

# IAEA BULLETIN

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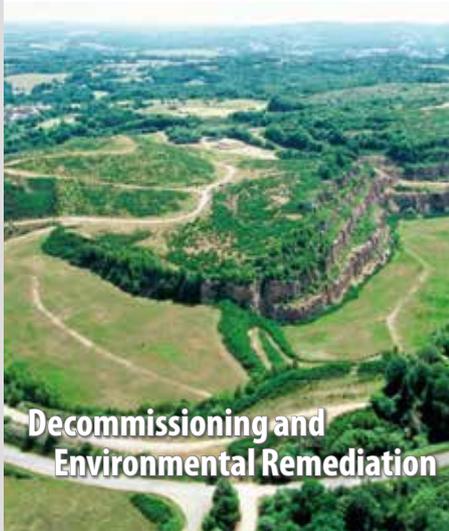


## Decommissioning and Environmental Remediation



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Cover:

The successful outcome of environmental remediation in the Bellezane uranium site, Limousin region, France.

(Photo: AREVA/France)



**IAEA**

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

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

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

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

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.

# Decommissioning and remediation: enhancing safety of the public and the environment

By Yukiya Amano

Nuclear science and technology have many beneficial peaceful uses, including the generation of energy and the production of radioisotopes for use in cancer treatment. All nuclear materials must be carefully disposed of when they, and the facilities housing them, come to the end of their useful lives.

For countries embarking on new nuclear power programmes, preliminary plans for the eventual decommissioning of reactors and the safe disposal of material such as spent nuclear fuel are now developed before the first brick is laid. Advance plans are also made for how this should be funded. However, this was not always the case: When many of the more than 400 nuclear power reactors operating in the world today were built, there was no such requirement. Many countries are now implementing or devising plans for decommissioning such facilities. The IAEA helps them to do so, bringing its international expertise and nearly six decades of experience to bear.

This issue of the *IAEA Bulletin* highlights good practices in action around the world. In Spain, the decommissioning of the country's first nuclear power plant is progressing on time and on budget (page 7), while in France's Limousin region, environmental remediation has transformed former uranium mining sites into recreational areas for the public (page 14). In Central Asia, the IAEA is helping governments to safely clean up an estimated one billion tonnes of contaminated waste left over from uranium mining (page 12).

Innovative technologies and trends in decommissioning and environmental remediation are also examined (page 22), and

readers are offered a glimpse into the life of a decommissioning manager (page 10). We explain the challenges of decommissioning research reactors, which — unlike nuclear power plants — are often located in urban areas (page 16).

## Know-how

An essential component of planning for decommissioning and environmental remediation is knowledge sharing. Facility and site owners can build on the experience of counterparts in other countries to develop better and more comprehensive plans for the future. The IAEA serves as a platform for this cooperation. We also have an important role to play by providing safety standards and nuclear security guidance for decommissioning and the management of nuclear waste.

Countries and facility operators must always be prepared for the possibility of radioactive contamination as a result of a nuclear or radiological accident or an industrial mishap. Proper planning makes it possible to respond swiftly and effectively if an incident should occur and to minimize the harmful effects of contamination on people and the environment. Over the last five years, the IAEA has provided significant support to Japan in this area (page 8).

I hope that this edition of the *IAEA Bulletin* will increase awareness of these issues and that it will prove useful to participants in the IAEA International Conference on Advancing the Global Implementation of Decommissioning and Environmental Remediation Programmes to be held in Madrid from 23 to 27 May.



**“Many countries are implementing or devising plans for decommissioning facilities. The IAEA helps them to do so, bringing its international expertise and nearly six decades of experience to bear.”**

— Yukiya Amano,  
Director General, IAEA



(Photos: C. Brady, P Pavlicek/IAEA)

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# Decommissioning and environmental remediation: an overview

By Irena Chatzis



**Decommissioning staff cutting down a piece of large metal equipment at a nuclear facility.**

(Photo: Sellafield Ltd/UK)

Nuclear decommissioning and environmental remediation share a common objective: to reduce radiation exposure to people and the environment at sites where radioactivity levels require restrictions in their use.

Decommissioning is a planned activity at the end of life of facilities that have a regulatory licence to conduct nuclear or nuclear-related activities. It is concerned with all the activities needed to remove them from regulatory control and thus release the site for other uses (see box).

## Decommissioning

Decommissioning is a normal part of the lifecycle of almost all industrial facilities. When the facility no longer serves a useful social or economic purpose, it needs to be dismantled and the site made available for other uses.

Requirements for decommissioning should be considered during design and planning of facilities. The decommissioning plan and associated cost estimates need to be prepared in advance, to ensure that sufficient financial resources are available.

Environmental remediation, on the other hand, is concerned with reducing existing radiation exposure from land, soil and groundwater contamination that results from past activities involving the use of radioactive material for civil or military purposes (see box, next page).

## Oversight to ensure safety

The objective in both decommissioning and environmental remediation is to lower levels of residual radioactivity enough that the sites may be used for any purpose, without restriction. In some cases, however, this may not be practical and restrictions may be placed on future land use. Following decommissioning, for example, some sites may be reused for non-nuclear industrial activities, but not for habitation. Some former uranium mining sites may be released for reuse as nature reserves or for other leisure activities.

Both decommissioning and environmental remediation are major industrial projects in which the safety of the workforce, the local public and the environment must be ensured from both radiological and conventional hazards. Hence, an appropriate legal and regulatory framework, as well as proper training for personnel both in implementation and in regulatory oversight are among the necessary preconditions to ensure safety.

Both the decommissioning plan and the cost estimate will evolve during the lifetime of the plant and will become progressively more detailed toward the end of the plant life.

However, such plans do not exist for several facilities constructed in the early days of the nuclear industry. In the case of these older plants, there may also be a lack of comprehensive records of the plant configuration and detailed accounts of the operational history. Such situations add additional complexity to the decommissioning process.

## Radioactive waste management

A well-coordinated system for managing the wastes that arise from decommissioning or environmental remediation is another important requirement. Decommissioning generally results in the production of large amounts of material with low levels of radioactivity. Depending on the material and on national regulations, a large part of the waste may be disposed of in near surface disposal facilities compliant with international safety standards for permanent disposal. Such facilities already exist in several countries; for others the waste material has to be held in temporary storage until a long-term solution is identified.

The amount of radioactive waste involved can be reduced significantly through decontamination of the plant systems prior to their dismantling. Some countries also have facilities for recycling scrap metal, e.g. by melting. Waste with higher levels of radioactivity or long lived components will generally have to be placed in repositories located deep underground.

For environmental remediation, the quantities of waste material involved can be much larger if, for example, soil needs to be removed and subsequently disposed of as waste. Opportunities for volume reduction also exist in this case, for example by separating soil components with higher contamination levels from those with lower levels.

## Environmental remediation

Environmental remediation aims to reduce radiation exposure from contaminated soil, waste storage facilities or other contaminated infrastructure, groundwater or surface water. Its purpose is to protect the people and the environment from potential harmful effects due to exposure to ionizing radiation. This may result from activities such as the mining and processing of uranium or the release of radioactive substances to the environment after a nuclear or radiological accident.

The generation of radioactive materials may also be a result of non-nuclear industries, such as oil and gas production, in which exploration and mining activities can increase the potential for exposure from naturally occurring radioactive material.

## Funding

Sufficient funding is a key factor in decommissioning and environmental remediation projects, which are generally very expensive. A significant proportion of sites requiring decommissioning or remediation are state-owned and implementation costs are paid from national budgets. Often, the amount of funds allocated to environmental cleanup activities depends on the priorities of the government.

For commercial power plants, funding decommissioning is generally the responsibility of the plant's owner. The funding is usually either invested in a special fund dedicated to cover decommissioning costs or, in the case of some large utilities, are provided directly from the company's operational revenues and cash flow.

## Current status

Although some countries have achieved substantial progress, many are facing significant difficulties in implementing their decommissioning and environmental remediation programmes.

Having plans in place for managing the entire lifecycle of nuclear facilities is nowadays a universal requirement for commencing new projects.



**Application of a combined scheme for covering and draining uranium mill tailings.**

(Photo: Wismut GmbH/Germany)

There are four major elements that need to be considered in environmental remediation:

1. The levels of radiation exposure to people that result from the contamination.
2. Reducing radiation doses and risks, making best use of the available financial, technical and labour resources.
3. Returning a site to the conditions before the event that caused the contamination may not be necessary, and is often not easily achievable anyway.
4. In many cases, the main driver for remediation is the public perception of the risks and benefits of undertaking the cleanup activity. In such situations, the overall well-being of the local community is an important factor in determining the planned final state of the site.

# Tying up loose ends: Spain's successful decommissioning project

By Laura Gil

**“Our advice? Plan in advance, prepare all the relevant licensing documents in good time, and monitor progress of all operations closely and continuously.”**

— Juan Luis Santiago Albarrán,  
Director of Operations, Enresa

Globally, only 17 of the 157 nuclear power reactors that have been permanently shut down have undergone full decommissioning — a resource-intensive process that often takes decades to complete. While the process is complex, a case in Guadalajara, western Spain, illustrates how careful planning, the right policy and regulatory environment, government commitment and stakeholder involvement can ease the way towards successful decommissioning.

On schedule since the start, the decommissioning of José Cabrera, Spain's first nuclear power plant with an electrical output of 150 MW, is almost 70% complete and in line with the original budget of approximately €150 million at 2016 prices. Spain's National Company for Radioactive Waste (Enresa), the state agency in charge of the project, aims to complete decommissioning by 2018.

Dismantling of José Cabrera is unlike other commercial decommissioning projects, which are typically the responsibility of — and are carried out by — plant operators. “The Spanish case is almost unique, first of all, because decommissioning is the responsibility of a specialized state agency,” said Juan Luis Santiago Albarrán, Director of Operations at Enresa.

In Spain, once a plant is shut down and a decommissioning permit is granted, control

is transferred from owners and operators to Enresa, which is responsible both for decommissioning and long term management of radioactive waste.

For over 20 years, Enresa has been the centre of decommissioning expertise in Spain, responsible for the decommissioning of all major installations that involve the use of radioactivity, including uranium factories in Jaén and Badajoz and a nuclear power plant in Tarragona. The decommissioning of José Cabrera is the first dismantling project in Spain to start immediately after shutdown.

## Plan, plan again and innovate

The key to success in decommissioning is careful planning, including consideration of all aspects of the project from start to finish, Santiago Albarrán said. These include government licensing and approvals, dismantling and decontamination operations, waste management and, ultimately, return of the site to its owner.

Estimating a decommissioning timeline of seven years, Enresa began gathering the regulatory documentation and licences three years ahead of the plant's shutdown in 2006. By 2010, it had the necessary approval documents in place, had obtained full responsibility for the decommissioning process and was able to begin the project.

**Schedule of the decommissioning of the José Cabrera nuclear power plant**



(Source: Enresa)

“Our advice? Plan in advance, prepare all the relevant licensing documents in good time, and monitor progress of all operations closely and continuously,” Santiago Albarrán said.

Decommissioning projects require a great deal of innovation to optimize the process, making the most of all available tools and mitigating potential hazards. Enresa repurposed the turbine hall — which has thick, protective walls — into a waste management facility, a place where they could treat, manage and store radioactive waste.

This possibility to explore, to make things better and to innovate adds a layer of creativity to the decommissioner’s job, said Santiago Albarrán. “You should be prepared for the unexpected and a range of solutions should always be considered.”

### Protect your people

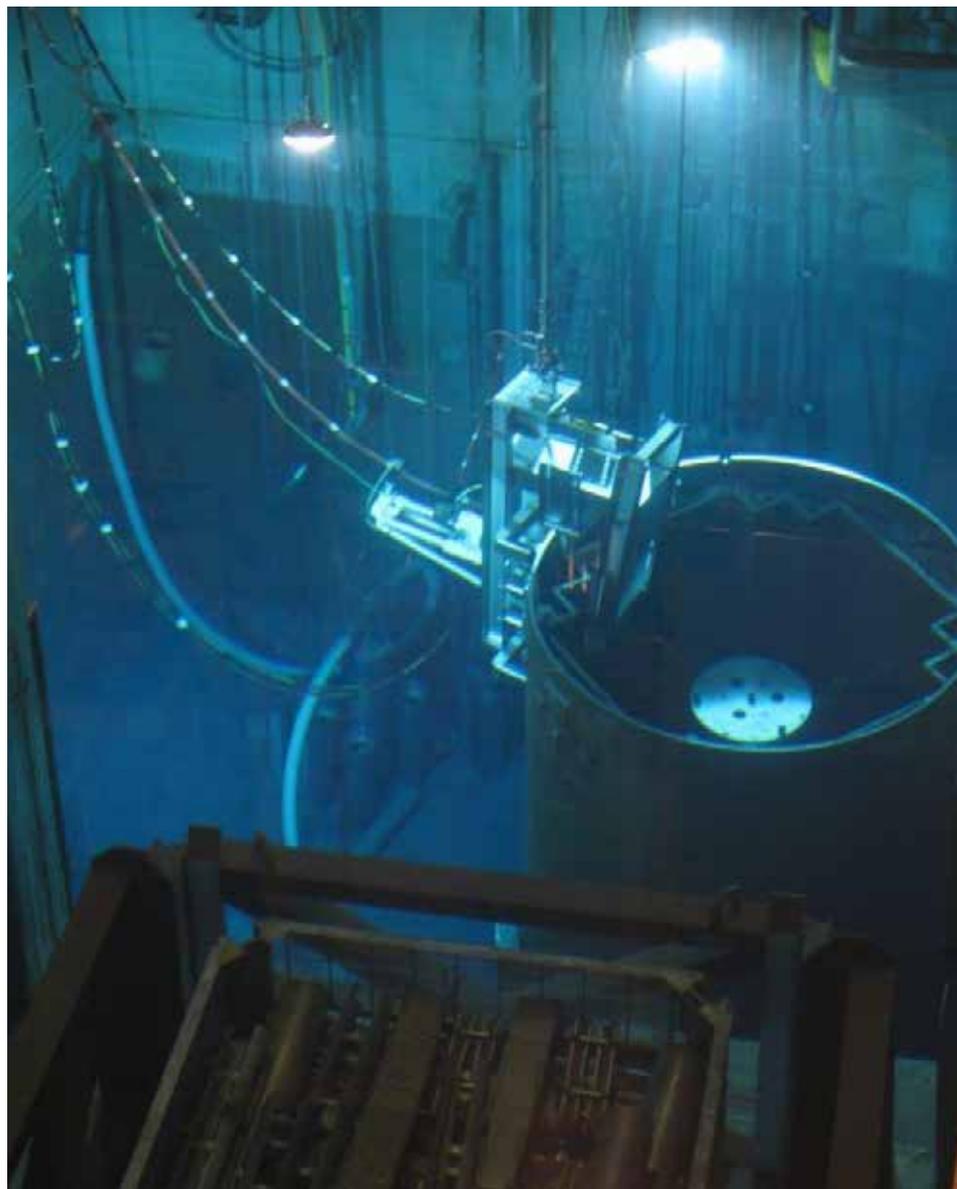
A priority in decommissioning is to minimize workers’ exposure to radiation. To this end, Enresa explored ways to protect its staff and found that if they removed the major plant components as large rather than small pieces and transferred them in large containers, they could shorten the time workers handled the materials, thereby lowering exposure.

“The segmentation and packaging of waste into big containers were a challenge because we required new tools,” Santiago Albarrán said. “But it was worth it. We reduced costs and radiation doses to workers.”

Similarly, underwater segmentation of the reactor vessel and its components offered another avenue for protection. Water serves as an efficient natural barrier against different types of radiation. By using it as a buffer, specialists could stand alongside the top of the spent fuel pool and use remotely operated mechanical tools to segment all internal parts of the reactor underwater. “The metallic chips that originate from the cuts stay in the water, which acts as a shield,” he explained. “Cutting big contaminated components underwater made the whole process safer for our workers and for the environment.”

### See it through to the end

After they dismantle all the components, Enresa will demolish the buildings, decontaminate the site and make sure that all waste has been removed. Then, in



the final step of decommissioning, it will restore the site. “Once we’ve restored the site, the regulator will have to verify that no significant contamination remains, before we hand it back to the owners, who may then reuse the site for other purposes,” Santiago Albarrán said.

The decommissioning process is completed once the regulator certifies that the site no longer presents a risk to the safety of the public or the environment and that the nuclear licence may therefore be revoked. “It’s a question of leaving the site clean for future generations,” said Patrick O’Sullivan, a decommissioning specialist at the IAEA. “A question of returning it to society for new uses.”

### Underwater segmentation of a reactor vessel at the José Carbera nuclear power plant.

(Photo: Enresa)

## Behind the scenes: Q&A with a decommissioner

No two days are the same when on the job as a decommissioning manager. Nuclear facilities come in all shapes and sizes, and with each facility having its own unique design, decommissioners have to develop highly detailed and tailored plans and often create new, innovative solutions for safely dismantling a facility piece by piece.

To get an idea of what is involved in a decommissioning manager's job, IAEA Contributing Editor Nicole Jawerth sat down with Steven Slater, Head of the Programme for Site Remediation and Decommissioning Projects at the Sellafield site in the United Kingdom, which is home to several active and shutdown nuclear power and reprocessing facilities, nuclear waste stores, and nuclear research and development laboratories. He is responsible for the safe management and decommissioning of over 150 nuclear facilities and for more than 500 staff across Sellafield.

### How does the job of a decommissioner differ from that of an operator?

I am responsible for the safe maintenance of facilities until we commence decommissioning activities, at which point I am responsible for the safe management of the decommissioning project and removal of the radioactive materials. The main objective of my job is to safely remove any residual radioactive materials after the post-operational clean out phase and make the remaining materials safe for long term disposal.

Some of the decommissioning work I undertake is completely alien to an operator. In my role, I expose the inventory, recover the inventory, and put it into a safe, passive form. For an operator, that would appear to be very alien. The main job of an operator is keeping radioactive materials contained at all times throughout the entire process and lifetime of a nuclear operation.

The key difference between decommissioning and operations is that decommissioning is project-based with a defined start and end point. Operations are process-oriented where you move from one process to another process.

### What is the biggest or most significant challenge in your job?

Because of the age of facilities, they are often not as expected in terms of drawings, and legacy issues associated with age-related defects are often a challenge. We would love a facility to be exactly as it is on the drawing, but some of these facilities are almost 50 years old. They have been modified many, many times during those 50 years of use. Our plants



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**“Some of the decommissioning work I undertake is completely alien to an operator.”**

— Steven Slater, Head, Programme for Site Remediation and Decommissioning Projects, Sellafield Ltd, United Kingdom

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are not what we would have expected based on drawings and records. So each time we go into some of these facilities, it's a voyage of discovery.

## How has the decommissioning process changed over the years?

We have moved from fully remote decommissioning to more of a human-machine interface decommissioning. At one time, we got really excited about doing fully remote decommissioning, but fully remote adds a scale, complexity, and cost that can often make it prohibitive. In some instances, you've still got to go with fully remote decommissioning, but where there are opportunities, we now do what is called 'semi-remote decommissioning', where a person enters an area, sets up the tool and operates it from a remote station. This means the person isn't in the danger zone, but they are present and available to observe and make modifications as things happen. That has been a real change for us in the last ten years.

The other thing we have done is to move away from wide-area decommissioning to a more tactical decommissioning. Some of these cells and areas are as big as football pitches. In times gone by, we would effectively go into facilities and do a wide scale decommissioning, but in doing this we have faced a spread of contamination throughout the exposed area. Now we opt for more tactical decommissioning where we address one area at a time and put a local containment structure around it, and then move to the next section. This prevents contamination throughout the whole structure. It's really a more surgical decommissioning method.

## What kinds of innovations have you made? How does that fit into the future of this field?

We do innovative things all the time. Recently, we have been developing something called a 'laser snake'. The laser snake is a flexible robotic arm driven by wire ropes, and can be easily navigated through confined spaces and cluttered environments. The real benefit of this kit is that its toolset enables the 'arm' to perform all kinds of activities, from inspection to cleaning to laser cutting. So once the snake is sent through an existing cell penetration, the laser cutting technique



allows for easier breakdown of hard-to-reach and often radioactive parts. This prevents any direct contact by the operator, which in turn minimizes a person's exposure.

We are also working with REACT Engineering, a partner company in our supply chain, together with which we have been developing remote characterization approaches. For example, we have taken a scanning device, attached it to a drone and flown it into a radioactive cell. In this way, we can then take 3-D pictures of the inside of the cell. We then overlay the radiological map on top, so we can get a clear visual picture of what's inside a cell before we commit to putting someone to work. It's part of how we reduce the radiation exposure of our workers.

Drones are used more and more for characterization purposes. In the future, as we start work on some of our more challenging plants and get to the areas where individuals simply cannot be exposed, remote decommissioning techniques and drones will play a much bigger part. I expect technologies like these and other new innovations will continue to evolve and help us find new ways to take on decommissioning and adapt to new challenges.

## Where does the IAEA fit into your work and decommissioning?

Sellafield is one of the most hazardous sites in Western Europe in terms of its inventory. We work with many expert peers across the nuclear community, sharing experience and techniques to enhance our decommissioning. The IAEA continues to be a source of support and collaboration for us and others in the field.

**In some cases, a decommissioner working manually can be more quick and effective than other options.**

(Photo: Sellafield Ltd/UK)

# Cleaning up a toxic legacy: environmental remediation of former uranium production sites in Central Asia

By Andrew Green

Nearly 60 abandoned uranium production sites dot the landscape and represent a hazard to the environment and inhabitants throughout rural Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan. Each site poses a challenge for local and national governments that lack technical expertise and resources for remediation.



●: Former uranium production sites in Kyrgyzstan.  
 ①: Mailuu-Suu ②: Min-Kush

(Source: Ministry of Emergency Situations/Kyrgyzstan)

The sites were used to produce uranium until the 1990s. They were built before proper regulatory infrastructure was in place to ensure eventual decommissioning, so leftover residues with long-lived radioactive and highly toxic chemical contaminants still pose substantial risks to the health of the public and the environment.

By some estimates, the quantity of uranium production residues in Central Asia — such as waste rock and tailings — approaches one billion tonnes, said John Rowat, Head of the Decommissioning and Remediation Unit at the IAEA Department of Nuclear Safety and Security. Many of these materials are stored in an unsafe manner at sites scattered across the region. Due to lack of funding, work over the last decade has focused mostly on short term measures to protect the public and the environment, Rowat said.

## Challenges in Kyrgyzstan

According to the Ministry of Emergency Situations of the Kyrgyz Republic, Kyrgyzstan has 35 tailings dumps and 25 sites with waste rock piles. Many of these contain toxic residues. The possibility of seismic instability, such as landslides dispersing these residues, poses the biggest risk to the surrounding environment, said Asel Seitkazieva, Deputy Director at the Ministry.

With this in mind, the government considers the Mailuu-Suu uranium legacy site (mark ① on map) and the Min-Kush uranium legacy site (mark ② on map) as the first priorities for remediation.

At the Min-Kush site, which lies in the centre of the country, the Kyrgyz authorities have received assistance in environmental remediation planning and project implementation from the IAEA's Coordination Group for Uranium Legacy Sites (CGULS). Through IAEA technical cooperation projects, specialists from the country's Ministry of Health, the National Academy of Sciences and the State Agency for Environmental Protection and Forestry have also learned how to use gamma and alpha spectrometry to assess and monitor radiation levels.

Although plans for remediation are beginning to be developed, the entire Min-Kush site remains in poor condition due to lack of funds, and remediation activities have yet to be implemented. However, by beginning to transfer tailings to safer sites and working to restore them, the groundwork has been set for future remediation. Once funding is secured, physical transfer of the waste and recultivation of the site will take place, Seitkazieva said.



## Progress and lessons learned in Mailuu-Suu

Landslides, flooding and the possible failure of containment barriers are also a concern at the Mailuu-Suu site, which houses a significant amount of residual radioactive contaminants. However, progress is being made. With assistance from the IAEA and at the request of Kyrgyzstan's Government, international aid for remediation of uranium legacy sites is provided by the Commonwealth of Independent States and the European Commission.

A total of 36 waste piles and mill tailings have been partially remediated and cultivated, and several landslide-prone spots near tailings have been improved and re-engineered to reduce the likelihood of seismic impact. Many of these projects remain incomplete, and many mines in need of remediation are in poor condition due to lack of funding. As with the Min-Kush site, regular monitoring and surveillance programmes need to be established, and better public communication and institutional control measures need to be put in place, Rowat said.

## What neighbouring countries can learn from Kyrgyzstan's experience

Kyrgyzstan's experience with internationally supported remediation efforts may be helpful

for neighbouring countries working on similar projects, Seitkazieva said.

Tajikistan and Uzbekistan, for instance, have engaged the IAEA Technical Cooperation Programme to procure laboratory equipment, arrange training of staff and assist in site characterization exercises, much like what Kyrgyzstan has done. Seitkazieva said that Kyrgyzstan's positive experience with the IAEA could serve as a useful roadmap for future international remediation efforts, especially when seeking ways to implement programmes within existing national regulatory frameworks.

Member States in Central Asia often share common challenges when it comes to remediation. For instance, the Ferghana Valley is a watershed that spans Kyrgyzstan, Tajikistan and Uzbekistan, and it is a valued agricultural region for all three countries. But former uranium production sites impinge on the valley, threatening to contaminate it with toxic substances.

"The Ferghana Valley is a good example of why it's important to take a regional approach to uranium legacy site remediation in Central Asia, to complement country-specific programmes," Rowat said. "Kyrgyzstan, Tajikistan, and Uzbekistan all draw upon the water resources of the Valley."

## The Min-Kush uranium production legacy site is situated in an area prone to landslides.

(Photo: IAEA)

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**"Once funding is secured, physical transfer of the waste and recultivation of the site will take place."**

— *Asel Seitkazieva, Deputy Director, Ministry of Emergency Situations of the Kyrgyz Republic*

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# From uranium mine to fishing lake: environmental remediation in France's Limousin region

By Aabha Dixit



## Before and after: environmental remediation in France's Limousin region.

(Photo: AREVA/France)

Artificial lakes, fishing spots and solar farms dot the landscape in France's Limousin region, where uranium operations have gradually come to an end. This transformation would not have been possible without stakeholder involvement, transparent processes and well-coordinated activities, said Yves Marignac, the coordinator of the French Pluralistic Expert Group (GEP), involved with remediation activities in the region. The local population had an important consultative role during the environmental remediation programme, and they now use the former mining sites for recreation.

"A consultative approach to remediation management is key to having the people's support when we had to deal with the closing of the uranium mining sites in Limousin," Marignac said. Uniquely, the non-governmental organizations (NGOs) were the driving force behind broadening the scope of environmental remediation, he added.

An important factor for any successful remediation project is public engagement in the decision-making process. The local communities have the most interest in successful environmental remediation, and they need to get satisfactory answers to questions on why, when and how will it impact them. "Their involvement is vital and necessary to ensure technically sound and socially acceptable decisions," Marignac said.

## Public involvement

Initially, the responsible organization for remediation work, AREVA, did not widely advertise its plans, Marignac explained. However, with NGOs and experts conducting independent assessments on radioactive residues, the responsible parties for the remediation activities quickly broadened the scope of the remediation work to take into consideration public concerns. That was

achieved through greater public participation in the decision-making process, he said.

Acting decisively and swiftly, the French authorities established GEP to develop a dialogue by taking on board experts from stakeholder communities to freely discuss and address remediation issues for the closed mines. This interactive dialogue also provided a platform for discussions of priority remediation activities and awareness-building.

The GEP was composed of more than 20 experts with diverse backgrounds, including independent experts as well as those from institutions in France and abroad, associations and industry groups.

They were involved in dealing with specific technical and operational aspects of the remediation implementation programme.

The environmental remediation plan shared with GEP involved securing the areas surrounding the closed mines, building

special disposal sites, removing and covering contaminated rocks and taking special measures to eliminate the risk of radioactive elements seeping into the water system. “Contaminated drainage from waste rock piles was an essential concern. The water had to be collected and treated before being released for public consumption,” Marignac said. In some areas, water monitoring and management are still going on.

The Institute for Radiological Protection and Nuclear Safety and the National Institute for the Industrial Environment and Hazards provided guidance and support in the remediation work. International experts from the IAEA, Belgium, Israel, Luxembourg, Switzerland and the United Kingdom were also consulted.

Today, the former uranium mining sites hardly reveal the past activities, perfectly blending into the surrounding landscape.

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**“A consultative approach to remediation management is key to having the people’s support.”**

— Yves Marignac, Coordinator,  
Pluralistic Expert Group, France

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## Remediation activities

Once the Limousin uranium mines were shut down, management strategies were developed, including a methodology in line with the 2006 French law on sustainable management of radioactive waste and materials.

The Regional Directorate for Industry, Research and the Environment (DRIRE) and the Nuclear Safety Authority (ASN) were given the task to oversee and implement the remediation process. The main objectives were to make sure the process was transparent, to ensure public safety and to seal any leaks and other contamination from the shutdown mines, Marignac said.

The authorities also evaluated the condition of the uranium mines, including mining work done, status of the waste rock piles, mill tailing ponds, water collection and treatment systems, identification of disposal sites for contaminated sediments and the possible re-use of waste rocks.

Information on the impact on the local ecosystem, workers’ radiation dose

assessment, monitoring of radioactive release to the environment and proposals for corrective actions were also reviewed.

Between 2006 and 2008, priority actions, such as safe transfer of the radioactive and non-radioactive wastes to disposal sites, safe transportation of radioactive waste material and ensuring that stringent legal measures were applied for public and environmental protection were implemented.

The public also had access to the government inventory of the mines in the region and details of the radioactive waste to be disposed of, Marignac said.

In remediating the sites, the French authorities in Limousin sought to minimize residual impact of former mining activities, and to reintegrate the site into the landscape. To make the areas safe for public use, they also performed rigorous radiological and environmental monitoring, and undertook extensive water treatment.

# IAEA Missions Review Decommissioning Activities at the Fukushima Daiichi Nuclear Power Plant

On 11 March 2011 a massive earthquake and tsunami caused a major accident at the Fukushima Daiichi nuclear power plant in Japan, the world's worst nuclear accident since Chernobyl in 1986. Fuel removal and post-accident stabilization and cleanup activities are ongoing at the plant, with the aim that active dismantling can proceed in due course.

In the five years since the accident, at the request of the Government of Japan, the IAEA sent more than ten expert missions to advise the country in various areas, including three on the safety and technological aspects of decommissioning and remediation.

The objective of the decommissioning peer review missions was to provide an independent assessment of the activities associated with the planning and implementation of decommissioning the plant.

The most recent mission, in February 2015, involved 15 international experts, who

provided an independent review of the decommissioning based on IAEA safety standards and other relevant good practices. The reports of these peer reviews are available on the IAEA website, at [www.iaea.org/newscenter/focus/fukushima](http://www.iaea.org/newscenter/focus/fukushima)

In August 2015, the IAEA published The Fukushima Daiichi Accident Report by the Director General, along with five technical volumes prepared by international experts, assessing the cause and consequences of the accident. The publication brings together lessons learned from the accident and provides a valuable resource to all countries that use, or plan to use, nuclear power. One volume deals with post-accident recovery, including decommissioning and environmental remediation.

The following photos document the last IAEA decommissioning mission in February 2015.



Water tanks holding contaminated water in front of the reactor buildings at Fukushima Daiichi.



The IAEA decommissioning team listens to an explanation about the function of a purification system that removes almost all radioactive elements from contaminated water.



An expert member of the IAEA mission team gets help to kit up for a tour of the site.

IAEA decommissioning review team members walk past the Unit 4 structure.



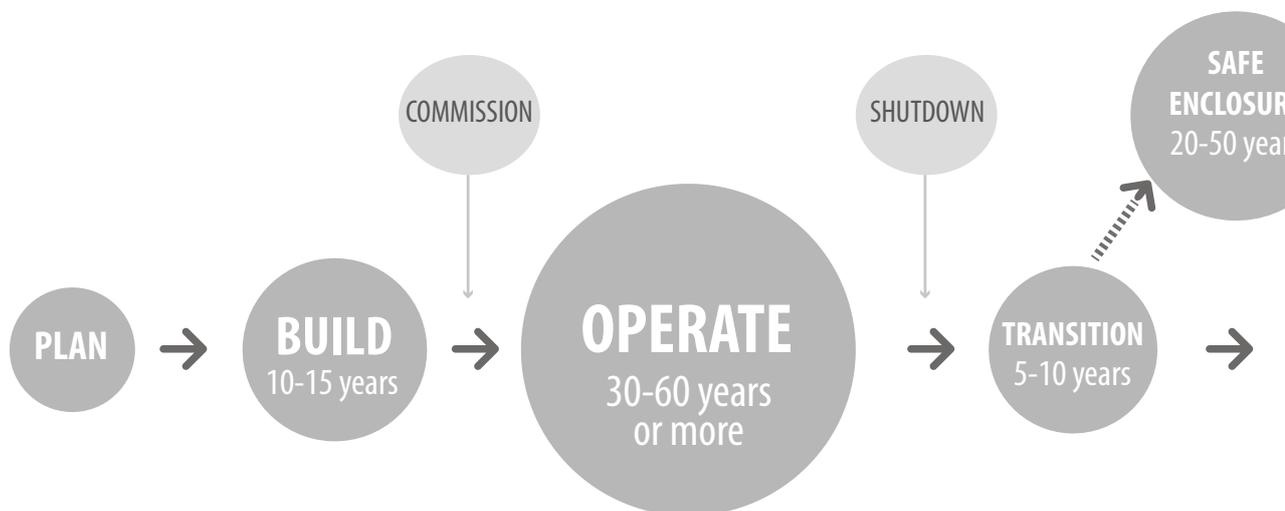
An expert member of the IAEA mission team peers into the emptied spent fuel pool.

The IAEA team looks at a purification system that removes almost all radioactive elements from contaminated water.



(Photos: S. Lööf/IAEA)

# FROM PLANNING TO DECOMMISSIONING:



## PLANNING



1

The key to success in decommissioning is to carefully plan and consider all aspects of the project, including funding and licensing.

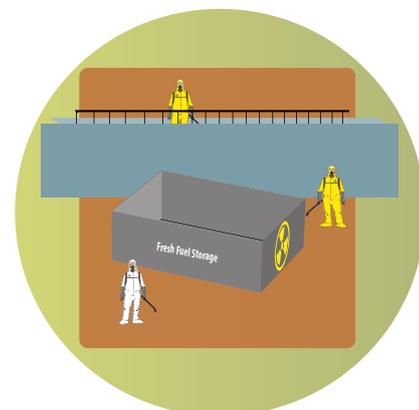
## PHYSICAL & RADIOLOGICAL CHARACTERIZATION



2

Experts need a clear idea of the characteristics of the facility and the levels of radiation that they expect to encounter.

## DECONTAMINATION



3

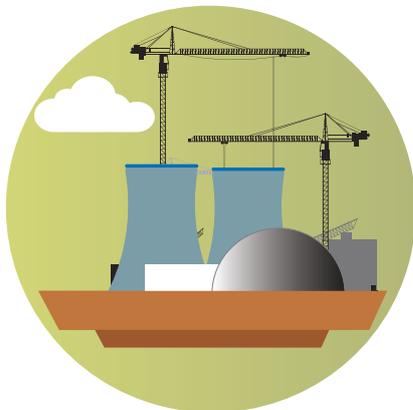
Workers decontaminate materials, which significantly reduces the amount of radioactive waste.

# LIFE OF A NUCLEAR POWER PLANT

DECOMMISSION  
10-20 years

When a facility no longer serves a useful social or economic purpose, it needs to be dismantled and the site made available for other uses. The six phases below highlight the steps in the decommissioning process.

## DISMANTLING & DEMOLITION



4

All buildings, walls and components are broken down into pieces, organized and recycled. Radioactive waste is treated apart, and sent for storage or disposal.

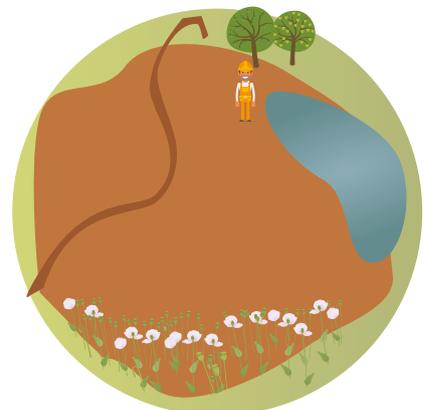
## PREPARATION FOR REUSE



5

Workers prepare the site for eventual reuse.

## FINAL SURVEY & RELEASE FROM REGULATORY CONTROL



6

Once the site is restored, the regulator verifies and confirms that there is no significant contamination; the site can now be reused.

# No small fry: decommissioning research reactors

By Miklos Gaspar



**On 24 September 2015, irradiated liquid highly enriched uranium (HEU) fuel was removed from a research reactor at the Radiation and Technological Complex in Tashkent, Uzbekistan and repatriated to Russia.**

(Photo S. Tozser/IAEA)

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**“Once we shut down the reactor, we will want to decommission it as soon as possible.”**

—Ketut Kamajaya, researcher, National Nuclear Energy Agency (BATAN), Indonesia

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To get a permit to build a research reactor, would-be operators need to submit an initial decommissioning plan for the eventual shutdown of their new facility. This, however, was not a requirement back in the 1950s, 60s and 70s when most research reactors that are now nearing the end of their working lives were built. The result: many unused reactors sit idle in the middle of university campuses, research parks and hospital compounds, because their operators lack the proper plans to decommission them.

“Our research reactor has recently received a licence to continue operations for at least a few more years, but we need to decide what we are going to do with it afterwards,” said Ketut Kamajaya, researcher in charge of the decommissioning of the Triga-2000 research reactor in Bandung, Indonesia.

## 180 to go

There were 246 operational research reactors in 55 countries at the end of 2015, and over 180 that had been shut down or were undergoing decommissioning, according to the IAEA’s *Nuclear Technology Review 2016*. More than 300 research reactors and critical assemblies have been fully decommissioned.

Around half of the operational research reactors are over 40 years old — making ageing management and decommissioning key challenges for the research reactor community today.

Many countries do not have the institutional, legal and regulatory framework, expertise and technical infrastructure required for decommissioning, said Vladan Ljubenov, waste safety specialist at the IAEA. “Countries without a nuclear power programme typically have significantly less expertise in decommissioning and often lack the facilities to manage all but low level waste,” he said. While much of the decommissioning waste from a research reactor would indeed be low level waste, countries also need to deal with the small amounts of medium and high level waste generated.

Sometimes countries also lack the funds for decommissioning, even though in the long run they would save money by immediately decommissioning facilities they can no longer use, said Vladimir Michal, Team Leader for Decommissioning and Environmental Remediation at the IAEA. Unless a research reactor has obtained a decommissioning

license from its regulator, the safety and security regulations for operational reactors apply, even if the reactor is not in use and may not even have any fuel left. “Complying with regulatory requirements over time is more costly than biting the bullet and decommissioning,” Michal said. “It is better and safer to be under the decommissioning regime than in limbo.”

## Decommission fast

This is the approach Indonesia is taking, Kamajaya said. There are already plans in place to shift medical isotope production from Bandung to the country’s two other research reactor facilities. Training of scientists on reactor physics and thermal hydraulics will also move to the other locations. “Once we shut down the reactor, we will want to decommission it as soon as possible,” he said. In order to prepare for decommissioning, experts from the operators have participated in several IAEA technical cooperation projects, and have had the chance to witness ongoing decommissioning work in Australia and Belgium.

In Uzbekistan, the government decided to permanently shut down its research reactor at the Institute of Nuclear Physics in Tashkent in July 2016, and begin decommissioning as soon as feasible, said Umar Salikhbaev, Director of the Institute of Nuclear Physics. “We are working very closely with the IAEA on the preliminary decommissioning plan, which we want to submit to the government by May,” he said. This follows the decommissioning of the FOTON research reactor in Tashkent, which began last year and is scheduled to be completed by mid-2017. The reactor fuel was repatriated to Russia as part of a programme coordinated by the IAEA last September (see photo, page 16).

## Old reactor, new reactor

Several operators would like to build new research reactors, technically more advanced than the previous generation. They will have an easier time obtaining a regulatory licence and earning the trust of the public for a new research reactor if they can demonstrate that they have properly decommissioned their previous reactor, Ljubenov said. The site of the previous facility could also provide a natural location for the new one, he added.

In some respects, research reactors are more complex to decommission than power



reactors, despite their smaller size, Ljubenov explained. They are often in the middle of a university campus or a research institute, surrounded by other facilities and buildings in use. A research reactor may have connections and share systems with laboratories or other research facilities, for instance a common waste storage tank. “Where are the boundaries of the reactor, what has to be decommissioned and what has to remain? This is not always obvious,” Ljubenov said.

## The right regulation

IAEA support also extends to regulators, so that they can prepare their country’s legal framework for decommissioning. “With just three research reactors and no power reactors, we are too small to develop our own guidelines,” said Reno Alamsyah, Senior Regulator at Indonesia’s Nuclear Energy Regulatory Agency (BAPETEN). The IAEA has trained BAPETEN staff on drafting legislation and guidelines, and will also help them with reviewing the decommissioning plan once it is submitted.

Following their initial training, staff in both Indonesia and Uzbekistan say they are now better equipped for any subsequent decommissioning work, either at home or abroad. “There are two more reactors in Indonesia. And while for now they are going strong, the time will come to decommission these also,” Kamajaya said.

In Uzbekistan, experts from the Institute of Nuclear Physics have recently begun working on preparing the decommissioning plan of the country’s second research reactor. “We can reuse a lot of the material and knowledge we gained the first time around,” Salikhbaev said.

**Engineers in charge of the research reactor operated by Uzbekistan’s Institute of Nuclear Physics get advice from international and IAEA experts on preparing a decommissioning plan.**

(Photo: D.Calma/IAEA)

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**“Countries without a nuclear power programme typically have significantly less expertise in decommissioning and often lack the facilities to manage all but low level waste.”**

— Vladan Ljubenov, Waste Safety Specialist, IAEA

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# Promoting understanding, enhancing safety: IAEA services for decommissioning and environmental remediation

Putting nuclear facilities safely and securely to rest once they have reached the end of their useful lives and making their sites available for future reuse require careful planning and implementation. The IAEA offers Member States a wide range of services related to decommissioning and environmental remediation, from legal, regulatory and technical advice through capacity building and training to maintenance of networks for information exchange. The services also assist States Parties to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which requires Parties to report on safety for remediation and decommissioning.

This article provides an overview of these services.



Remediation site in Australia.

(Photo: IAEA)

## The ARTEMIS review service

The IAEA has developed an integrated review service for radioactive waste and spent fuel management, decommissioning and environmental remediation, referred to as ARTEMIS. It was launched in 2014, and is intended for facility operators and other implementing organizations responsible

for radioactive waste management, decommissioning of nuclear facilities and the remediation of sites contaminated with radioactive materials.

This service may be used by regulators, government agencies and national policy makers and may cover existing or planned national or institutional policy and regulation frameworks as well as associated waste management programmes, projects or facilities. The reviews may also involve detailed assessment and technical advice on the implementation of specific decommissioning or environmental remediation programmes.

## Workshops and training

The planning and implementation of decommissioning and environmental remediation programmes depend on the availability of a sufficient number of suitably qualified and experienced professionals both at implementing and regulatory organizations.

The IAEA runs training courses, workshops and expert missions and offers fellowships through its Technical Cooperation Programme to assist in developing technical knowledge and expertise. Specialist online learning courses complement face-to-face training.

## International Decommissioning Network

The International Decommissioning Network (IDN) is a forum for experts to enhance cooperation and knowledge sharing related to decommissioning activities. The network is concerned with the decommissioning of all types of nuclear facilities, including power plants, fuel cycle facilities, research reactors, former research sites and other facilities in which radionuclides are utilized for industrial, medical or research purposes.

The Network organizes several collaborative activities, including an annual forum for participants.

## **Network of Environmental Management and Remediation (ENVIRONET)**

ENVIRONET promotes and facilitates collaboration between less experienced and more experienced countries and organizations to share knowledge in the implementation of environmental remediation projects.

The network offers a broad and diversified range of training and demonstration activities with a regional or thematic focus providing hands-on, user-oriented experience and disseminating proven technologies.

## **Connecting the Network of Networks for Enhanced Communication and Training (CONNECT)**

IAEA CONNECT is a web-based platform available to members of IAEA professional networks and communities of practice with the objective to facilitate collaboration and sharing of information and experience between network participants, both within or among several networks.

Eleven networks are hosted on CONNECT, including IDN and ENVIRONET, as well as networks dealing with waste disposal, spent fuel management and nuclear knowledge management, among others.

## **Modelling and Data for Radiological Impact Assessments Programme (MODARIA)**

The aim of the MODARIA Programme is to improve capabilities in the field of environmental radiation dose assessment through the use of improved data, model testing and comparison, reaching consensus on modelling approaches and parameter values, developing improved methods and exchanging information.

The results of radiological assessments are used, for example, in the evaluation of the radiological relevance of routine and accidental releases of radionuclides, to support decision making in remediation work and for the performance assessment of radioactive waste disposals.

The Programme has ten working groups that focus on a range of interrelated issues, such as routine discharges of radionuclides into the environment, the migration of radionuclides in contaminated rural and urban environments, the dispersion of radionuclides in marine systems and the remediation of land contaminated during nuclear accidents or as a result of poorly regulated activities in the past.

## **Other collaborative efforts**

In 2012, the IAEA formed the Coordination Group for Uranium Legacy Sites (CGULS) to provide technical coordination for national and multilateral activities in the remediation of uranium legacy sites, primarily in Central Asia.

Another service, the International Working Forum on Regulatory Supervision of Legacy Sites (RSLs), was established in 2010 to promote effective and efficient regulatory supervision of legacy sites, consistent with IAEA Safety Standards and international good practices. It offers participants an opportunity to gain hands-on experience through international workshops that focus on specific sites. This service builds technical competence, strengthens regulatory capacity for remediation and helps devise effective national strategies to enhance national decision-making processes.

Through the International Project on Managing the Decommissioning and Remediation of Damaged Nuclear Facilities (DAROD), which was launched in January 2015, experts can learn more about and benefit from the experience derived from decommissioning and remediating nuclear facilities damaged by severe accidents. DAROD addresses regulatory, technological and planning aspects of decommissioning and remediation.

DAROD is one of the initiatives undertaken by the IAEA under the IAEA Action Plan on Nuclear Safety adopted in the wake of the 2011 accident at the Fukushima Daiichi nuclear power plant.

# New technologies in decommissioning and remediation

By Vincent Fournier

**Drones can be mounted with sensors and cameras to remotely collect data in preparation for environmental remediation.**

(Photo: R. Duran/IAEA)



New and emerging technologies are making decommissioning and remediation more cost effective, faster and safer. From planning to execution and control, the use of new technologies is on the rise.

## Lasers and drones for better planning

Before starting decommissioning or environmental remediation, experts need to plan each step of the process, and to do that, they first need a clear idea of the characteristics of the structure and the level of radiation that they can expect to encounter.

While characterization for planning purposes can be done using manual approaches, such as drawing up blueprints and taking measurements and photos, laser scanning technologies are now allowing decommissioning teams to more quickly and accurately map out the physical characteristics of a facility's structures, systems and components. This is complemented by highly sensitive measurements taken with high-tech devices, such as remotely operated gamma cameras that can precisely and efficiently measure the radiological characteristics of the facility, including the amount and type of radiation. Similar measurements are needed once the contamination has been removed, to verify that any residual radiation levels are indeed insignificant.

For environmental remediation specialists, understanding the nuanced dimensions of how a site's environment — and the contaminants within it — behave over time is increasingly important. New tools such as drones equipped with sensors allow specialists to remotely evaluate the site's surface and, when combined with data collected on the ground, can help determine the nature, concentration and distribution of contaminants in the soil. This provides a high-resolution characterization of the site's physical and radiological characteristics, as well as of the underlying environmental behaviour and dynamics.

In both cases, once the data has been collected, state-of-the-art 3D modelling software can generate highly detailed reproductions of the facility or site and an overlay map of its radiation levels. Modelling software can also be used in environmental remediation for simulating the behaviour of pollutants in the environment, a key step in the selection and implementation of safe, sustainable and cost effective approaches for remediation and long term monitoring and management of a site.

## Humans and robots

Nuclear facilities are full of nooks and crannies that can be hard to reach and, in some areas, highly radioactive and dangerous for workers to enter. Robots are offering new ways to handle these challenges.

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**“Remotely controlled tools can be used to measure radioactivity, decontaminate nuclear power plants and eventually to segment and handle the plant components, avoiding the risk a human being would face.”**

— Vladimir Michal, Team Leader,  
Decommissioning and Environmental  
Remediation, IAEA

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“There are some parts of these facilities where workers simply cannot go, either because they are too small and narrow or too radioactive and dangerous. That’s where robotics can make a difference,” said Vladimir Michal, Team Leader for Decommissioning and Environmental Remediation at the IAEA. “Remotely controlled tools can be used to measure radioactivity, decontaminate nuclear power plants and eventually to segment and handle the plant components, avoiding the risk a human being would face.”

As technology advances, robots have become smaller, more sophisticated and refined, allowing them to operate in a variety of terrains and in extreme environments. Multifunctional robotic arms, for example, can be operated remotely by workers and equipped with tools such as laser cutters to allow dismantling of hard-to-reach pipes and reactor components, among others.

Remotely controlled cutting tools may also operate underwater, with operators located close by, protected by the natural shielding water provides against radiation. By breaking down radioactive components underwater, these robots can help to protect workers and prevent the emission of airborne particles.

## Innovative nature

Innovation is not always about creating complex new gadgets. ‘Engineering with nature’ is an emerging concept in environmental remediation. In some situations the optimum remedial solution may not be the one involving costly tools and chemical operations.

“Letting nature run its course may, in some cases, be the best course of action, but it requires highly detailed understanding and prediction of the relevant environmental processes. It is only more recently that computational tools, techniques for characterization and monitoring became powerful enough to enhance confidence in the use of this approach,” said Horst Monken-Fernandes, an environmental remediation specialist at the IAEA.

Nanoscale remediation, or nanoremediation, is a new technique that makes use of tiny man-made structures known as nanoparticles to rapidly and efficiently reduce contaminant concentrations in soil and groundwater. These



particles, which are about 100 000 times smaller than the width of a single hair, have excellent storage, transportation, penetration and distribution capabilities. They can be injected into the subsurface of a contaminated source to degrade or immobilize the contaminant. They can also be used to trap contaminants through nanostructures that behave like a molecular sieve. This technique has the potential to be more cost-effective than traditional techniques, such as excavation in reaching the clean-up goals in environmental remediation.

## A whole new world

Innovation opens the door to new possibilities, but also imposes new training requirements. One solution to address this is virtual reality. The 3D world offers an opportunity for practitioners to get first-hand experience in each step of the decommissioning and environmental remediation process. This can include, among other things, specification of the cutting sequence to be followed, the levels of exposure to radiation that workers may face, the most efficient options for component removal and packaging of the segmented waste pieces and potential safety hazards.

While the potential benefits of new technologies and innovations are vast, it often takes years to scale these up for wider use, particularly in countries where budgets and resources are limited. The IAEA’s support helps countries get the information, experience and training they need.

“The vision of the IAEA is to assist Member States in developing and maintaining their capacity to manage decommissioning and remediation projects in a timely, safe and cost-effective manner,” Michal said.

**Snake-like robot equipped with a laser cutter allows the decommissioning team to access confined and hazardous areas.**

(Photo: Sellafield Ltd/UK)

# Decommissioning of nuclear facilities: Germany's experience

By Boris Brendebach



Boris Brendebach is a research associate and the chief decommissioning expert with the Installation and Reactor Safety Company (GRS) that supports the German government in its decommissioning and remediation activities.

Germany has gained considerable experience in the decommissioning of nuclear facilities since the 1970s. Currently 16 nuclear power plants, both power and prototype reactors, are at different stages of decommissioning. Three decommissioning projects have been completed (see map).

Following the Fukushima Daiichi nuclear power plant (NPP) accident in March 2011, the German Government decided to end the use of nuclear energy for the commercial generation of electricity by gradually phasing it out. This decision resulted in an amendment of the German Atomic Energy Act (AtG) on 31 July 2011, withdrawing the authorization to operate an installation for the fission of nuclear fuel for the commercial production of electricity for the seven oldest NPPs and NPP Krümmel on 6 August 2011, and setting end dates for the authorization for the remaining nine NPPs in a phased approach ending in 2022.

Since then, all eight NPPs, which were shut down in 2011, applied for a decommissioning licence. Additionally, NPP Grafenrheinfeld was shut down on 27 June 2015, half a year before its originally scheduled end date. An application for decommissioning was submitted well in advance, and the same was done for NPP Gundremmingen B, which is still in operation and which is scheduled to be shut down at the end of 2017.

The map on next page provides an overview of the nuclear power plants under decommissioning in Germany, as well as those already either dismantled, permanently shut down but awaiting granting of the decommissioning licence, or in operation with end dates in place. In addition to the power and prototype reactors, more than 30 research reactors of various size and more than ten nuclear fuel cycle facilities have been shut down and have been or will be decommissioned.

## In many shapes and forms

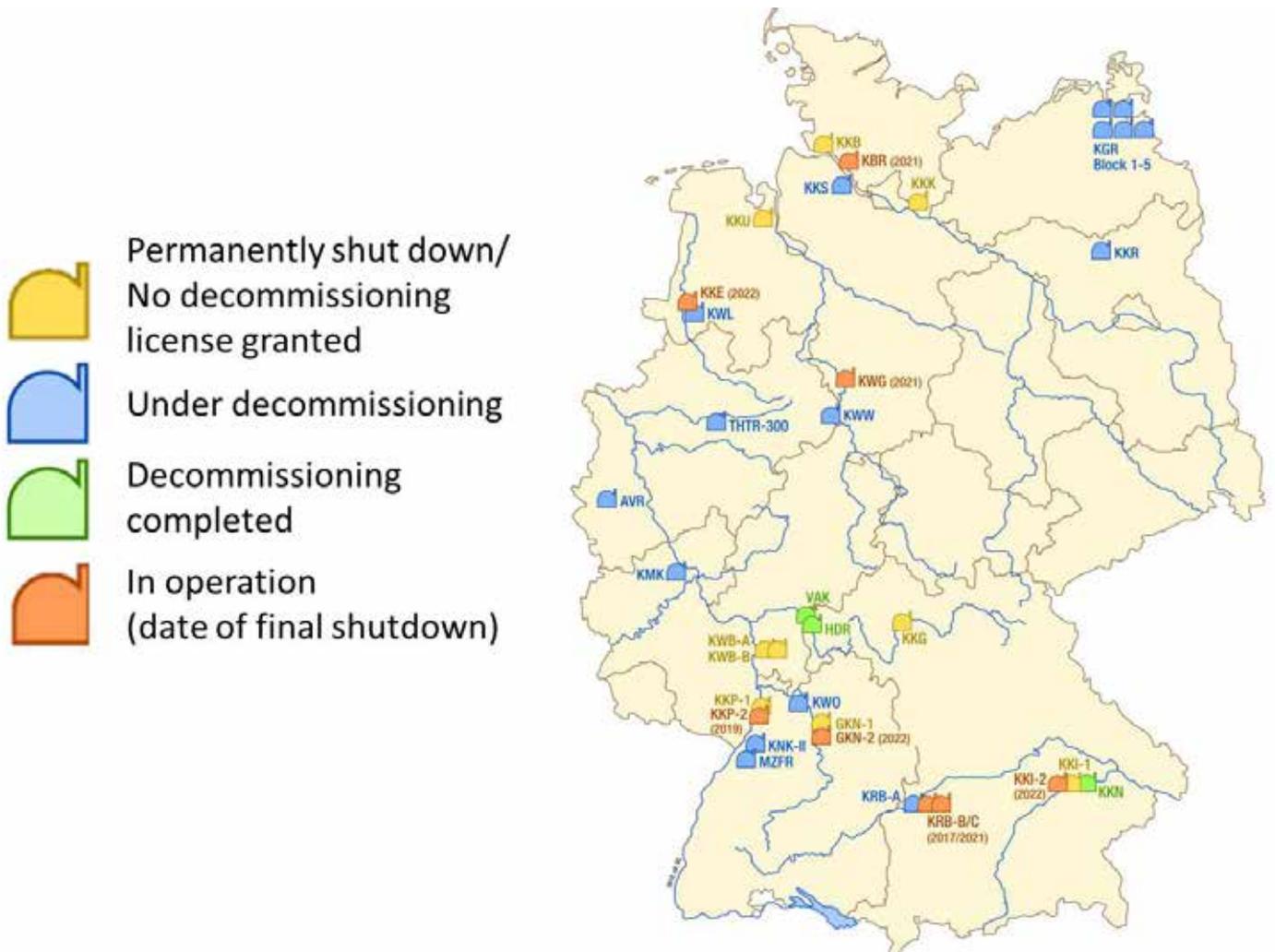
There may be many decommissioning projects proceeding concurrently, but each project is unique. The course of the project, its financing, the choice of decommissioning strategy and many other conditions depend on the type of facility and its owner:

- Power reactors and plants for uranium enrichment and fuel fabrication belong to the power utilities and the companies operating in this sector.
- Research reactors, prototype reactors for electricity production and prototype nuclear fuel cycle facilities are, on the other hand, established at research centres or universities. They are financed publicly.
- The decommissioning of the Greifswald and Rheinsberg NPPs of the former East Germany is financed from the federal budget, as are the decommissioning and remediation of the uranium mining and processing facilities of East Germany.

The legal framework for the decommissioning of nuclear facilities results from the AtG. It stipulates that decommissioning is subject to licensing by the competent authority. According to the AtG, there are two different strategies allowed: immediate dismantling or dismantling after safe enclosure. The decision as to which decommissioning strategy to implement is taken by the operator. Most operators have opted for dismantling immediately.

For the licence application, specified documents and information have to be submitted to the competent authority of the state in which the nuclear facility is located. These have to describe, among other things, the procedure applied for, the planned dismantling measures and associated techniques to be used, the environmental impact and the provisions for radiation protection. Further details are regulated by the

## The status of Germany's power reactors



(Source: Installation and Reactor Safety Company, Germany)

Nuclear Licensing Procedure Ordinance and are included in the Decommissioning Guide.

Compliance with the requirements for work permitted in the decommissioning licence is supervised by the competent local state authority. The authority verifies whether the conditions specified for the work and the licensing conditions imposed are complied with. Additional inspections are carried out by independent experts commissioned by the authority for assistance. Furthermore, the techniques and methods specified in the licence will be fully specified and a detailed

plan prepared in the course of the supervisory procedure.

Future tasks in Germany are the completion of the current decommissioning projects and the decommissioning of the nuclear facilities that are still operating once they have reached the end of their operating life. The number of parallel decommissioning projects of large scale facilities required by the phase-out of nuclear power could pose challenges in terms of the availability and maintenance of competences at all levels (operators, regulatory body, technical support organizations, and suppliers).

# Current trends in decommissioning and environmental remediation of nuclear facilities

By Juan José Zaballa Gómez



Juan José Zaballa Gómez is an economist and veteran of the nuclear decommissioning industry. He is the President of Enresa, Spain's National Company for Radioactive Waste, and the chair of the IAEA International Conference on Advancing the Global Implementation of Decommissioning and Environmental Remediation Programmes from 23 to 27 May 2016 in Madrid.

The decommissioning and environmental remediation of civil nuclear facilities represents a considerable challenge for the countries involved in this activity around the world. It includes aspects and problems associated with management, technology, safety and the environment.

Over the past few decades, operators worldwide have acquired important experience in the decommissioning and environmental remediation of nuclear sites. A large number of nuclear facilities have ceased operations, and it is envisaged that this number will increase considerably over the coming years. Seventeen power reactors have already been decommissioned, out of more than 150 power reactors shut down or undergoing decommissioning, while more than 180 research reactors have been shut down or are being decommissioned with more than 300 already fully decommissioned. A total of 170 other nuclear cycle facilities have been shut down or are being decommissioned and a further 125 have been completely decommissioned. Spain is one of the countries with experience and activity under way in this field.

It has been demonstrated that decommissioning activities can be performed without creating additional risks to health, safety or the environment, and that it is a mature industrial activity.

But what are the fundamental elements that make this activity possible? In our experience, the complete cycle is related to the effective availability of three key elements: a regulatory legal framework that guarantees safety, the necessary provisions with regards to the funding and availability of resources, and access to technologies and experience in this field including the presence of logistical and management solutions for the resulting materials, particularly spent fuel and radioactive waste.

It is necessary to establish a suitable legal framework that clearly defines the responsibilities of the different stakeholders, including the authorities. The transition from operation to dismantling and decommissioning requires changes to the regulatory framework to ensure that the required measures associated with the specific risks of this type of project are adopted in a way that facilitates its implementation, while respecting the established safety requirements.

## The importance of R&D

It is, therefore, necessary to provide continuity to research, development and innovation activities in order to develop and improve techniques and technology. This effort should respond to the specific characteristics of decommissioning and environmental remediation, which are unique in that they are dominated by non-routine operations, subject to continuous changes in the environment and risk profile. It must be developed in an environment that simultaneously requires ongoing improvement in safety conditions, project management efficiency and the associated costs.

A critical aspect in these activities is the required separation of non-radioactive materials from radioactive waste. This process minimizes the amount of waste requiring special treatment and management due to its radiotoxicity.

The availability of facilities and management pathways for the materials generated during decommissioning up to their final disposal, particularly for radioactive waste and spent nuclear fuel, ensures that no responsibility is passed on to future generations. Consequently, a lack of management pathways and destination facilities may generate difficulties in the approval process and, in all cases, adds uncertainties regarding the final costs.



### Training young professionals

These activities require the availability of personnel and qualified contractors. The nuclear sector is dealing with an ageing professional workforce faced with the difficulty of attracting and keeping young professionals that can replace them. This situation affects both regular operations as well as, and perhaps more so, decommissioning and environmental remediation.

Public acceptance is a necessary condition and is essential for the effective execution of these activities. In this respect, there is wide consensus regarding the responsibility of the operators and authorities when it comes to facilitating responsible and informed participation of a wide range of stakeholders in decision-making.

Participants in these activities in any country should be prepared for the

unexpected. A diverse range of factors — political, economic, social, regulatory and environmental — may influence the development of these activities from their initial planning phase right up to their finalization.

Last but not least, I wish to turn to costs and funding for decommissioning and environmental remediation. The costs vary significantly, depending on the type of facility, the dismantling strategy, the objective of freeing the sites, the proximity and availability of infrastructure for managing the resulting materials, the regulatory framework and regulations in force. In this respect, increasing attention is being given to ensuring the availability of sufficient financial resources to execute and complete these activities in a way that avoids liabilities being passed on to future generations.

**Enresa has repurposed the turbine building into a radioactive waste management facility at the José Cabrera nuclear power plant.**

(Photo: Enresa)

## Newcomer countries face common challenges in nuclear infrastructure development



**Belarus is constructing its first NPP at the Ostrovets site.**

(Photo: Directorate for Nuclear Power Plant Construction/Belarus)

Countries embarking on a nuclear power programme need to make sure that the development of their legal, regulatory and support infrastructure keeps pace with the construction of the power plant itself. This is the only way to ensure that the programme proceeds in a safe, secure and sustainable way, concluded participants of a workshop on nuclear power infrastructure development hosted at the IAEA last February. “Embarking on a nuclear power programme is a serious undertaking that requires significant financial resources, as well as the implicit responsibility to ensure that the necessary infrastructure is in place,” said Milko Kovachev, Head of the IAEA Nuclear Infrastructure Development Section. “A country should start a nuclear power programme only when it is ready and can be realistic about the time and resources involved.”

Countries introducing nuclear power for the first time, called ‘newcomers,’ face a number of similar key challenges in infrastructure development: completing a national policy and strategy for the programme, developing a legal framework and an independent nuclear regulatory body,

strengthening project management and building a skilled workforce.

Participants at the 10th annual technical meeting on Topical Issues in the Development of Nuclear Power Infrastructure from 2 to 5 February included representatives of national governments, future owner/operator organizations, regulatory bodies and other institutions from both nuclear newcomer and operating nuclear power countries.

Presenting case studies, the participating newcomer countries discussed different issues including the complexity of developing a regulatory framework and licensing process. “A knowledgeable and independent regulator is essential to balance the role of the operator of a nuclear power plant and set standards for nuclear safety and a nuclear safety culture in a transparent way,” said Meeting co-chair Per Lindell from Sweden.

### Nuclear milestones

“All newcomer countries have adopted the framework of the IAEA’s Milestones approach which is the Agency’s key guidance for developing

the nuclear infrastructure for a nuclear power programme,” said Abdelmajid Caoui, former General Secretary of the Nuclear Research Center of Morocco, who co-chaired the meeting. “This is reflected in Member States’ expressed commitment to the safe, secure and peaceful use of nuclear energy, strong government support as a key pillar for a new nuclear power programme, and the early creation and involvement of the regulator, owner/operator and technical support organizations.” Morocco is considering nuclear power as a long term low-carbon energy source and hosted an IAEA Integrated Nuclear Infrastructure Review (INIR) mission in October 2015.

Belarus is currently constructing its first nuclear power plant at Ostrovets. Two 1170 MW(e) units are scheduled to be in operation by 2018 and 2020, respectively. At the meeting, Mikhail Mikhadiuk, Deputy Minister of Energy of Belarus, presented the roadmap and key milestones for the nuclear power programme development.

“Belarus made the decision to embark on a nuclear power programme in 2008 in order to enhance security of energy supply by diversification of energy resources, reduce electric power production costs and curb greenhouse gas emissions,” Mikhadiuk said. “We are realizing the nuclear power programme based on IAEA standards.” Belarus hosted an INIR mission in 2012.

### INIR: Assistance from the IAEA

INIR missions are the most important service a Member State can request in the area of nuclear infrastructure development, said Mikhail Chudakov, IAEA Deputy Director General and Head of the Department of Nuclear Energy. “I strongly encourage any Member State that is seriously considering the introduction of nuclear power to discuss the possibility of hosting an INIR mission.” Since 2009, the IAEA has conducted 17 such

missions in 13 countries and recently published a document that summarizes six years of experience with INIR missions.

Participants also addressed financial risks, which include regulatory risks, and how to mitigate them. In light of the ever-changing cost of energy and the costs and complexity of nuclear power, this is a growing area of interest for Member States, to be also addressed at future IAEA meetings.

In addition, human resource development remains a consistent challenge. Not only do countries have to find the right personnel and train them, but they also have to ensure that there is a place for them to work once they are trained, for example if a programme encounters delays.

Concerning initial considerations that many Member States are making as they determine whether to embark on a nuclear power programme, energy

planning is the first step toward the consideration of nuclear power. Such studies will lead to further analysis through prefeasibility studies and comprehensive reports. The IAEA will shortly publish new guidance on this process and on the development of a national position, as well as several other relevant publications for countries considering nuclear power.

— *Lenka Kollar and Elisabeth Dyck*

## Safety and licensing requirements for small modular reactors: IAEA hosts first workshop for regulators

A new generation of advanced, prefabricated nuclear power reactors called small modular reactors (SMRs) could be licensed and hit the market as early as 2020, and the IAEA is helping regulators prepare for their debut. In a series of workshops that began earlier this year, the IAEA is working closely with regulators on approaches to safety and licensing ahead of potential SMR deployment worldwide.

Safety requirements, guidelines and licensing procedures for SMRs were among the topics that participants from the Arab Atomic Energy Agency (AAEA) and the Arab Network of Nuclear Regulators learnt about during an IAEA workshop held in Vienna in January 2016.

“Small modular reactors are a very attractive proposition for the Arab world as more than half the countries in our region don’t have the resources to build large, traditional nuclear power plants. SMRs are more feasible, manageable and require lower investment — it is a very realistic option for Arab countries to consider,” said Abdelmajid Mahjoub, Director General of the AAEA and the Chairman of the workshop.

Co-sponsored by the United States Nuclear Regulatory Commission, the workshop brought together regulatory bodies, operator companies, and other governmental organizations, working



**Advances in SMR technology development.** (Image: IAEA)

or expected to work towards the establishment of national safety and technical infrastructures for SMRs.

Workshop participants received detailed information about the role of regulatory bodies and licensing requirements, including the approval of SMR designs, siting and operations. The IAEA facilitated discussions among regulators on the use of relevant IAEA safety

standards and on changes that may be needed in national regulations.

### Small and safe

Designed to be modular using prefabricated modules, SMRs, with an output of less than 300 MW, will have shorter construction times and are expected to be cost-competitive to build. Four SMRs in three countries are

already under construction. “Though smaller, the safety and security measures for this next generation of nuclear power reactors are no different from the international obligations that present-day reactors are subject to,” said Stewart Magruder, a senior nuclear safety officer at the IAEA.

The global safety and security standards that are applicable to existing nuclear power reactors as well as those under construction are mostly applicable to SMRs, too. “We need to establish a set of clear and pragmatic requirements for safety and licensing,” said Greg Rzentkowski, Director of the Division of Nuclear Installation Safety at the IAEA. “Regulatory certainty is essential for successful deployment of SMRs.”

The IAEA will coordinate additional work in this area in coming years. This is likely to include the development of an overarching safety objective and a guidance document on establishing relevant requirements in accordance with the facility type and size, Rzentkowski said.

### Develop, assess and deploy

These prefabricated nuclear reactor modules can be shipped to specific destination points, much like transporting a manufactured

component from one industrial park to another. The potential benefits to countries and end users resulting from the commercial operation of SMRs are immense — for example, by providing much needed electricity to remote regions, thereby enhancing the dynamics of worldwide energy supply.

The development of SMRs began nearly two decades ago, and several countries are independently engaged in deploying prototypes. The IAEA has observed a significant increase in Member State participation in SMR technology development that reflects the vast potential seen in the deployment of such reactors with regard to expanding national electricity grids, and improving energy supply security.

The IAEA is also drawing up a technology roadmap for SMR deployment and conducting a study on SMR deployment indicators in developing countries to assist Member States in developing, assessing or deploying SMRs.

### Current developments

There are around 50 SMR designs under development for various purposes and applications, and four reactors under construction: CAREM-25, an industrial prototype

in Argentina; KLT-40S and RITM-200, floating SMRs in the Russian Federation; and HTR-PM (‘High Temperature Reactor–Pebble-Bed Module’), an industrial demonstration plant in China. Last year, Saudi Arabia’s atomic energy authority signed an agreement with the Republic of Korea to build an SMR called SMART (‘System-integrated Modular Advanced Reactor’) in Saudi Arabia. Even traditional fossil fuel producers are now looking at the potential which SMRs offer to provide a more diversified energy supply to national and regional electric grids.

“SMRs are among the most advanced reactor technologies for meeting future energy demands, and Member States need to be fully aware of the applicable safety standards and regulations to enable successful deployment of this new type of power reactor,” said Hadid Subki, a nuclear engineer at the IAEA Nuclear Power Technology Development Section.

The next IAEA workshop on the safety and licensing requirements for SMRs is for members of the Forum of Nuclear Regulatory Bodies in Africa and will take place in June 2016.

— *By Aabha Dixit and Miklos Gaspar*

## IAEA reaches milestone in disposal of radioactive sources

Successful tests of a promising technology for moving and storing low level radioactive sealed sources are paving the way for a new disposal method for dealing with small volumes of radioactive waste around the world. The method, which involves placing and covering sealed sources in a narrow hole a few hundred metres deep, would allow countries to safely and securely take charge of their own disused radioactive sources. The proof of concept for the technology was tested in Croatia late last year — without the use of actual radioactive material.

Virtually all countries use radioactive sources in health care, industry and other sectors. Many, though, do not have the equipment or staff needed to deal with these once they are no longer usable. Under typical circumstances, a developing country using sealed radioactive sources may generate hundreds of disused sources with low levels of radioactivity over several years, according to IAEA estimates.

“Low activity sources pose the larger challenge because they exist in large quantities around the world and in different forms and variations,” said Andrew Tompkins, a nuclear engineer at the IAEA.

In most developing countries, sealed radioactive sources are stored temporarily. Some developed countries have disposal facilities close to the surface. Both of these pose a security risk if they are not sufficiently protected. The new disposal method represents a long term solution to this problem, and will ultimately help protect people and the environment.

Equipment tests conducted by IAEA engineers and a Croatian radiation protection company confirm the feasibility of a system that safely moves and inserts low activity sources into boreholes for disposal.



**IAEA engineers and a Croatian radiation protection company test a new system used to safely and securely dispose of low-activity sources in boreholes.** (Photo: L. Gil/IAEA)

The tested technology, developed for disused sources with low levels of radioactivity, relies on a robust metal platform and a mobile container called a transfer cask, which is used to move the sources into the borehole safely. “It’s simple, affordable and can be deployed worldwide,” said János Balla, a waste technology engineer at the IAEA.

“We realized that countries that had low levels of waste, modest infrastructure and limited human and financial resources needed a safe, straightforward and practical solution,” said Balla.

### Preventing theft and terrorism

Increasing nuclear security is an important driver behind the development of the new method. “Given that disused sources remain radioactive, we want to limit the probability of these being reached and used for terrorist activities,” said Gert Liebenberg, a nuclear security officer at the IAEA. “Once in the borehole, they are no longer easily accessible to anyone.”

The original borehole idea was developed by the South African Nuclear Energy Corporation (Necsa), and subsequently adapted by the IAEA to incorporate the disposal of sources with higher levels of radioactivity. Today, borehole technical preparations and safety assessments are taking place in several countries, including Malaysia and the Philippines, so that the method can be implemented in the coming years.

The IAEA is ready to train experts in countries interested in using the borehole disposal method and provide them with the necessary assistance, either equipment or technical specifications, to build their own transfer cask. The technology to drill the hole is similar to that used to extract water, and is widely available in most countries, including less developed ones.

### Treating sources

Radioactive sources are used widely in medicine and industry, from radiotherapy machines for treating cancer, to industrial tools for sterilizing

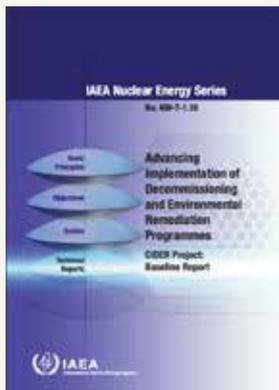
disposable medical supplies. The most common sealed sources have low levels of radioactivity or a short half-life, meaning they will remain radioactive for only a few months to a few hundred years.

Before disposal, all sources are treated and repackaged through a process called conditioning. When prepared according to this method for disposal, hundreds of sources — the typical amount generated by a developing country each year — take up less than a cubic metre, the size of a small wardrobe.

Once the borehole is in place, the conditioned sources will be loaded into a specially-designed canister, or disposal package, which is then sealed. The sealed canister will then be placed inside the transfer cask and moved over — and eventually into — the borehole.

— *By Laura Gil*

## Publications Alert

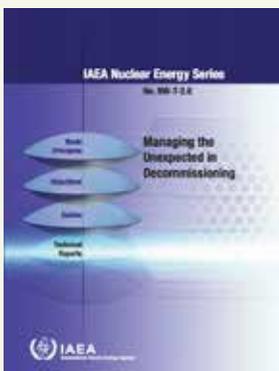


### Advancing Implementation of Decommissioning and Environmental Remediation Programmes

#### CIDER PROJECT: Baseline Report

discusses the barriers that prevent decommissioning and environmental remediation projects from being implemented and provides options to overcome these barriers. Despite significant progress in recent years, much remains to be done to address legacies from the early development of nuclear energy, including the dismantling of redundant research and fuel cycle facilities and power plants, and the remediation of sites affected by past uranium mining and processing operations. Several countries are dealing with such legacy issues, and have built up appropriate technical resources and expertise, but many national programmes still face significant challenges.

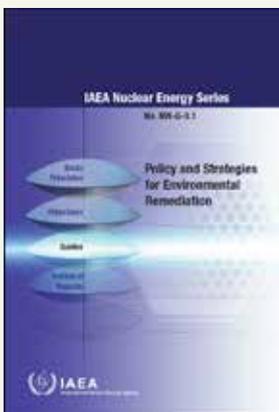
IAEA Nuclear Energy Series No. NW-T-1.10; ISBN: 978-92-0-101316-3; 37.00 Euro; 2016  
[www-pub.iaea.org/books/IAEABooks/10993/CIDER](http://www-pub.iaea.org/books/IAEABooks/10993/CIDER)



### Managing the Unexpected in Decommissioning

explores the implications of unexpected events encountered during decommissioning and ways to mitigate them. It provides practical guidance on how to plan and manage such projects, taking into account unexpected events. It classifies and sets out some instances where unexpected findings made it necessary to either suspend or reconsider the decommissioning work. The publication includes an evaluation of past experience in tackling decommissioning challenges. It will enable future decommissioning teams to learn from these lessons, thereby helping them to reduce additional costs, time delays and unnecessary radiation exposure.

IAEA Nuclear Energy Series No. NW-T-2.8; ISBN: 978-92-0-103615-5; 35.00 Euro; 2016  
[www-pub.iaea.org/books/IAEABooks/10786/Unexpected](http://www-pub.iaea.org/books/IAEABooks/10786/Unexpected)

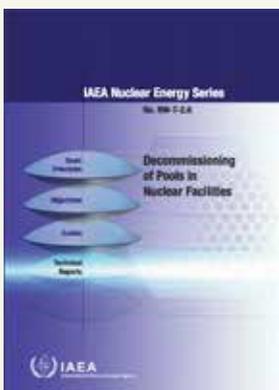


### Policy and Strategies for Environmental Remediation

describes the goals, timescales and efforts needed to implement environmental remediation. It clarifies the differences between a policy and a strategy, and provides advice to Member States on how to formulate and compose these types of documents. It touches on aspects such as cost allocation and the different interests of the parties concerned in environmental remediation.

Along with previously issued IAEA safety publications on environmental remediation, this book will help national authorities to recognize the need for including environmental remediation as a required component in the planning and execution of nuclear-related initiatives.

IAEA Nuclear Energy Series No. NW-G-3.1; ISBN: 978-92-0-103314-7; 20.00 Euro; 2015  
[www-pub.iaea.org/books/IAEABooks/10622/Policy](http://www-pub.iaea.org/books/IAEABooks/10622/Policy)



### Decommissioning of Pools in Nuclear Facilities

describes the technical and planning aspects of decommissioning nuclear pools. It reviews and consolidates globally available experience related to pool decommissioning, including project planning, health and safety and the management of resulting waste.

A number of nuclear installations utilize pools to cool spent fuel or to shield research reactor cores or irradiator sources. Over a service lifetime that can span decades, nuclear pools may become contaminated as a result of the deposition of radioactive substances. Although cases of pool decommissioning have been sporadically described in the technical literature, no report had covered the treatment of decontamination and dismantling strategies and technologies for contaminated pools as comprehensively as this publication.

IAEA Nuclear Energy Series No. NW-T-2.6; ISBN: 978-92-0-103115-0; 55.00 Euro; 2015  
[www-pub.iaea.org/books/IAEABooks/10669/Pools](http://www-pub.iaea.org/books/IAEABooks/10669/Pools)



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