about spent fuel storage and started to develop a database to assist in the evaluation of spent fuel storage technologies for storage over extremely long periods of time. Beginning in 1997, a new series of CRPs was launched, this time more specifically targeting spent fuel performance assessment and research (SPAR).

Research under the BEFAST and SPAR projects involved 30 organizations from 21 countries and the European Commission. The research has led to information exchange that is useful for fuel operators, nuclear power plant designers, regulators, manufacturers and, particularly, those engaged in developing



safety assessments. "Each one of us can offer a different angle on the same shared issue," said Takáts.

When Takáts was working for a Hungarian consultancy firm in 1997, Hungary had been running its nuclear power programme for more than ten years. Without the possibility of exporting their spent fuel, they had to build an extra dry storage facility next to the power plant. This was a difficult task, as there was a worry among the regulators that the spent fuel, which was still radioactive and, initially, emitted a lot of heat, would be too hot to be stored.

"Because of these uncertainties we had a temperature limit to store the spent fuel under temperatures below 350 degrees Celsius, which was an unnecessary extra burden on the designer," Takáts said, adding that the outcomes of the IAEA project were helpful in educating the regulators. "Thankfully, I was participating in the BEFAST CRP and could consult with an expert from Germany, where there was much better knowledge about the behaviour of fuel cladding in dry storage at high temperatures. By collecting evidence from abroad, we were able to show that our regulations were too stringent and should be amended, based on the collective research."

A study was prepared on the basis of the CRP conclusions, which was then submitted to the regulator, who accepted the reasoning and increased the storage temperature limit. This is one of the many examples of how IAEA-coordinated research efforts of experts in the field have benefited operators.

"All the research helps us maintain a continuous technology watch on the performance of spent fuel," said Laura McManniman, Spent Fuel Management Specialist at the IAEA. "The projects are a good vehicle for collaboration and research because they provide a platform for experts to share information freely."

The highlights of the research work, compiled in IAEA-TECDOC-1862, are available online and, on request, in print.

Building safeguards into the design of spent fuel storage facilities

By Adem Mutluer

"From a design perspective, there is value in understanding the full range of potential safeguards activities and their impact on a spent fuel facility design before design choices are finalized."

—Jeremy Whitlock, Head, Concepts and Approaches Section, Department of Safeguards, IAEA

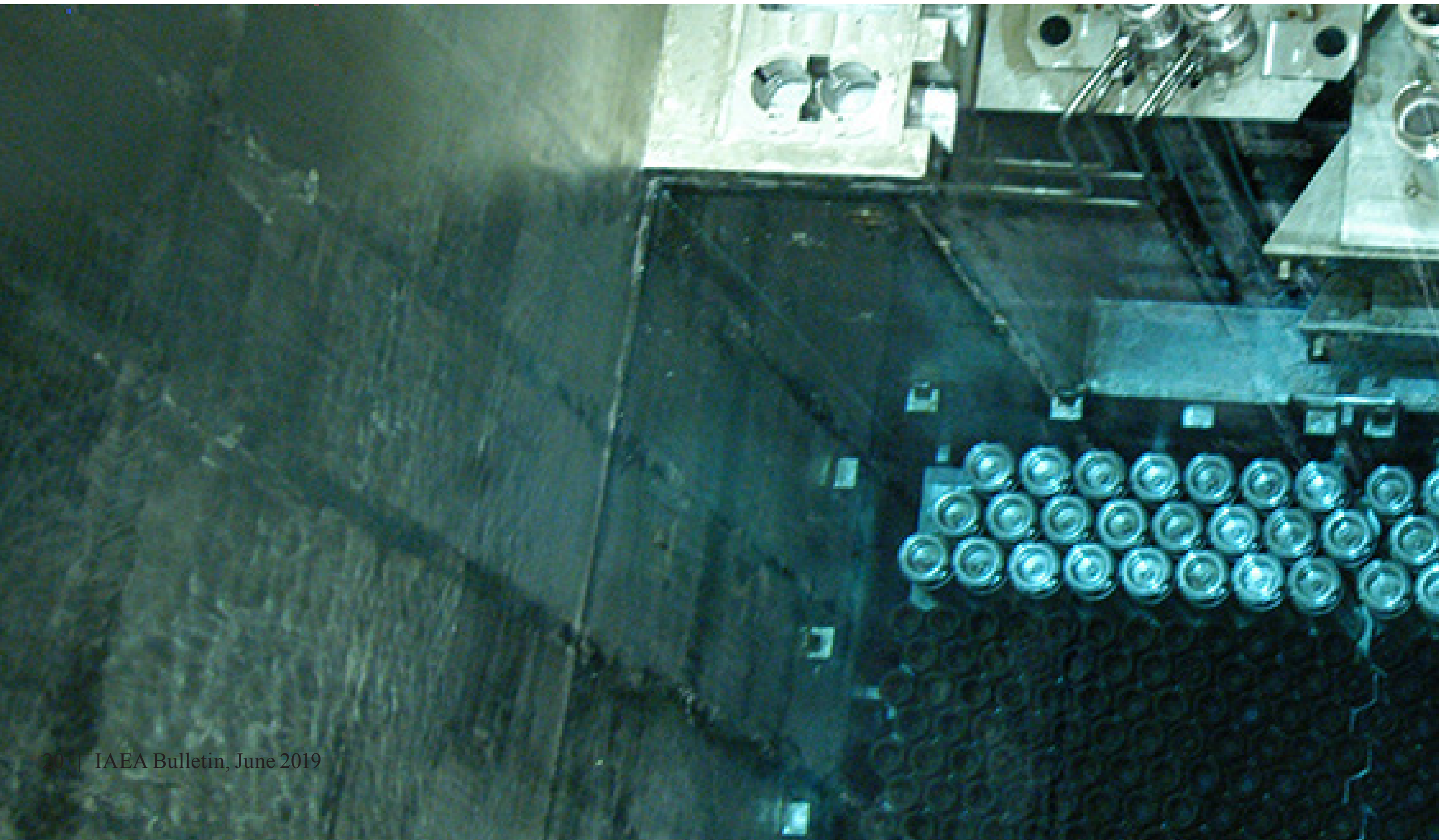
The IAEA works to enhance the contribution of nuclear technology to peace and prosperity around the world, while verifying that nuclear material is not diverted from peaceful use. IAEA safeguards, an important part of the global nuclear non-proliferation regime, provide for independent verification of States' compliance with their international legal obligations. To help with this, the IAEA issues guidance through its safeguards by design (SBD) document series to assist nuclear facility designers and operators in contemplating, at an early stage of the design process, the safeguards activities relevant to nuclear facilities, including spent fuel storage facilities.

Consideration of safeguards requirements prior to embarking on the construction or modification of a facility, a concept known as SBD, is voluntary and aims to facilitate the improved implementation of existing safeguards requirements. However, if SBD is applied, safeguards inspections can be implemented more effectively and efficiently, while reducing the burden on the operator of a facility.

"The intention is for new spent fuel facilities to be built with safeguards-enabling features," said Jeremy Whitlock, Head of the Concepts and Approaches Section at the IAEA's Department of Safeguards. "By considering these features in the design and building of spent fuel facilities, safeguards activities can be carried out with minimal disruption to the operations of an inspected facility."

Acknowledging safeguards early in the design and construction process facilitates open dialogue among stakeholders on facility operation, safeguards requirements and related topics. This allows for the development of verification methods that will minimize the impact of safeguards implementation on the operator, without reducing the effectiveness of the safeguards activities performed. Furthermore, these methods will improve the efficiency of safeguards by helping the IAEA carry out its verification activities in an optimal way.

Armed with an understanding of safeguards activities, a designer can also plan more effectively for expected verification activity



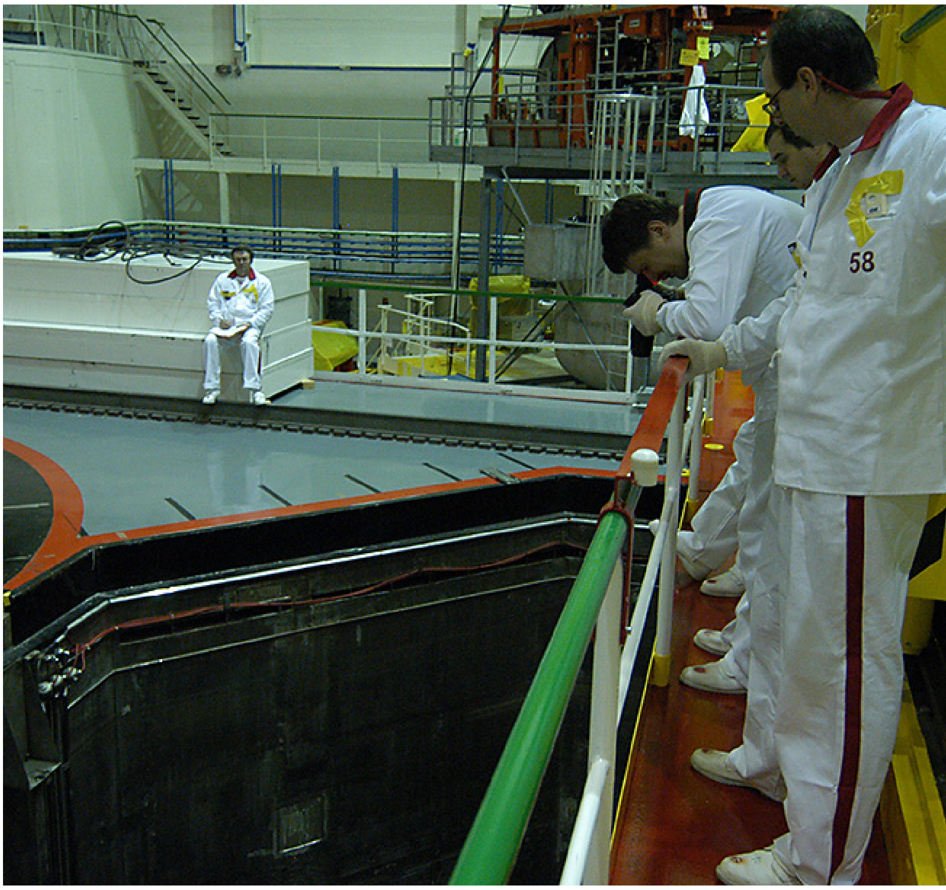
needs. This includes minimizing the exposure of inspectors to radiation, enhancing access to safeguards equipment for maintenance, ensuring capabilities for on-site remote data transmission and mitigating the impact of events that may disrupt verification.

Spent fuel storage facilities are a vital part of the nuclear fuel cycle and IAEA safeguards will continue to evolve to address the associated verification challenges. Applying safeguards to spent nuclear fuel storage facilities is also a substantial part of the IAEA's verification work. In 2018, safeguards were applied to 82 spent nuclear fuel storage facilities in more than 25 States around the world. Around 57 000 significant quantities of nuclear material were being held at these facilities.

In drawing a blueprint for spent nuclear fuel storage facilities, it is particularly important that the designers recognize the lifetime of spent fuel. Spent fuel facilities can be required to ensure that material be retrievable for a long period of time, for example 100 years.

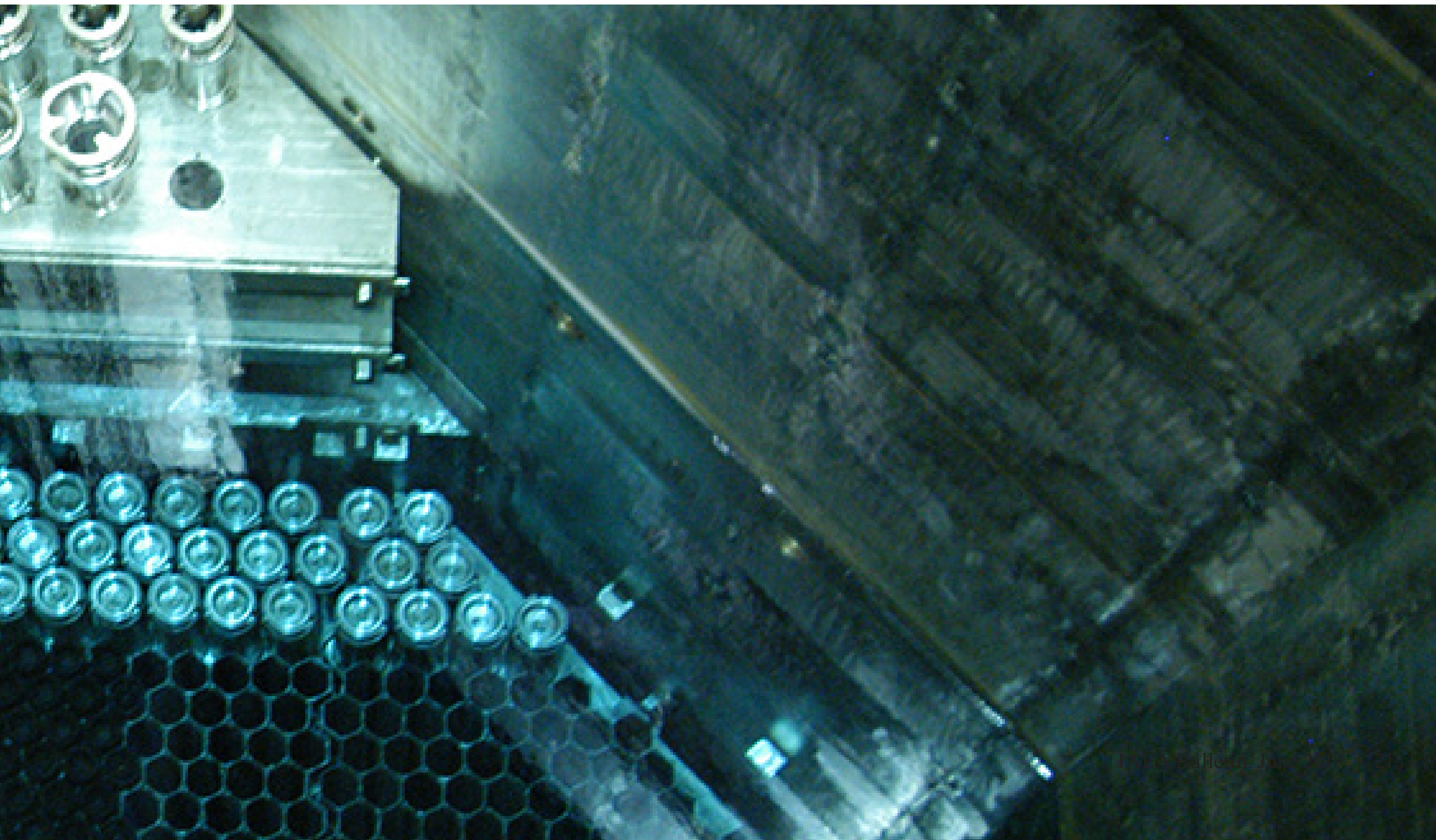
"From a design perspective, there is value in understanding the full range of potential safeguards activities and their impact on a spent fuel facility design before design choices are finalized", said Whitlock. "Early planning can incorporate flexibility into the facility's infrastructure in order to support future technology innovations that may benefit both the operator and safeguards implementation."

The SBD document series is available on the IAEA website.



Inspector training at the spent fuel storage facility at the Mohovce Nuclear Power Plant in Slovakia.

(Photo: D. Calma/IAEA)



Robotics Challenge winning design helps speed up spent fuel verification

By Adem Mutluer

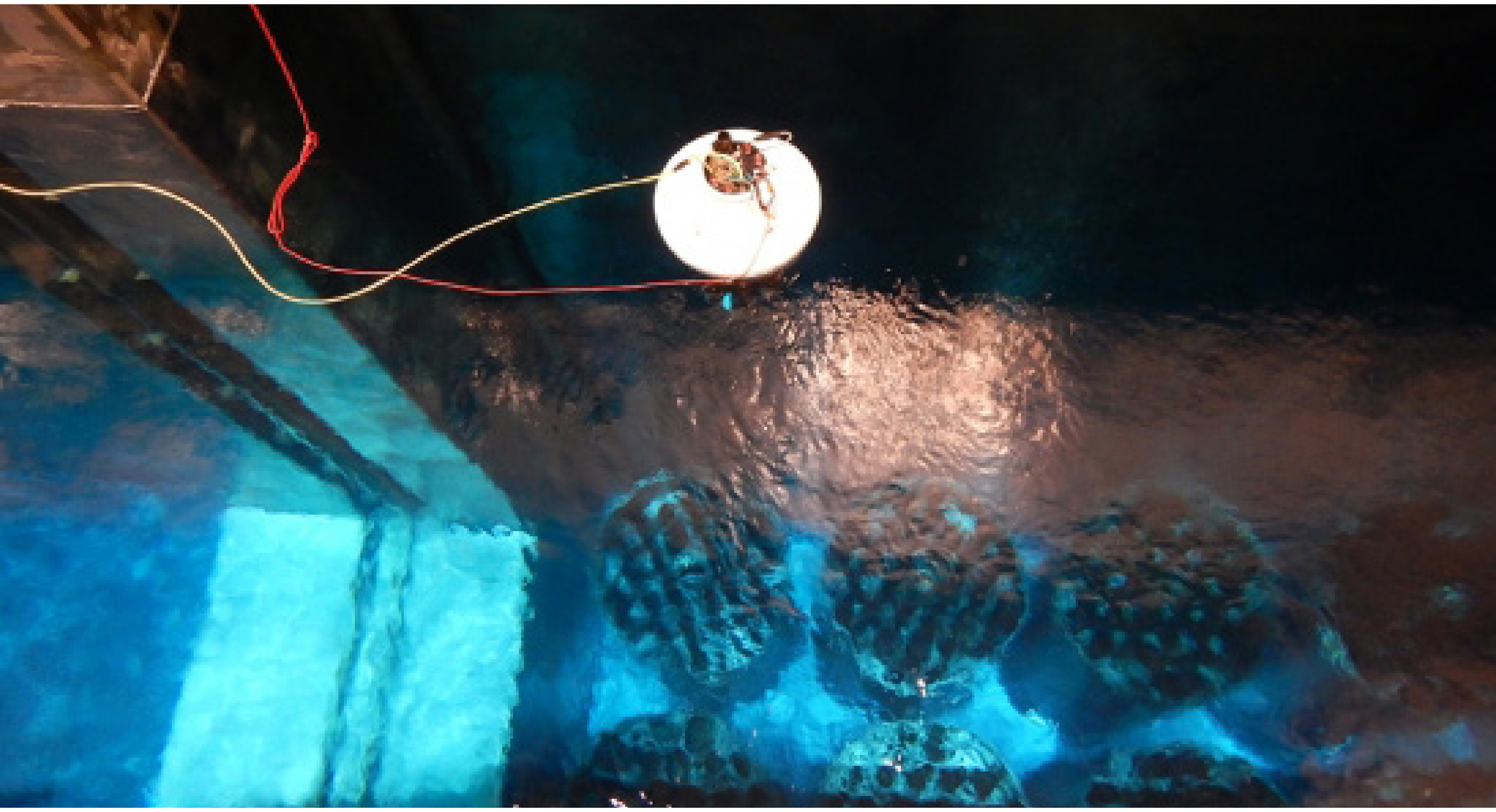
> **"To be able to contribute to nuclear non-proliferation efforts and the important verification work of the IAEA is very exciting."**
>
> *—Peter Kopias, owner and Chief Executive Officer, Datastart*

While spent nuclear fuel no longer sustains nuclear chain reactions that can generate electricity, it still contains nuclear material for potential use in weapons. This is why the verification of spent fuel is a central component of the IAEA's nuclear safeguards work.

Spent fuel is typically stored under water for cooling. Verifying spent nuclear fuel under water can be a tricky and lengthy process. It requires IAEA inspectors to position themselves above the spent nuclear fuel pools to take pictures of individual spent fuel assemblies, of which there can be hundreds at a time. This process was identified as an area where robotics has the potential to play a useful role, and, in 2017, the IAEA launched a challenge to crowdsource ideas and seek solutions to make spent fuel verification more effective and efficient.

When performing their inspection activities at nuclear facilities around the world, nuclear safeguards inspectors frequently use a small hand-held optical instrument called the improved Cerenkov viewing device (ICVD). The ICVD confirms the presence of spent nuclear fuel stored under water, where it is typically placed for cooling following its removal from the reactor core. Inspectors are tasked with verifying whether the amount of fuel stored matches the amount declared by national authorities, and that none of it has been removed and potentially diverted from peaceful use.

Currently, safeguards inspectors need to hold the ICVD from a gantry suspended above a spent fuel pool and manually peer through a lens at the individual fuel assemblies. For the Robotics Challenge, the IAEA sought designs that could mount the newly developed next generation Cerenkov viewing device (XCVD), capable of providing digital recording, inside a small robotized floating platform that would autonomously propel itself across the surface of a spent fuel pool. By stabilizing the XCVD in a vertical position, the unmanned surface vehicle



The winning design for the Unmanned Surface Vehicle undergoes real-world testing at the Loviisa Nuclear Power Plant in Finland.
(Photo: IAEA)

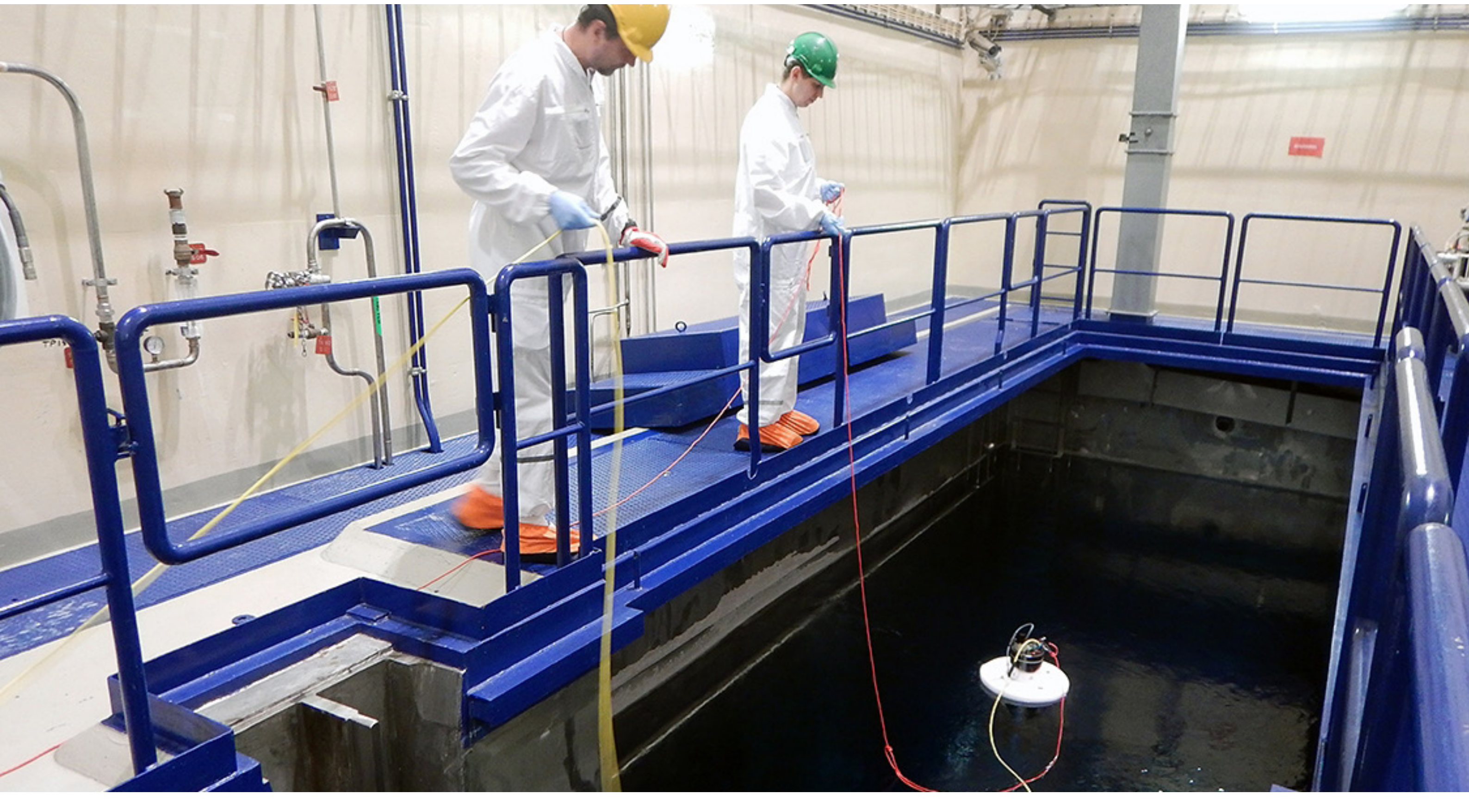
(USV) could enable the provision of clearer images in a shorter timeframe.

The Robotics Challenge attracted more than 300 submissions. Of the 12 proposals selected for demonstration, 3 designs were tested in a real-world setting. In early 2019, a USV, designed by a group of Hungarian engineers was announced as the winner of the IAEA Robotics Challenge. The winning design was selected having first undergone a thorough design and performance evaluation by IAEA experts. “For the final phase of the Robotics Challenge in November 2018, the designs underwent real-world testing in a spent fuel storage pool at a nuclear power plant in Finland,” said Dimitri Finker, Technology Foresight Specialist in the IAEA’s Department of Safeguards. “This gave our experts the chance to review the merits of each design and evaluate which of them suited safeguards operational needs, had safety considerations built in, and gave the best image quality for verification.” The IAEA will now work with its Member States, nuclear facility operators and the designers of the winning USV to finalize the design and ensure it is compliant with all applicable requirements and regulations. Pending this, the IAEA will seek authorization from its Member States to use the USV in the field.

“We are very happy that our design was chosen from among such strong competition. To be able to contribute to nuclear non-proliferation efforts and the important verification work of the IAEA is very exciting,” said Peter Kopias, owner and Chief Executive Officer of Datastart, the winning company. “The Robotics Challenge required a creative engineering solution. I’m delighted our unique design met the needs of users.”

In addition to the Robotics Challenge, the IAEA also conducts other technology challenges to identify and support the development of promising technologies that have the potential to aid its work. “Usually responses to official tenders for technical equipment with potential applications for safeguards work are only sought from a few highly specialized institutions. With the IAEA’s technology challenges, scientific solutions are sought from hundreds of technology stakeholders,” said Finker. The latest challenge, the IAEA Tomography Reconstruction and Analysis Challenge, looks to improve the verification process of spent nuclear fuel with advanced data processing techniques to analyse the images taken from ICVDs and, potentially, XCVDs.

IAEA experts review the performance of the winning Unmanned Surface Vehicle design.
(Photo: IAEA)



Simplifying the transport and storage of spent fuel from nuclear power reactors

By Nicole Jawerth

Storing AND transporting highly radioactive spent nuclear fuel requires taking precautions and strong safety and security measures. Until now, separate containers, or casks, have typically been used for storage and transport of spent fuel from nuclear power plants to the place of storage and eventually to the place of disposal or recycling. Another approach, using dual purpose casks fit for both storage and transport, simplifies this process, in turn making it both cheaper and safer.

To learn more about these unique casks and their role in the safe management of spent nuclear fuel, IAEA Bulletin Managing Editor Nicole Jawerth sat down with Bernd Roith, from the Transport and Predisposal Section of the Swiss Federal Nuclear Safety Inspectorate (ENSI). Roith has eight years of experience working with transport and storage solutions for spent nuclear fuel. He is also regularly involved as an expert in IAEA projects on strengthening the safe management of spent fuel.

Q: With spent nuclear fuel being a mixture of radioactive elements, such as uranium and plutonium, its safe and secure handling is paramount. What exactly is a dual purpose cask and how does it fit into the safe and secure management of spent fuel?

A: There is no 'one-size-fits-all' solution for spent fuel management; each country has its own process and strategy. Some countries store spent fuel in pools and others use canister-based systems or special buildings with dry conditions. Reprocessing fuel is another approach used by some countries.

Dual purpose casks (DPCs) are one of the dry storage and transport options. These casks are designed to ensure that there is no release of radioactive material, whether they are in storage or being transported. While their exact features depend on a country's spent fuel management needs, these casks are, generally speaking, large, fairly narrow, barrel-like containers that hold spent nuclear fuel or high level radioactive waste during transport and interim storage. DPCs are normally made of steel or cast iron and have a bolted, double-lid system that prevents leaks, while still making it possible to safely and simply retrieve the fuel as necessary.

"Each DPC must meet strict safety standards and cover four major functions: mechanical integrity, heat removal, shielding and criticality control."

—Bernd Roith, Transport and Predisposal Section, Swiss Federal Nuclear Safety Inspectorate

Each DPC must meet strict safety standards and cover four major functions: mechanical integrity, heat removal, shielding and criticality control. Putting all of this into one design, while also conforming to international transport and national storage requirements, makes the development and use of DPCs very complex, but, once set up, they simplify other steps in the management process.

Q: What are the advantages of DPCs when compared to other storage methods?

A: DPCs eliminate some of the additional handling of spent fuel. Typically, with many other options, different storage containers or facilities are needed at each step, which means additional fuel transfers, and often these containers are not designed to be transported on public roads. With DPCs, they can be packed with fuel, transported to and placed in interim storage and then transported to the final storage or reprocessing facility, all without rehandling or repacking. This makes them one of the most popular options for countries where spent fuel is transported on public roads.

Q: How does the IAEA fit into the development and use of DPCs?

A: A DPC's design is influenced by the type of storage facility and its location. This means it's not easy to set up defined requirements that fit all DPCs worldwide without taking these differences into account. The IAEA has established safety requirements related to DPC transport and is in a position to harmonize the different storage requirements for DPCs across countries. So, when countries start producing nuclear energy, they can turn to the IAEA's supporting documents to decide whether DPCs work for them, and how to design and use DPCs for dealing with spent fuel.

The IAEA also coordinates research on how to optimize the design and use of DPCs. For example, one of the discussions raised at IAEA meetings involves the ageing of fuel placed in dry storage. DPCs are generally designed for at least 40 or 50 years of use, but now there is more consideration being given to using them for 100 years or more. This might require modifications of the actual designs or new designs to reduce the possible impact of long-term storage on the DPCs and ensure that they continue to meet high safety standards, whether they are in transport or in storage.

Q: What do you think the future holds for DPCs?

A: DPC designers are always trying to improve their designs as nuclear power plants evolve. As nuclear power plants are operating for longer periods, more spent fuel is generated, and therefore there is an aim to optimize designs to maximize the fuel content of each DPC. It also means using new materials to accommodate longer storage, as well as higher heat loads as nuclear power plants use more enriched fuel. The new designs are also likely to be more simplified, making them easier and cheaper to manufacture, while still meeting all transport and storage requirements.

Some countries are phasing out nuclear energy production, and the current generation of experts will eventually retire. Younger people's interest in working in this industry may also go down, but it's clear that we will need people in the future. This is where the IAEA can really help through organizing e-learning courses and providing training to build knowledge.

Dual-purpose casks at the ZWILAG storage facility in Switzerland.

(Photo: ZWILAG)

Learning from my past

What more than 28 years in the nuclear energy fuel cycle taught me about systems, knowledge management and running nuclear facilities

By Susan Y. Pickering

Susan Y. Pickering, Director Emeritus, Sandia National Laboratories, has over 28 years of experience in nuclear-related research and development at Sandia National Laboratories.

The theme for the 2019 IAEA International Conference on the Management of Spent Fuel from Nuclear Power Reactors is "Learning from the Past, Enabling the Future." There are important lessons to be learned from our collective experience working in nuclear energy, whether we come from mature or emerging nuclear power programmes, and the conference provides an ideal venue for sharing them.

Nuclear energy programmes require a very long commitment of time and resources in order to be successful. They generate many challenges — both technical and non-technical. I worked in the nuclear energy fuel cycle for over 28 years. I faced many challenges and learned many, many lessons. Let me share a few of my observations and thoughts.

Nuclear energy systems are complex and integrated. For example, disposal facilities are multi-barrier containment systems comprised of the waste form, container, backfill and host rock, and the performance of each component impacts the others. How will storage decisions made today affect future disposal options? Could a spent fuel container preclude a specific mode of transport or disposal concept/site? We need to view these systems using a cradle-to-grave approach.

The life of nuclear facilities can span many decades. Over the lifetime of a nuclear facility, questions will arise that will have to be answered by people who did not do the original work — possibly by people who were not even born when the original work was completed! A quality assurance (QA) and knowledge management programme should therefore be initiated as soon as possible.

Issues at nuclear facilities can often be attributed to inadequacies in people, parts or procedures; also known as the Three Ps. People in leadership positions have a great deal of influence over the Three Ps. A strong QA and knowledge management programme will introduce controls to strengthen the Three Ps. Such a programme will (1) provide objective evidence of personnel qualifications, (2) provide a process for resolving differing professional opinions, (3) ensure equipment and parts are adequate for their intended use, (4) enhance consistency by defining work processes, (5) increase the credibility and defensibility of technical work, (6) provide for knowledge management across the project's lifespan and (7) provide insights into project issues and their resolutions. A well-designed, well-implemented QA and knowledge management programme is a critical success factor.

I believe there are two broad categories of information to be preserved in a QA and knowledge management programme: information defined by traditional standards, e.g. QA records, and information not defined by such standards, e.g. the logic behind key decisions. This second category of information is often overlooked even though it is essential for defending a nuclear facility when issues arise. For example, does the nuclear facility capture how results and conclusions from critical activities were generated? Can they be reproduced?

Nuclear systems are often perceived as controversial. Stakeholders are many, often with opposing views, and may be a source of conflict. The impact of stakeholders must be appreciated, as they may influence policy and decision makers. Stakeholders generally want frequent engagement, transparency and influence. The relationship between a nuclear facility and its stakeholders is important, and resources must be applied

Spent fuel pool of Unit 2 at the Brunswick Nuclear Power Plant, USA.

(Photo: Nuclear Regulatory Commission, USA)

to support it. Collaborating with the public, stakeholders and local governments increases the likelihood of success.

Maintaining a high level of operational excellence will be difficult over the long lifespan of a nuclear facility. Pressure to reduce costs could lead to unwise decisions. Personnel and organizational turnover can lead to lost knowledge. Complacency could grow over time. Facilities age and could become less reliable. New, unanticipated vulnerabilities could emerge over the years, such as cybersecurity.

An understanding of risk is critical to properly managing a nuclear programme. An accident at a nuclear facility typically falls into the risk category of “high-consequence, low-probability events.” Even though accident frequency estimates are extremely low, consequences could be significant, costly and long-lasting. The systems are complex and require credible science and sophisticated engineering to ensure risks are managed properly. Technically competent leadership in the government sponsor, regulatory agency and implementing team is a major success factor.

A strong tool for leaders is independent review. This can occur as peer review or independent assessment. The IAEA provides many types of review. In all cases, the reviewers must be qualified and independent of the work under review. We are all human and make mistakes. Wise leaders rely on independent review at critical steps and decision points to identify problems while impacts are still small and solutions are less costly to implement.

Leaders at all levels of an organization must embrace the behaviours that foster a strong nuclear safety culture. Every day and in every situation, they must demonstrate their commitment to safety, reward positive behaviours and discipline negative behaviours. They much accept that there will be surprises, and plan for normal and abnormal events. They must understand uncertainty, risk, margin, defence in depth and resilience. Competent people are the most important success factor for a strong safety culture. As Admiral H.G. Rickover, the father of nuclear safety in the USA, said, “Rules are not a substitute for rational thought.”

From lab to field: Indonesian scientists develop new crops for farmers by using nuclear science

BATAN researchers celebrate the success of rice varieties developed using irradiation
(Photo: National Nuclear Energy Agency (BATAN))

Over the last few years, farmers in Indonesia have grown enough rice for more than 20 million people using plants developed through the country's plant mutation breeding programme. The programme first took root through collaboration with the IAEA and the Food and Agriculture Organization of the United Nations (FAO) in 1997 and has since grown into a comprehensive partnership network that brings the results of scientific research using nuclear techniques to farmers' fields.

"Nuclear technology in Indonesia has been used in various areas of life, including agriculture," said Suryantoro, the Deputy Chairman of Indonesia's National Nuclear Energy Agency (BATAN). "Through radiation mutation engineering research, BATAN has improved the quality of local crop varieties so that the new and improved seeds can be widely used by the community."

When the first plant breeding cooperation project with the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture began in 1997, scientists at BATAN's research institutes received state-of-the-art equipment, extensive training in nuclear technologies and support from experts through IAEA coordinated research projects and technical cooperation projects. This laid the foundation for Indonesia's plant mutation breeding programme.

More than 35 new varieties of crops, including soybeans and rice, have since been developed through the programme. The new varieties are bred using irradiation and selected based on their improved characteristics compared to other local varieties, such as higher yields, shorter cultivation time, and resistance to climate change stressors and diseases (see Plant mutation breeding). Once ready, seeds for these new crops are then multiplied and made available to farmers.

"It's important that more seeds are produced to increase the area under cultivation," said A. Sidik Tanoyo, an official from the Ministry of Agriculture in East Java. "This will contribute to increased productivity and farmers' incomes."

To help ensure widespread use of these new crop varieties, the programme has grown into a comprehensive partnership network that is clearing the way for large-scale cultivation. The model is built on collaboration between research institutes, ministries, governmental agencies, seed breeding companies, farmers' cooperatives, market stakeholders and export groups. These partnerships span the whole supply chain, from seed development and multiplication to distribution and cultivation in fields.

"The programme, involving many national ministries and institutions and three international organizations, is designed to run from upstream to downstream," said Totti Tjiptosumirat, Head of BATAN's Center for the Application of Isotope and Radiation Technology. "In the upstream position, BATAN develops superior seeds; the Ministry of Agriculture then distributes seeds to seed producers, and the Ministry of Industry transfers the innovation downstream to small and medium-sized enterprises or start-up companies."

Growing more rice around the country

Three of BATAN's 23 new rice varieties are now being widely cultivated in different regions around the country. Known as Bestari, Inpari Sidenuk, and Mustaban, these rice plants were selected because they can produce, on average, more than 150% more rice in a shorter time than other local varieties. They are also more resistant to changes in the climate, as well as to diseases and insects.

"In my area, the planthopper insect is everywhere, and when I saw these good Mustaban plants, I thanked God that the planthopper does not affect it," said Hamid, a seed breeder in Serang, Banten province. Nearby, in Kaseman village, another seed grower, Tatang, added: "We did not have to use insecticides. Once the flowers from our Mustaban plants came out, there were no rice stink bugs to be found."

Experts at BATAN plan to continue research and development to expand the number of new plant varieties and to incorporate farmers' feedback to further refine and improve how the plants perform. The research will also be geared towards optimizing how plants grow using local agricultural practices, such as fertilizer systems, and under different environmental conditions, such as local soils, strong winds and heavy rains.

—By Driss Haboudane

Nuclear professionals share how to promote strong safety cultures: the IAEA's school on leadership for safety

Junior and mid-career professionals learn about safety leadership skills through group exercises at the IAEA's school on leadership for safety.

(Photo: J. Gil Martin/IAEA)

Leadership for nuclear safety and the development of a strong safety culture within organizations requires creating a space for open and meaningful discussions between nuclear professionals with different backgrounds, said participants of the School of Nuclear and Radiological Leadership for Safety, held in Ankara, Turkey from 22 April to 3 May 2019.

Safety leadership is particularly important in nuclear and radiological work environments, in both routine and emergency situations, owing to their inherent complexities. The IAEA's school on leadership for safety helps early- to mid-career nuclear and radiation professionals develop the skills they need to lead for safety throughout their careers.

A total of 29 professionals from regulatory bodies, nuclear operators and technical organizations from 14 countries participated in the course. They analysed case studies, conducted exercises, took part in discussions and listened to invited experts' presentations on nuclear and radiation safety, including emergency preparedness. The course was held in the framework of an IAEA technical cooperation project on enhancing capacity building activities in European nuclear and radiation safety organizations for the safe operation of facilities.

Participants said the school provided an environment for discussions on building safety leadership and offered them inspiration and strategies for implementing such leadership at their institutions.

Introducing new ways to communicate within teams

School participant Milijana Steljic, Head of the International Cooperation and Project Management Unit at the Serbian Radiation and Nuclear Safety and Security Directorate, highlighted the importance of personal behaviour and the use of certain tools to build strong teams for promoting safety.

"This course encouraged me to think in a new way, particularly of my role as a leader and how I balance my professional output with the ability to inspire my team members through my own actions," said Steljic. "Combining presentations and lectures with case studies, group work, games and technical visits, the school exposed our leadership behaviour and introduced us to a set of leaders' tools for us to use daily."

"I want to introduce team-building exercises and regular discussions of case studies into my team and use these new leaders' tools to evaluate my team's performance," she continued. "Ideally, I would like to introduce this idea to the entire organization, as I would like us all to have more open communication in order to build a strong safety culture in our organization."

Promoting a commitment to leadership among all team members

Another participant, Aysel Hasanova, Senior Advisor at the Department of Technical Legislation and Standards of Azerbaijan's State Agency for Regulation of Nuclear and Radiological Activity, emphasized the role of appropriate programmes in inspiring nuclear safety professionals and noted that all team members — not only managers — can be leaders for safety.

"Leaders' behaviours strongly impact safety. Leadership for safety means a continuous desire to develop and be a role model for all of one's team members, regardless of whether one is a manager or not," said Hasanova. "I work to promote a strong safety culture and the transfer of knowledge from experienced professionals, engaging younger professionals and professional women and I am committed to introducing new tools for human resources development across the country — which is why I opted to participate in this course."

"Previously, I thought you had to be born a leader, but I now believe everyone can uncover and develop their own leadership skills," she said. "Nothing is built in one day, but we need to start with clear goals and make a great commitment in order to achieve them."

—By Nathalie Mikhailova

Viet Nam enhances food quality using irradiation

Food products undergo irradiation processes at VINAGAMMA using an electron beam irradiator, pictured here, and a gamma irradiator.
(Photo: E. Marais/IAEA)

Each morning hundreds of boxes filled with frozen seafood, dried fruits and vegetables, traditional oriental medicines and health foods are queued up in a storeroom in Ho Chi Minh City, Viet Nam. They will undergo a process similar to security screening at airports, but with higher intensity beams of photons or electrons, as part of a food irradiation programme installed with IAEA support over the last two decades.

Depending on the dose, food irradiation ensures that root vegetables and fruits do not sprout or ripen prematurely; that parasites are killed and spices are decontaminated; that salmonella is destroyed; and that fungi that could spoil meat, poultry and seafood is eliminated.

The process of food irradiation was first introduced in Viet Nam in 1999 with the help of the IAEA and the Food and Agriculture Organization of the United Nations (FAO), and a large market for irradiated products has since opened up, significantly increasing the ability of companies to export their food products. Food irradiation has matured into a mainstay of the country's food industry and is an important contributor to the country's agricultural competitiveness.

"In 1999 we were irradiating 259 tonnes of food per year, and this had grown to 14 000 tonnes by 2017," said Cao Van Chung, Head of the Electron Beam Department at the Viet Nam Atomic Energy Institute's Research and Development Center for Radiation Technology (VINAGAMMA). "This shows a real boom in the demand for our work. Today, we are one of the country's leading facilities in the field of radiation technology — pioneering in food irradiation."

Introduction of gamma and electron beam irradiation

This considerable growth has been possible thanks to the introduction of two irradiation methods. A gamma irradiator, introduced in 1999, which uses ionizing energy from a radiation source shielded in a concrete room, and an electron beam (EB) irradiator, in use since 2013. EB irradiators do not rely on a radioactive source, using instead streams of highly charged electrons produced from specialized equipment, such as a linear electron accelerator. The food never comes into contact with radioactive material, and the irradiation both maintains the quality and increases the safety of the food while leaving no residual radioactivity.

Although the process of irradiation using the two methods is the same, each brings distinct and complementary advantages, Chung said. The gamma irradiator uses tall aluminium boxes, which can accommodate a broad range of product sizes, and the boxes are moved through the irradiation chamber around the radioactive source suspended from an overhead monorail system. Food products require two rounds of irradiation to ensure that all sides of the packaged product have been properly treated.

The EB irradiator, on the other hand, contains double-sided beams, which makes the irradiation process three times quicker than using the gamma irradiator, because the whole product can be irradiated in a single round. However, the EB irradiator has a limited dimension, with a maximum box size of 60x30x50 cm and weight of 15 kg, so gamma irradiation must be used for larger and heavier products. The machines work side by side, running 24 hours a day, 7 days a week, only stopping over the Vietnamese New Year period.

Before the introduction of the gamma irradiator and the EB irradiator, spoilage prevention of food products such as seafood, fruits and vegetables was carried out using traditional methods, including canning, refrigeration and freezing, and chemical preservatives, which, owing to their lower effectiveness, hindered the manufacturers' ability to export their products.

The irradiation machines were acquired with support from the IAEA's technical cooperation programme, which also provided training and expert advice for staff. Viet Nam is 1 of 40 countries that the IAEA is supporting in this area.

Growth in the use of radiation technology

VINAGAMMA has grown from just 20 employees when it was set up in 1999 to 79 today. Besides food irradiation services, it offers radiation sterilization of medical products and pasteurized foodstuffs, and commercializes its research and development products, such as plant protectors used in agriculture and gold and silver nanogels used in medicine.

VINAGAMMA also carries out research and development and provides training in the field of radiation technology. It works with international partners to find ways of further improving irradiation technology.

—By Estelle Marais

IAEA develops new method for tracking sources of water pollution

Excessive nitrate in lakes, seas and rivers can increase algae growth that can lead to toxic blue-green blooms. The IAEA, in collaboration with the University of Massachusetts Dartmouth, has developed an innovative method for tracing the origin of nitrate pollution in water.
(Photo: L. Wassenaar, IAEA)

The IAEA, in collaboration with the University of Massachusetts, has developed an innovative method for tracing the origin of nitrogen pollution in lakes, seas and rivers. The nuclear-derived analytical tool provides a cheaper, safer and faster way to determine whether excessive nitrogen compounds in water stem from agriculture, sewage systems or industry, helping prevention and remediation efforts.Nitrogen, an essential and abundant element on earth, is an important fertilizer that has been widely used in agriculture since the mid-1900s. “One of the major global problems in terms of water quality is that we have been overfertilizing our landscapes for decades, either with manure or synthetic fertilizers,” said Leonard Wassenaar, head of the Isotope Hydrology Section at the IAEA. “All of these nutrients, particularly nitrogen forms such as nitrates, are seeping into groundwater and eventually into rivers, lakes and streams.”

Excessive nitrate levels increase algae growth that can lead to toxic blooms on the surface of lakes. These can also sink to the bottom of lakes, feeding bacteria and creating what is known as dead zones. “We now see more fish kills, where thousands of fish float to the surface because the bottom of the lake — their usual habitat — is depleted of oxygen owing to this rain of organic material,” Wassenaar said.

Removing nitrates from water is very difficult and expensive, so tools are needed to understand nitrogen sources and pathways in order to better inform water protection and remediation efforts.

The new method, published in the journal Rapid Communications in Mass Spectrometry, measures the amount and proportion of nitrate stable isotopes in water. Nitrogen has two stable isotopes, or variations of its atoms, with different weights. Since the weight difference is not the same in human waste or fertilizers, for example, the isotopes can be used to identify the source.

“Isotope tools are very powerful for measuring nutrients in water,” said Wassenaar, “but their use has historically been very difficult, hampered by cost and accessibility. The new technique allows scientists to run more samples, and much more cheaply, for large-scale studies. I think it is a game changer.”

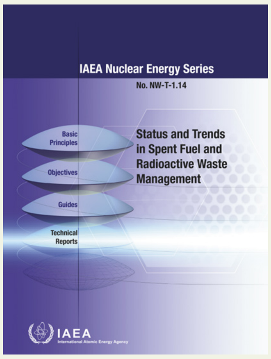
The new method uses a form of titanium chloride — a salt — to convert nitrate in a water sample into nitrous oxide gas. From this gas, the isotopes can be analysed with equipment such as a mass spectrometer or laser. Current methods use genetically modified bacteria or the highly toxic metal cadmium for the nitrous oxide conversion, making them laborious and costly and their use limited to a few very specialized laboratories.

“It’s a relatively simple method for what used to be a very complex and expensive process,” said collaborator Mark Altabet, Professor of Estuarine and Ocean Sciences at the University of Massachusetts Dartmouth’s School for Marine Science and Technology. Sample analysis costs five to ten times less than in the past, and it takes only minutes to prepare samples.

Altabet plans to use the method to study the impact of measures to control pollution in Long Island Sound, an estuary on the eastern coast of the United States, which was heavily impacted by excessive nitrate in the past.

The IAEA promotes the application of nuclear and isotopic techniques to determine water source, age, quality and sustainability, in order to help countries better manage this vital resource.

—By Luciana Viegas

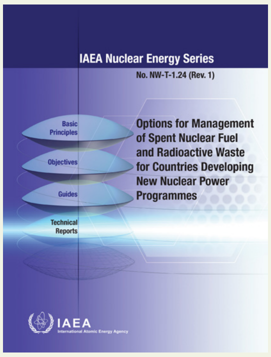


Status and Trends in Spent Fuel and Radioactive Waste Management

provides a global overview of the status of radioactive waste and spent fuel management concerning inventories, programmes, current practices, technologies and trends. It includes an analysis of national arrangements and programmes for radioactive waste and spent fuel management, an overview of current waste and spent fuel inventories and estimates of future amounts. International and national trends in these areas are also addressed.

IAEA Nuclear Energy Series NW-T-1.14; ISBN: 978-92-0-108417-0; English Edition; 39.00 euro; 2018

www.iaea.org/publications/11173/status-and-trends

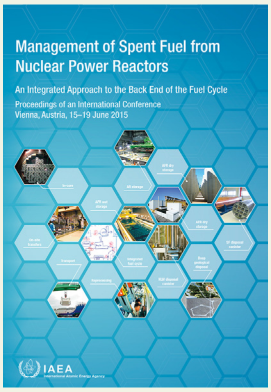


Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes

provides a concise summary of key issues related to the development of a sound radioactive waste and spent nuclear fuel management system. It is intended to brief countries with small or newly established nuclear power programmes about the challenges of, and to describe current and potential alternatives for, managing reactor waste and spent fuel arising during the operation and decommissioning of nuclear power plants.

IAEA Nuclear Energy Series NW-T-1.24 (Rev. 1); ISBN: 978-92-0-103118-1; English Edition; 32.00 euro; 2018

www.iaea.org/publications/12255/options-for-management

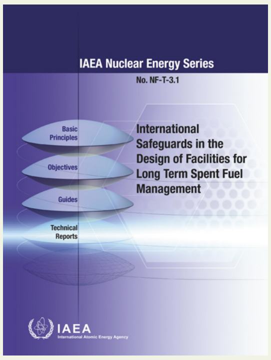


Management of Spent Fuel from Nuclear Power Reactors: An Integrated Approach to the Back End of the Fuel Cycle

presents the outcome of the 2015 IAEA International Conference on Management of Spent Fuel from Nuclear Power Reactors, at which achievements and lessons learned in connection with the back end of the nuclear fuel cycle and associated challenges were shared and reviewed. The key goals of the conference were to raise awareness on how developments in power generation and availability of disposal can impact spent fuel management, to evaluate the advances in the management of spent fuel from power reactors since the inception of IAEA conferences on this topic and to identify pending issues and anticipated future challenges.

Proceedings of International Conference; ISBN: 978-92-0-101819-9; English Edition; 28.00 euro; 2019

www.iaea.org/publications/13488/management-of-spent-fuel



International Safeguards in the Design of Facilities for Long Term Spent Fuel Management

is intended for designers and operators of facilities for long-term spent fuel management. Vendors, national authorities and financial backers can also benefit from the information provided. The publication complements the general considerations addressed in International Safeguards in Nuclear Facility Design and Construction, IAEA Nuclear Energy Series No. NP-T-2.8.

IAEA Nuclear Energy Series NF-T-3.1; ISBN: 978-92-0-100717-9; English Edition; 36.00 euro; 2018

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