IAEA BULLETIN

INTERNATIONAL ATOMIC ENERGY AGENCY

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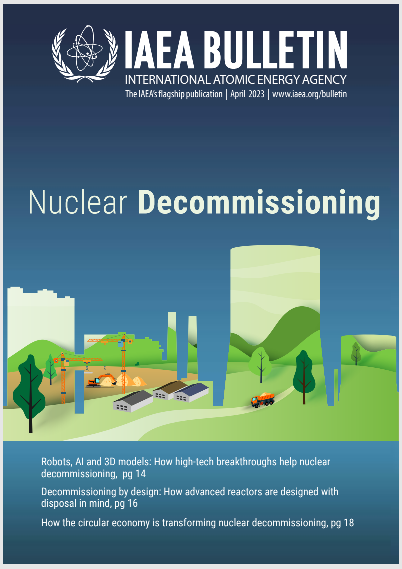
Nuclear **Decommissioning**



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The International Atomic Energy Agency's mission is to help 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.

Meeting the challenges of decommissioning

By Rafael Mariano Grossi, Director General, IAEA

As more countries embrace nuclear power to improve energy security and mitigate climate change, the challenge of successfully decommissioning nuclear facilities is set to grow. A crucial factor in meeting that challenge is to address it up front.

Today, 56 reactors are under construction worldwide, and many countries are putting into motion plans to expand their nuclear fleet or build their first nuclear power programme.

When it comes to the end of life of a nuclear reactor, forethought and innovation today play pivotal roles. New nuclear power plants, including those with small modular reactors (SMRs), are being designed with their decommissioning in mind. In other words, designers are planning how their nuclear power reactors will be dismantled even before construction begins.

The IAEA has a unique global role in facilitating the adoption of emerging nuclear technologies, coupled with greater harmonization of regulations to enable safe and efficient decommissioning when the time comes.

Almost half of the 423 nuclear power reactors the world relies on today are expected to enter the decommissioning process by 2050. Each one could take up to 20 years or more to fully decommission.

The IAEA assists countries in ensuring that decommissioning work is carried out within the appropriate technical and regulatory frameworks, by promoting safety standards and good international practices through workshops, forums, missions and publications.

Decommissioning reflects a responsibility and commitment to a circular industrial and nuclear cycle. More material is being recycled, while cost savings are being made and timeframes condensed. Meanwhile, new technologies such as data science, artificial intelligence, robotics and drones are bringing greater effectiveness and safety to decommissioning activities.

The IAEA ensures lessons and innovations from successful decommissioning projects are shared, including through our International Decommissioning Network. It also plays a vital role ensuring safety, even under challenging circumstances. The Fukushima Daiichi nuclear accident in 2011 required innovations, such as the use of cosmic-ray muon mapping to help locate the damaged fuel and the building of a frozen subterranean wall to prevent groundwater seeping into contaminated water inside the reactor buildings, as well as the use of robotics for work in areas with limited access. These innovations helped boost effectiveness and efficiency while minimizing the danger to workers, the general public and the surrounding environment.

Safety is crucial, but it is not the only consideration. Safeguards are key to the decommissioning process. IAEA inspectors are on hand when spent fuel is moved or disposed of to verify that materials used in nuclear plants are not diverted from peaceful use.

International cooperation and knowledge sharing supported by the IAEA are vital to meeting the growing global demand for nuclear decommissioning. It is important to get the back end of the nuclear fuel cycle right so that nuclear can play a full and sustainable role in addressing the world's most pressing challenges, from mitigating climate change and air pollution to providing energy security and the nuclear medicine needed to fight cancer and heart disease.

"The IAEA ensures lessons and innovations from successful decommissioning projects are shared, including through our International Decommissioning Network. It also plays a vital role ensuring safety, even under challenging circumstances."

— Rafael Mariano Grossi, Director General, IAEA

(Photos: IAEA)

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Nuclear decommissioning

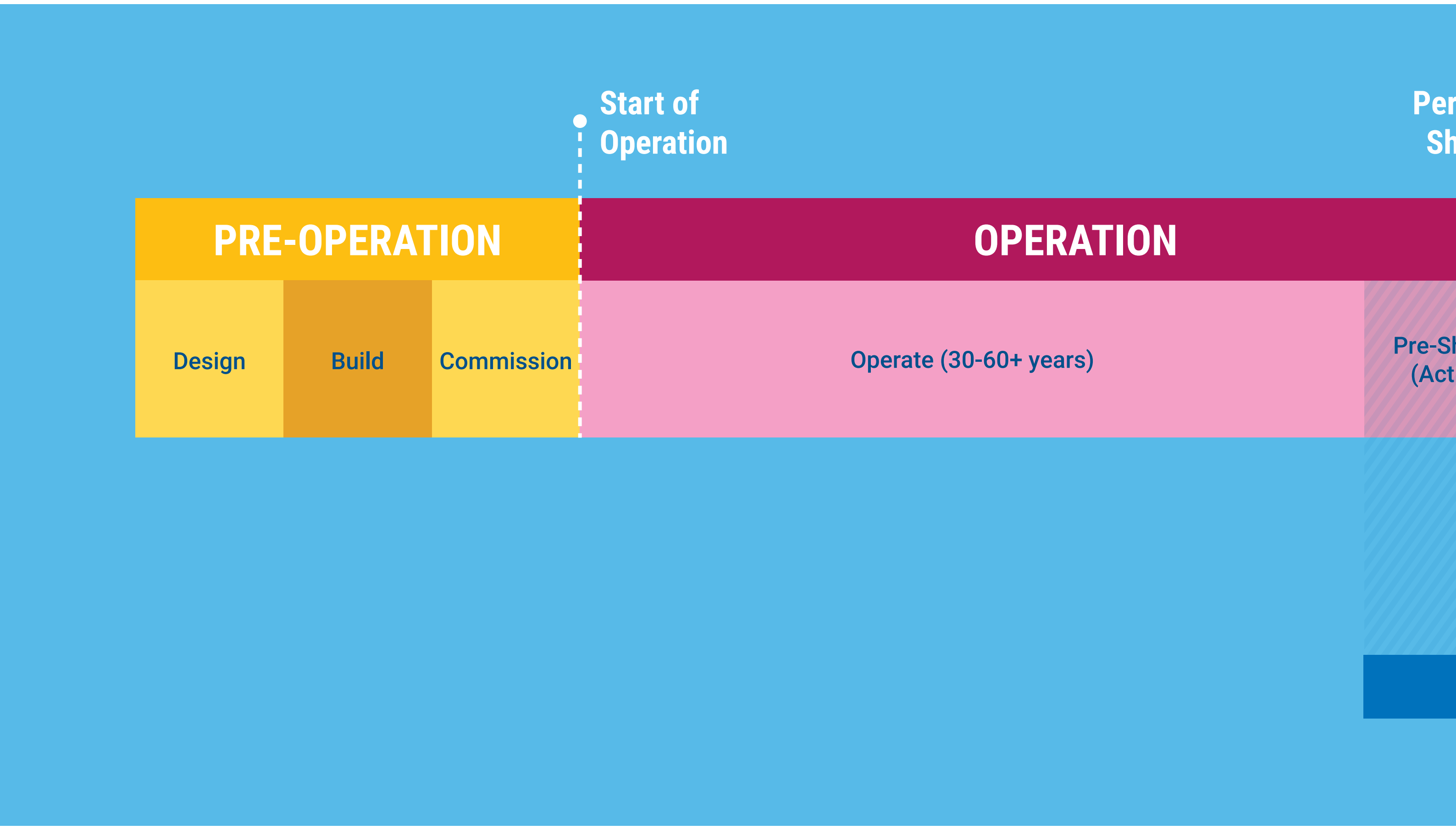
Addressing the past and ensuring the future

By Patrick O'Sullivan

The number of nuclear facilities that require decommissioning is expected to increase significantly over the next 10 to 20 years. There is no simple relationship between the age of a facility and the timing of permanent shutdown, as multiple factors, including political and economic forces, can influence this decision. The timing may also depend on maintenance, refurbishment costs and electricity market conditions, among other things (see pages 8 and 9). However, government policies are increasingly promoting strategies for immediate dismantling in line with sustainability principles, so that the burdens associated with decommissioning, such as the management of waste, are not passed on to future generations. The potential of sites to be reused for the construction of new nuclear facilities or other purposes is also an important consideration.

Timespan and budget

The decommissioning of a large nuclear facility is a complex undertaking which usually requires a significant timespan and budget. For example, the cost of decommissioning a nuclear power reactor, including the associated waste management costs, typically ranges from $500 million to $2 billion, with gas-cooled graphite moderated reactors being significantly more expensive to decommission than pressurized or boiling water reactors, owing to their much greater size and complexity. The decommissioning process typically takes around 15 to 20 years, although this can vary. The cost of decommissioning a large fuel cycle facility, such as a facility used to reprocess spent fuel, is generally around $4 billion, while the decommissioning of such facilities may take more than 30 years to



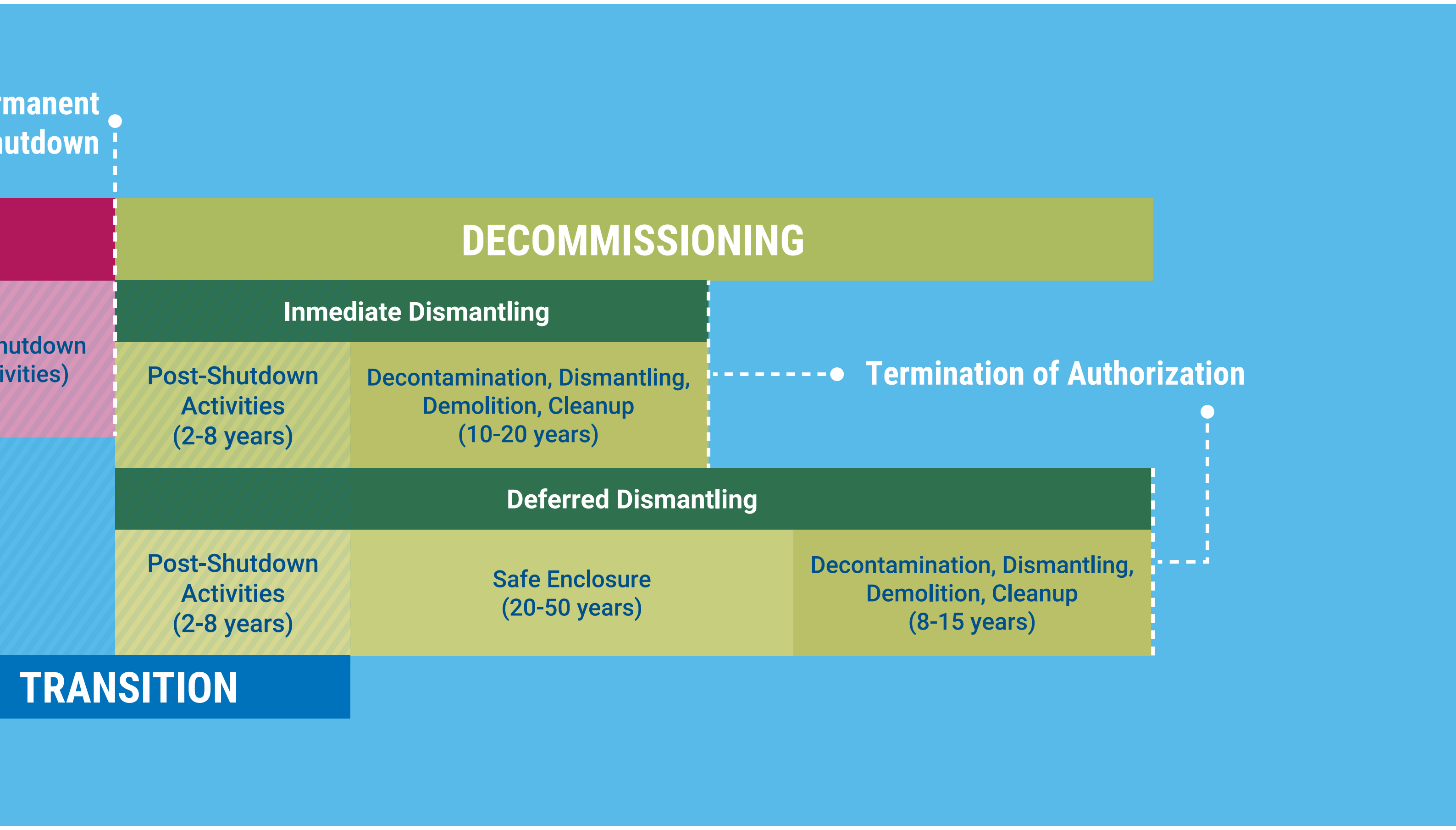
complete. A research reactor with a thermal power output of 10 megawatts may cost over $20 million to decommission and take 5 to 10 years to implement, although the cost depends on the reactor's size, purpose and operational history. However, some successful examples suggest that there is potential for a more time efficient and less expensive decommissioning process.

Biggest challenges for the decommissioning industry

The anticipated increase in the number of nuclear facilities to be permanently shut down between now and 2050 means that significant resources — human, as well as financial — will be needed to implement the necessary decommissioning programmes, some of which will run to the end of this century. For commercial facilities, funds have generally been set aside during operation to cover the costs of decommissioning. However, the decommissioning of a significant number of facilities is funded either directly or indirectly from State resources. In these cases, the availability or not of sufficient funding may delay such implementation. A large, highly skilled workforce will also be needed to implement future decommissioning programmes. Encouraging young people to pursue careers in decommissioning and radioactive waste management is one of the most significant challenges currently facing the industry (see page 30).

Recycling and reusing waste material

Decommissioning results in the generation of large quantities of materials and waste, most of which have not been radioactively contaminated. Efforts are being made to ensure that a large proportion of this non-contaminated waste, including metals,



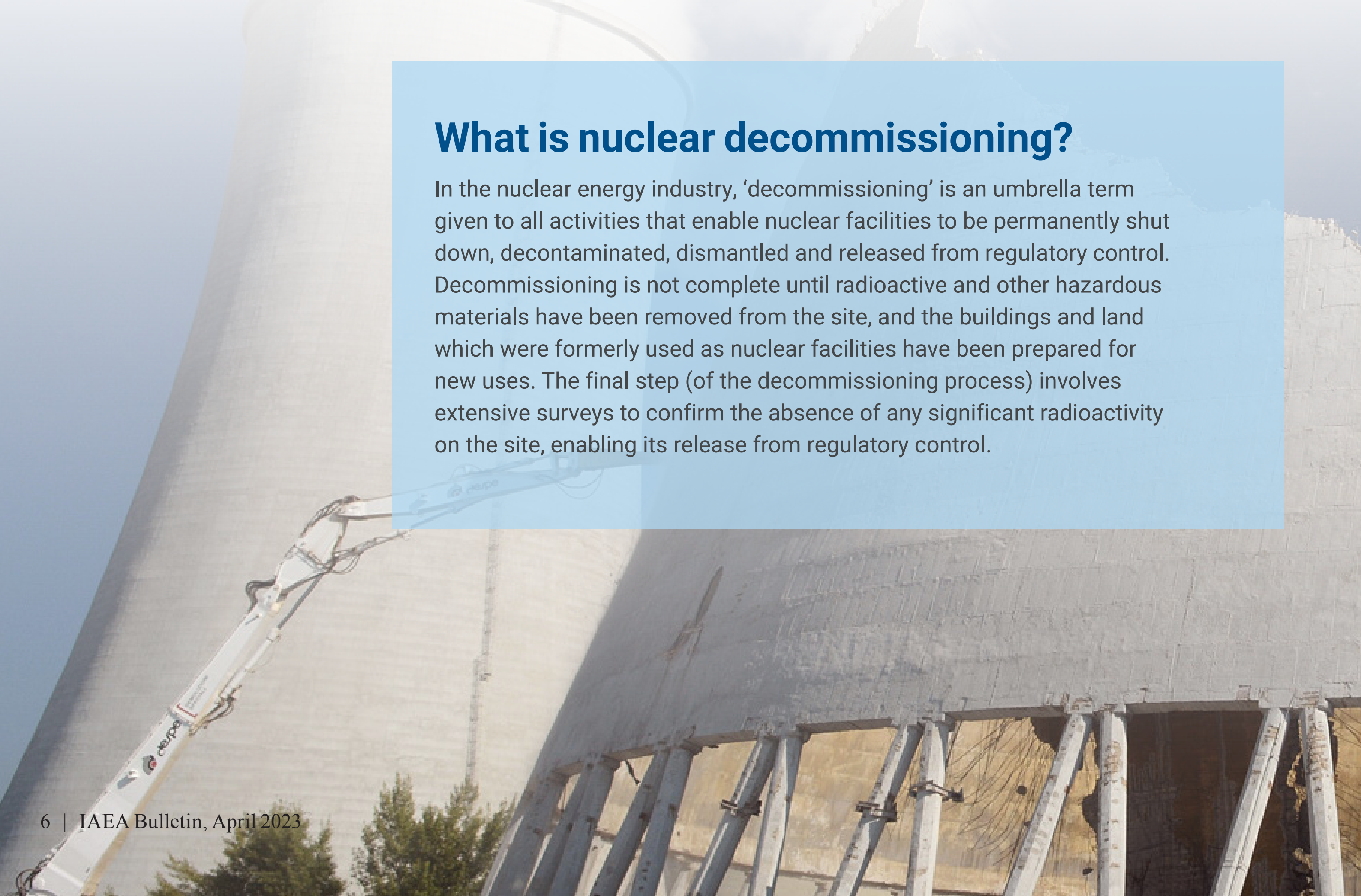
concrete debris and soil, is recycled or reused, in line with circular economy principles (see page 18). In some cases, rubble from demolition can be used to fill the spaces that are created by the removal of structures below ground level. The greater use of metal recycling, including for reuse within the nuclear industry, is also being considered.

A large proportion of the material that has been radioactively contaminated — which typically represents about five per cent of the total material generated by decommissioning — contains very low levels of radioactivity and is suitable for disposal in near surface repositories. A small proportion of the radioactively contaminated material (less than five per cent of the total material generated) is not suitable for release from regulatory control or for near surface disposal, owing to high levels of activity and the presence of highly active or long-lived radionuclides; this material will ultimately be safely disposed of in underground disposal facilities (see pages 20, 21, 22 and 23).

Meeting future needs

Given the extent of future decommissioning needs and the potential for new and emerging technologies to improve the efficiency of decommissioning, it is likely that there will be significant changes in project implementation in the near future, once such technologies are widely adopted and their cost-effectiveness has been proven. Developments include the application of digital techniques to support planning and to optimize project implementation; the greater use of remotely operated tools, including drones and robotics, for the segmentation of plant components, material handling, measurements and decontamination; the increased automation of waste management activities; and the use of artificial intelligence (see page 12).

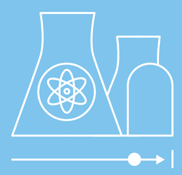
The role of the supply chain is crucial in ensuring that future projects are implemented as effectively and efficiently as possible. There is already evidence of supply chain organizations developing expertise to provide a wider range of decommissioning services in fields such as research and development on new technologies, engineering, dismantling and radioactive waste management. A recent development specific to nuclear power plant decommissioning has been the emergence of decommissioning consortia that bring together specialized companies in order to implement entire decommissioning projects within a fixed budget, by following standardized approaches and assuming all associated project risks (see pages 24).



What is nuclear decommissioning?

In the nuclear energy industry, ‘decommissioning’ is an umbrella term given to all activities that enable nuclear facilities to be permanently shut down, decontaminated, dismantled and released from regulatory control. Decommissioning is not complete until radioactive and other hazardous materials have been removed from the site, and the buildings and land which were formerly used as nuclear facilities have been prepared for new uses. The final step (of the decommissioning process) involves extensive surveys to confirm the absence of any significant radioactivity on the site, enabling its release from regulatory control.

Global decommissioning in numbers

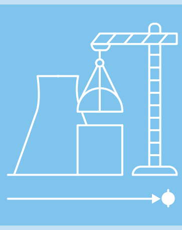


420+
Nuclear power reactors in operation around the world

There are currently around 420 nuclear power reactors in operation around the world, a majority of which are approaching the end of their original design lives.

1/2
Shut down by 2050

Up to half of the current operating fleet may be permanently shut down by 2050 and would therefore need to be decommissioned.



≈200
Retired from service

Over two hundred nuclear power reactors have already been retired from service and twenty one of these have been fully decommissioned.

222 **research reactors in 53 countries**

353 **fuel cycle facilities in 40 countries**

likely to be permanently shut down

Significant numbers of research reactors currently in operation (222 in 53 countries) and fuel cycle facilities (353 in 40 countries) are also likely to be permanently shut down over this timeframe.

≈450 **Research reactors** and **+150** **Fuel cycle facilities**

have been fully decommissioned

Around 450 research reactors have already been fully decommissioned, as well as more than 150 fuel cycle facilities.

Significant decommissioning experience has already been gained since the turn of the century, particularly in countries that established their nuclear programmes in the middle of the 20th century, such as France, Germany, Italy, Japan, the Russian Federation, the United Kingdom and the United States. Others, including Bulgaria, Canada, Lithuania, Slovakia, Spain and Ukraine also have expertise in this field, while significant programmes may be expected over the next 30 years in Belgium, China, India, Korea, Pakistan and Sweden.

Decommissioning a nuclear power plant

By Joanne Liou

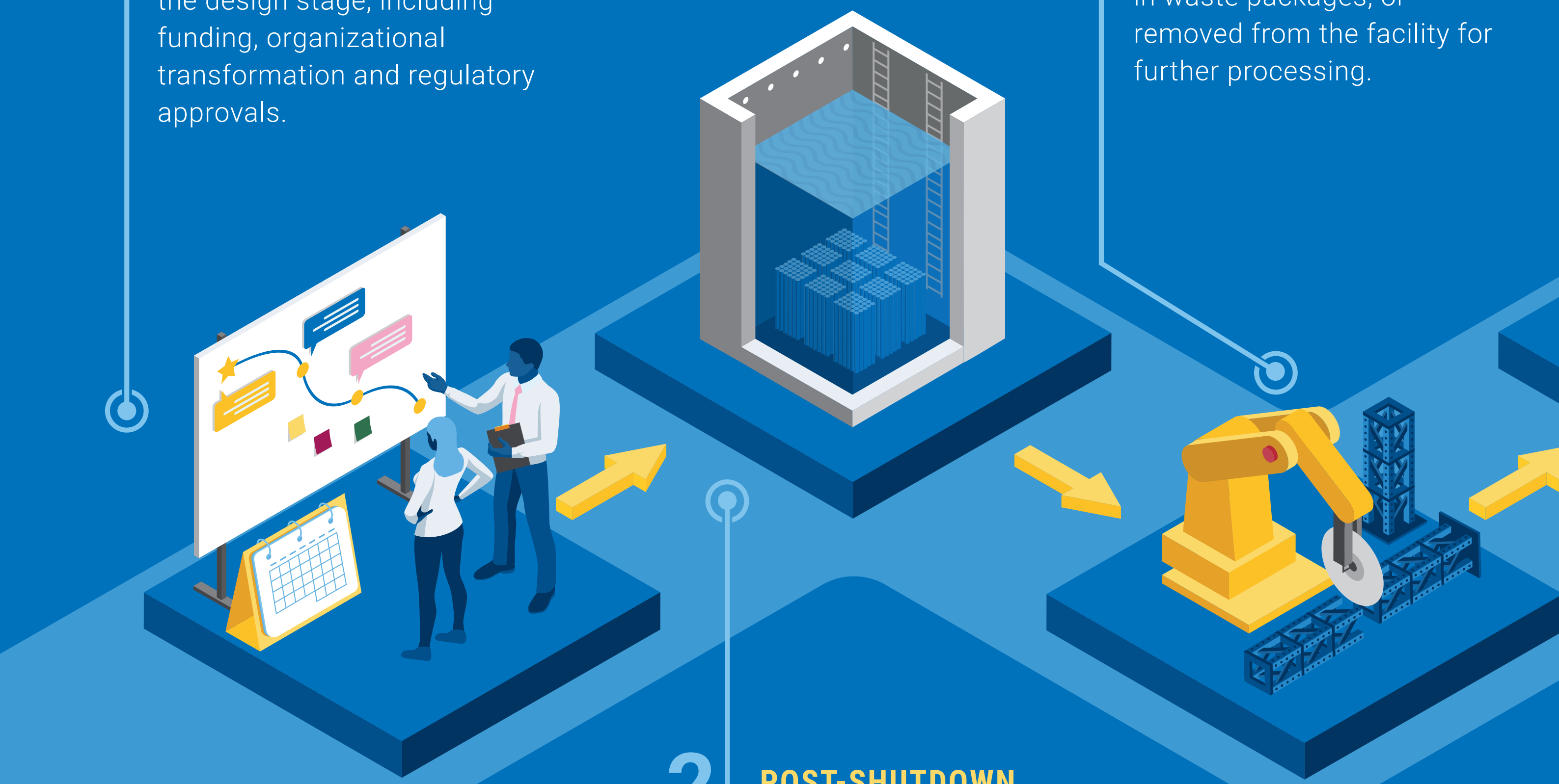
Decommissioning is the last stage of the lifecycle of a nuclear power plant. Planning for decommissioning begins from the design stage of the plant to ensure that dismantling and associated waste management can be safely and effectively implemented without negatively impacting the environment, human health and society. Once a nuclear power plant is permanently shut down, it transitions from a facility involving operational processes for electricity production to activities associated with preparation and implementation of decommissioning, including changes to the organization and to plant safety systems. When dismantling is deferred, the facility

1 PREPARATION

The key to success in decommissioning is to carefully **plan and consider all aspects of the project**, from the design stage, including funding, organizational transformation and regulatory approvals.

3 DECONTAMINATION AND DISMANTLING

The radioactive components are decontaminated, reduced in size by cutting and placed in waste packages, or removed from the facility for further processing.



2 POST-SHUTDOWN

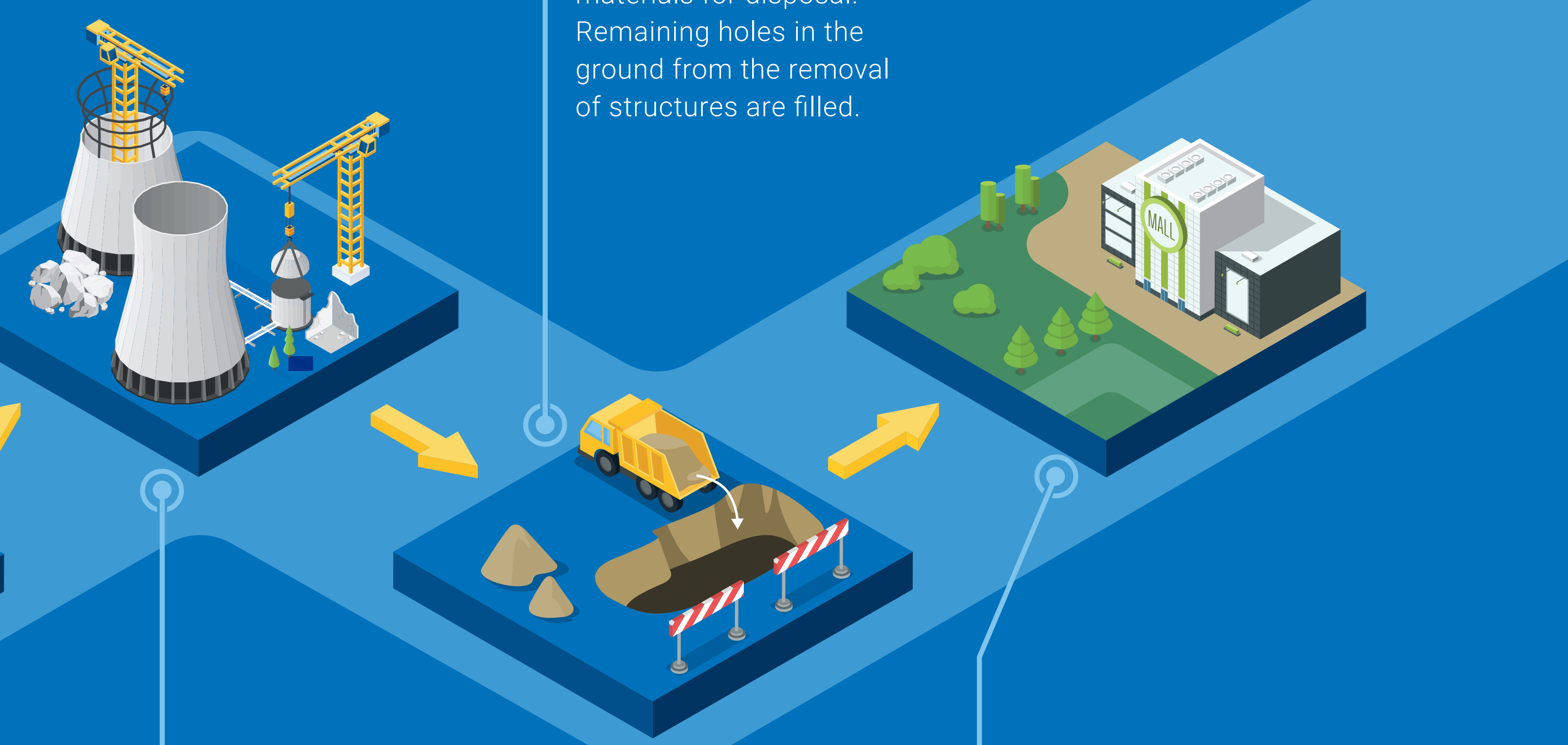
Fuel is removed from the reactor core and transferred to a spent fuel storage facility. **Safety and waste management systems of the facility are adapted**. The decommissioning-related characteristics of the facility and the levels of radiation expected to be encountered are determined.

is placed in a stable condition until dismantling occurs, while radioactivity levels naturally decay. The time taken between the permanent shutdown of a nuclear power plant and the completion of decommissioning, which can range from one to several decades depending on the strategy adopted.

After decommissioning, the site is available for other social or economic purposes. The decommissioning process comprises the following main activities:

5 CLEANUP AND PREPARATION FOR REUSE

The site is prepared for eventual reuse by removing any contaminated soil or other materials for disposal. Remaining holes in the ground from the removal of structures are filled.



4 DEMOLITION

All buildings, structures and non-radioactive components are broken down into pieces, organized and recycled to the greatest extent possible. **Radioactive waste is separately treated and sent for storage or disposal**.

6 FINAL SURVEY AND RELEASE FROM REGULATORY CONTROL

A detailed survey of the site provides assurance to the regulator that agreed **levels of cleanup have been achieved**, allowing the site to be released from regulatory control and **reused for other purposes**.

Slovakia sets global example for nuclear power plant decommissioning

By Michael Amdi Madsen

> **"Throughout decommissioning, JAVYS has turned to innovative digital tools to ensure that the process was safe and efficient. These tools are now being adopted by decommissioning projects around the world."**
>
> *— Olena Mykolaichuk, Director, Division of Nuclear Fuel Cycle and Waste Technology, IAEA*

When Slovakia joined the European Union (EU) in 2004, it did so on an important condition relating to nuclear safety: the country would need to shut down and decommission its V1 reactors at the Bohunice nuclear power plant. These were Soviet-era reactors that were considered to no longer meet the relevant nuclear safety standards of the day. The Slovakian Government made a commitment to decommission the reactors and, in the process, it set an example for others to follow on decommissioning a nuclear power plant safely, efficiently and effectively. With support from the IAEA and the European Commission, Slovakia is now sharing what it has learned in order to benefit other countries.

Slovakia generates a little more than half of its electricity from nuclear energy. The four reactors at the Bohunice site have played a large role in this. The Bohunice V1's first unit, which started up in 1978, was the site's first pressurized water reactor using a water cooled, water moderated power reactor (WWER) 440 V230 design. It was one of the earliest versions of 'water-water energetic reactors' developed by the Soviet Union. However, there were challenges regarding the containment building's design, as it was at greater risk of large pipe breaks compared to later buildings that were constructed using improved designs.

Olena Mykolaichuk, Director of the Division of Nuclear Fuel Cycle and Waste Technology at the IAEA, has worked closely with experts from Slovakia's State-owned Nuclear and Decommissioning Company (JAVYS) as the Bohunice V1 decommissioning project has progressed. "Throughout decommissioning, JAVYS has turned to innovative digital tools to ensure that the process was safe and efficient. These tools are now being adopted by decommissioning projects around the world," Mykolaichuk said.

The tools that were employed by JAVYS included virtual modelling and simulations. Using simulations, engineers developed procedures to extract the reactor vessel, which was embedded in the concrete reactor shaft, and then to move it and lower it into pools of water where it could be safely cross sectioned using saws for further packaging towards safe storage.

Eva Hrasnova, a project manager at JAVYS, said that the project showed that mechanical cutting tools, such as band and circular saws used underwater, were safe and productive ways to fragment the radioactive primary circuit components of WWER-440 reactors. She also said that the experience showed that a combination of decontamination methods — chemical, electrochemical and ultrasonic, as well as mechanical methods such as blasting and grinding — proved to be crucial for the follow-up effective waste management.

"The Bohunice V1 decommissioning uncovered a host of practical insights for decommissioners," said Mykolaichuk. "From determining ways to save space and money by reusing buildings for storage, to recycling a high degree of steel, metals and concrete so as to support circular economy principles."

The decommissioning of Bohunice V1 is ongoing and is expected to continue until 2027. With financial support from the EU and the European Bank for Reconstruction and Development, the project's final bill is expected to reach €1.239 billion.

In recognition of the achievements made by JAVYS in decommissioning Bohunice V1, and in order to further strengthen the implementation of similar projects around the world, the company was designated an IAEA Collaborating Centre in March 2021. Consequently, as a Collaborating Centre for nuclear facility decommissioning and radioactive waste management, JAVYS has been able to share its experiences with others, in coordination with the IAEA.

"In Bohunice we can effectively demonstrate technical progress and safety in physical and radiological characterization, decontamination, dismantling, demolition and associated waste management," said Pavol Štuller, Chief Executive Officer of JAVYS, at the Collaborating Centre's signing ceremony, which was held in Vienna, Austria. "Our cooperation with the IAEA is centred on implemented and planned work, and will be further enhanced as the Collaborating Centre progresses over the coming years."

The partnership between the IAEA and JAVYS is already bearing fruit, and the IAEA held the International Workshop on Lessons Learned from the Implementation of Decommissioning Projects for Water Cooled, Water Moderated Power Reactors in Trnava, Slovakia, in May 2022. At the workshop, experts from JAVYS shared the company's decommissioning insights with experts from Armenia, Belgium, Bulgaria, China, the Czech Republic, Finland, Hungary, Italy, Norway, Türkiye and Uzbekistan as well as representatives of EBRD and EC.

"Some of these countries currently operate WWER reactors and are planning for their decommissioning, while others are embarking on nuclear power programmes or building nuclear facilities and are already considering their long-term decommissioning requirements," said Mykolaichuk. "We are seeing the emergence of more responsible and forward-looking nuclear activities, where decommissioning and its challenges are considered from the beginning. These activities are strengthened by the lessons from the efforts by JAVYS at Bohunice V1."

A group scientific visit to Trnava and the Bohunice nuclear power station in Slovakia included experts from Georgia, Greece, Hungary, Lithuania, Russia, Slovenia and Ukraine.
(Photo: D. Calma/IAEA)

Next generation tools enable faster, more effective decommissioning of nuclear reactors after severe accidents

By Nayana Jayarajan

Within days of the most powerful earthquake ever recorded in Japan, it was apparent that Units 1-4 at the Fukushima Daiichi nuclear power station (NPS) would be shut down permanently. On 11 March 2011, huge tsunami waves caused by the earthquake broke through Japan's coastal defences, including the perimeter of the NPS, causing extensive damage. Flooding knocked out the emergency generators, causing nuclear fuel in three reactor units to overheat and partially melting the cores. The NPS also experienced several hydrogen explosions which damaged buildings and led to the release of radioactive material. More than 150 000 people were evacuated from the Fukushima prefecture and authorities set up an exclusion zone. However, even once the immediate crisis following the tsunami had largely been resolved, the challenges of decommissioning the heavily damaged facility were just beginning.

> **"Remotely operated robots that carry radiation measurement/visualization tools are a priority area of research and development to help minimize the radiation exposure to site workers, and to systematically advance the decommissioning of Fukushima Daiichi."**
>
> *— Kentaro Funaki, Executive Director, Japan Atomic Energy Agency.*

Decommissioning a nuclear facility after a severe accident is a complex endeavour and, in comparison with decommissioning after a planned shutdown, often requires specific approaches, techniques and practices. This makes guaranteeing radiation safety while carrying out all operations a major challenge. For instance, one of the most delicate jobs in the decommissioning of a damaged reactor is the removal of spent and damaged fuel.

In the case of the Fukushima Daiichi nuclear accident, some nuclear fuel had melted and fallen to the lower containment sections of reactor units 1, 2 and 3. High levels of radiation inside the containment buildings restricted worker access to the area close to the reactor. The operators faced a major challenge: how were they to remove the damaged fuel when they did not know its exact location?

Enter cosmic-ray muon mapping, a technique that was first deployed over six decades ago and that has been used since in applications from mapping the insides of volcanoes and ancient Egyptian pyramids to detecting nuclear material in shipping containers. Muon tracking devices detect and track naturally occurring, high energy subatomic particles as they pass through materials, using changes in trajectory to determine material density. Nuclear materials such as uranium and plutonium are very dense and, therefore, relatively easy to identify using this technique.

Cosmic-ray muon mapping was deployed at the Fukushima Daiichi NPS to estimate the location and condition of fuel debris in the reactor cores. In 2015, experts in Japan developed a modified technique that allowed debris as small as 30 centimetres in size to be tracked. This technique was used to determine the status of the damaged fuel in the Fukushima Daiichi Unit 1 reactor, an essential precursor to decommissioning.

This example is just one of many where technological innovation has been used to solve the unique and unforeseen challenges of post-accident decommissioning and recovery.

"The consequences of an accident are always unpredictable, and existing organizational and technical infrastructure, and available technologies, may not be suitable or sufficient for post-accident needs. Often, when decommissioning damaged nuclear facilities, technological approaches and associated equipment are developed on a case-by-case basis," said Vladimir Michal, a decommissioning expert at the IAEA, who co-led a project to document and analyse the decommissioning and remediation of damaged nuclear facilities, 'the International Project on Managing the Decommissioning and Remediation of Damaged Nuclear Facilities' or DAROD. "In many instances, as in the example of cosmic-ray muon mapping, these technologies found wider application in decommissioning, or even in other industries."

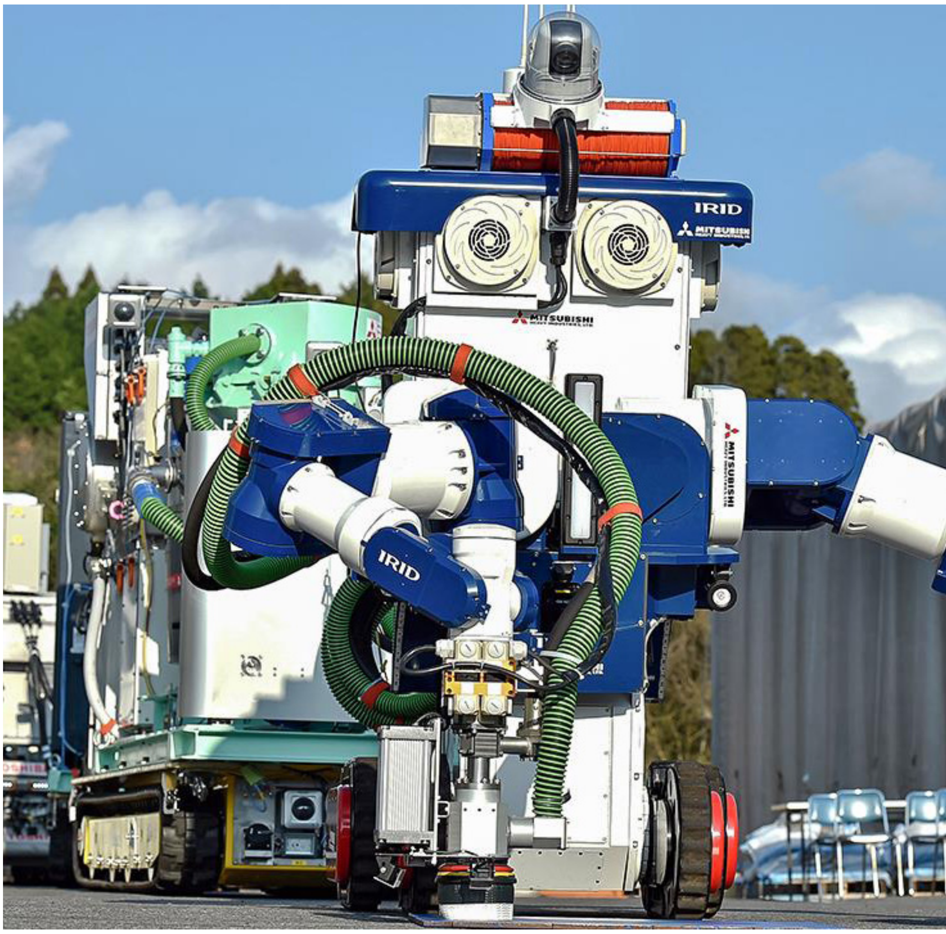
Another notable example is the construction of a new safe confinement 'shield' over the Unit 4 reactor building of the Chornobyl Nuclear Power Plant (NPP) in Ukraine between 2016 and 2019. Constructed to replace the temporary shelter built after the 1986 disaster, it is the largest land-based movable structure in the world and is designed to last a century and to withstand a severe tornado. The new confinement structure was constructed some 180 metres west of the damaged Unit 4. Its construction and subsequent positioning involved the use of state-of-the art civil engineering techniques.

"The new safe confinement does more than prevent the release of radioactive material: it assists with future decommissioning," said Valeriy Seyda, the Acting General Director of State Specialized Enterprise Chornobyl NPP. The safe confinement structure is designed to prevent the release of radioactive contaminants, protect the internal structures of the reactor and facilitate decommissioning. For the latter purpose, the confinement structure incorporates two state-of-the-art remotely operated cranes. These hang from just under the roof and are designed to allow the eventual decommissioning of Unit 4, while protecting workers and the environment.

At the Fukushima Daiichi NPS, the well-established engineering technique of building a subterranean frozen soil wall was used to prevent groundwater from flowing into the site and mixing with the already-contaminated water inside the reactor buildings. The 1500 metre wall was established by freezing the soil so that it became impermeable to groundwater, thus reducing the overall amount of contaminated water requiring treatment.

Advanced remote operation and robotic technologies can now enable decommissioning work to proceed in areas with high radiation levels. At the Fukushima Daiichi NPS, for example, robots are used for monitoring and measurement, to carry out surveys, for decontamination and to prepare for the removal of fuel debris.

"Remotely operated robots that carry radiation measurement/visualization tools are a priority area of research and development to help minimize the radiation exposure of site workers, and to systematically advance the decommissioning of Fukushima Daiichi," said Kentaro Funaki, an Executive Director of the Japan Atomic Energy Agency. Funaki highlighted international joint projects as one of the key areas among a wide range of government-funded research and development projects. "Extensive efforts are ongoing to visualize radioactive hotspots in three dimensions near Units 1 and 2 of Fukushima Daiichi. A great deal of success has been achieved by incorporating the results of national and international joint research, and these efforts will continue to be pursued in the future," he said.



Decontamination robot deployed at Fukushima Daiichi to support decommissioning activities

(Photo: The International Research Institute for Nuclear Decommissioning (IRID), Japan)

The use of non-nuclear technologies in nuclear environments brings many challenges, including significant development costs, particularly owing to the presence of radiation and uncertainty concerning the precise conditions in which the equipment will operate. However, advances in wiring and other critical components, along with the development of radiation-resistant equipment, make it possible to safely and effectively apply robotic technologies in these challenging environments. In addition, laser technologies enable the interiors in such environments, which are often inaccessible to humans, to be scanned, while protecting the health and safety of workers. "These advances greatly enhance the possibility of safely and effectively dismantling, even in very challenging situations, facilities that have suffered a severe nuclear accident," said Michal.

Robots, AI and 3D models

How high-tech breakthroughs help nuclear decommissioning

By Jeffrey Donovan

> **“The aim of the project is to harness the expertise of a diverse range of organizations involved in decommissioning to fully realize the potential of new and emerging technologies.”**
>
> *— Olena Mykolaichuk, Head, Division of Nuclear Fuel Cycle and Waste Technology, IAEA*

Robots, drones, artificial intelligence (AI) and other emerging digital technologies, which are already helping to advance nuclear decommissioning projects worldwide, are set to play an increasingly key role in the sector, as more and more countries choose to immediately dismantle their retired nuclear facilities.

To help get the job done efficiently and reduce risks, including financial and radiological ones, countries are turning to high-tech tools such as virtual reality and 3D simulation — a trend that looks set to intensify in the coming years as several ageing nuclear power plants and other nuclear facilities are phased into retirement.

“Whether it’s radiation-defying robots working at accident sites such as Fukushima Daiichi in Japan, or 3D modelling used to better plan dismantling at retired power plants, the nuclear decommissioning sector increasingly finds itself at the forefront of technological innovation,” said Mikhail Chudakov, IAEA Deputy Director General and Head of the Department of Nuclear Energy. “These technologies provide vital insights for planning and implementing projects, especially in situations which could be risky for people, thereby helping to ensure these jobs are carried out safely and effectively.”

From across Europe to Asia and the Americas, examples of cutting edge tech being used to overcome unique challenges and advance decommissioning projects abound. One organization at the forefront of this trend is Norway’s Institute for Energy Technology (IFE), which in 2019 became an IAEA Collaborating Centre focused on supporting IAEA activities and Member States in the digitalization of knowledge management for nuclear decommissioning. IFE has pioneered the use of virtual reality systems to support maintenance and decommissioning in nuclear environments.

“These technologies are used to train workers, including in radiation visualization, so that they have an understanding of the radiological conditions,” said István Szőke, a research manager at IFE. “The core of IFE’s expertise is integrating 3D digital models of nuclear assets with physics and AI models, including real-time radiation physics models. This means that there is real physics behind the radiation visualization, and radiation transport models can calculate, for instance, the radiation levels present in the environment surrounding equipment to be dismantled, which is visualized for planning and training purposes.” This practice is now becoming increasingly commonplace in decommissioning programmes, including for power and research reactors, as well as for fuel cycle facility dismantling.

More recently, IFE has supported international collaboration aiming to establish modular, integrated information management systems for use throughout the entire decommissioning process. This involves building an integrated system based on 3D scanning and computer-aided design (CAD) or producing building information management (BIM) models incorporating 3D radiological and other data. Such a model or design manages all information, is integrated with radiological physics models and other systems, and brings them all together into a system that supports the principle of reducing the radiological risk to ‘as low as reasonably achievable’ (ALARA).

Digital simulations and 3D modelling have also been successfully used in decommissioning projects in both Italy and Slovakia. Italy’s State decommissioning and radioactive waste management company, Sogin, has used 3D models and simulations to help prepare for reactor dismantling and for managing generated waste streams. The Slovak Nuclear and Decommissioning Company (JAVYS) has employed 3D models and simulations in the dismantling of power reactor components at the country’s Bohunice

A1 and V1 nuclear power plants. Like IFE, Sogin and JAVYS share their knowledge and experience with the global nuclear community as IAEA Collaborating Centres for decommissioning and radioactive waste management.

A related current trend involves the increased use of robotics. This can reduce the risk to personnel by enabling them to work away from the tools deployed to manipulate components, as well as improving efficiency, as autonomous and remotely operated robots are better able to access and work in hard-to-reach areas. Mobile robots carrying sensors and 3D systems are increasingly used to scan facilities and collect data that can be used to build 3D models of the site. “One of the very urgent objectives right now for the industry is to work out how to use AI to turn 3D scans, which are now very easy to produce, into intelligent BIM models,” Szőke said. “Allied to this is the development of ‘digital twins’ of facilities, which can be used to support the decommissioning of complex systems, but also to organize knowledge of the facility throughout its life cycle.”

In 2022, the IAEA launched a global initiative aimed at boosting the role of new and emerging technologies in the decommissioning of nuclear facilities. The initiative, a collaborative project among organizations involved in the planning or implementation of decommissioning and associated research activities, aims to provide information on the new and emerging digital tools and technologies used in data management, planning, licensing and implementation of decommissioning.

“The aim of the project is to harness the expertise of a diverse range of organizations involved in decommissioning to fully realize the potential of new and emerging technologies,” said Olena Mykolaichuk, Head of the IAEA’s Division of Nuclear Fuel Cycle and Waste Technology. The IAEA will publish the project findings in a report in 2025, including information on experiences gained from several countries, with the aim of further supporting successful decommissioning projects around the world.

“Dog robot”: Autonomous legged robot making radiation mapping around Chernobyl Unit 4
(Photo: Boston Dynamics, USA)

Decommissioning by design

How advanced reactors are designed with disposal in mind

By Joanne Liou

Planning for the end of life from the outset might not be either particularly appealing or a priority. However, when it comes to a nuclear facility's life cycle, the value in accounting for that end of life is driving designers, vendors and regulatory bodies to address decommissioning upfront. This proactive approach, known as decommissioning by design, draws on best practices and lessons learned from past experience, and implements a 'by design' concept that is also applied to nuclear safety, security and safeguards. When decommissioning is considered from the outset, facility developers can make design choices that will make decommissioning safer, more efficient and more cost-effective.

> "By taking into account decommissioning in the design stage of a nuclear facility, it is possible to optimize its final phase — its decommissioning — which is mandatory in the life cycle of a reactor."
>
> *— Helena Mrazova, Decommissioning Technology Specialist, IAEA*

"By taking into account decommissioning in the design stage of a nuclear facility, it is possible to optimize its final phase — its decommissioning — which is mandatory in the life cycle of a reactor," said Helena Mrazova, a Decommissioning Technology Specialist at the IAEA. Early generations of nuclear power plants (NPPs) were designed with a focus on short-term operational performance, with decommissioning as an afterthought. For example, the designs of some graphite gas cooled reactors built in France in the 1970s did not address how they would be dismantled, and this is now proving difficult to implement.

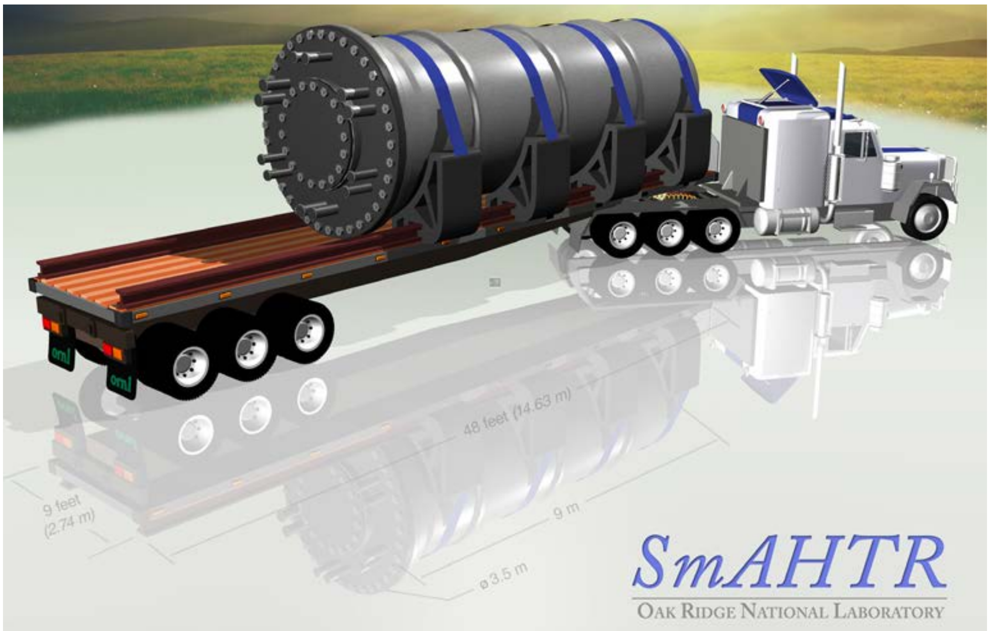
"We have facilities that are more than 60 metres in height, 30 metres in diameter and with thick walls of more than 5 metres of concrete, housing tonnes of graphite in the reactor core. The dismantling of these reactors is very challenging, because they were simply not designed to be decommissioned. The French electricity utility company EDF (Électricité de France) has recently established a Graphite Reactor Decommissioning Demonstrator (which has also become an IAEA Collaborating Centre) to test, improve and optimize innovative tools and remote handling technologies on full-scale mock-ups and digital 3D models in order to verify the feasibility of decommissioning scenarios and optimize the decommissioning of these reactors," Mrazova said.

Great expectations and opportunities

The aims of decommissioning by design are to better plan the sequence of decommissioning activities, to reduce potential radiation exposure of workers, and to reduce the amount of radioactive waste, thereby lessening the burden on waste facilities and future generations. "Decommissioning by design does not only involve physical design features, it also includes how businesses are structured to plan and conduct the decommissioning activities," said Marcel Devos, Director of Regulatory Affairs for Prodigy Clean Energy, a developer of marine- and land-based transportable NPPs. Devos formerly managed the Vendor Design Review (VDR) programme at the Canadian Nuclear Safety Commission (CNSC). "Determining funding mechanisms and establishing responsibilities for decommissioning are essential to enable a successful end-of-life process," he said.

Although decommissioning by design has not been universally adopted, Canada is one country that has taken steps towards this forward-looking practice. The CNSC's review for reactor vendors includes decommissioning by design, which applies lessons learned from experiences documented by the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development. "Future owners and operators in Canada are increasingly expecting vendors to complete the VDR process and to have a clear plan to resolve gaps that have been identified. Industry is recognizing that end-of-life considerations are a priority in the licensing and environmental assessment processes," Devos said.

There is growing interest in small modular reactors (SMRs), which are a type of



Many SMR reactors are designed to be small enough to be transported by truck or shipping container.

(Photo: Oak Ridge National Laboratory, US Department of Energy)

advanced nuclear reactor with a limited power capacity — typically up to 300 MW(e) per reactor. "Developers of the next generation of NPPs, including SMRs, have a tremendous opportunity to address, through the design and deployment process, the social questions associated with the end of life of a nuclear facility, while speeding up decommissioning and reducing waste burdens on future generations," Devos said.

Decommissioning for SMRs

There are more than 80 SMR designs and concepts in various stages of development around the world. With the portfolio of SMRs varying in size, materials and technology, decommissioning approaches for these advanced reactors will vary. "The decommissioning process will depend on the facility's design, its accessibility and compactness, as well as a country's spent fuel and radioactive waste management plans and practices," Mrazova said.

The modularity of SMRs and their various deployment models could redefine conventional decommissioning practices. Some smaller SMRs, commonly referred to as microreactors, are designed to be factory-assembled and transported as a unit to a location for installation. At the end of life, the module would be returned to the factory of origin to be refuelled or moved to a decommissioning facility. "This approach could reduce costs and the scope of activities taking place in the locality of the power plant, increase nuclear and radiation safety, and increase acceptance of SMR deployment," Mrazova said. "There is also potential for the standardization of some decommissioning activities, such as the decontamination or dismantling of primary equipment." However, this approach leaves tasks outstanding, such as the development of specialized dismantling tools and remote handling equipment.

Knowledge of the materials used, such as the type of steel, and of the required standards for steel producers, including the need for very low levels of impurities in order to minimize activation, will positively impact the management of waste from decommissioning. By practising decommissioning by design, impurity levels and the associated cost impacts on dismantling at the end of life could be limited when material composition is addressed carefully beforehand.

"The general rule for decommissioning nuclear facilities, including SMRs, is to have a 'decommissioning-friendly' design, underscoring the value of the early approach," Mrazova said. "The distinguishing features of SMRs, such as their modular design and material selection, should make the decommissioning process more efficient, less costly and reduce the daily dose rate of global workers involved in decommissioning."

The IAEA is developing a publication focused on the design aspects of SMRs for decommissioning, which is expected to be published in 2024.

How the circular economy is transforming nuclear decommissioning

By Artem Vlasov

The traditional linear economic model — extracting materials, turning them into manufactured goods and discarding them after consumption — is often criticized for creating a considerable amount of waste and pollution, as well as contributing to climate change and biodiversity loss. According to the United Nations Environment Programme International Resource Panel, the extraction and processing of natural resources account for about half of all global greenhouse gas emissions.

A departure from this model, known as the circular economy, offers a way to reduce waste and associated pollution. It is a model of production and consumption that seeks to effectively keep resources in use for as long as possible by reducing, reusing and recycling them.

When nuclear facilities are being decommissioned, the adoption of circular economy principles can provide many benefits. Decommissioning is a multidisciplinary process, typically lasting a decade or more, that involves the decontamination, dismantling and demolition of nuclear facilities so that a site can be released from regulatory control and reused. By recycling materials during this process, less waste is generated. This has the added benefits of lowering the cost of decommissioning and reducing the risk of delays.

"By applying the principles of a circular economy to decommissioning, we can reduce the amount of radioactive and non-radioactive waste to be disposed of and, at the same time, reduce the amount of raw material pulled out of the ground," said Arne Larsson, radioactive waste technology and decommissioning manager at Cyclife Sweden. "Instead, we can reuse materials and equipment from existing installations, buildings and structures, and support making the site available again for other useful purposes."

Worldwide, more than 200 nuclear power reactors have been shut down for decommissioning, while it is expected that hundreds of reactors currently in operation will be shut down and decommissioned in the coming decades. Today's nuclear facilities are designed with decommissioning and waste management plans in place before the first brick is laid. The designs of nuclear reactors constructed in the 1960s and 1970s, by contrast, did not take circularity principles into account.

The French city of Grenoble used to be home to six nuclear facilities. After successful decommissioning, the site now serves as a centre for research and development in the field of renewable energy.
(Photo: Unsplash)

However, even old facilities can be effectively decommissioned by using circularity principles: up to 90 per cent of the non-radioactive materials at a nuclear power plant, such as metals, concrete and even work clothing, can be reused or recycled. Only around three per cent of materials, mainly spent fuel, are highly radioactive and, even then, more than 95 per cent of this fuel can be reprocessed to make new fuel and by-products.

“Adopting circular economy principles can provide significant drivers for minimizing waste, increasing efficiency and enhancing sustainability,” said Vladimir Michal, Acting Head of the IAEA’s Decommissioning and Environmental Remediation Section. “Decommissioning of nuclear facilities generates noteworthy amounts of materials that can be recycled and reused for other purposes.”

From six nuclear facilities to a renewable energy centre

Recycling is already widespread in decommissioning work. After dismantling, large metal components can be melted down and turned into ‘new’ metal to be returned to the economy. Equipment parts can be reused in other operating nuclear facilities, and materials from demolished buildings, such as concrete, can be used as fill material for site restoration or in other construction projects, including for houses and roads. For example, when the Australian research reactor MOATA, located in Sydney, was decommissioned in 2009, more than 85 per cent of the materials were reused or recycled.

Materials left over after decommissioning that cannot be decontaminated and cleaned up for reuse or recycling are disposed of as radioactive waste in repositories of different types until it no longer presents a hazard to humans or the environment (see page 22).

There are several examples of repurposed nuclear sites, including nuclear power plants, research reactors and other facilities used in medicine or industry. Nuclear power plant sites can be turned into waste processing and storage facilities or research centres for training operating personnel. The sites can become industrial parks and buildings can be given new life through repurposing for other conventional industries, attracting businesses and creating new jobs.

In the French city of Grenoble, six nuclear facilities, including three research reactors, one laboratory and two radioactive waste storage facilities, were successfully decontaminated and dismantled in 2012. The site is now used as a research and development centre for green energy technology and renewable energy sources, focusing on electric vehicles, batteries and hydrogen.

The IAEA provides a space for countries, organizations and individuals to cooperate and share knowledge and technology in the field of decommissioning. The IAEA’s e-learning platform contains lectures on decommissioning, environmental remediation, radioactive waste and spent fuel management.

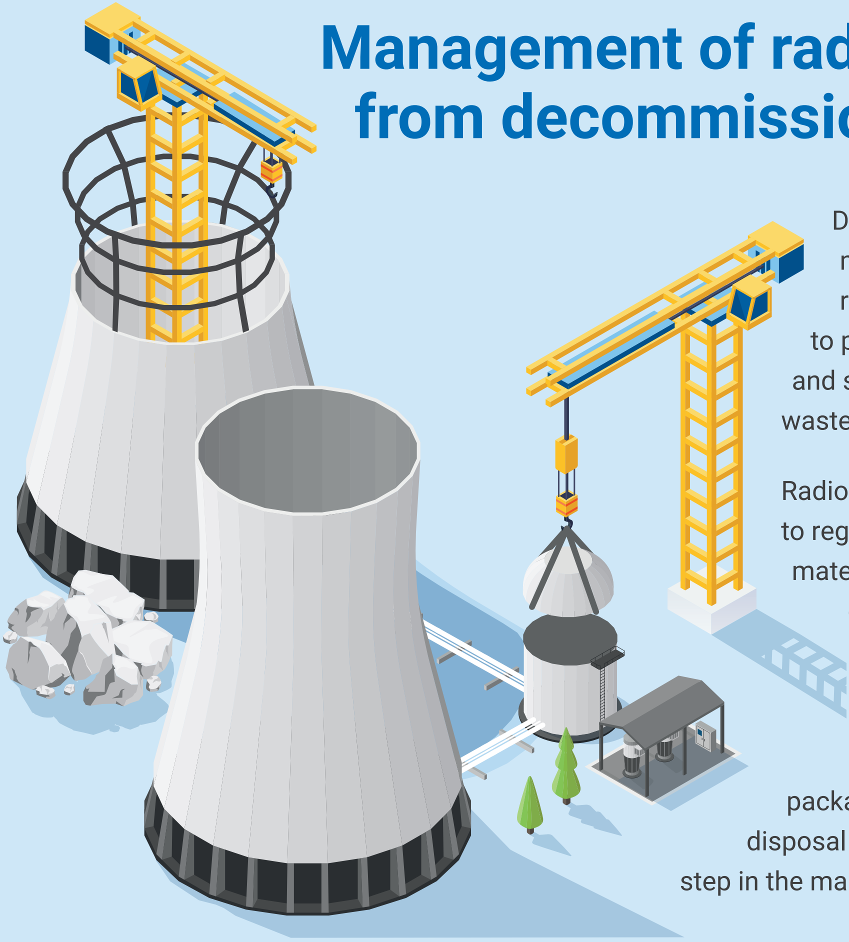
The IAEA’s International Decommissioning Network (IDN) was set up in 2007 to provide a forum enabling professionals involved in decommissioning to collaborate and interact. In addition, the IAEA supports capacity building in Member States and facilitates expert missions, peer review and advisory services for decommissioning programmes and other related activities, such as radioactive waste and spent fuel management.

“The circular economy offers a promising approach to adapting the industry to sustainability and circularity, reducing the environmental impact and conserving resources for future generations,” Michal concluded.

“Adopting circular economy principles can provide significant drivers for minimizing waste, increasing efficiency and enhancing sustainability.”

— Vladimir Michal, Acting Head, Decommissioning and Environmental Remediation Section, IAEA

Management of radioactive waste from decommissioning



During decommissioning, radioactive materials and objects contaminated with radioactivity — from protective clothing to parts of a reactor — are characterized and sorted to ensure waste prevention and waste minimization, reuse and recycling.

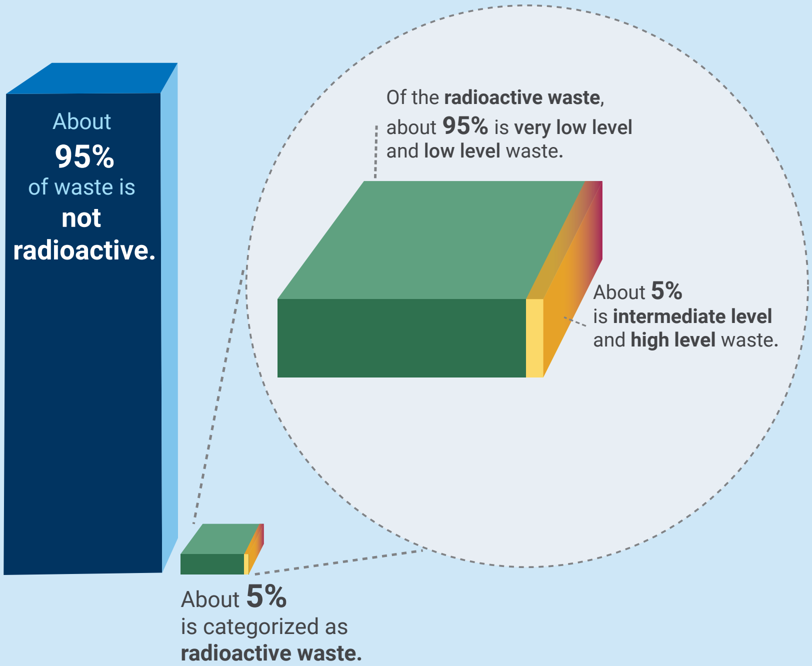
Radioactive materials and objects are subject to regulatory control. However, most of the material resulting from decommissioning is cleared from regulatory control, owing to its very low level of radioactivity.

Radioactive materials not suitable for recycling are sorted and packaged for temporary storage before disposal in purpose-built facilities — the final step in the management of radioactive waste.

The waste hierarchy

The waste hierarchy, a key element in the implementation of sustainable decommissioning and waste management, sets the priority for managing waste. By taking decommissioning into account during the design phase of a nuclear facility, the creation of waste is prevented and minimized.

Amounts of waste from decommissioning



The range of waste resulting from decommissioning varies widely in terms of quantity and radioactivity. About 5% of the material resulting from decommissioning a nuclear power plant is radioactive at levels that mean it must be managed as radioactive waste (see classification below).

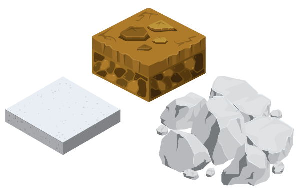
Classes and types of radioactive waste

The classification of radioactive waste may vary from country to country.

VLLW

Very low level waste

Concrete, soil, rubble...

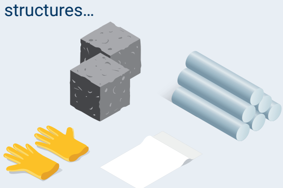


Suitable for disposal in near surface landfills.

LLW

Low level waste

Personal protective equipment, wipes, auxiliary systems for decontaminating and dismantling structures...

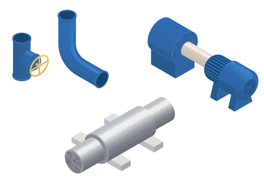


Suitable for disposal in near surface facilities; requires isolation and containment for up to several hundred years.

ILW

Intermediate level waste

Reactor primary circuit components, highly contaminated metals...

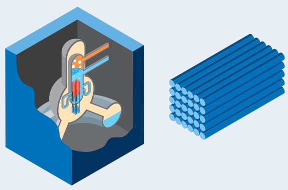


Suitable for disposal at greater depths in geological repositories; requires isolation and containment for several thousand years.

HLW

High level waste

Spent fuel, spent fuel cladding hulls, vitrified waste from reprocessing...

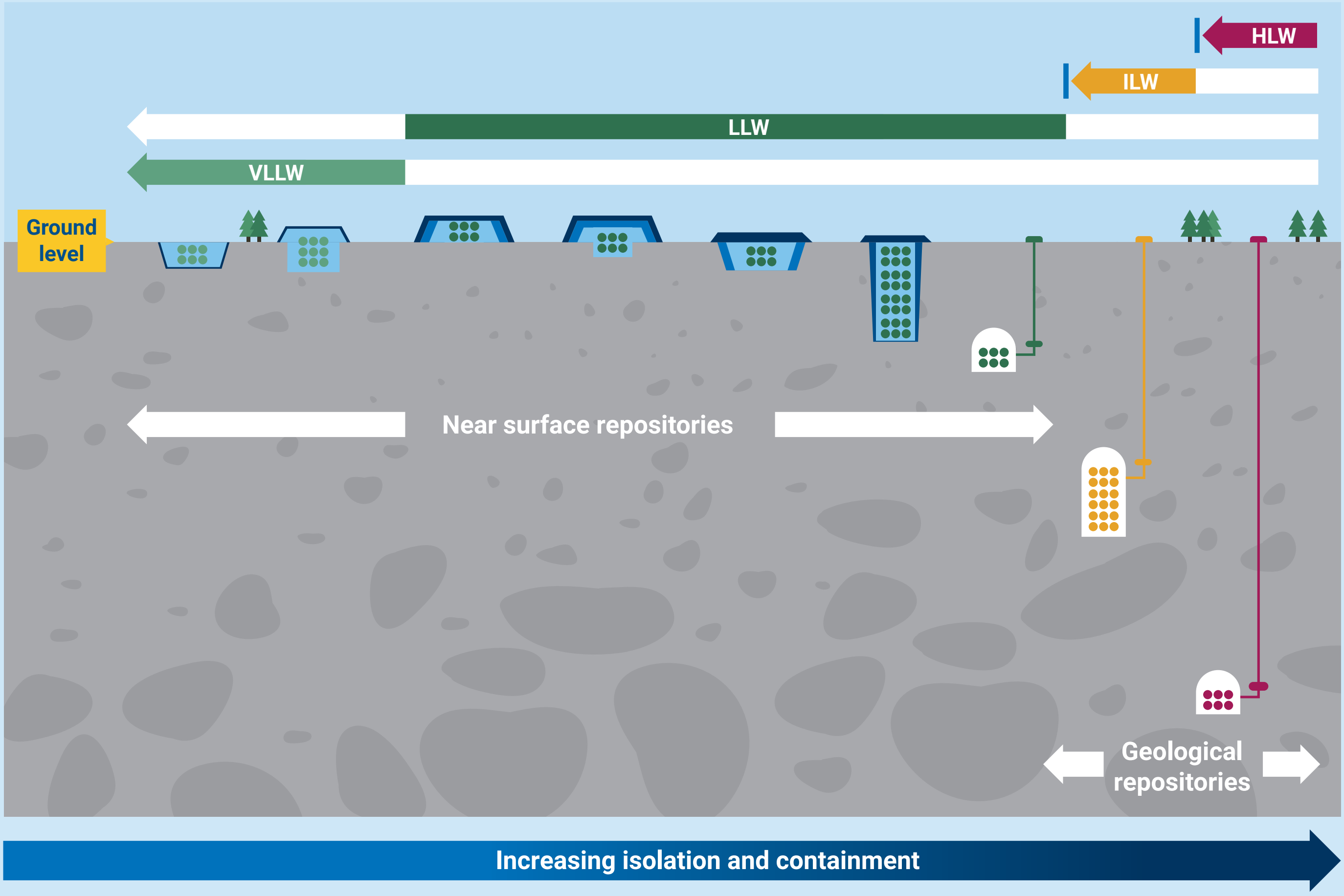


Suitable for disposal in deep geological formations several hundred metres below the surface; requires isolation and containment for several thousand years.

Disposal facilities for radioactive waste provide isolation and containment based on multiple barriers and safety functions.

Reuse and recycling of materials cleared from regulatory control

Disposal options based on the class of radioactive waste



How is radioactive waste safely managed?

There have been several decades of research, development and demonstration of the **safe disposal of radioactive waste.**

With multiple layers of protection, the public and the environment are safe from hazards and risks arising from the use of ionizing radiation — including from radioactive waste.

Access is strictly controlled to the sites where radioactive waste is managed.

In accordance with strict procedures, the safety of radioactive waste management is the prime responsibility of the operator and is overseen by independent regulators.

Radioactive waste is managed by qualified and experienced personnel.

Regulatory authorization of waste management facilities and activities is based on a safety case and detailed safety assessments.

How does the safe management of radioactive waste contribute to the UN Sustainable Development Goals (SDGs)?

- Safe management of radioactive waste, environmental releases, decommissioning and remediation protects life on land and life below water.
- Safe management of radioactive waste, environmental releases, decommissioning and remediation contributes to recycling and reuse of materials, objects and sites.
- Nuclear technologies are sustainable when safe throughout their lifetime including safe management of radioactive waste, environmental releases and decommissioning.
- Sustainable use of nuclear technologies contributes directly to nine SDGs.

Nuclear decommissioning market set to boom

By Joanne Burge and Emma Midgley

As many nuclear power plants (NPPs) around the world near the end of their life cycle, a new industry based around decommissioning nuclear facilities is emerging. In addition to NPPs, many other facilities involved in the nuclear fuel cycle, such as research centres and facilities for reprocessing spent fuel or for waste treatment, will need to be decommissioned when they reach end of life. In total, it is likely that several hundred billion dollars will be spent on decommissioning worldwide between now and 2050, and businesses and investors are already securing their positions.

There are around 420 nuclear power reactors currently in operation around the world. Around 200 nuclear reactors are expected to begin the decommissioning process by 2050. In addition to the work of decommissioning the reactors (projects which may last 20 years or more from start to finish), decommissioning expertise is also required in the design of new nuclear facilities. There are currently over 50 reactors under construction globally. Before they were constructed, each of these required a decommissioning plan to be in place. The decommissioning industry, therefore, looks to have strong long-term prospects.

Nuclear engineering, construction, demolition and waste management companies are expected to be the main service providers to the decommissioning industry. Their role will be to decontaminate and dismantle nuclear facilities and to rehabilitate sites for a safe, useful future, taking into account sustainability and socio-economic factors. Nuclear facilities must also be dismantled and made safe in a way which considers environmental impacts, in line with circular economy principles, including by recycling recovered metals, wires and cables, and segregating clean concrete from reinforcement steel concrete. At the same time, this complex task requires a highly skilled nuclear workforce, which must be expanded in order to avoid a nuclear skills shortage in the future.

In order to retain knowledge and advance the industry, the IAEA International Decommissioning Network provides a forum for organizations and individuals involved in the decommissioning and dismantling of nuclear facilities to share experiences and lessons learned. The IAEA assists countries in the planning and implementation of decommissioning by providing safety, legal and technical advice, and by supporting knowledge sharing through training courses and workshops. It plays an important role in facilitating broad international collaboration, as well as conducting technical reviews to establish good practices and to ensure that lessons are learned from experience.

“The network brings together organizations and individuals involved in the decommissioning and dismantling of nuclear facilities,” said Tetiana Kilochytska, a Decommissioning Specialist at the IAEA. “It helps disseminate information relevant to the decommissioning process, such as the sharing of best practices and innovations, to enhance cooperation and coordination in the decommissioning industry around the world.”

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— Tetiana Kilochytska, Decommissioning Specialist, IAEA

One of the oranizations sharing its expertise for the benefit of others is the organization responsible for the Sellafield site in the United Kingdom. The site has hosted a range of nuclear facilities, such as nuclear power reactors, fuel reprocessing facilities and waste treatment plants. When it opened in the 1950s, Calder Hall on the Sellafield site was the first commercial nuclear power station in the world. The large range of aged nuclear facilities on a compact footprint means the decommissioning professionals working site has had to develop innovative and unique solutions during decommissioning, including digitalization and robotics.

“It is a very complex nuclear decommissioning challenge,” said Mike Guy of Sellafield Limited.

“That is due to the large number and diverse nature of the facilities in close proximity on a congested site. We must deal with a wide range of waste challenges, including waste that has been stored in underwater ponds and the removal of waste from very large and complex cells."

Decommissioning at the Sellafield site began in the 1980s and is expected to continue throughout this century, and even beyond. This wealth of experience means that Sellafield is in an ideal position to share its unique expertise and experiences with the international decommissioning community. It has already implemented new processes to simplify and accelerate the treatment of radioactive waste at legacy sites, and shared its knowledge on the dismantling of structures in order to help engineers design facilities which are easier to deconstruct.

In addition, investment in supply chains that work with Sellafield Limited shows the potential financial benefits for companies entering the nuclear industry. In 2021, the United Kingdom's Nuclear Decommissioning Authority, the public body which oversees decommissioning at the Sellafield site, spent around 55 per cent of its 4 billion US dollar annual budget on services provided by partner companies.

Accelerated decommissioning

The experience gained from implementing decommissioning programmes over several years is increasingly being used to shorten the duration of decommissioning projects. Reducing the number of years spent on various projects can achieve significant budget reductions, as labour costs account for a large proportion of the cost of a project. Decommissioning projects that have recently been launched for commercial power reactors in the United States of America aim to reduce the duration of the main phase of dismantling (not including activities related to licence termination) to between five and seven years, which is about half the current global average duration for this phase of activity.

By optimizing the interaction between the main project activities and dismantling and waste management, it is possible to shorten the length of time required for the completion of projects. Good project management and good relationships between the facility owner and the supply chain are vitally important. Major programmes, such as that at Sellafield, typically aim to develop long-term partnering approaches with the supply chain, based on contracts with durations of up to a decade.

Achieving early authorization for decommissioning also helps to reduce the length of time required to achieve the release of the facility from regulatory control. Recent programmes in Germany aim to obtain decommissioning authorizations at about the same time as the permanent shutdown of the facility. Such an approach requires that detailed planning activities and associated safety assessments are undertaken prior to the facility being permanently shut down.

Decommissioning projects produce extremely large quantities of material that need to be managed effectively. Having the opportunity to recycle or reuse a large amount of this material and being able to quickly dispose of material that must be managed as waste is also key to reducing overall costs, and is a significant contributory factor for future accelerated decommissioning.

Decommissioning at the Sellafield site in the UK is expected to last many decades.
(Photo: Sellafield Ltd.)

Applying nuclear safeguards during decommissioning

By Jennifer Wagman

The IAEA helps deter the spread of nuclear weapons through a set of technical measures known as safeguards, which work by verifying that countries are honouring their international legal obligations not to misuse nuclear material and technology. These obligations extend to decommissioning projects. As of March 2023, a total of over 200 nuclear facilities had permanently ceased to operate, either because they had reached the end of their natural life cycle or due to national policy decisions. Countries remain legally obligated to fulfill safeguards agreements throughout the process of decommissioning, and, in some cases, afterwards too.

Since decommissioning is a variable and lengthy process, the IAEA has established guidelines to ensure that safeguards continue to be applied until the facility has been determined to be decommissioned for safeguards purposes.

These IAEA guidelines require two main safeguards objectives to be met: the first is to verify that all nuclear material has been removed from the facility to a known location; the second is to ensure that all essential equipment has either been removed from or made inoperable at the facility.

During decommissioning, countries are encouraged to work with the IAEA to periodically submit plans for related activities and to update design information to reflect changes within the facility. As nuclear material and essential equipment are removed, the IAEA constantly reassesses the safeguards measures and activities implemented at the facility, and revises them as necessary in consultation with the country concerned. Early engagement with countries on the details of this process is known as safeguards by design.

"Safeguards by design is a timely and cost-effective process of collaboration, where we ensure that safeguards obligations are fully understood by all stakeholders well ahead of time," said Jeremy Whitlock, a Senior Technical Advisor in the IAEA Department of Safeguards. Whitlock works with industry, regulators and other stakeholders to incorporate safeguards in the design phase of new or modified nuclear facilities, including those undergoing decommissioning. "To assist countries in decommissioning a nuclear facility, we have developed guidelines outlining safeguards requirements and activities. These help countries and facility operators understand the necessary steps, and how to work with the IAEA to ensure that decommissioning progresses on the desired timeline."

As part of decommissioning a nuclear reactor, IAEA safeguards should be followed during a 'campaign' that transfers spent fuel to another facility for storage or long-term disposal. For such a campaign, additional safeguards surveillance and/or monitoring equipment is typically installed, with regular reviews of the recorded data.

"By verifying the movement of nuclear material to a storage location, the IAEA maintains continuity of knowledge of the material at all times. This helps to provide credible assurance that the nuclear material is not diverted from peaceful use," said Lai San Chew, a Nuclear Safeguards Inspector at the IAEA. Chew is responsible for verifying spent fuel items, observing transfers and reviewing updated design information during spent fuel transfers in preparation for final decommissioning.

Once all nuclear material has been removed, the operator of the facility will start dismantling essential equipment. Finally, the

operator removes the most important piece of essential equipment, the reactor core, which is disposed of at a waste treatment facility. The country then sends the final updated facility design information to the IAEA in order to formally notify it that the facility has been decommissioned.

After the nuclear material is secured under appropriate safeguards in a storage or long-term disposal facility, the IAEA verifies the absence of nuclear material at the original facility being decommissioned, and also confirms that all essential equipment has been removed or made inoperable. Once the determination is made that a facility has been decommissioned for safeguards purposes, the IAEA discontinues routine inspection and design-verification activities at the facility.

"By working with the country and facility operator to ensure a full understanding of the special needs of decommissioning a safeguarded facility, we help achieve a safe and secure transition to closure of operations that meets all of the country's international obligations," says Kerrin Swan, a Safeguards Analyst at the IAEA.

Safeguards Inspection at URENCO, Almelo, Netherlands.
(Photo: D. Calma / IAEA)

Preparing 60 years in advance

The UAE's first nuclear power plant and plans for future decommissioning

By Artem Vlasov

> "The UAE, which has successfully launched its first nuclear power plant, already has an initial decommissioning plan for when the plant reaches its end of life."
>
> *— Tetiana Kilochytska, Decommissioning Specialist, IAEA*

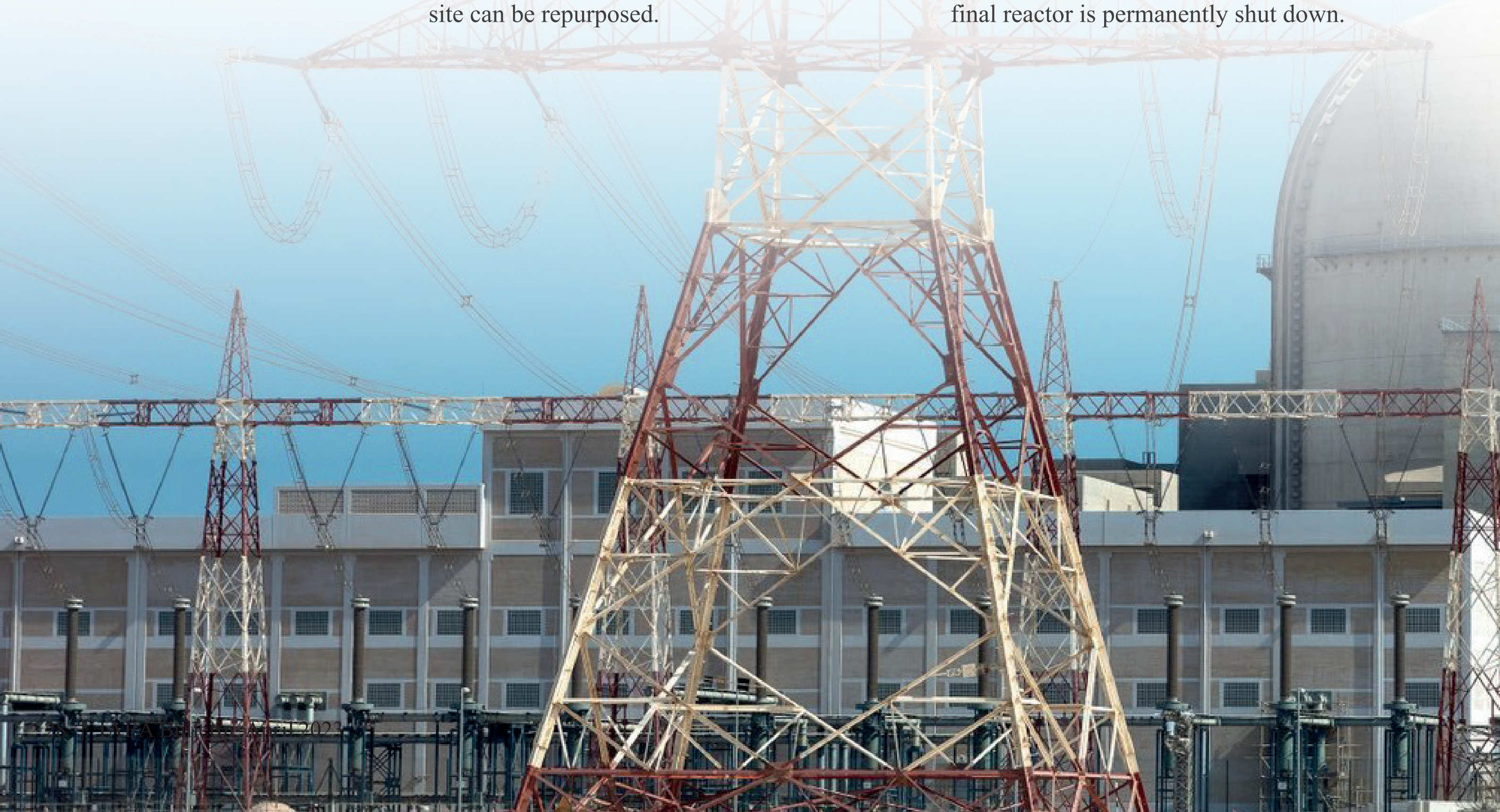
Since the discovery of oil and gas reserves over half a century ago, the United Arab Emirates (UAE) has undergone a remarkable economic transformation. In just a few decades, the country has transitioned from a small fishing and pearl trading economy to a global hub for tourism, trade, business and finance. With a view to sustaining this economic progress while reducing its carbon emissions, the UAE is diversifying its energy mix, including through the introduction of nuclear energy.

The Barakah nuclear power plant (NPP), the first in the UAE and the Arab world, began operating in 2020. Three reactors are currently in operation and one is close to construction completion. The NPP is expected to provide up to 25 per cent of the country's electricity — with the capacity to power more than half a million Emirati households — when it becomes fully operational in the coming years. However, as with any other NPP, it will have to be disassembled at the end of its useful life, in around 60-80 years. Today, every country embarking on a nuclear programme is required, when designing a nuclear facility, to develop preliminary plans for decommissioning the facility so that the site can be repurposed.

"Decommissioning is a multidisciplinary process. Planning for decommissioning, including the establishment of the necessary finances, should begin at the early stages of the development of the nuclear facility and continue during the operational stage. Detailed planning of decommissioning typically begins a few years before the facility is permanently shut down; this includes activities to ensure organizational and technical preparedness, enabling a smooth transition from operation to decommissioning," said Tetiana Kilochytska, Decommissioning Specialist at the IAEA. "The UAE, which has successfully launched its first nuclear power plant, already has an initial decommissioning plan for when the plant reaches its end of life."

The power of careful planning

The operator of the Barakah NPP, Nawah Energy Company, submitted an initial decommissioning plan as part of its application for an operating licence to the UAE's nuclear authority – the Federal Authority for Nuclear Regulation (FANR). The plan envisages that decommissioning will be handled by Nawah and will begin five years after the final reactor is permanently shut down.



According to the Emirates Nuclear Energy Corporation (ENEC), which is responsible for the UAE's nuclear power programme, the decommissioning process is forecasted last around 13 years for each of the four units.

A recurring challenge in decommissioning is uncertainty regarding the total cost of the associated activities, including the cost of the long-term management of radioactive waste resulting from decommissioning and of spent nuclear fuel. For example, the cost of establishing a geological repository for the disposal of long-lived radioactive waste and spent fuel can run to several billion dollars.

The UAE is prepared for this challenge and has taken steps to establish a 'Decommissioning Trust Fund' that is financed by annual contributions and is responsible to cover the cost of decommissioning of the NPP and related activities. To ensure that this fund is able to meet future expectations, it is intended that the annual contributions be reviewed regularly and the NPP's decommissioning plan be updated at least every three years over the course of the plant's lifetime.

"One of the key elements of successful decommissioning is adequate access to expertise and technology when the decommissioning takes place," Kilochytska said. The UAE is taking steps to ensure the timely availability of qualified and competent staff for decommissioning, radioactive waste disposal and the radiation protection of people and the environment during this process. As technology, such as robotics and artificial intelligence, is constantly evolving, new advancements are expected to offer greater opportunities for more efficient decommissioning by providing faster dismantling techniques, higher decontamination efficacy and better protection of workers.

Preparing today for a sustainable tomorrow

The IAEA assists countries in the planning and implementation of decommissioning, providing safety, legal and technical advice and supporting knowledge sharing through training courses and workshops. It plays an important role in facilitating broad international collaboration as well as conducting technical reviews to establish best practices and to ensure that lessons are learned from past examples.

"The development of the UAE's nuclear energy policy took benefit of its ongoing interaction with the IAEA," said Kilochytska. The UAE collaborates with IAEA experts to ensure strong nuclear safety, security and transparency throughout the operation of the Barakah NPP, including in relation to its plans for decommissioning.

The Barakah NPP will play a key role in the UAE's 2050 'net zero' strategy, which aims to drastically increase the country's production of clean energy. It will prevent the release of over 22 million tonnes of greenhouse gases per year — equivalent to the emissions of nearly five million cars — constituting a quarter of the UAE's emission reduction commitments under the Paris Agreement, the international treaty on climate change to that effect. The Barakah NPP is already the largest single generator of electricity and the largest source of clean electricity in the region.

The UAE's first nuclear power plant is not yet fully operational, but the country is already carefully planning future decommissioning.
(Photo: ENEC)

Encouraging the next generation to pursue careers in decommissioning

By Annie Engstroem

One of the major challenges currently facing the decommissioning industry is attracting young professionals to the field. The need for a new generation to enter the workforce is being driven by two factors. On the one hand, there is an immediate need to have an increased workforce in place to decommission the growing number of ageing reactors now reaching the end of their life spans. On the other, the industry needs to prepare for the future, when the decommissioning sector is expected to boom and create even greater demand for science and engineering professionals.

It is estimated that between 12 and 15 per cent of nuclear power reactors currently in operation will be retired by 2030, and decommissioning them will require a range of professionals from various disciplines to ensure that they are dismantled safely, in a cost-effective manner and with consideration for their future use. At the same time, new nuclear facilities that will also eventually have to be decommissioned are being built worldwide.

"Young professionals, such as myself, are eager to use our skills to help advance decommissioning programmes and increase public trust in the nuclear field."

— Simona Šandalová, Nuclear Chemist and recipient of the IAEA Marie Skłodowska-Curie Fellowship Programme scholarship

"Young professionals, such as myself, are eager to use our skills to help advance decommissioning programmes and increase public trust in the nuclear field," said Simona Šandalová, a 25-year-old nuclear chemist and recipient of the IAEA Marie Skłodowska-Curie Fellowship Programme scholarship.

The complex challenges involved in decommissioning nuclear sites mean that there is a range of career opportunities for younger people in this field. These include roles involving emerging technologies such as artificial intelligence, data science and robotics, as well as opportunities for those wishing to specialize in careers in physics, chemistry, engineering, project management, waste management or environmental remediation. In short, the decommissioning sector will offer both job security and career opportunities for people entering the industry now, and for the foreseeable future.

"Forty years ago, decommissioning was not a priority concern for developers of nuclear power plants or fuel cycle facilities, and little consideration was given to ensuring the availability of an appropriately skilled workforce when these facilities reached the end of life," said Patrick O'Sullivan, Decommissioning Specialist at the IAEA. "Today, attracting young nuclear professionals to decommissioning and associated waste management activities has become a major priority in most programmes."

To decarbonize the economy countries are also investing in advanced nuclear reactors, such as small modular reactors, which are expected to be easier and cheaper to decommission from a technical standpoint, as they can be transported back to the factory for dismantling and recycling.

"If countries are going to exert efforts and include nuclear energy in their energy mix, they really need to position themselves well in terms of developing essential skills to consider the dismantling of nuclear power plants from the beginning," said Marorisang Makututsa, Deputy President of African Young Generation in Nuclear (AYGN). The AYGN is a non-profit organization which aims to mobilize and empower young nuclear professionals in Africa by organizing training and national networking events. Currently, South Africa operates two nuclear power reactors, while Egypt is building its first reactors and Ghana, along with around ten other countries on the continent, is considering introducing nuclear power into its energy mix.

Opportunities for young people

Decommissioning is the final step in the nuclear life cycle; however, the multidisciplinary process of dismantling a nuclear power plant requires insight into the whole nuclear life cycle. Engineers, scientists and other professionals specialized in decommissioning, therefore, possess competencies that are transferable to other parts of the nuclear life cycle, including the design, construction and operation of the nuclear installation.

"Young people with expertise and experience in decommissioning have many opportunities in other industries as well," said Lisa Lande, a Nuclear Human Resource Development Specialist at the IAEA. "The ability to manage projects, obtain the technical expertise required for waste management, and understand the impact of pollutants on the environment is invaluable in the environmental sector and within various domains in the technology industry."

In France, the National Institute for Nuclear Science and Technology (INSTN) is actively encouraging students to explore new, innovative solutions to decommissioning. Florent Lemont is Research Director at the CEA and head of INSTN - Marcoule. In 2022 he organized a challenge in France called "Hackadem", in which 600 high school and university students competed in teams by pitching creative solutions for decommissioning nuclear facilities in the future. "Many participants were not aware that decommissioning is a cross-cutting innovative area involving high-tech technology, digitalization, chemistry, and more," Florent Lemont said. "Through the challenge, they gained insights about the future opportunities in the decommissioning field and the value of obtaining experience in this area."

IAEA initiatives to engage students and young professionals

The IAEA organizes a range of initiatives to highlight career opportunities in the decommissioning field and to support nuclear capacity building in its Member States.

The IAEA actively cooperates with universities around the world — in the Czech Republic, France, the Republic of Korea, Slovakia and the United Kingdom, among others — to conduct research and exchange technical information, experiences and best practices in decommissioning and environmental remediation. At Florida International University (FIU) in the United States of America, this cooperation has enabled the IAEA to offer training and internship programmes to students with backgrounds in science, technology, engineering and mathematics, and to integrate the IAEA's material on decommissioning into FIU's curricula.

In September 2022, the IAEA organized the IAEA Challenge: Innovations in Nuclear Facility Decommissioning 2022, inviting students and young professionals to submit original essays on dismantling nuclear facilities. Topics included how to make decommissioning more effective, how to plan and carry out decommissioning using a circular economy model, and how to incorporate a decommissioning strategy into a nuclear power plant's design.

"Decommissioning is a future challenge that needs a future workforce with relevant skills," said O'Sullivan. "That's why the IAEA organizes and implements a range of initiatives — both directly and through its Collaborating Centres — to promote the involvement of young people in decommissioning, including university partnerships, training and fellowship programmes, as well as encouraging involvement by young people in its specialist workshops and conferences."

Workers taking part in decommissioning activities at a nuclear fuel reprocessing plant in La Hague in France.
(Photo: M. Klingenboeck/IAEA)

Expert insights on decommissioning France's spent fuel reprocessing facility

By Michael Amdi Madsen

Today, around 70 per cent of France's electricity is generated from 56 nuclear power plants (NPPs). All of the spent fuel from these reactors, and some from other countries, is reprocessed and partially recycled at La Hague, a site in the country's northern Cotentin Peninsula.

After 35 years of operation, La Hague's first reprocessing facility, UP2-400, was shut down in 2003 and is being decommissioned — a project which is expected to take decades. To better understand how this project is progressing and the challenges involved in decommissioning a facility like UP2-400, we spoke with Eric Delaunay, Senior Vice President of End-of-Lifecycle Operations at Orano, the majority French state-owned company tasked with ensuring that the site is safe and suitable for future uses.

Q: What are some of the implementation challenges faced by the UP2-400 decommissioning project and how do they compare to the decommissioning of other major nuclear facilities, such as NPPs?

A: The main challenge faced by the UP2-400 decommissioning project is the presence of radioactive deposits and contamination in a vast proportion of the shut-down facilities. In an NPP, the removal of spent fuel and a full system decontamination removes more than 99 per cent of the initial radioactivity present in the NPP. Only the reactor pressure vessel and its internal equipment are still significantly radioactive. In a reprocessing plant such as UP2-400, it is a little different. Each piece of equipment and each room is contaminated with a level of radioactivity, and these components need to be retrieved and conditioned before dismantling can take place. This means that the reprocessing plant's safety functions need to be preserved during most of the decommissioning project, whereas in NPPs, safety classes and systems can be reduced once defuelling is complete and the spent fuel pool has been emptied.

> "In the future, robotics will increase productivity, enhance safety for workers, and improve working conditions and motivation for our staff."
>
> *— Eric Delaunay, Senior Vice President, End-of-Lifecycle Operations, Orano, France*

Q: What are the main operational and strategic decommissioning risks facing the project and what is being done to manage them?

A: The main strategic risks are cost overruns and delays in completing the project, since delays generate additional costs. Delays can be caused by a variety of operational risks covering all aspects of the project. The two most significant are, firstly, a lack of knowledge concerning the initial radiological condition of the high activity cells and equipment; and, secondly, challenges related to career development and staff retention. To mitigate the first risk, we have pursued a very comprehensive characterization programme that significantly reduces uncertainty concerning the condition of the reprocessing plant and its cells for several years. In the meantime, we have tried to manage the human resources challenge with a range of actions, including involvement in regional and national training programmes, a proactive recruitment policy, the continuous training of our staff to facilitate versatility and mobility in the organization, and innovation in decommissioning practices to improve the working environment.

Q: The UP2-400 decommissioning project began some 20 years ago and may be expected to continue for several more years. How has innovation in technology affected the project over time and what future technological developments do you think will create the greatest impact?

A: Over the past 20 years, the most significant technological changes have been related to digitalization at all levels of the project. Digital technologies have evolved in three ways, in relation to power and efficiency, cost, and diversity. Twenty years ago, virtual models were complex and costly to develop, virtual reality technology was limited, and smartphones and tablets did not exist. In the past few years, these technologies have evolved to such an extent that they now bring real and measurable benefits to our activities and have completely transformed and improved processes in our organization. In the future, robotics will increase productivity, enhance safety for workers, and improve working conditions and motivation for our staff.

Q: Sustainability and circular economy principles are of growing importance in the nuclear industry. What impact do these principles have on decommissioning activities at La Hague?

A: A challenge for us when considering circular economy principles is that we are decommissioning facilities that were built forty to fifty years ago and that were not designed with any circular economy considerations. However, since creating an entire division in our company dedicated to the decommissioning of our own nuclear facilities in 2008, Orano has been engaged in closing the nuclear industrial cycle and liberating disused buildings for future reuse for 15 years. We also focus on the minimization of waste generation at all stages of the decommissioning process, and we increasingly reuse equipment and recycle materials. Recent regulatory changes in France have also opened the door to recycling metal from decommissioned nuclear facilities for reuse within the nuclear industry.

Q: What are the main socio-economic impacts of the decommissioning work at La Hague and how do you see your responsibility to the local community?

A: Decommissioning activities represent roughly 20 per cent of the overall activity and socio-economic impact of the La Hague site, which also hosts two operating spent fuel recycling plants. Orano's Normandy sites are major employers and sources of revenue for the local community. Orano's annual spending represents over €850 million per year, of which more than 70 per cent stays in the region of Normandy. Orano la Hague has also established a partnership with the Chamber of Commerce and Industry of Cherbourg Cotentin to train and employ local workers. In 2023, Orano's sites in the Cotentin area will recruit 500 people, 20 per cent of whom will work on decommissioning. Furthermore, 200 work-study trainees will be hired for periods of one to three years.

Q: How does the IAEA's work support the decommissioning activity at La Hague and how can international collaborative activities better support decommissioning projects?

A: Our decommissioning project is very intensive and requires us to focus on project delivery. However, it is also a long-running endeavour that benefits from the innovations and experiences of others. The IAEA's support on decommissioning and environmental remediation provides a unique forum to exchange and learn from others, including trends and innovations that could support our activities, such as digital technologies, robotics, training and competence development. For example, ongoing developments in the Technical Meeting on New and Emerging Technologies to Advance Decommissioning Projects is of particular interest to us and we expect that such initiatives will prevent the duplication of development efforts.

A new business model for decommissioning nuclear power plant

By Bruce A. Watson

Bruce A. Watson is the Special Assistant in the Division of Decommissioning Uranium Recovery and Waste Programs in the Office of Nuclear Material Safety and Safeguards at the United States Nuclear Regulatory Commission (NRC). A former nuclear operator, he gathered extensive experience in decommissioning reactors and materials at sites as the technical lead for the licence termination of United States (US) nuclear power reactors. Bruce also has extensive international decommissioning experience with the IAEA, helping to develop decommissioning Safety Guides and training programmes. He has served as an expert on several IAEA peer review and advisory missions.

As a long-standing pioneer of nuclear technology, the USA now operates one of the world's oldest and largest nuclear power programmes. As fleets of reactors age out of service, increasingly large numbers of decommissioning projects are being created. Currently, the NRC oversees 17 nuclear power plants (NPPs) that are in active decommissioning, and eight NPPs in safe storage, as well as the decommissioning of two research reactors and several other nuclear sites. In addition, several defence-related sites that fall under the regulatory powers of the Department of Energy are also being decommissioned. This demand is driving innovation, with companies finding creative ways of meeting this challenge.

In 2010, a completely new business model for decommissioning emerged in the USA. Prior to this, all decommissioning projects involving NRC-licensed reactors used a similar business model. The operator of the NPP continued to hold full responsibility for the duration of the decommissioning process. The operators would either choose to implement all decommissioning work themselves or contract a company to do the work for them. In the early 1990s, ten NRC-licensed reactors were shut down and their decommissioning was completed by 2009, all using this traditional model.

However, by the end of 2010, lengthy discussions between decommissioning companies and operators had borne fruit and opened the field for a new way of carrying out decommissioning projects. In the first instance, a US operator agreed to transfer a temporary licence to a decommissioning company. After decommissioning had been completed, the licence for the land and the spent fuel dry storage facility would transfer back to the original operator. The NRC approved this, and also approved a similar process between another operator and a decommissioning company shortly afterwards.

Opportunities and challenges

These agreements materialized only after years of negotiations. The prospective licensees had to weigh up both the opportunities and the challenges thoroughly. On the one hand, such a licence transfer would provide the decommissioning company with full access to the NPP's decommissioning trust fund. On the other hand, they would also become fully responsible and liable for all financial and regulatory risks resulting from the operation. Ultimately, the deals went ahead despite these risks. Three years later, in 2013, the first companies agreed to a permanent, rather than temporary, licence transfer as part of the sale of the facility.

In many ways, 2013 was a landmark year. It was the first time a decommissioning company spoke to the operator of an NPP that was about to shut down and offered to buy the plant in order to decommission it. A sales agreement was then negotiated for an

NPP that shut down that year. The operator and the decommissioning company applied to transfer the licence permanently to the decommissioning company.

Decommissioning companies that acquired such licences could often integrate these activities into their established businesses, as they might already operate nuclear waste disposal sites or be certified to provide spent fuel storage services.

Significant acceleration in planning timelines

One remarkable result of this 2013 licensing transfer was a significant acceleration in the planning timelines for decommissioning activities. The plant's licence termination was initially planned for 2073. This meant that, originally, the operator would take advantage of the NRC regulations that require that the licence termination be completed in 60 years. For licence termination, the plant had to be fully decommissioned, including the environmental remediation of the land, which would enable it to be repurposed for other uses. A new licensee plans to finish the same process by 2030, with the spent fuel dry storage facility remaining a licensed and inspected facility.

Some other operators whose older NPPs in safe storage are nearing a 2030 decommissioning deadline might also want to consider such a licence transfer to switch to a more accelerated process. One important consideration is that, in the USA, an NPP must be decommissioned and the licence terminated within 60 years of ceasing operations.

Licence transfers have now become quite common in the USA and apply to a significant number of NPPs being decommissioned. Nonetheless, the traditional business model of operators continuing with plant decommissioning persists and still provides the basis for many ongoing decommissioning projects.

Also, it quite unlikely that other countries will be inspired to follow the USA's model for decommissioning. The main reason is that, in contrast to most other countries, US NPPs are commercially independent. As a result, the US business model is different from most other countries.

Speed up similar projects around the world

However, the accelerated decommissioning processes that are being implemented in the USA could help to speed up similar projects around the world. We share our lessons learned with other countries, which is enabled by international organizations and through IAEA safety standards, workshops, forums, missions and publications. The IAEA does essential work to promote consistency in how decommissioning is conducted, ensuring that it is implemented safely and carried out within solid regulatory frameworks.

The IAEA plays an important role in providing information on consistent approaches to decommissioning, such as dose limits, to ensure that there is wide agreement on when a site is successfully cleaned up and enhance safety for local communities. The IAEA's documents are highly useful in this area. There is a real thirst for knowledge across the international community in the decommissioning sector on how to perform decommissioning safely and effectively.

Climate-Smart Agriculture Shows Promise in Improving Azerbaijan's Cotton Productivity

Isotopic techniques help Azerbaijani researchers and farmers to obtain key information on how to optimize fertilizer use and increase the efficiency of cotton production while maintaining soil health.
(Photo: M. Zaman/IAEA)

In Azerbaijan, researchers and farmers implementing climate-smart agricultural practices based on nuclear and related techniques have been able to more than double their cotton production yields in a project supported by the IAEA in partnership with the Food and Agriculture Organization of the United Nations (FAO). Through the use of a new variety called 'cotton super', combined with carefully-implemented climate-smart agriculture (CSA) practices which provide insights into how to sustainably increase agricultural productivity, the pilot project has seen yields increase from the country's average of three tonnes per hectare to eight tonnes per hectare.

The pilot project, which is part of an IAEA technical cooperation project and which was implemented in 2021, focused on developing climate-smart agricultural guidelines for cotton production, training Azerbaijani researchers and progressive farmers in climate-smart agricultural practices, and designing on-farm demonstration trials. A further project, initiated in 2022 and focusing on strengthening best practices in agricultural practices related to soil, nutrient and water management for cotton production, aims to help improve cotton productivity, as Azerbaijan's land is particularly vulnerable to climate change and soil degradation. The country's average annual temperature has risen by 0.4 degrees Celsius since 1991, with Azerbaijan also experiencing decreasing rainfall and more frequent extreme weather events, such as floods, droughts and heat waves.

"Generally speaking, 60 per cent of improvement in crop productivity comes from capitalizing on the strategic application of soil nutrients and water management," said Mohammad Zaman, a soil scientist at the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture and Technical Officer of the project. "It's about the right amount, in the right way, at the right growth stage."

Climate-smart agricultural practices involve the use of isotopic techniques to obtain essential information on how to optimize fertilizer use and increase the efficiency of agricultural production while maintaining soil health.

"When we started, Azerbaijan's soils were heavily degraded, the fertility was very poor, and so the soil did not have the capacity to provide all the essential nutrients required for the cotton growth," Zaman said. To address this, IAEA experts developed a complete package of nuclear and related farming techniques, from preparing soil and selecting the best cotton varieties to applying nutrients and irrigation to cotton fields and ensuring weed, pest and disease control.

"Applying improved soil, nutrient and water management practices, along with using the 'cotton super' variety, has led us to increase our cotton productivity, quality and profit," said Sakhavat Mammadov, a farmer from Azerbaijan who took part in the pilot project and who has been using CSA practices on his farm for the last two years.

Nuclear and related techniques help not only in increasing agricultural productivity but also in building the resilience of agricultural systems to climate change. In Azerbaijan, the researchers used a technique involving nitrogen-15 (N-15), a stable isotope. Nitrogen plays an important role in plant growth and photosynthesis — the process whereby plants convert carbon dioxide and sunlight into plant food. Zaman explained that a lack of nutrients in the soil, such as nitrogen, leads to low and less nutritious yields. The excessive or incorrect application of nitrogen fertilizers, on the other hand, contributes to greenhouse gas emissions and the pollution of surface and groundwater.

"Cotton in Azerbaijan is expected to be one of the crops experiencing the greatest yield decline due to climate change and rapid soil degradation," Zaman said. "Taking advantage of isotopic techniques, such as the use of N-15, can help adapt to this situation, making the cotton sector more competitive as well as ensuring employment and improving the welfare of the rural population."

In the past, Azerbaijan was a leading producer and major exporter of cotton, harvesting more than 830 000 tonnes, which provided up to a quarter of the country's income, in the 1980s. However, the transition to a free market and the rapid growth of other industries in the 1990s contributed to cotton losing its key role in Azerbaijan's economy, with production falling to a record low of 31 000 tonnes in 2009.

The project outcome shows the significant potential of climate-smart practices in increasing agricultural productivity. "Considering the total cotton growing areas of 105 000 hectares in Azerbaijan, a 10 per cent adoption of the IAEA climate-smart agricultural practices would produce 84 000 tonnes of cotton compared to 31 500 tonnes, representing a 166 per cent increase over conventional cotton farming practices," Zaman said. "Seeing the extraordinary success in applying climate-smart agricultural practices in this project provides an exciting indication and tremendous promise on how it can help Azerbaijan to increase their cotton production significantly and, thus, greatly impact the Azerbaijani economy."

The IAEA, through its technical cooperation programme and through the Joint FAO/IAEA Centre, assists countries in applying climate-smart agricultural methods to increase productivity, adapting agricultural systems to climate change and reducing their impact on the environment. The Joint FAO/IAEA Centre also supports research in this area. In a coordinated research project focused on the use of climate-smart nuclear solutions to help minimize the impacts of farming on climate, scientists from Brazil, Chile, Costa Rica, the Islamic Republic of Iran and Pakistan reported a 50 per cent reduction in greenhouse gases. Other climate-smart agricultural practices are helping to develop balanced diet solutions for livestock amid recurring droughts in Angola, to improve the water use and nutrient management of soils in Kenya, and to combat soil erosion in Tunisia.

— By Artem Vlasov

Using the stable isotope nitrogen-15, scientists collect quantitative data about how much nitrogen fertilizers cotton needs and how effectively they are taken up by the plant.
(Photo: M. Zaman/IAEA)

Using Nuclear Techniques to Respond to Natural Disasters in Latin America and the Caribbean

Non-destructive testing (NDT) techniques provide reliable data on the strength and integrity of materials without interfering with potentially weakened or hazardous structures.
(Photo: Regional Co-operation Agreement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL))

Latin America and the Caribbean is the second-most disaster-prone region in the world. Its unique tectonic structure and weather patterns make it vulnerable to natural events like earthquakes, floods and hurricanes. Owing to the exacerbation of these vulnerabilities by climate change, the region urgently needed the capacity to assess the safety and integrity of built structures following natural disasters, particularly in urban areas. With the IAEA's help, the region has achieved self-reliance in this capacity.

Four response centres, capable of using nuclear non-destructive testing (NDT) techniques to evaluate the integrity of civil structures, such as roads and bridges, in their own and neighbouring countries, have been established in Argentina, Chile, Mexico and Peru, with IAEA assistance. These centres will support a coordinated regional response in cases of emergency.

NDT techniques provide reliable data on the strength and integrity of materials without interfering with structures that are potentially already weakened or hazardous, using different types of radiation to detect defects in concrete, pipes and welding. The techniques are safe and quick, contributing to the protection of civilians.

The four response centres were established through an IAEA technical cooperation (TC) project that was initiated in 2018 to enhance the assessment of city structures and improve the quality of industrial goods and services in Latin America and the Caribbean using nuclear techniques.

"Recent earthquakes in the region dramatically highlight the importance of networks that improve the coordination of emergency response in the disaster-prone region. Through the development of the response centres, the region has become self-sufficient in mitigating the effects of disasters," said Gerardo Maghella, an Associate Industrial Technologist at the IAEA.

As part of establishing the centres, the IAEA organized the training and certification of experts in NDT techniques in Buenos Aires, from 7 to 18 November 2018, through the ongoing regional TC project. Nine participants from Argentina, Brazil, Costa Rica and Mexico were either newly certified or recertified in advanced methods of digital radiography using X-rays and gamma rays. They are now qualified to inspect civil engineering structures using the latest NDT techniques.

A further 24 participants from ten countries — Argentina, Chile, Costa Rica, Cuba, the Dominican Republic, Ecuador, Mexico, Peru, Uruguay and the Bolivarian Republic of Venezuela — qualified in civil methods of NDT, including visual inspection and ultrasonic testing, which uses sound waves to detect flaws in a material and measure its thickness.

“The certification represents a very important boost to the promotion of NDT methodologies in the civil engineering field in our respective countries,” said Eduardo Robles, Project Head at Mexico’s National Institute for Nuclear Research, one of the newly certified experts and representative of Mexico’s NDA response.

The training and certification were provided by the non-profit Italian Society for Non-Destructive Testing Monitoring Diagnostics (AIPnD) under Practical Arrangements with the IAEA and in accordance with the international standards ISO 9712, on non-destructive testing, and ISO 17024, on general requirements for certification bodies, enabling the experts to train others.

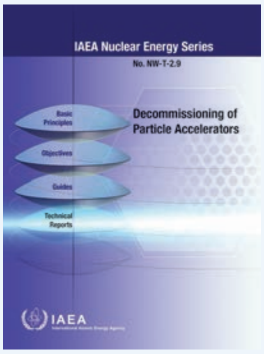
Hernán Xargay, Head of Division at the Argentinian National Atomic Energy Commission and coordinator at the new response centre in Argentina, said: “The training and certification at the ISO level organized by the IAEA creates confidence that international requirements are met and supports the harmonization of methodologies throughout the region.”

Mario Barrera Méndez, Quality Control Coordinator at the Chilean Nuclear Energy Commission, who leads the new response centre in Chile, agreed: “The network established by the IAEA is the cornerstone of the region’s new emergency response capability. As one of the four response centres, we intend to share the vast amount of knowledge we have gained in NDT techniques where it’s needed in Latin America and the Caribbean.”

Non-destructive testing is a quality control method that uses nuclear techniques to examine materials without damaging them. The IAEA supports the use of NDT technology to maintain the stringent quality control necessary for the safe operation of nuclear and other industrial installations. This support is expressed through the provision of equipment and assistance to Member States, including training local staff in applying the technology. Read more about the IAEA’s work on NDT.

— By Pauline Sophie Hennings

NDT is a quality control method that uses nuclear techniques to examine materials without damaging them.
(Photo: ARCAL)



DECOMMISSIONING OF PARTICLE ACCELERATORS

This publication presents information on experience and lessons learned from implementation of decommissioning projects for particle accelerators. Based on this information, and highlighting typical issues and concerns, the publication provides practical information for all those having a role in this process. The publication is written for operators of accelerator facilities, particularly those approaching the decommissioning stage, or maintaining a facility in a deferred dismantling state, as well as for regulators, waste managers, decision makers at government level, local authorities, decommissioning contractors and designers of accelerators. It is anticipated that the lessons learned described in this publication will contribute to decommissioning planning during the design stage of new facilities, hence minimizing the generation of radioactive waste without compromising structural characteristics and the effectiveness of the construction.

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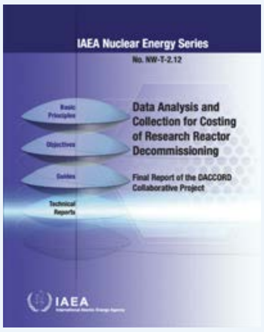

DATA ANALYSIS AND COLLECTION FOR COSTING OF RESEARCH REACTOR DECOMMISSIONING: FINAL REPORT OF THE DACCORD COLLABORATIVE PROJECT

This publication reports on the DACCORD project, which supports Member States in preparing preliminary cost estimates for the decommissioning of research reactors. The report is of particular benefit to programmes with limited decommissioning experience. Costing projects for the decommissioning of research reactors can be broad in scope with many possible inputs and influences that require due consideration in developing the estimate. The publication provides information on unit factors for research reactor decommissioning and a basis for estimating uncertainties and contingencies and for assessing the impact of decommissioning planning and characterization activities. It also addresses the use of the CERREX-D2 (Cost Estimate for Research Reactors in Excel) software code, developed by the IAEA to enable non-specialist users to develop preliminary cost estimates for decommissioning.

ISBN: 978-92-0-108621-1

MANAGING THE DECOMMISSIONING AND REMEDIATION OF DAMAGED NUCLEAR FACILITIES

As part of the Action Plan on Nuclear Safety, the IAEA led the International Project on Managing the Decommissioning and Remediation of Damaged Nuclear Facilities (DAROD Project). The DAROD Project focuses on providing practical guidance for the decommissioning and remediation of accident damaged nuclear facilities based on case studies of actual damaged facilities and lessons learned. This publication summarizes the outcomes of the DAROD Project. It is intended for regulatory bodies, operating organizations, technical support organizations and governmental officials who are involved in the decommissioning and remediation of nuclear facilities damaged after an accident or owing to a legacy deterioration.

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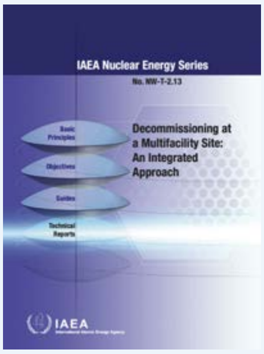

DECOMMISSIONING AT A MULTIFACILITY SITE

In recent years, several Member States have completed the decommissioning of multifacility nuclear sites. This publication consolidates their technical and organizational experience, and provides information and practical guidance that promotes safe, timely and cost effective implementation. All phases of decommissioning are discussed, from planning and dismantling to waste management and site release, as well as organizational schemes and funding. This publication is intended for decision makers, plant operators, contractors and regulators involved in planning, management, authorization and execution of decommissioning activities. It is particularly relevant for multifacility site operators with nuclear facilities approaching the end of their foreseen lifetime. The publication will also be of interest for the designers and builders of new nuclear installations in order to facilitate eventual decommissioning.

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