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Research Reactors

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IAEA

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

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

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

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

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

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

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

Tapping into the power of research reactors

By Cornel Feruta, Acting Director General, IAEA

Research reactors have been a powerful tool driving innovation in nuclear science and technology throughout the world for decades.

There are 224 research reactors operating in 53 countries today. Their numerous applications include producing radiopharmaceuticals for cancer care and nuclear medicine, helping to create new materials for research and industry and training nuclear scientists and engineers. They are generally not used for power generation.

For more than 60 years, the IAEA has helped countries to set up, operate and maintain research reactors in order to reap the great benefits that they offer to science and society.

This edition of the *IAEA Bulletin* examines research reactors and the many ways in which the IAEA helps countries to derive optimal benefit from them. It provides an overview of how they are used (page 4), such as for the production of radioisotopes for medical scans (page 12) and the education and training of nuclear professionals (page 14). A photo tour offers an inside look at a research reactor facility in Jordan (page 16).

For countries embarking on a research reactor programme, the IAEA's Milestones approach offers a holistic, step-by-step method to develop the necessary infrastructure to use these versatile tools safely and reliably (page 6). For countries that already have research reactors or are seeking to build more, the IAEA's expert peer review services offer an avenue for assessing and improving safety, security and operation (page 22).

Many countries work with the IAEA to maximize the utilization of their research reactors, particularly those that were built decades ago without a long-term strategic plan (page 20). Belgium, for example, is adopting ageing and management plans to optimize the use of its research reactor for decades to come (page 30). Uzbekistan, on the other hand, has worked with IAEA experts to decommission one of its research reactors (page 32).

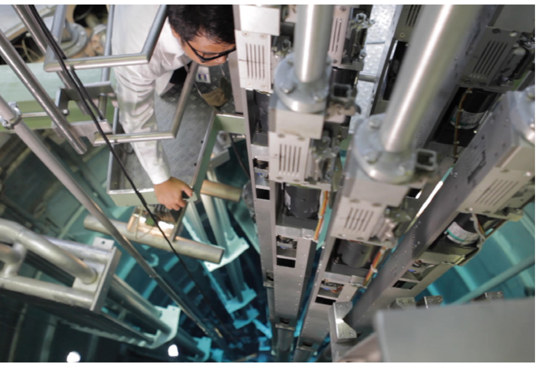
Research reactors must always be used in a safe and secure manner. Many countries work with the IAEA to integrate security systems and measures into existing and new research reactors (page 24), implement safety regulations (page 8) and establish a strong safety culture (page 10).

The IAEA has played an active role in international efforts to convert research reactor fuel from high enriched uranium (HEU) to low enriched uranium in order to minimize civilian use of HEU and reduce associated security and proliferation risks (page 26). IAEA safeguards inspectors verify that nuclear material and technology at research reactors are not diverted from peaceful uses (page 28).

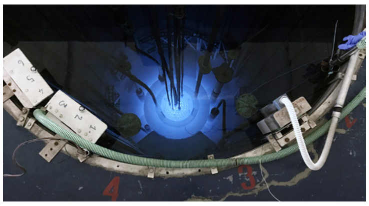
The IAEA's International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability from 25 to 29 November 2019, will review all of these areas and provide a platform for reactor operators, managers, users, regulators, designers and suppliers to exchange best practices and learn from each other. I hope that this edition of the *IAEA Bulletin* will offer useful insights that help to encourage discussions at the conference and beyond.

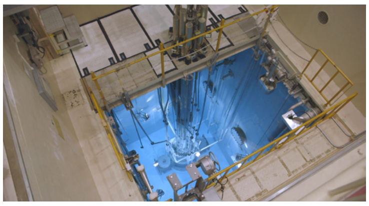
"For more than 60 years, the IAEA has helped countries to set up, operate and maintain research reactors in order to reap the great benefits that they offer to science and society."

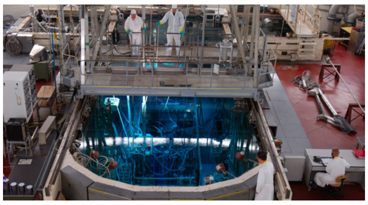
— Cornel Feruta, Acting Director General, IAEA



(Photos: IAEA)







World View

IAEA Updates

Exploring research reactors and their use

By Nicole Jawerth and Elisa Mattar

For over 60 years, research reactors have provided the world with a versatile tool to test materials and advance scientific research, as well as to develop and produce radioactive materials that are key to diagnosing and, in some cases, treating diseases. There is a wide array of designs for research reactors and an even wider array of applications that offer socio-economic benefits to help countries worldwide achieve their sustainable development objectives.

More than 800 research reactors have been built to date. Although many have been shut down and decommissioned over the years, 224 continue to operate in 53 countries. Currently, 9 new research reactors are under construction, and more than 10 have been constructed over the last 10 years. Since most research reactors were built in the 1960s and 1970s, half of the world's operational research reactors today are more than 40 years old and around 70% are over 30.

What are research reactors?

Research reactors are small nuclear reactors that are primarily used to produce neutrons, unlike nuclear power reactors, which are larger and used to generate electricity. Compared to nuclear power reactors, research reactors have a simpler design, operate at lower temperatures, require far less fuel and, therefore, result in far less waste. Given their important role in research and development, many research reactors are housed at university campuses and research institutes.

The power of research reactors is designated in megawatts (MW), with 1 MW being equal to 1 million watts, with watts being a unit of power. The output of research reactors ranges from 0 MW, such as that of a critical assembly, up to 200 MW, which is in contrast to the 3000 MW (also denoted as 1000 MW (electrical)) of a large nuclear power reactor unit. However, most research reactors have an output of under 1 MW.

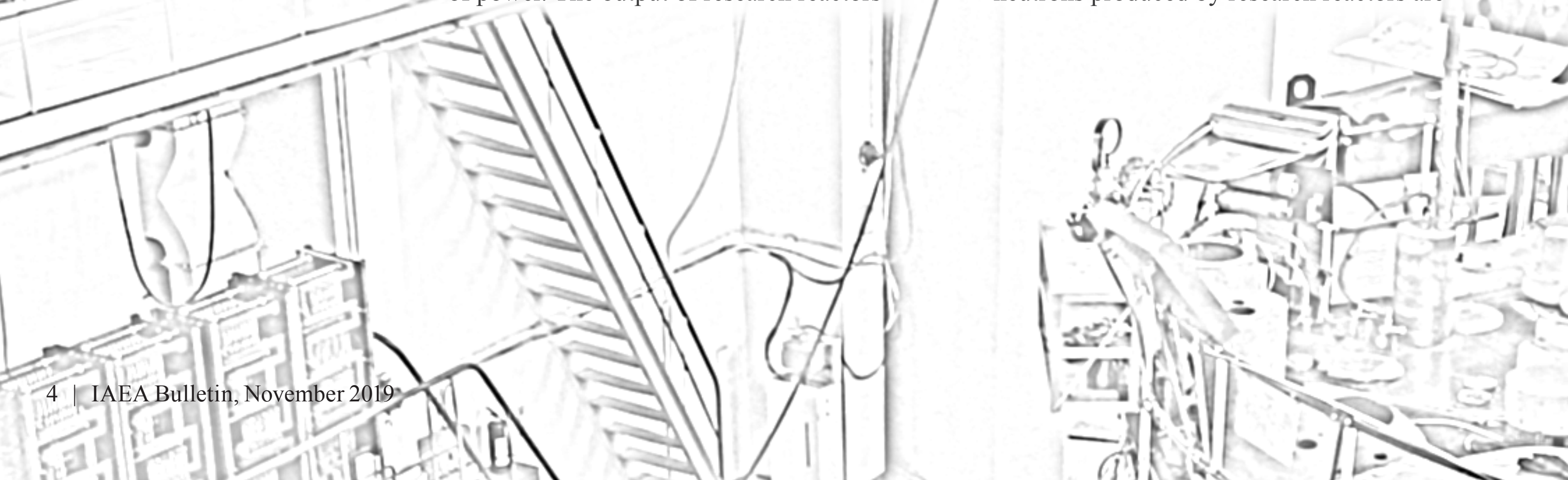
How are research reactors used?

The neutrons — subatomic particles found in almost all atoms — produced by research reactors are useful for scientific studies at the atomic and microscopic levels. They are used to produce radioisotopes for medicine and irradiate materials for the development of fission and fusion reactors, among other applications. These particles are primarily used in areas such as industry, medicine, agriculture, forensics, biology, chemistry and geochronology.

Unlike power reactors, research reactors are also well suited for education and training. This is due to their lower complexity, which means their systems and overall designs are simple and easy to access, thereby making it possible to safely simulate different reactor conditions. Research reactors can be used to train reactor operators, maintenance and operational staff of nuclear facilities, radiation protection personnel, regulatory personnel, students and researchers.

Some of the specific uses of research reactors

Research with neutrons started after physicist James Chadwick discovered neutrons in 1932. By the mid-1950s, the use of neutrons in research had become more widespread, in particular as researchers began applying neutron scattering techniques. Today, neutrons produced by research reactors are



used for a variety of purposes. Here are a few of their applications.

Neutron scattering is an analysis technique for understanding the structure and behaviour of solids and condensed matter. As neutrons interact with atoms in matter, their energy and other properties may change. These changes can be used to study the structure and dynamics of matter. The properties of neutrons also make them particularly useful for studying hydrogen, small and large objects, and a myriad of materials, including magnetic materials. This is useful for understanding how bones repair themselves, studying proteins in the brain, improving batteries and creating magnets, among others.

For **analyzing materials**, neutrons and X-rays are often combined, as they provide complementary information. Neutrons are sensitive to lighter elements, particularly to hydrogen in water and to biological material, whereas X-rays are more sensitive to heavier elements, like iron in steel. Combining neutron and X-ray techniques allows for greater sensitivity to all components of a sample or object.

Using neutrons for **materials research** and materials development contributes to scientific understanding and the development of technologies across a variety of areas, from electronics to medicine and construction materials for extreme conditions, such as equipment for work in space and nuclear power plants.

Research reactors also provide neutrons that can be used to help researchers characterize cultural heritage objects, such as paintings and monuments. Neutron-based techniques can distinguish between different types of materials used in artwork, such as paint, and the elemental composition and texture of artefacts, such as rocks. These methods are referred to as '**non-destructive testing**', because they allow researchers to study the objects without damaging them.

Neutron irradiation can also be used to create new materials with useful properties. For example, silicon is irradiated with neutrons to change its conductivity for use in high power application semiconductors.

Research reactors are also used for **radioisotope production**. Radioisotopes are unstable elements that regain stability by undergoing radioactive decay. During the decay process, various kinds of radiation are released, which can be used in medicinal or industrial applications.

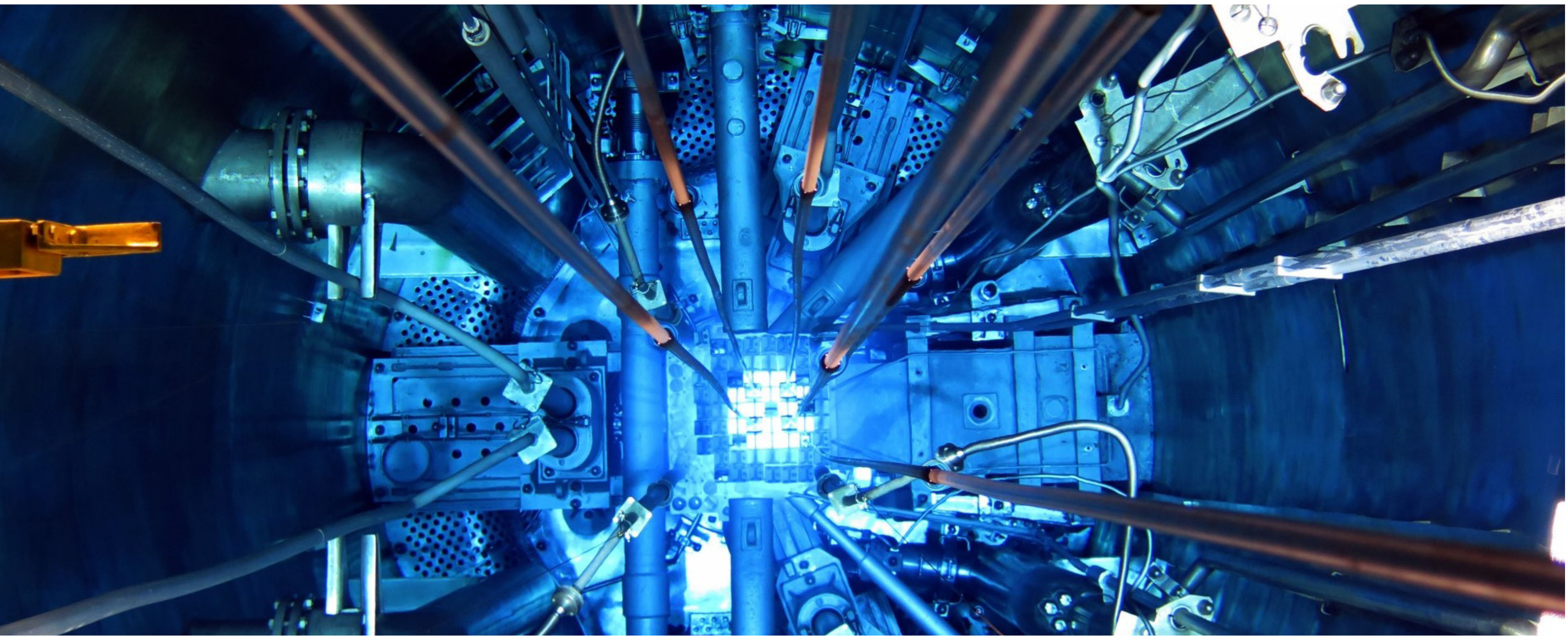
One of the most common uses of radioisotopes is for diagnosing and treating health conditions like cancer and cardiovascular diseases. The most widely used radioisotope in medicine is technetium-99m, which comes from the radioisotope molybdenum-99 and is used for diagnostic imaging (see page 12).

Supporting the use of research reactors

The IAEA has decades of experience in promoting the use of research reactors worldwide. It assists countries at all phases of a research reactor project, from planning, building, commissioning and operating, to end-of-service decommissioning and dismantling. The IAEA also supports countries in optimizing the efficient and sustainable use of their research reactors (see page 20) and helps countries without research reactors to gain access to them so that they can also benefit from these powerful tools. This support comes in the form of training, workshops, sharing expertise and best practices and peer review services (see page 22), as well as published guidance documents, standards, remote access for education and e-learning courses. The IAEA also supports countries in addressing safety and security at research reactors, including the safe and secure conversion of research reactors from high enriched uranium fuel to low enriched uranium fuel (see page 26).

Nuclear infrastructure development to reap the benefits of research reactors

By Matt Fisher



A research reactor core.
(Photo: IAEA)

Research reactors can be used for a variety of purposes, from training nuclear engineers and conducting scientific research, to producing radioisotopes and developing advanced materials. But before a country can embark on a new research reactor project, it must first have in place the proper infrastructure.

"The IAEA provides guidance on issues in establishing and implementing research reactor projects. These include legal and regulatory frameworks, human resource development, safeguards, safety and security, among others," said Andrey Sitnikov, Technical Lead for research reactor nuclear infrastructure and capacity building at the IAEA. "The IAEA's Milestones approach helps countries effectively and holistically develop their research reactor programmes so they can safely and reliably utilize their research reactors."

Milestones approach

The Milestones approach is a comprehensive scheme divided into three phases that lay out what a country must accomplish in 19 areas of infrastructure development, including nuclear safety, human resources, financing and management. It can be used both for nuclear power programmes and research reactor programmes.

While the general contours of the approach are largely similar for research reactor programmes and nuclear power programmes, the main distinction is related to the level of utilization: research reactors have a wide range of applications, whereas nuclear power reactors are primarily used to generate electricity. This means that when a country uses the Milestones approach for research reactors, it must first determine what the research reactor will be used for. Knowing the research reactor's purpose is essential not only to identify the specific infrastructure elements required, such as the types of specialists to hire and facilities to build, but also to effectively apply the Milestones approach.

Three main phases of development

The research reactor development process is organized into three main phases: preparing a feasibility report to justify the need for a research reactor project; setting up for construction of the reactor, including the establishment of legal and regulatory frameworks; and constructing and commissioning the new reactor.

Each phase has a completion marker, or ‘milestone’, to help a country track its progress and assess its preparedness before beginning work on the next phase. Milestone 1 is achieved when a country is ready to commit to a research reactor programme; Milestone 2 is completed when a country is ready to begin negotiating a contract for the construction and operation of the reactor; and Milestone 3 is attained when the reactor is ready to be commissioned.

Review and improve

Assessing what infrastructure already exists and what still needs to be further developed is an important step in establishing or expanding a research reactor programme. The IAEA helps countries, upon request, review their status and determine areas that may need improvement through Integrated Nuclear Infrastructure Review for Research Reactors (INIR-RR) missions. These are IAEA-coordinated peer review missions, which are holistic in nature and are conducted by international teams made up of both IAEA and external experts who have direct experience in specialized research reactor nuclear infrastructure.

Before a mission, the interested country will first complete a self-evaluation report on the 19 infrastructure issues according to the IAEA’s publication Specific Considerations and Milestones for a Research Reactor Project. Experts then assess the situation based on evidence, including strategic plans and site considerations, gathered during the INIR-RR mission.

After the mission is concluded, the INIR-RR team prepares a report with recommendations on action items to be implemented. A follow-up mission may take place approximately two years after the initial mission in order to assess the implementation status of the recommendations. An action plan to provide targeted capacity building on some of the 19 infrastructure issues, taking into account the review findings, is usually put in place between the country and the IAEA.

First ever INIR-RR mission

The first ever INIR-RR mission took place in Nigeria in February 2018. Nigeria has a 30 kW(th) miniature neutron source research reactor (MNSR), which has been in operation since 2004 and is used for training activities and neutron activation analysis but cannot be used for other applications.

The country’s authorities envisage a larger, more versatile multipurpose research reactor (MPR) for applications including the production of radioisotopes for both cancer care and food preservation. The MPR would also serve to scale up experience in operating larger reactors and assist the country on its journey towards a potential nuclear power programme in the future.

As Nigeria already has a research reactor programme, most of the infrastructure requirements for the MPR have already been addressed to a certain extent; however, operating a larger research reactor requires further strengthening and building on the existing infrastructure. The recommendations made by the INIR-RR mission team emphasized increasing the focus on human resource development. Nigeria plans to commission the reactor by 2025.

Expansion to achieve more

An MPR is also part of Viet Nam’s plans to expand its programme to broaden the scope of what the country can achieve with research reactors. Viet Nam currently operates a relatively small research reactor — a 500 kW(th) pool-type reactor — for a variety of applications, including limited radioisotope production and neutron beam research and development.

An INIR-RR mission to Viet Nam was conducted in December 2018. The mission team concluded that Viet Nam had made significant progress towards establishing the infrastructure necessary for an MPR. Recommendations included conducting a more detailed utilization assessment for the MPR and bolstering the independence of the regulatory body.

“The planned 10–15 MW(th) research reactor will enhance our capacity in scientific research, education and training, and radioisotope production,” said Hoang Anh Tuan, Director General of the Viet Nam Atomic Energy Agency. Viet Nam plans to commission the MPR by 2026. “The INIR-RR mission has helped us identify areas for further infrastructure development, including our radioactive waste management strategy and our regulatory framework.”

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— Hoang Anh Tuan, Director General, Viet Nam Atomic Energy Agency

Regulating research reactors in Morocco and beyond

By Laura Gil

Research reactors may be smaller, simpler and require less fuel than a nuclear power reactor, but they still need to adhere to rigorous safety and security regulations.

“Any activity or practice involving ionizing radiation sources, unless exempted or excluded from a regulatory regime, has to be regulated and controlled. If it is not controlled, it could do more harm than good,” said Khammar Mrabit, Director General of the Moroccan Nuclear and Radiation Safety and Security Agency (AMSSNuR). “To ensure safety and security, you need regulatory supervision.”

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—Khammar Mrabit, Director General, Moroccan Nuclear and Radiation Safety and Security Agency (AMSSNuR)

Supporting regulatory authorities around the world in ensuring nuclear safety and security of research reactors is one of the IAEA’s key functions. In the case of Morocco, which operates a TRIGA Mark II research reactor, the IAEA has helped the regulatory body become an example of robust inspection, independence and reliability.

The TRIGA Mark II research reactor, which is part of the National Centre for Nuclear Energy, Sciences and Technology (CNESTEN), began operation in 2007. The country’s nuclear law, enacted in 1971, and its law on civil liability, enacted in 2005, did not foresee potential threats such as nuclear terrorism, and, according to Mrabit, the regulatory body at the time did not have sufficient independence so it turned to the IAEA for help.

“On the one hand, you have legislation and regulations and, on the other, you have the operators, who are primarily responsible for safety. In the middle and continuously, you need an independent regulatory body with clear functions, roles and responsibilities to, for example, authorize and inspect,” Mrabit said.

The IAEA supported Morocco in elaborating and enacting a new nuclear law in 2014 and in creating a new, independent regulatory body under the country’s Prime Minister. In 2016, AMSSNuR experts developed a strategic action plan to upgrade their regulatory system. Over 30 stakeholders from the relevant ministries, professional organizations, technical support institutes and the IAEA were involved in the process.

The TRIGA Mark II research reactor is Morocco's biggest nuclear installation and is therefore a high priority for authorities and technical experts in the country. It contributes to various activities, including research and training in nuclear medicine, industrial applications and radioactive waste management. The IAEA's support in regulatory supervision includes review missions (see page 22), assistance with developing regulations and technical expertise.

Morocco has also become a training hub for regulatory supervision of research reactors in North Africa and beyond.

"You need to have a clear vision and plan," said Farhana Naseer, a nuclear safety officer at the IAEA. "Morocco has had a coherent, strategic and graded approach since day one. The country's experience will serve as a good source of best practices and as a model for other countries."

FORO

Countries in other regions, too, are sharing best practices on regulatory supervision of research reactors. For example, the regulatory bodies of FORO — the Ibero-American Forum of Radiological and Nuclear Regulatory Agencies — are sharing their own best practices and supporting one another in the area of regulatory inspection as part of a joint project.

"The idea is that we exchange experience and have common regulatory criteria for all reactors," said Gerardo Lázaro, coordinator of the project and the expert responsible for the inspection of research reactors at the Peruvian Institute of Nuclear Energy. "We have been working very well for 30 years, using the IAEA standards as our reference," he said. "There is significant experience at all the research reactors throughout the region. It is important we share that experience and the knowledge we have gained so that we continue to improve."

The goal of the project is, with the IAEA's support, to produce a standardized inspection manual in Spanish for operators of nuclear research reactors. The manual is expected to be finalized in 2020 and will be complemented with reference regulatory guidance on the oversight of research reactors' ageing management. Ageing is of growing interest because all research reactors in FORO countries have accumulated several years of operation.

There are 16 research reactors currently in operation across 9 Latin American and Caribbean countries, 15 of which are in FORO countries. These reactors provide essential services, ranging from academic research and education to applications in agriculture and the environment and the production of radioisotopes for use in medicine and industry.

Conducting a regulatory inspection at a research reactor.
(Photo: AMSSNuR)

Leadership and management for safety

Q&A with Operations Director at the Nuclear Research and Consultancy Group (NRG) in the Netherlands

By Laura Gil

Safety is paramount in all nuclear installations, research reactors included. Cultivating a culture of understanding among staff of the importance of safety and the measures required to sustain it — a safety culture — is important. A weak safety culture can lead to weak safety measures, which can ultimately affect the well-being of people and the environment. But how do we ensure safety? What are some of the major safety issues in research reactors, and why are leadership and management essential to addressing them? To find out, we interviewed Jelmer Offerein, Operations Director and one of NRG's five leaders. He has decades of experience in management and leadership for safety.

NRG is a research company of 650 employees that operates the European Commission's High Flux Reactor, a multipurpose research reactor located in the Netherlands. NRG produces isotopes, conducts nuclear technological research, advises industry on the safety and reliability of nuclear installations and provides services related to radiation protection.

"If you don't talk about safety at all, workers don't know what is expected of them. Leaders need to listen to their staff and know what their concerns are. They also have to motivate and inspire them."

— Jelmer Offerein, Operations Director, Nuclear Research and Consultancy Group, the Netherlands

Q: Can you tell us a little about NRG's strategy and how it approaches safety?

A: NRG's strategy is quite simple: we want to be the largest medical isotope producer in the world. We started saying in 2008 that we would be a medical isotope producer. Fast forward 11 years and here we are. We are one of the biggest molybdenum-99 producers but still not the largest medical isotope producer. It takes time.

The medical isotope industry is a growing industry. Production volumes increase every year, which is positive, of course, but you have to adapt your organization to that. You need more operators, more equipment, more containers, more tooling, more training and more qualified personnel. And you have to do this in such a way that safety and reliability are not compromised.

To ensure safety, you need a clear strategy. We noticed that, in the past, we were doing a lot of things simultaneously. If people tend to do five or six things at the same time, quality decreases and, if quality decreases, safety levels can also decrease. It's smarter to do fewer things but do them better. Fewer things but right. And for this, you need a clear focus and strategy in place.

Q: How do leaders and managers influence safety at research reactors?

A: For me, one of the most important things to consider is people's expectations. We've had managers in the past who did not talk about safety at all, and if you don't talk about safety at all, workers don't know what is expected of them. Leaders need to listen to their staff and know what their concerns are. They also have to motivate and inspire them.

A leader also has to show exemplary behaviour, particularly when we're talking about safety. I have a good anecdote to illustrate this. It's related to how cars are parked at our research reactor facility site — for safety reasons, they must be reversed into a parking spot. One morning, at the beginning of my career, when I had just started working as a managing engineer, I had parked my car in the wrong direction, and one of my co-workers said, "Jelmer, you've parked your car the wrong way!" And that's when I realized that if I park my car the wrong way, everyone would have the right to do it, too. This was a big eye opener; it made me realize the importance of setting an example. In safety, you cannot afford to 'park your car' the wrong way. I've parked it right ever since.

Q: When talking about safety culture, there is a distinction made between leadership and management. What is this distinction and why is it important to safety?

A: A great illustration of this difference is the fact that managers are behind a group of people telling them what to do and that leaders are part of the group of people, guiding them. For me, managers develop and control the annual plans and make sure they're implemented. Leaders, in addition, create a vision, tell their people why those plans are necessary and work together with their people on the execution of those plans. Ultimately, a good manager is also a leader and a good leader is also a manager.

Q: What part has the IAEA played in safety at your research reactor?

A: NRG has been working closely with the IAEA for a long time now. The IAEA has helped us by creating a platform to exchange experiences and knowledge and to develop safety guides in close consultation with industry, as well as by visiting us with missions, such as Integrated Safety Assessment of Research Reactors (INSARR) missions, that were heavily focused on safety in a technical way. Since we also wanted to know the status of our safety culture and receive input on which areas to improve, we requested an IAEA Independent Safety Culture Assessment (ISCA) mission.

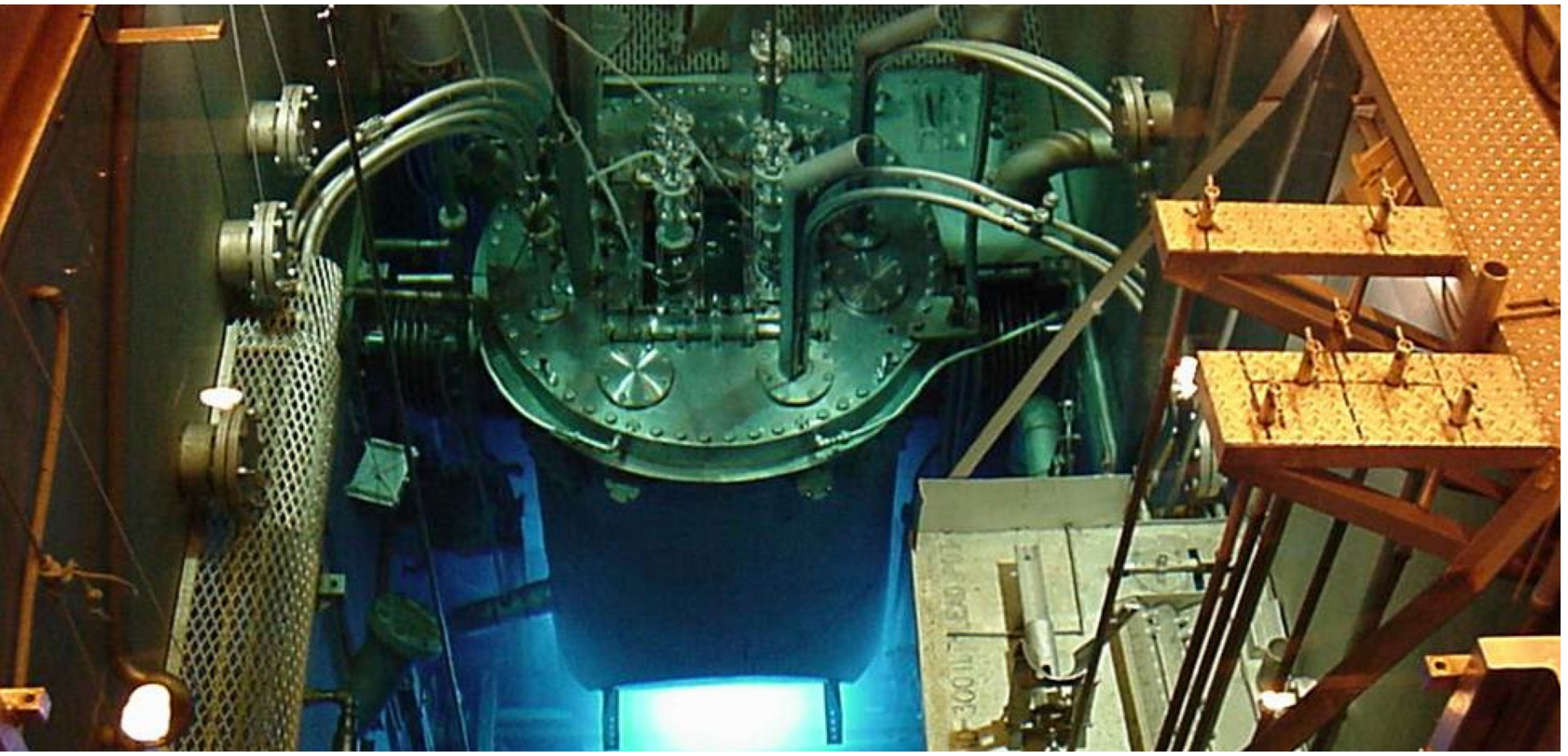
In 2017, an expert-led ISCA team came to assess our safety culture. They reviewed documents, interviewed workers, looked into our integrated management system, as well as our training and qualification programme, and organized focus groups to see the dynamics and interactions between employees. The ISCA report showed we were definitely on the right track, but there were areas for improvement.

One of these was our island culture; we have different installations with large security fences around them, which makes it hard for employees to meet. For security reasons, that's perfect, but if you want to closely interact with colleagues on all kinds of topics, it is not ideal. We also worked on improving the descriptions of our roles and responsibilities and the integration of those roles into our management system.

We worked on these areas. The team came back 18 months later to look at the implementation of the recommendations and found that we had made progress in improving our safety culture. Of course, we are never quite finished — the world around us is changing quite rapidly, so we always have to keep improving and adapting.

How research reactors help make medical imaging possible

By Aleksandra Peeva and Nicole Jawerth



The SAFARI-1 research reactor in operation.
(Photo: Necsa)

More than 80% of the medical imaging used each year to diagnose diseases like cancer is made possible by the pharmaceutical drugs produced, for the most part, in research reactors. These radiopharmaceuticals contain the radioisotope technetium-99m (^{99m}Tc), which comes from the radioisotope molybdenum-99 (^{99}Mo) that is primarily produced in research reactors.

"While ^{99}Mo or even ^{99}mTc can be produced using other approaches, research reactors are particularly cost-effective and well-suited to this, especially for commercial, large-scale production," said Joao Osso, Head of the IAEA's Radioisotope Products and Radiation Technology Section. "This is because they can produce large amounts of ^{99}Mo with the right characteristics that make it easy to extract ^{99m}Tc using a generator in a hospital, thereby keeping supplies of radiopharmaceuticals flowing consistently and reliably for more patients."

From reactor to patients

Research reactors are reactors that, instead of generating electricity, are primarily used to produce neutrons for other applications. These neutrons can be used for various purposes, such as to produce ^{99}Mo by irradiating uranium-235 targets.

Being a radioisotope, ^{99}Mo is an unstable atom that undergoes decay. It takes 66 hours for half of any ^{99}Mo produced to decay — this is known as its half-life. The decay product of ^{99}Mo, also called its 'daughter product', is ^{99m}Tc.

To get ^{99m}Tc, the irradiated uranium-235 targets are moved to a processing installation, usually near a research reactor, to separate ^{99}Mo from the other fission products and purify it. The purified ^{99}Mo is then transported to a production facility for ^{99}Mo /^{99m}Tc generators — devices used to safely hold, transport and chemically extract ^{99m}Tc from ^{99}Mo directly on site at a hospital or other medical facility.

Inside a typical generator, aluminium oxide containing ^{99}Mo is washed with a saline solution. The ^{99}Mo clings to the oxide, whereas the ^{99m}Tc is removed by the solution. This produces a ^{99m}Tc solution that is then used to create different radiopharmaceuticals ready to be injected into a patient's body. Once inside the body, the small amounts of radiation released by the decaying ^{99m}Tc are detected by a special camera outside the patient's body to create medical images for diagnosing diseases.

Short half-lives, constant production

As ^{99m}Tc has a half-life of six hours, it must be used quickly after it is extracted otherwise it loses its effectiveness. With ^{99}Mo's short lifespan and ^{99m}Tc's being even shorter, they have to be constantly produced to meet global demand.

One of the major global producers of ^{99}Mo, and of other radioisotopes, is the South Africa Fundamental Atomic Research Installation (SAFARI-1), which is part of the South African Nuclear Energy Corporation (Necsa) and is the leading medical isotope-producing research reactor on the African continent. In collaboration with the radioisotope supplier, NTP Radioisotopes SOC Ltd — a subsidiary of Necsa — the SAFARI-1 reactor has become one of the world's 5 largest suppliers of ^{99}Mo and is part of the medical radioisotope supply chain for more than 50 countries worldwide. It now produces around 20% of the global ^{99}Mo demand, and the ^{99m}Tc derived from generators using SAFARI-1's ^{99}Mo is used in more than 40 hospitals and other health facilities across Africa.

"Becoming a global player in the radiochemical and radiopharmaceutical community has been a matter of implementing management systems, maintenance programmes, personnel training and strategic plans in a well-structured and controlled way," said Koos du Bruyn, Senior Manager at SAFARI-1. This has also supported the reactor's secondary use for research and education and for industry.

With the IAEA's support, SAFARI-1 has undergone continuous development and improvements since it began operation in 1965, including its conversion from high enriched uranium fuel to low enriched uranium fuel in 2009 (learn more about this kind of conversion on page 26) and its transition from high enriched to low enriched uranium targets, which was completed in 2017. These activities have helped to ensure better utilization of the reactor and its successful transition to more commercial use.

Molybdenum-99 target plate and the holder used to irradiate the plates in a research reactor.
(Photo: Necsa)

"In the 1990s, we changed our operational approach and put more emphasis on maintenance and management, including building up a team of specialized staff who are highly skilled in a range of areas. This allowed us to go from being a low-use reactor to an extremely high-use and more sustainable facility," du Bruyn said. In the nine years between 1995 and 2004, the reactor was used more than in the previous three decades combined. Then only seven years later it achieved the same result. As of 2019, SAFARI-1's use has almost quadrupled since 1995.

In the last 15 years, SAFARI-1 has operated around the clock, nearly non-stop for around 300 days each year and is expected to continue supplying ^{99}Mo until at least 2030. However, as the reactor is ageing, a new 15 to 30 MW (thermal) multipurpose research reactor (MPR) is being considered to replace it. This process will take up to ten years from the start of feasibility studies to completion.

"If a new MPR is built, it will be equipped to flexibly operate over the next 60 or more years so we can adapt to potential changes, such as fluctuations in medical isotope markets and research requirements, as well as provide South Africa and the region with a critical nuclear fuel and material testing facility," du Bruyn said.

"Becoming a global player in the radiochemical and radiopharmaceutical community has been a matter of implementing management systems, maintenance programmes, personnel training and strategic plans in a well-structured and controlled way."

— Koos du Bruyn, Senior Manager, SAFARI-1, South Africa

Building skills and knowledge using research reactors

By Nicole Jawerth

Students perform real-time laboratory experiments remotely by connecting to a classroom at the RA-6 research reactor in Argentina.
(Photo: P. Cantero/CNEA)

Research reactors are an important resource for training nuclear professionals worldwide, but only around a quarter of countries have their own research reactors.

"Not having a research reactor doesn't need to limit a country's options when it comes to educating and training nuclear professionals. There is now a variety of possibilities," said Christophe Xerri, Director of the IAEA's Division of Nuclear Fuel Cycle and Waste Technology.

To help ensure that students and nuclear professionals can get the education and training they need, whether their country has a research reactor or not, the IAEA supports international training courses, both on-the-ground and remotely, as well as facilitates collaboration between countries to increase access to research reactors.

A research reactor is a nuclear reactor that, instead of generating power, is primarily used to produce neutrons. Although research reactors are mainly used for research and applications, they also play a major part in the education and training of budding and established professionals who work in nuclear facilities, radiation protection and nuclear regulation.

"Research reactors offer a hands-on way to gain a deeper understanding of the fundamental principles behind reactor operation, and, given how they are designed, they can be used to safely simulate different types of reactor conditions, which is not possible with a nuclear power reactor," said David Sears, a senior safety officer at the IAEA.

Connecting online

For students of physics and nuclear engineering, experiments using a research reactor are a key learning tool. However, being physically present at a research reactor is not always possible, especially when a student's country does not have a research reactor. This gap is now being bridged by alternatives such as the IAEA's Internet Reactor Laboratory (IRL) project. Established in 2015, the IRL offers a cost-effective, practical component to the training of both students and professionals by connecting classrooms anywhere in the world to classrooms associated with operating research reactors via the Internet. This allows the participants to engage in live reactor physics experiments and learn more about reactor operations.

"When I got involved in the IRL in 2018, I had already learned a lot about reactors, but I had never seen one before," said José David Cremé Angel Bello, who is now a professor and researcher at the Atomic and Molecular Physics Department at the Higher Institute of Technologies and Applied Sciences in Cuba. "The IRL project was an amazing experience for my training as a nuclear engineer because we don't have a nuclear reactor in Cuba, so this allowed me to see and practice what we had studied in theory, to interact with a nuclear reactor in real time and to do experiments. It helped to prepare me for my career."

Cremé was a nuclear engineering student when he benefited from the IRL project set up through an agreement between the IAEA and Argentina's National Atomic Energy Commission (CNEA). The agreement was signed in 2013 and formed the basis for the IRL project in Latin America, which was one of the first IRL projects, in addition to an IRL project with France. Although the IRL project with France ended with the host reactor's permanent shutdown, IRL projects have since expanded into Africa, Asia and the Pacific and Europe, with host reactors in the Czech Republic, the Republic of Korea and Morocco, and new hosts are now being considered in other parts of Europe and Southeast Asia.

On-the-ground training

While the IRL offers remote access to education using research reactors, on-the-ground, face-to-face training courses organized by the IAEA continue to offer an important avenue for building skills, knowledge and networks. For decades, the IAEA has supported and coordinated training for hundreds of students, young professionals and established specialists. These courses cover topics such as operation and maintenance, regulatory safety inspections, nuclear security and physical protection and application-specific uses, such as radioisotope production for medicine and materials testing for industry.

"It's an invaluable experience to visit a research reactor and perform some experiments and feel what it's like to operate a research reactor," said Luka Snoj, a reactor physicist at Slovenia's Jozef Stefan Institute, who is also involved in an IAEA group fellowship training course called the Eastern European Research Reactor Initiative (EERRI). This initiative involves a six-week course for young professionals that focuses on all aspects of research reactors.

"Many EERRI course attendees use their experience and contacts from these kinds of courses to go back to their countries and become successful scientists and engineers. In some cases, they become leading nuclear experts in their countries," Snoj said.

"For us as a host, the EERRI has been an important way to increase the international visibility of our reactor and has allowed us to make contacts in the field for long-term collaboration, scientific visits and training." The EERRI is one of several IAEA-supported activities, with others including regional courses and research reactor schools in Africa, Asia and the Pacific and Latin America.

For more advanced training, as well as to facilitate wider access to research reactors for scientific work, the IAEA launched the IAEA-designated International Centre based on Research Reactor (ICERR) scheme in 2014. As part of the scheme, major research centres around the world volunteer to proactively offer international cooperation opportunities. For a country to access an ICERR, it must become an affiliate by signing a bilateral agreement with an ICERR. The IAEA facilitates this process by, for example, sharing information on the capabilities offered by ICERRs.

"The ICERR scheme plays an important role not only in training operators but also in facilitating access to the research reactors that are best suited to specific types of experiments," Xerri said. There are ICERRs in Belgium, France, the Republic of Korea and Russia, and two in the USA.

Get online to learn more

E-learning courses developed by the IAEA are useful resources that complement education and training related to research reactors. These courses are available on topics such as:

- Introduction for research reactor personnel (also in Spanish)
- Neutron activation analysis
- Nuclear analytical techniques for forensic science
- Operational radiation protection and waste management
- Regulatory inspection programmes
- Safety of research reactors
- Strategic planning for national nuclear institutions

"The IRL project was an amazing experience for my training as a nuclear engineer because we don't have a nuclear reactor in Cuba, so this allowed me to see and practice what we had studied in theory, to interact with a nuclear reactor in real time and to do experiments. It helped to prepare me for my career."

— José David Cremé Angel Bello, former IAEA Internet Reactor Laboratory participant, Cuba

Safety from start to finish

A tour through Jordan's research reactor facility

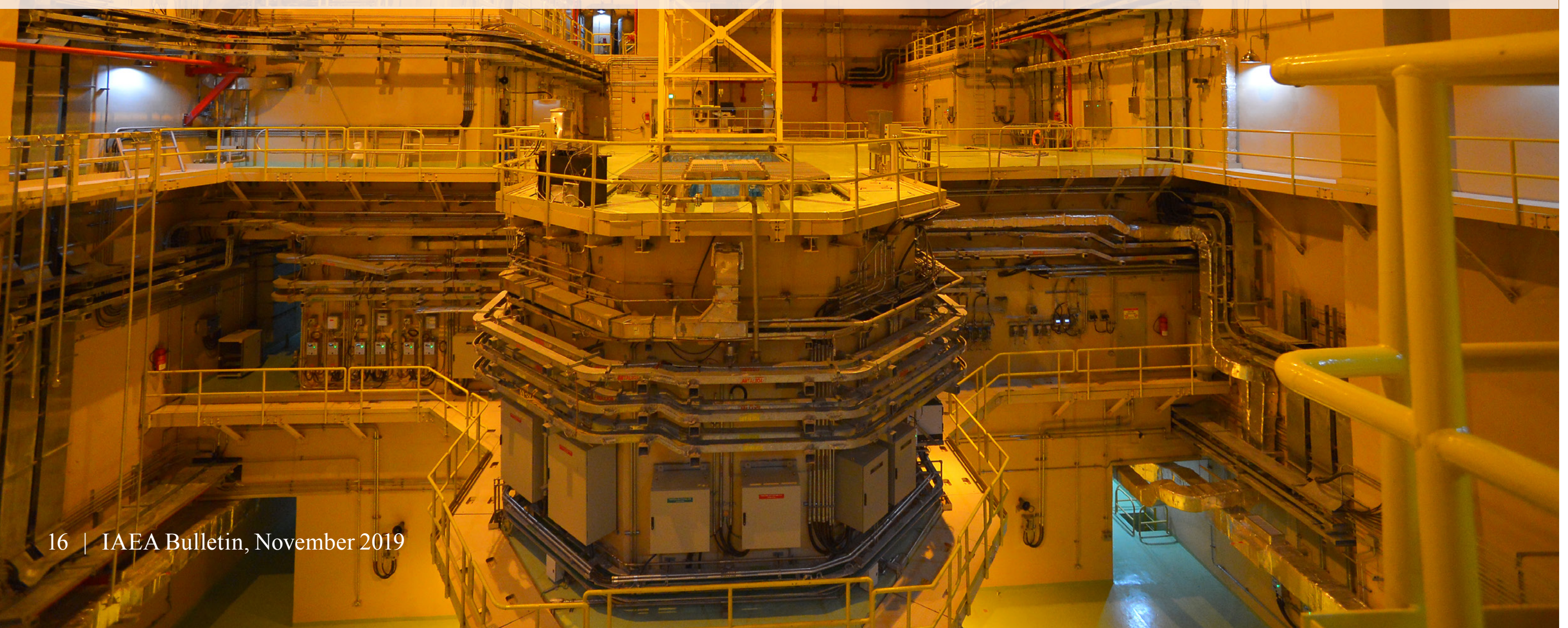
By Aabha Dixit

A look inside the JRTR reactor hall.

Following its construction on the campus of the Jordan University of Science and Technology in Irbid, Jordan, the JRTR received its operation license on November 2017.

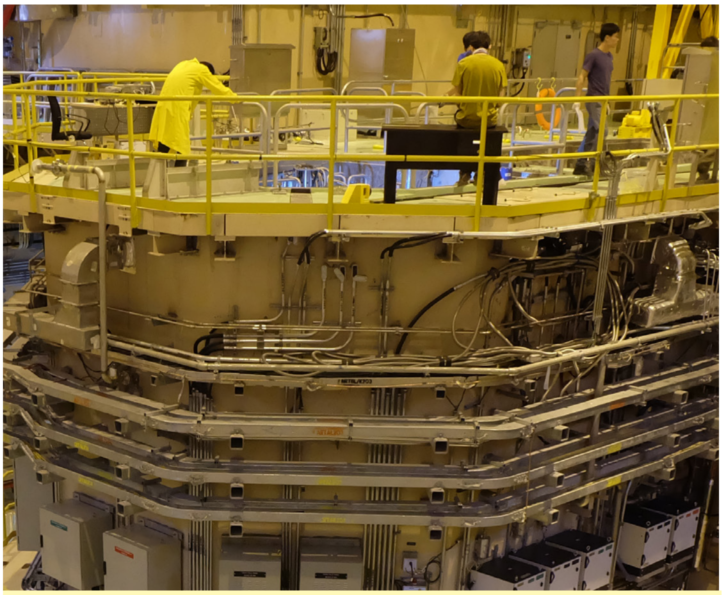
The JRTR has also received its license from the Jordan Food and Drug Administration to distribute its iodine-131 product line, which consists of various dosages of the isotope in both liquid and capsule form. Iodine-131 is a radioactive isotope of iodine that is often used in radiopharmaceuticals for diagnosing and treating diseases, such as thyroid cancer. The JRTR supplies radiopharmaceuticals to 13 medical centres in Jordan and is continuing to expand its clientele.

Plans are under way to expand the JRTR's radiopharmaceutical products and to provide other irradiation services, such as the production of silicon, with specifications suitable to the electronics industry.

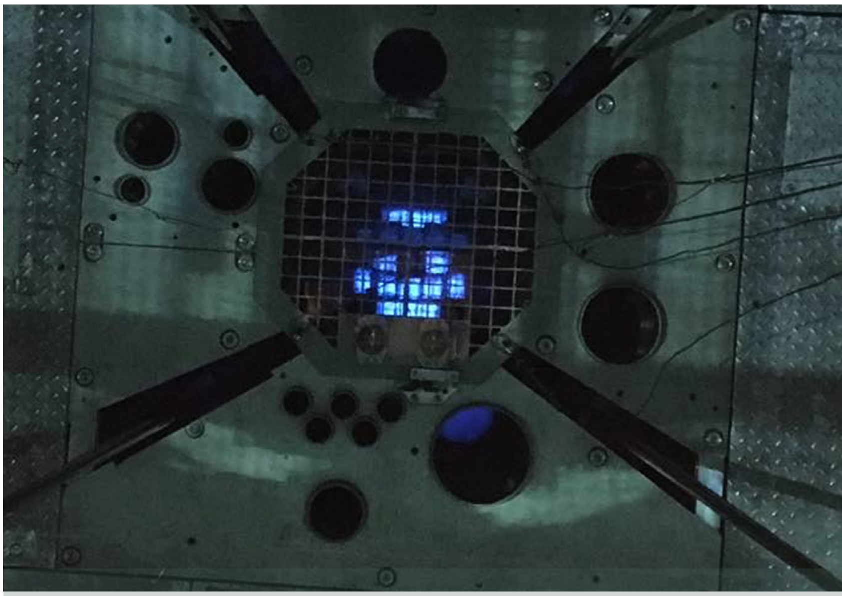


Research reactors are often used for more than just research; they are used for education and training, materials testing and producing radioisotopes for medical and industrial applications. Like nuclear power reactors, research reactors must adhere to the highest safety standards during all stages of a project, from design and commissioning to operation and maintenance.

Take a tour through the Jordan Research and Training Reactor (JRTR) project to learn more about research reactor utilization and how safety is implemented every step of the way. The JRTR is a 5 megawatt (MW) reactor and has been designed to be upgradable to 10 MW. This gives Jordan the option of expanding the research reactor's capabilities in the future.

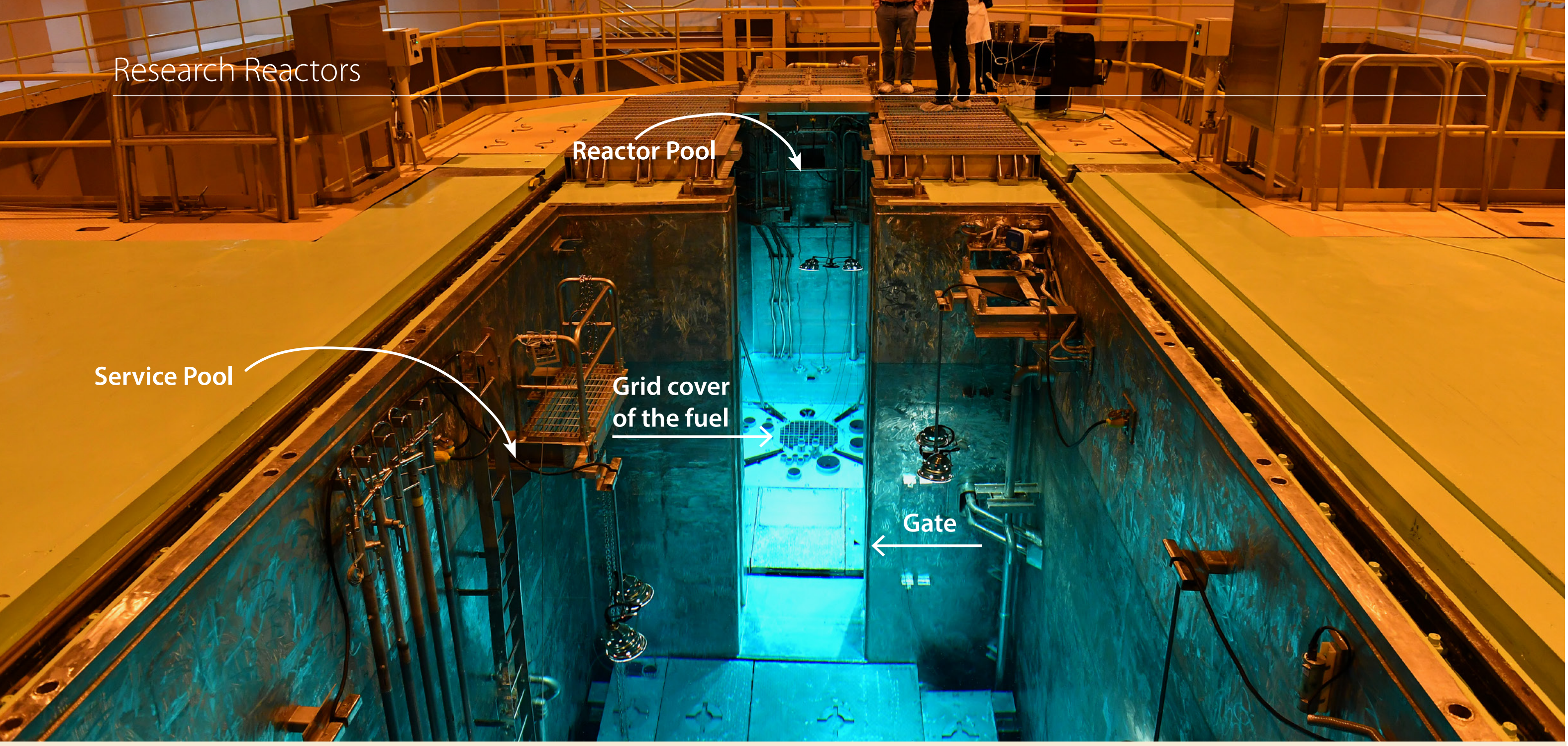


The JRTR's neutron beam ports will be used to conduct experiments and the irradiation holes inside the tank will be used to produce radioisotopes for medical and industrial purposes, as well as for other research activities.



The brilliant blue glow in the reactor pool is created by electron particles being released by the fuel and interacting with water. This piercing blue light is known as the Cerenkov effect. As the reactor's power level increases, the blue glow becomes more intense.

The round openings around the grate are the irradiation holes — located inside the heavy water reflector — that are used for producing radioisotopes, for neutron transmutation doping and for other types of irradiation.



The reactor and service pools contain around 325 545 litres of high purity (demineralized) water. Together, they are 3.7 metres wide and 10 metres deep. The image shows the view through the service pool into the blue reactor pool. It shows the grid on top of the fuel assemblies — a structured group of fuel plates providing fuel to reactors — which is used to store the fuel assemblies in specific arrangements for nuclear safety purposes. The gate that separates the reactor pool from the service pool is also visible.

Water is used to provide a shield against radiation hazards. The water used in such reactors has a high purity level to preserve the physical integrity of the fuel assemblies and prevent the release of radioactive material. The gate between the two pools helps to facilitate operation and maintenance work and makes it easier to handle radioactive components. It is also used to separate the two pools in the event of accidental water drainage.

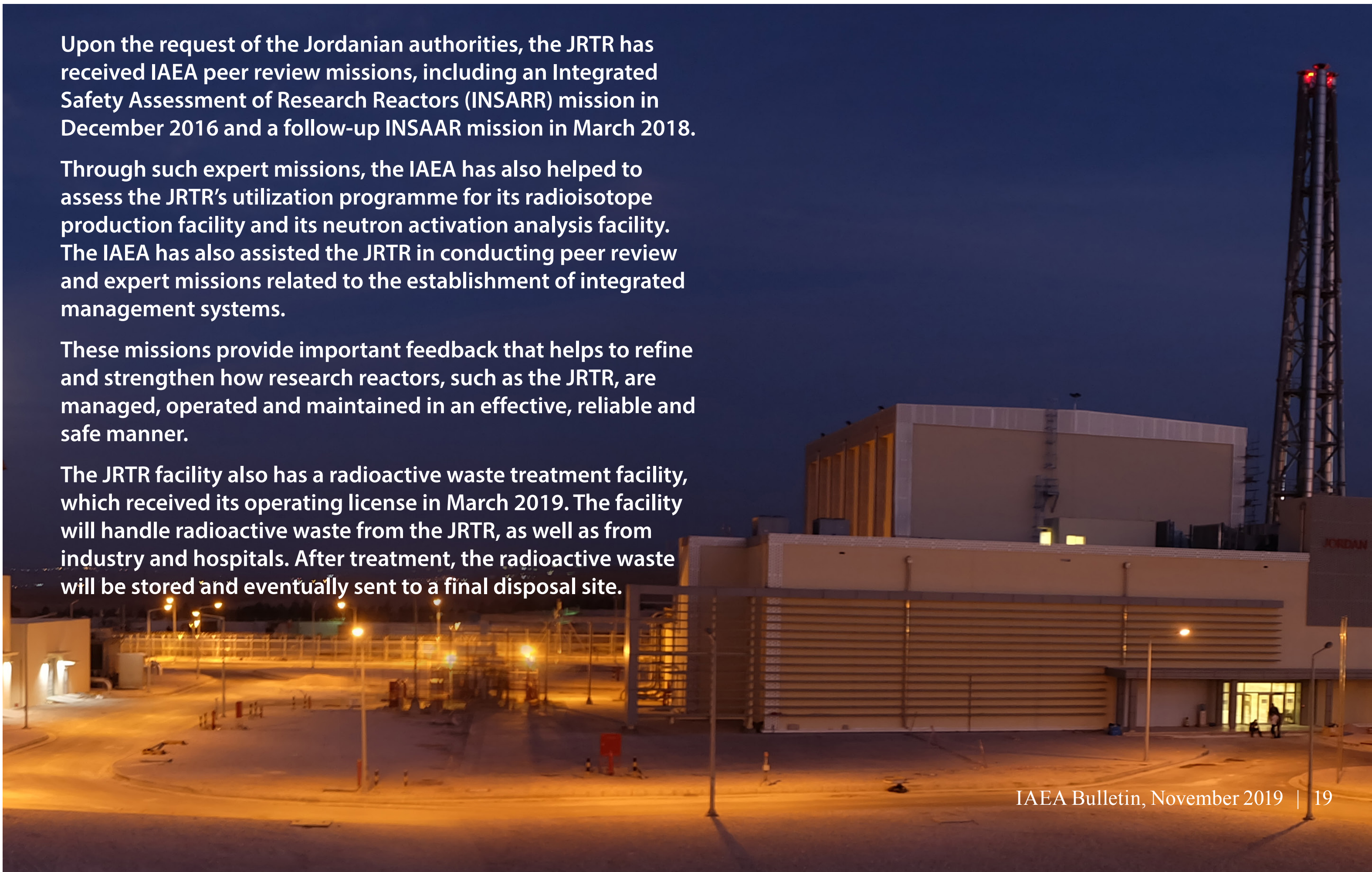
The state-of-the-art JTRT facility also houses three irradiation facilities that are used to support neutron activation analysis, forensic analysis and archaeological research.

‘Hot cell banks’ are another important feature of the JRTR. They allow for the handling of highly radioactive material, such as the material used in the production of radioisotopes for medical and industrial applications. Hot cells are specially designed chambers that shield workers as they use the manipulator arms to work with radioactive materials.

To support the training of JRTR operators and nuclear technology engineers, the JRTR training centre is equipped with a fully functional simulator. These simulators help them to understand and practice the ins and outs of research reactor operation, including possible safety incidents, so that they are well prepared to operate the reactor.

Staff monitoring the JRTR systems from the main control room during the initial operation testing phase.

"Training facilitated by the IAEA for our engineering, scientific and project staff members has been tailored to meet our needs, helping us to prepare our staff and provide them with the knowledge and skills that enabled Jordan to operate this state-of-the-art and versatile facility equipped with advanced safety features," said Samer D. Kahook, JRTR Manager and Commissioner for Nuclear Research at the Jordan Atomic Energy Commission.



Upon the request of the Jordanian authorities, the JRTR has received IAEA peer review missions, including an Integrated Safety Assessment of Research Reactors (INSARR) mission in December 2016 and a follow-up INSAAR mission in March 2018.

Through such expert missions, the IAEA has also helped to assess the JRTR's utilization programme for its radioisotope production facility and its neutron activation analysis facility. The IAEA has also assisted the JRTR in conducting peer review and expert missions related to the establishment of integrated management systems.

These missions provide important feedback that helps to refine and strengthen how research reactors, such as the JRTR, are managed, operated and maintained in an effective, reliable and safe manner.

The JRTR facility also has a radioactive waste treatment facility, which received its operating license in March 2019. The facility will handle radioactive waste from the JRTR, as well as from industry and hospitals. After treatment, the radioactive waste will be stored and eventually sent to a final disposal site.

Strategically harnessing the full potential of research reactors

By Aleksandra Peeva

Research reactors have the power to influence science, education, industry and medicine, but tapping into their full potential takes strategic planning. Although some of the 224 research reactors currently in operation across 53 countries are used to their full capacity, several are underutilized.

"Many research reactors were built to address an immediate need at that time. Now, many years later, their mission statement must be reviewed," said Nuno Pessoa Barradas, Research Reactor Specialist at the IAEA.

Many of today's operational research reactors were built during the 1950s and 60s when they were a new tool, and many countries were interested in exploring and discovering their potential. Now that this potential is better understood and new applications are being developed, it has become widely recognized that some research reactors could be better utilized to harness their full potential.

Many countries are now actively collaborating to maximize the use of existing research reactors, and some have already built, or are planning to build, new research reactors with plans for maximum utilization.

The aim is to fully harness the benefits of these powerful tools for many uses, such as developing nuclear power programmes, pursuing research and development, providing analysis and irradiation services and producing radioisotopes to be used in medicine and industry.

Over the last 5 years, experts and officials from over 40 countries have received support from the IAEA in setting priorities and improving business plans for more than 50 research reactors. These plans typically involve assessing the national and regional needs for the research reactor's potential services and products, prioritizing these needs and matching them to the reactor's capabilities and defining the objectives for a reactor's long-term, sustainable operation.

Improving sustainable use

In early 2019, the IAEA launched an expert review mission in Italy, where an international team of experts reviewed the University of Pavia's 250 kW TRIGA Mark II research reactor. The mission was focused on improving the sustainable use of the research reactor.

The core of the TRIGA Mark II research reactor at the University of Pavia.
(Photo: N. Pessoa Barradas/IAEA)

The team assessed the strategic plan and corresponding action plan for the university's reactor and evaluated the level of its utilization. This was based on key performance indicators and on opportunities and constraints that could further limit the development of the reactor's services and products, as well as on areas for improvement for the effective, efficient and sustainable utilization of the facility.

The experts concluded that the research reactor is a well-utilized facility that plays an important role in national socio-economic development, as well as in medicine, archaeology and materials science, among other areas. They also provided recommendations and suggestions to further enhance the utilization of the facility, including feedback on the facility's strategic plan, as well as the development of outreach and communication activities and the expansion of educational activities.

"Utilization and strategic planning are areas of particular importance to us and our stakeholders," said Andrea Salvini, Manager of the University of Pavia's research reactor. "The IAEA mission helped us to zoom in on strengthening our user community and enhancing our scientific capability in new areas."

The experience gained from the mission in Pavia is expected to help the IAEA further strengthen its response to requests from countries to help them improve research reactor use, including through a new service called the Integrated Research Reactor Utilization Review (IRRUR).

"The mission provided valuable insights and could be replicated to assist countries in developing efficient national strategies for effective utilization and sustainable operation of research reactors. This is particularly relevant for organizations that may not have the capabilities to perform an integrated assessment," Pessoa Barradas said.

Review missions are one of several avenues through which the IAEA helps countries to improve the sustainable use of their research reactors. In early 2019, the IAEA also launched an e-learning course to provide guidance on developing strategic planning for efficient and sustainable utilization of different facilities operated by national nuclear institutions, including research reactors. The course is based on a 2017 IAEA publication entitled Strategic Planning for Research Reactors. This goes hand-in-hand with IAEA-supported training courses, expert and fellowship visits and workshops on research reactor applications, as well as technical meetings and publications. Many of these resources can be accessed through the Research Reactor Information Hub, hosted on the IAEA CONNECT platform.

"Utilization and strategic planning are areas of particular importance to us and our stakeholders. The IAEA mission helped us to zoom in on strengthening our user community and enhancing our scientific capability in new areas."

—Andrea Salvini, Manager, University of Pavia's research reactor, Italy

Enhancing safety, security and reliability

IAEA peer review missions for research reactors

By Elisa Mattar

Setting up and maintaining a research reactor is a complex process — from siting and design, to commissioning, operation and protection of nuclear materials. At each step of the way, countries can request a peer review service from the IAEA to assist them in enhancing nuclear safety and security, as well as the performance of research reactors.

"The goal of peer review missions is to ensure research reactors continue to be used effectively and sustainably for the benefit of society."

— Amgad Shokr, Head, Research Reactor Safety Section, IAEA

"The goal of peer review missions is to ensure research reactors continue to be used effectively and sustainably for the benefit of society," said Amgad Shokr, Head of the Research Reactor Safety Section at the IAEA.

IAEA peer review missions, which are available upon request, involve teams of international, multidisciplinary experts who compare actual practices with IAEA standards for nuclear safety and international good practices, as well as with IAEA guidance for security and operation.

The missions identify areas that could be improved and provide host facilities with corresponding recommendations. Follow-up missions, if requested, are normally conducted 12 to 18 months later to review the actions taken by host facilities to address the original mission's findings. Through these follow-up visits, the IAEA can also assist, upon request and as needed, in addressing the findings. The IAEA also supports countries in addressing mission recommendations as well as, where relevant, through its technical cooperation projects.

The IAEA peer review services focusing specifically on research reactors are the Integrated Safety Assessment of Research Reactors (INSARR) and the Operational and Maintenance Assessment for Research Reactors (OMARR), while the broader International Physical Protection Advisory Service (IPPAS) related to nuclear security, also covers research reactors.

INSARR: a lifetime of safety

INSARR missions review nuclear safety during all phases of a research reactor's lifetime. This covers the design and siting, commissioning and operation of research reactors. Areas reviewed include organization and management, training programmes, safety analysis, operational limits and conditions, operating procedures, maintenance, radiation protection, modifications, experiments and emergency planning. The host facility operators can request a full-scope mission or a review that focuses on specific areas of interest.

In 2017, an INSARR mission was conducted in Jamaica at the country's only research reactor, a JM-1 research reactor. "The INSARR mission in 2017 helped us chart the way forward for the safe operation of the facility for the next decade," said Charles Grant, Director General of Jamaica's International Centre for Environmental and Nuclear Sciences (ICENS).

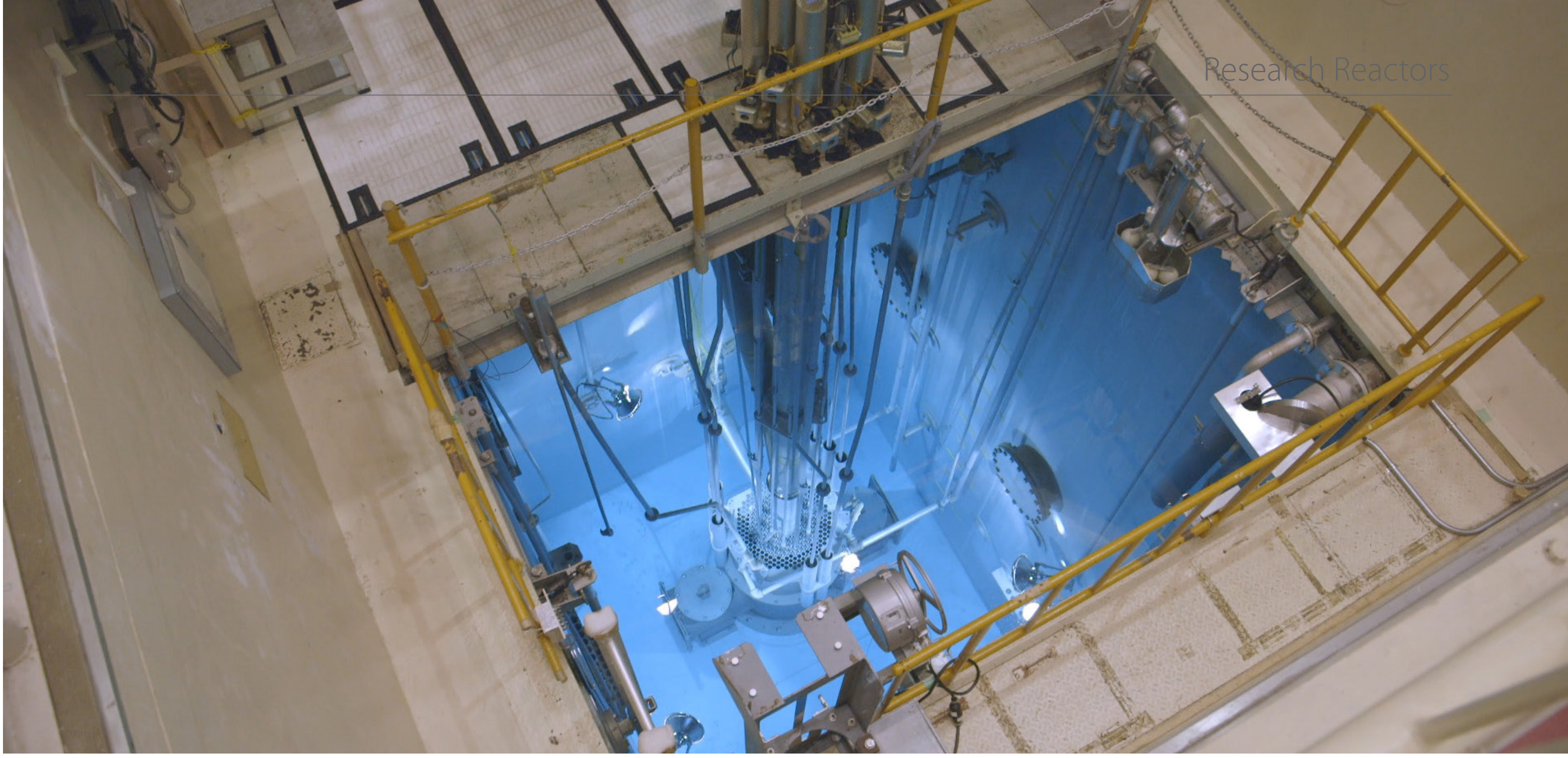
Since the IAEA's INSARR service was first launched in 1997, over 90 INSARR missions have been carried out at research reactors in 45 countries across the globe.

"An analysis of INSARR reviews since 2005 has shown that over 75% of the findings are resolved or have had satisfactory progress by the time of the follow-up visits," said Shokr. "These findings indicate significant safety enhancements in many research reactors around the world and that our service is found useful by the hosts."

OMARR: reliable and efficient operations

OMARR review missions are focused on the operational and maintenance aspects that need to be addressed throughout a research reactor's lifetime, including when starting a new research reactor project or reaching a particular milestone (learn about the Milestones approach on page 6). These missions identify areas for improvement, address specific operational challenges and create a platform for sharing experiences and good practices between international experts and local personnel.

"About 50% of the world's operating research reactors are over 40 years old," said Ram Sharma, a nuclear engineer in the IAEA's Research Reactor Section. "They face a range



A research reactor pool from above.
(Photo: JAEA)

of issues, including those related to ageing. OMARR missions help research reactor facilities reach optimal utilization of all financial and human resources throughout the facilities' operational life cycle."

Based on IAEA and international standards and related technical reports, OMARR missions provide recommendations and suggestions related to operations and maintenance, ageing management, human resources, quality assurance, management systems, plant asset and configuration management and plant modifications. The expected results include more efficient long term operation, better performance, improved safety and safety culture and optimized utilization of human and financial resources.

When implementing OMARR recommendations or planning for long term operation, countries can also request a follow-up OMARR mission to address ongoing research reactor issues.

In 2019, an OMARR mission was conducted in Indonesia and helped the country chart out the future operation of its research reactor. "The OMARR mission was very useful for our plan for the long term operation of our reactor and timely in support of ongoing activities," said Anhar Riza Antariksawan, Chairman of Indonesia's National Nuclear Energy Agency (BATAN). "It was especially important in helping us with resuming our reactor operation at full power using fresh TRIGA fuel, once it is available, and determining which modifications would be necessary if we were to convert to indigenous plate-type fuel instead."

IPPAS: secure and protect

While INSARR and OMARR missions are primarily focused on the facility level, IPPAS review missions operate on a national level and focus on the physical protection of nuclear and other radioactive material. The review team compares the national nuclear security measures implemented to the IAEA Nuclear Security Series publications, the Convention on the Physical Protection of Nuclear Material and other international legal instruments.

"An IPPAS mission is an important step for a country to address any areas of improvement it may have in nuclear security on a facility or national level," said Kristof Horvath, a senior nuclear security officer at the IAEA. "They provide a positive opportunity to learn, without the need for an inspection or other intrusive measures."

Working with the national authorities — police force, customs and regulators — IPPAS missions also cover the transport of nuclear material and contingency situations. National legislation and regulations, licensing and response to theft or sabotage, as well as computer security, are also areas covered by these missions.

An IPPAS mission was conducted in Hungary in 2013 after the country set up a new nuclear security regime, with a follow-up mission in 2017. "The mission in 2013 led to significant improvements, particularly to our legal framework, computer security and security during transport," said Zsolt Stefanka, Acting Head of the Department of Radiation Sources, Safeguards and Security at the Hungarian Atomic Energy Authority.

Finding the right fit

How nuclear security is incorporated into research reactors

By Inna Pletukhina

Research reactors benefit society in many ways. However, they can only fulfil their mission if their nuclear material is well protected and does not fall into the hands of terrorists. One of the ways in which countries protect their nuclear material today is by working with the IAEA to build nuclear security systems and measures into their research reactor designs.

But integration has not always been the case.

“More than 30 years ago, when most research reactors were built, they were designed for education, industry and research according to safety standards but without comprehensive security specifications built in,” said Juan Carlos Lentijo, IAEA Deputy Director General and Head of the Department of Nuclear Safety and Security. “Security of nuclear material and installations has long since emerged as a key concern, and now most of the research reactors built back then have been retrofitted.”

Achieving the goals of nuclear security — to prevent, detect and respond to criminal or intentional unauthorized acts involving nuclear or other radioactive material — is complicated by the specific characteristics and wide diversity of research reactor types and their related facilities. For older research reactors, additional complications stem from inherent facility vulnerabilities resulting from changing threat environments, inadequate security measures and equipment and the attractiveness of nuclear and other radioactive material for unauthorized removal and sabotage.

Physical protection measures help to ensure nuclear security at research reactors.
(Photo: D. Calma/IAEA)

A research reactor facility may have been originally laid out with buildings allowing maximum accessibility and minimal physical protection measures. For example, research reactors built using an open pool-type design allow for easy access to the nuclear material found in the reactor's core. This is an efficient design for educational purposes but could pose a security risk.

While each research reactor has its own nuclear security requirements, there are some common challenges, such as large groups of individuals accessing a research reactor for up-close, hands-on educational purposes. Unlike nuclear power plants, which are operated by a relatively consistent staff for years at a time, research reactors are often used by students and researchers who carry out short-term projects and who move on once their work is completed. This requires nuclear security measures that allow for education and research to continue without access delays, while still maintaining a high level of protection.

Given the variety of materials used, power levels, fission products, configurations, funding arrangements and staffing of a research reactor, standardization of nuclear security systems and measures is not possible, said Doug Shull, a senior nuclear security officer at the IAEA.

"When it comes to research reactors, there is no one-size-fits-all approach for protection. It has to be evaluated and implemented on a case-by-case basis," Shull said. "Each reactor has a unique design and features that require the design of physical protection systems to allow the facility's mission to be accomplished while ensuring protective measures are effective in a security event."

While each country is responsible for nuclear security within its own borders, many draw on the IAEA's advice on the level of nuclear security systems and protective measures available and its assistance with physical protection upgrades, insider threats and nuclear security culture programmes.

Integrated security support plans

For many countries, a key part of incorporating nuclear security at research reactors is within the scope of IAEA Integrated Nuclear Security Support Plans (INSSPs). These tailored plans help countries set up their nuclear security regimes. They are coordinated, upon a country's request, with the IAEA to help a country review its nuclear security regimes and identify areas in need of improvement. They also highlight opportunities for assistance to support the development of an effective and sustainable nuclear security regime.

Thanks to its flexibility, an INSSP may be tailored to identify the specific needs of a State's research reactor programme. These may include specific training activities in nuclear security and support in developing administrative procedures, exercises or physical protection upgrades.

"Developing an INSSP with the IAEA's assistance helped us evaluate our national nuclear security regime as a whole and allowed us to determine how we can tailor nuclear security to fit our research reactor and best use the IAEA's assistance for that process," said Nasiru Bello, Director of Nuclear Safety, Physical Security and Safeguards at the Nigerian Nuclear Regulatory Authority.

Nigeria has one research reactor, which has been in operation since 2004, and developed its INSSP in 2010. The INSSP helped Nigeria take steps, with the IAEA's support, to strengthen nuclear security at the country's research reactor in line with the IAEA's Nuclear Security Series publications. This systematic approach also focused on training research reactor personnel and on regulatory capacity building.

As the IAEA continues to seek ways to expand its support, one of the latest tools it is developing is the Hypothetical Atomic Research Institute (HARI) facility description. The HARI is a reference document describing many aspects, including security, that are related to research reactors and their associated facilities and that can be used to provide a country with a greater insight into nuclear security recommendations, as well as building knowledge and gaining practical experience in addressing nuclear security recommendations. The HARI will be an additional tool that countries can use to address their priorities, whether they have been identified through an INSSP, peer review missions or other avenues.

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— Nasiru Bello, Director of Nuclear Safety, Physical Security and Safeguards, Nigerian Nuclear Regulatory Authority

Countries move towards low enriched uranium to fuel their research reactors

By Laura Gil

Secured high enriched uranium being loaded for transport.
(Photo: GAEC)

Almost 3500 kg of high enriched uranium (HEU) has been removed from research reactor sites worldwide over the last few decades as part of global efforts supported by the IAEA. Upon the request of Member States, the IAEA has assisted with the conversion of research reactor fuels to low enriched uranium (LEU) in order to reduce the proliferation risks associated with HEU, which contains more than 20% fissile uranium-235.

While most research reactors were built in the 1960s and 70s with technology that required HEU to perform experiments intended for scientific research, today much of this research can be carried out using LEU, in which the concentration of radioactive uranium-235 is below 20%.

"The international community has successfully provided technological solutions for converting HEU fuel to LEU fuel in research reactors," said Thomas Hanlon, Nuclear Engineer Expert at the IAEA. "The trick is to do this without compromising the scientific research."

Today, about 220 research reactors operate across 53 countries, and 171 of these reactors were constructed with an HEU core. Seventy-one HEU fuel reactors have been converted to LEU since 1978. Nuclear power reactors, which are used to generate electricity, run on LEU.

The IAEA has supported HEU to LEU fuel conversions or HEU repatriations in Austria, Bulgaria, Chile, China, the Czech Republic, Georgia, Ghana, Hungary, Jamaica, Kazakhstan, Latvia, Libya, Mexico, Nigeria, Poland, Portugal, Romania, Serbia, Ukraine, Uzbekistan and Viet Nam. The IAEA has supported HEU minimization through technical cooperation projects, fact-finding missions, coordinated research projects, technical and consultancy meetings and procurement assistance.

Learning from others

A recent case is that of Ghana, where — with IAEA support — the successful conversion of their Ghana Research Reactor-1 (GHARR-1), a miniature neutron source reactor (MNSR), in 2017 turned the country into a case study for other MNSR operators. The Ghana Atomic Energy Commission, or GAEC, has built an international MNSR training facility that allows trainees from other countries to practice extracting mock HEU from the reactor vessel.

"With less enrichment, we are reducing the attraction to the material and making the world better," said Benjamin Nyarko, Director-General of GAEC, adding that the conversion from 90.2% enriched uranium to 13% was accompanied by technological change that has led to an increase in the reactor's power by over 10%.

In 2018, Nigeria's only operating research reactor, Nigeria Research Reactor-1 (NIRR-1), underwent HEU removal and conversion to LEU. The IAEA supported in the conversion as well as in training the relevant personnel and sharing other countries' experience. To practice converting the reactor, Nigerian experts conducted a dry run of HEU removal in Ghana's training centre. After the conversion of Nigeria's reactor, there are no more HEU-fuelled research reactors in Africa.

Conversion requires highly trained personnel and equipment. The most complex step in the process is often transporting the spent HEU, using trucks, ships or planes. Once the HEU fuel reaches its destination, it is either securely stored or diluted to lower enrichment levels.

"In Chile in 2010, we transported approximately 14 kg of HEU to the USA; this was the last of 3 operations that have led to the country being free of this fuel," said Rosamel Muñoz Quintana, Head of Corporate Communications at the Chilean Nuclear Energy Commission. "It raised great public interest. Specially conditioned trucks and planes were used, and all the necessary security and radiation protection aspects that operations like these require were considered."

Converting more research reactors to LEU

Work remains to be done. Although 71 research reactors have been converted to LEU, and 28 that were HEU-fuelled have been shut down, another 72 are still powered by HEU. In many cases this is for scientific reasons.

"It takes a lot of creative engineering to figure out how to achieve a similar capacity for the reactor, using LEU in the same space initially designed for HEU," Hanlon said. "It's a bit like trying to make a cup of espresso of the same strength you're used to, using the same amount of liquid in the same container, but with fewer grains of coffee."

"With less enrichment, we are reducing the attraction to the material and making the world better."

— Benjamin Nyarko, Director-General, Ghana Atomic Energy Commission

Experts carrying out a dry run at Ghana's MNSR training facility.

(Photo: GAEC)

Verifying the research

Implementing safeguards at research reactors

By Adem Mutluer

IAEA safeguards inspectors are trained to check all nuclear material at a research reactor facility.
(Photo: D. Calma/IAEA)

Verifying the peaceful use of nuclear material and technology at research reactors constitutes a significant part of the IAEA's work in nuclear verification. While only 30 countries have nuclear power plants and fuel cycle installations, over 50 operate research reactors. In 2018, IAEA safeguards were implemented at around 150 facilities with research reactors. These facilities pose a challenge for safeguards, as unlike nuclear power reactors, research reactor designs vary widely, and the safeguards measures applied need to be tailored to each type of reactor.

"Low power does not mean low concern," said Djamel Tadjer, Senior Inspector for State Level Coordination at the IAEA. "While research reactors provide major benefits in health and development, the potential for the diversion of nuclear material from peaceful use or misuse of the reactor is still there. As such, applying safeguards at research reactors is a critical part of the IAEA's verification work."

A by-product of using research reactors is plutonium — a material than can be used for nuclear power and research but is also an ingredient used to produce nuclear weapons. Although only a small amount of plutonium is produced by a single research reactor, it is still a safeguards concern.

During verification, the IAEA considers the amount of time it takes for a research reactor to produce one significant quantity of nuclear material, i.e. the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. The IAEA also receives information from the host State about the facility's design and layout, as well as the form, quantity, location and flow of the material in use. Using this information, the IAEA sets out a safeguards approach that is tailored to the facility's specifications. The IAEA can then verify the correctness and completeness of the design information provided by the State and confirm that the facility and the nuclear material at the facility are being used as reported.

Different uses and designs

Many research reactor facilities contain hot cells. These containment chambers shield workers from nuclear radiation; the worker stands outside the cell and uses manipulator arms to safely handle the equipment and nuclear materials located inside the chamber.

Hot cells are most often used for isotope separation for medical purposes, but they can also be used for small-scale plutonium extraction from the irradiated fuel produced by a research reactor. IAEA safeguards inspectors are trained to detect plutonium extraction.

A smaller number of research reactors use high enriched uranium (HEU) — uranium enriched to greater than 20% uranium-235 — which is another material that can be used to produce nuclear weapons. Although many research reactors are already converted to use low enriched uranium (LEU) — which is not directly usable for nuclear weapons — IAEA safeguards inspectors still check all nuclear material at a research reactor facility in order to verify the correctness and completeness of the State's declaration.

"Due to the differences in the design and use of research reactors, there is no general checklist to satisfy safeguards requirements at such facilities," said Tadjer. "Instead, we train our inspectors to look for any signs of misuse at research reactors and the diversion of nuclear material. For inspectors, it's about spotting inconsistencies and then knowing the right questions to ask."

Meeting safeguards obligations

However, it is not solely the work of the IAEA inspectors to apply safeguards, as States also have certain requirements they have to meet. The IAEA offers States assistance in meeting these requirements in terms of incorporating safeguards into the design of a facility, implementing nuclear material accountancy and meeting the legal requirements of implementing safeguards. Such assistance includes guidance on building safeguards considerations into the design of research reactors. The IAEA also offers in-country advisory missions to support State systems of accounting for and control of nuclear material (SSAC) in meeting their obligations.

By considering safeguards requirements early in the research reactor design process, future demands on the facility operator for nuclear material verification can be reduced. For instance, the possibility of applying remote monitoring is cost effective and maintains safeguards effectiveness while reducing the need for inspector activity on-site. One example of remote monitoring is the use of an advanced thermohydraulic power monitor that assesses coolant flow and heat extraction to calculate the reactor's plutonium production. By knowing how much plutonium is produced by the reactor over a specific time period, inspectors can amend the frequency of inspection accordingly, thereby saving time for both the inspector and the operator.

"To apply safeguards at research reactors, as with applying safeguards at any nuclear facility, cooperation between the State and the IAEA is very important," said Tadjer. "By working together and applying modern technology, such as the advanced thermohydraulic power monitor, the IAEA can more effectively and efficiently verify that nuclear material remains in peaceful use."

"We train our inspectors to look for any signs of misuse at research reactors and the diversion of nuclear material. For inspectors, it's about spotting inconsistencies and then knowing the right questions to ask."

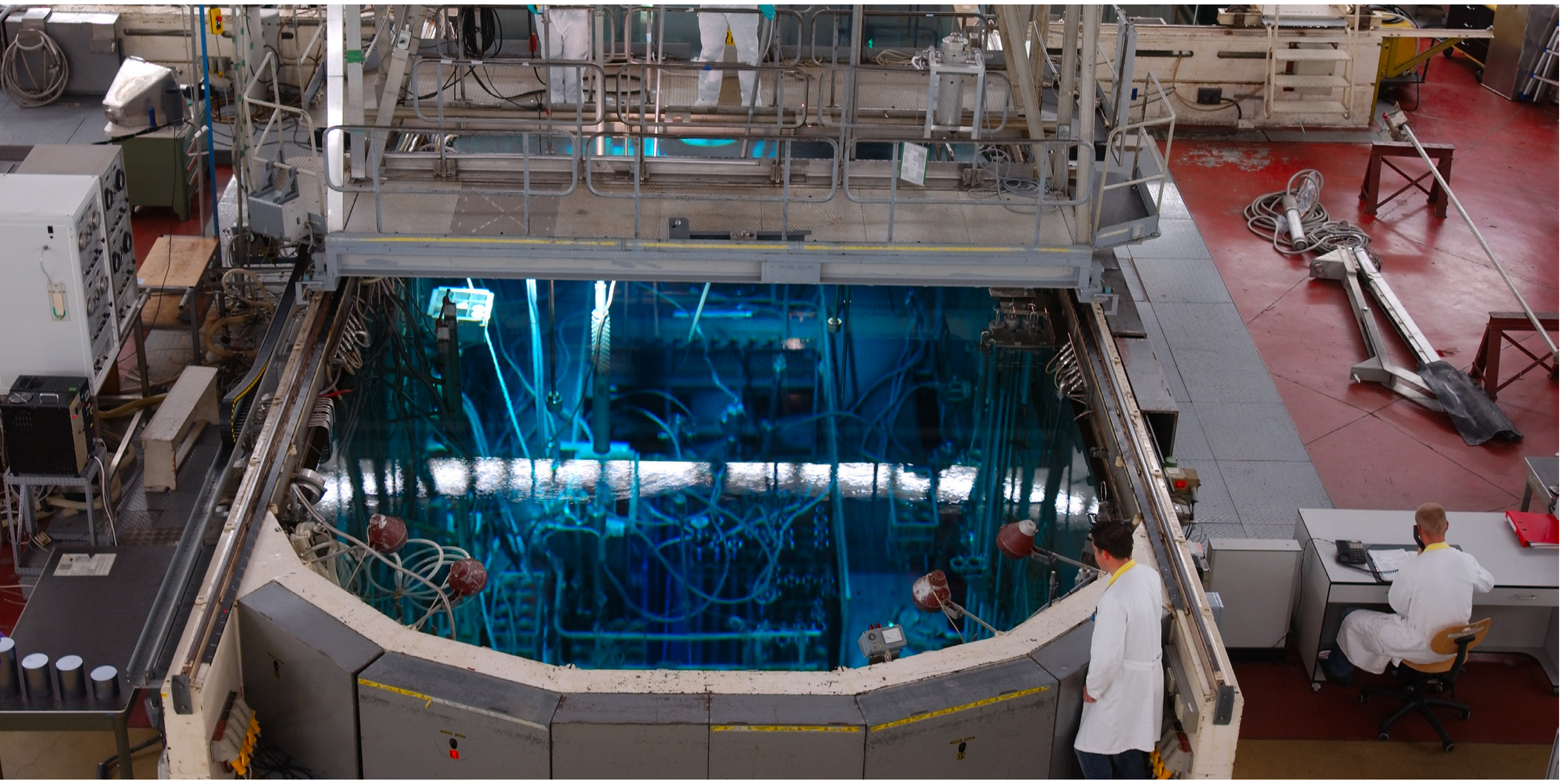
— Djamel Tadjer, Senior Inspector for State Level Coordination, IAEA

A hot cell is a containment chamber that shields workers from nuclear radiation.

(Photo: IAEA)

Managing ageing research reactors to ensure safe, effective operations

By Joanne Liou



The containment area inside Belgian Reactor 2.
(Photo: SCK•CEN)

As over two thirds of the world's operating research reactors are now over 30 years old, operators and regulators are focusing on refurbishing and modernizing reactors to ensure they can continue to perform in a safe and efficient manner.

"The lifetime of research reactors is normally determined by the need for their use and their conformance with up-to-date safety requirements, since most of their systems and components can be replaced, refurbished or modernized without major difficulty," said Amgad Shokr, Head of the IAEA's Research Reactor Safety Section. "Refurbishment and modernization should not be limited to just systems and components; operators should also review safety procedures against IAEA safety standards to prevent the interruption of research reactor services."

For more than 60 years, research reactors have been centres of innovation and development for nuclear science and technology programmes around the world. These small nuclear reactors primarily generate neutrons — rather than power — for research, education and training purposes, as well as for applications in areas such as industry, medicine and agriculture (learn more on page 4).

There are two kinds of ageing related to research reactors: **physical ageing**, which is the degradation of the physical condition of the reactor's systems and components, and **obsolescence**, which is when the technology used for computers, instrumentation and control systems or safety regulations become outdated.

The ageing of facilities was one of the concerns that led to the IAEA initiating its Research Reactor Safety Enhancement Plan in 2001. This plan aims to help countries ensure a high level of research reactor safety. It includes the Code of Conduct on the Safety of Research Reactors, which provides guidance to countries on the development and harmonization of policies, laws and regulations regarding the safety of research reactors.

As part of this plan, countries work with the IAEA to implement systematic ageing management programmes that, among others, use good practices to minimize the performance degradation of systems and components, to continuously monitor and assess reactor performance and to implement practical safety upgrades. These ageing programmes can also benefit from operating programmes in other areas, such as maintenance, periodic testing, inspections and periodic safety reviews.

"While the number of operating research reactors is decreasing, the average age is increasing," said Ram Sharma, a nuclear engineer on research reactor operation and maintenance at the IAEA. "So, it is of paramount importance to establish, implement and continuously improve plans for management, refurbishment and modernization to ensure cost-effective operation and utilization to get the most out of existing research reactors. IAEA support, such as peer review missions, can play a key part in achieving that goal." Learn more about the IAEA's research reactor-related peer review services on page 22.

Comprehensive support

Countries can draw on a range of IAEA support to address ageing at their research reactors. This includes assistance with developing safety standards and optimizing reactor availability, as well as adopting recommended practices based on IAEA-published collections on safety and using information disseminated by the IAEA on developing and implementing modernization and refurbishment projects. This assistance extends to new research reactor programmes and to assessing plans to proactively address ageing throughout all phases of the research reactor's lifetime, from the design and selection of materials to the construction and operation of the facilities.

Review missions are initiated upon the request of a country and are supported by the IAEA and teams of international experts who carry out assessments and provide recommendations for further improvements. In November 2017, the first ageing management peer review mission for a research reactor was completed at Belgian Reactor 2 (BR2), which is one of three operating research reactors at the Belgian Nuclear Research Centre (SCK•CEN). The mission was based on the methodology of Safety Aspects of Long Term Operation (SALTO) missions for nuclear power plants and adapted to suit research reactors.

"The mission identified a number of items that were overlooked, such as ageing management of radioisotope production facilities and experimental devices," said Frank Joppen, a nuclear safety engineer at SCK•CEN. "As a result, the classification systems of components are being updated, and feedback from maintenance, inspection and surveillance is being used to further improve ageing management programmes."

In operation since 1963, BR2 is one of the oldest research reactors in Western Europe. It produces around one quarter of the global supply of radioisotopes for medical and industrial purposes, including for cancer therapy and medical imaging. It also produces a type of silicon that is used as a semiconductor material in electronic components. BR2 is now permitted to operate until its next periodic safety review in 2026, when a decision on extending its operation for another ten years may be taken.

"The ageing management programme of BR2 will be further developed, which means taking into account the remarks made during the IAEA mission," Joppen said. "The efficiency of the programme will be reviewed and will be the subject of the next safety review."

The next IAEA ageing management missions for research reactors have been requested by the Netherlands and Uzbekistan and are planned for 2020. "The BR2 mission showed that the SALTO methodology could be effectively applied to research reactors. We will continue to improve the efficiency and effectiveness of this mission, as well as other services, to maximize the benefits from research reactors," Shokr said.

"The ageing management programme of BR2 will be further developed, which means taking into account the remarks made during the IAEA mission."

— Frank Joppen, Nuclear Safety Engineer, SCK•CEN, Belgium

Belgian Reactor 2 at SCK•CEN.
(Photo: SCK•CEN)

Decommissioning Uzbekistan's first research reactor

By Kendall Siewert

A sandy vacant lot lined by greenery in Tashkent, Uzbekistan may look like it's ready to welcome a new construction project, but this empty space is the result of the decommissioning of IIN-3M, a retired research reactor.

"A decision was made to decommission the IIN-3M reactor, since it had rarely been used in recent years, the equipment was obsolete and it was located near an airport that officials were considering expanding," said Fakhrulla Kungurov, Laboratory Head at the Institute of Nuclear Physics of the Uzbekistan Academy of Sciences. "No nuclear installation had ever been decommissioned in Uzbekistan before. The IAEA supported us during each step of the process, assisting in instances where we lacked the necessary experience and knowledge."

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Decommissioning the IIN-3M reactor at Uzbekistan's Radiation and Technological Complex (RTC) began in 2015 and ended in 2019. This process involved decontaminating, dismantling and demolishing the facility to release it, and its site, from regulatory control. The reactor had ceased operation in 2013 after being primarily used to test semiconductors and other devices since 1975. It is one of two research reactors in the country, with the second still in operation.

Research reactors provide a neutron source intended for applications in, for example, industry, medicine, research and education and training, in contrast to other larger nuclear reactors designed for power generation. When they have served their purpose and are retired, they need to be decommissioned, just like any other nuclear installation. The objective of decommissioning is to remove all sources of radioactivity, contaminated material and other structures so the site can be used for other purposes.

More than 60% of operating research reactors are now over 40 years old. The growing number of ageing reactors has resulted in increased decommissioning activity worldwide; there are currently over 220 research reactors in operation, while 443 have been decommissioned.

Countries may choose to decommission research reactors for a variety of reasons, such as the prohibitive costs of extending their lifetime for continuing operation, lack of funding or outdated technology, whereas others may decide to renovate and keep them in operation to continue benefiting from their use. However, an action plan is needed irrespective of whether operators and authorities decide to decommission an existing reactor now or much later in the future.

Upon request, the IAEA offers support and expertise to countries to ensure that they are well prepared to handle decommissioning safely and securely, said Vladimir Michal, a decommissioning team leader at the IAEA. In addition, the IAEA issues safety standards and reference publications that offer guidance and share good practices in this area, he said.

"Countries decide for themselves whether to continue operation or to shut down a reactor, but what's crucial is to decommission reactors that are no longer in operation," said Michal. "Not decommissioning idle research

reactors, or doing so improperly, can result in their structural deterioration and an increased risk for people and the environment."

Putting a plan in place

Today, it is standard practice to incorporate a decommissioning plan into the initial setup of a research reactor, but that was not the case in the 1970s when the IIN-3M reactor and many others were built.

"There was a general perception during the early years of building research reactors that decommissioning could be easily accomplished with minimal resources and planning. However, this is clearly not the case," said Kungurov. "As a consequence, we did not have a plan for the decommissioning process and no information on how to remove or deinstall the equipment, which is where the IAEA's support was vital."

IAEA staff and other international experts travelled to Uzbekistan in August 2012 to evaluate the site of the reactor. The goal of the visit was for experts to assess the state of the facility and gather the necessary information to assist Uzbek officials in preparing for decommissioning.

Based on the results of the 2012 visit and other meetings, IAEA experts worked with the national team to develop a decommissioning plan — including a project schedule and cost estimates — in accordance with the IAEA's recommendations and guidance on decommissioning planning.

"Estimating the costs for decommissioning was one of the most difficult parts of the planning process because our reactor operators had never done it before and it requires a lot of documentation," said Kungurov. All the information on decommissioning the IIN-3M reactor, such as the specifics of the procedures, equipment and tools to be used, was submitted to Uzbekistan's national regulatory body for approval prior to beginning work on the ground.

Preparing for decommissioning

An important step before the decommissioning process can begin is the removal of all fuel and radioactive sources from the premises, as outlined in the IAEA's safety standards. This typically requires specialized equipment and highly trained experts.

For the IIN-3M reactor, experts worked with the IAEA in cooperation with Russia and the USA to extract and ship the reactor's fuel back to its country of origin: Russia. A particular challenge in this case was the form of the spent fuel — liquid high enriched uranium — as this was the first time such fuel had been returned to its country of origin by air. This cooperation also included preparing and transporting various disused liquid radioactive sources from the site to a disposal facility.

The decontaminating, dismantling and demolishing process could then begin. The decommissioning process involved taking apart the equipment piece by piece, such as the reactor vessel; eliminating surface contamination and ensuring safe radiation levels; and removing layers of concrete that were used in the reactor box. The IAEA supported each step of the process.

Once the decommissioning process was complete, the IAEA supported a survey of the site, upon request by the Government of Uzbekistan, to check for safe levels of radioactivity. Results showed that the decommissioning was successful as no significant residual radioactivity was found. This independent measurement was in line with the Government of Uzbekistan's evaluation of the site, and together these findings confirmed it was safe to use for another purpose.

The IIN-3M research reactor facility during the demolition phase of decommissioning.
(Photo: Uzbekistan Academy of Sciences)

Maintaining the sustainability of research reactors

Helmuth Boeck
Associate Professor for Reactor Safety at the Vienna University of Technology's Institute of Atomic and Subatomic Physics. Boeck has over 45 years of experience in research reactor utilization and operation. He has also served as an expert on more than 80 IAEA-supported missions.

Research reactors continue to be an indispensable means of providing radioisotopes for medicine and industry, neutron beams for material research and non-destructive testing, and analytical and irradiation services for both the private and public sectors. Their use also plays a strategic role in educating and training a new generation of scientists and engineers to support nuclear science and technology programmes.

Of the 841 research reactors built to date, many have already been decommissioned, or are awaiting decommissioning, and, out of the 224 research reactors still in operation, over 50% are over 40 years old. While there are currently 9 research reactors under construction worldwide and about 30 new research reactors in different stages of planning, many research reactors have been shut down owing to a lack of funding, a lack of utilization or a lack of strategic planning, all of which were not previously considered to be important issues. With proper management and utilization, a research reactor can operate for 60 years or more. However, it is of paramount importance that adequate life management programmes, including those related to safety, security and utilization, are established well in advance.

Collaborating to reduce costs and increase utilization

The main challenges faced by research reactor operators today are issues concerning funding and utilization. Research reactors are not usually supported financially by the state, industry or the private sector if there is no visible benefit. The benefits could involve academic research within a national university programme, the production of medical radioisotopes or materials research within a national or an international cooperation programme. Depending on the research reactor's power level — which influences how it is used — a multipurpose research programme would be the optimal solution.

One possibility to reduce operational costs while increasing utilization is to form regional research reactor partnerships among two or more research reactor facilities, which can then share operation time and/or expensive equipment. Over the past decade, several such partnerships have been initiated and financially supported through the IAEA's group fellowship training (GFT) courses.

One example of this is the Eastern European Research Reactor Initiative (EERRI), which was established by four countries, Austria, the Czech Republic, Hungary and Slovenia, which, in total, operate six research reactors of various designs. Through this network, 15 GFT courses lasting 6 weeks and with more than 120 participants in total have been carried out since 2009. The participants were trained on at least 5 research reactors with power levels of between 100 kW and 10 MW and were educated about topics such as reactor physics, instrumentation and control systems, radiation protection and activation analysis.

Similar initiatives are, for example, the Global TRIGA Research Reactor Network (GTRRN), which was created to discuss and address common issues of TRIGA-type research reactors — of which more than 30 are in operation worldwide — including supply of fuel, technical support and enhanced utilization.

Ageing, shutdown and decommissioning

According to the IAEA's Research Reactor Database, several research reactors across the world are in extended shutdown for reasons such as the absence of a utilization plan or because the technical status does not meet internationally accepted safety standards and would otherwise require extensive refurbishment or modernization. In some cases, refurbishment or modernization may be so costly that it is cheaper to keep the reactor in shutdown; however, even in this state, maintenance costs continue. Consequently, there are several research reactors sleeping their way into an undecided future, which, in the long run, could raise real safety and security questions.

This situation is exacerbated by the question of how to deal with the reactors' spent fuel, which must be effectively managed, including storage at a national storage facility, reprocessing, final disposal, or shipping back to the country of origin. Such options are usually expensive and must be handled in a timely manner while also observing international safety standards and ensuring the necessary financial investment at an early stage.

Management systems for strategic planning

For long term research reactor operation, an effective ageing management programme should be established and should typically include, among others, a detailed safety assessment for long term operation and adequate plans for refurbishment and modernization in order to bring the facilities into line with up-to-date safety standards.

For many research reactors, there is a lack of decommissioning plans that should have been developed at the beginning of the reactor's operational lifetime and subsequently kept up-to-date. Several IAEA safety standards have been developed to provide guidance on establishing ageing management programmes, decommissioning and managing research reactors in extended shutdown.

These issues related to shutdown, ageing and decommissioning can be addressed when establishing an overall management system. These systems also need to be developed in such a way as to address important goals, including safety, health, security and related issues, in order to improve a research reactor's continued operation and services, as outlined in the IAEA safety standards. The system should provide generic guidance that aids the establishment, implementation and assessment of a research reactor and provides specific guidance on operation that complies with international standards.

To set up a management system, a detailed strategic plan tailored to a particular facility should be established and should involve all partners, such as national authorities, industry, users and facility managers, in order to streamline available funds and operational expenses. This strategic plan must be periodically revised to account for changes to the research reactor's mission over time. The IAEA has developed many documents to assist countries in developing and implementing strategic plans.

In conclusion, these topics indicate how research reactors can be maintained and/or improved to ensure sustainability. Depending on the particular status of a specific research reactor, the operating organization may decide on actions for improvement using, in particular, the IAEA's experience and support so as to maintain the sustainability of its research reactor.

IAEA, FAO help develop bananas resistant to major fungal disease

Field trials showing the new TR4-resistant banana variety, ZJ4, compared to the susceptible BaXi grown in Guangdong, China.
(Photo: G. Yi/Guangdong, China)

Bananas may be the world's favourite fruit, but plantations worldwide are increasingly under threat from a new fungus that destroys banana plants and endangers both the farmers' livelihoods and the industry.

Confined to Southeast Asia for decades, Fusarium wilt tropical race 4 (TR4) was spotted for the first time in Africa and in Latin America in 2019. Its outbreak in Colombia in August 2019 led to the declaration of a national emergency.

The IAEA — in cooperation with the Food and Agriculture Organization of the United Nations (FAO) — has worked with researchers worldwide to support the development of new varieties of banana species that could be resistant to the disease.

"Modern bananas can't grow seeds and so are difficult to improve using cross breeding," said Ivan Ingelbrecht, Head of the FAO/IAEA Plant Breeding and Genetics Laboratory. Therefore, the use of techniques such as irradiation or chemical mutagenesis to produce new varieties with favourable traits is often a favoured option to combat the disease.

After years of research, Chinese experts have released a new variety of Cavendish banana — the most commonly exported banana — that is resistant to TR4. The new variety was developed using chemical mutagenesis techniques, and other countries, including the Philippines, are in the advanced stages of developing their own varieties using gamma irradiation, Ingelbrecht said.

Fusarium wilt has been a major constraint to banana production for over a century. The disease is caused by a soil-borne fungus called Fusarium oxysporum f. sp. cubense. The pathogen remains viable in the soil for decades and is therefore difficult to eradicate. TR4 is a new strain of this fungus that has recently emerged. "The fungi enter susceptible plants through the roots and interfere with the uptake of water, causing wilting of the leaves, and the banana plant eventually dies," explained Ingelbrecht.

The FAO estimates that the annual direct damage caused by TR4 in Southeast Asia reaches about US $400 million, excluding indirect socio-economic impacts.

"The release of a new Cavendish variety will benefit many farmers; this success is due to the close collaboration with the IAEA and the FAO on mutagenesis techniques," said Yi Ganjun, Vice President of the Guangdong Academy of Agricultural Sciences in Guangzhou. "This state-of-the-art technology has resulted in a remarkable breakthrough in combatting Fusarium wilt."

"The exciting results of a new 'local' banana variety, which is resistant to Fusarium wilt TR4, give tremendous hope to banana farmers who have successfully tested the new plants in field trials," said Yi. "Mutagenesis techniques can contribute to the development of new banana plants to suit local environmental conditions."

The new variety is now being multiplied and distributed to other provinces. Chinese experts are willing to help their colleagues in other countries to develop varieties of banana that are resistant to TR4 and are suited to their climatic and soil conditions, Yi added.

Scientists are using in vitro techniques to grow thousands of small banana plants in test tubes that are suitable for mutagenesis using chemicals, gamma rays or X-rays. These techniques speed up the natural process of mutation in plants and create genetic diversity that can then be used to produce new varieties, including those with favourable traits. A coordinated research project involving scientists from six countries, including China and the Philippines, has spearheaded work on developing banana types with resistance to TR4 since 2015.

Plant breeders at a banana plantation with the new Cavendish varieties grown in Guangdong, China.
(Photo: G. Yi/Guangdong, China)

"The success achieved using chemical mutagenesis and the promising progress using irradiation in several Asian countries suggests that developing new, TR4-resistant varieties will be possible in the not-too-distant future in other parts of the world as well," Ingelbrecht said. "The IAEA and the FAO are committed to helping countries get there."

— By Miklos Gaspar

Fighting air pollution with a $1 tool

A simple new device that costs less than US $1 to make could help global efforts to reduce harmful air pollution caused by ammonia emissions, while also improving access to food. The small plastic tool was designed by Brazilian scientists in collaboration with the IAEA and the Food and Agricultural Organization of the United Nations (FAO). After isotopic techniques were used to test and confirm its accuracy, the tool is now being rolled out to help countries monitor and better manage ammonia emissions from agriculture, including the livestock industry.

Ammonia — a compound of nitrogen and hydrogen — is one of the major by-products of agriculture and is a gas released when, for example, fertilizers and animal manure breakdown. The presence of this gas (NH3) in the atmosphere can act as a secondary source of nitrous oxide (N20) — a powerful greenhouse gas — and can damage ecosystems by exacerbating water pollution, as well as causing health problems in people.

When fertilizer is not correctly applied, up to half of its nitrogen could be lost to the atmosphere, a loss which also has major financial consequences. Understanding this loss is essential for issuing recommendations to farmers on how best to manage their fertilizer use, which can help maximize productivity and benefits.

"On average, 35% of the nitrogen fertilizers used in Brazil are lost to the atmosphere as ammonia, which has a big impact on the environment and the economy," said Segundo Urquiaga, a soil scientist at the National Agrobiological Research Centre of the Brazilian Agricultural Research Corporation (Embrapa).

As the world population continues to increase, the demand for food grows with it. This, in turn, leads to expanding livestock industries and an increasing dependence on synthetic and organic nitrogen fertilizers for food production. It also means more ammonia emissions. This trend is expected to continue over the next decade and poses a threat to people's health and to the environment

Experts in countries such as Brazil are looking for ways to measure and mitigate the release of ammonia into the atmosphere. Many sophisticated methods, such as wind tunnels, cavity ring down spectroscopy and micrometeorological techniques, are already available, but they are expensive and require highly skilled field technicians to operate them.

"Measuring and mitigating this process has been laborious, time consuming and relatively expensive in the past," said Urquiaga. "This new technique is cost-effective, fast and can be adopted

A simple new tool made from a plastic bottle could help efforts to track and reduce ammonia emissions from agriculture and improve food security

(Photo: Embrapa)

anywhere. Using it will have a direct impact on farmers, who will not only be saving resources but also reducing air pollution."

A unique new tool

The new tool is so simple that it could easily be mistaken for a grade-school science project. A chamber is made by removing the bottom of a large plastic soda bottle and attaching it to the open bottle top. This shields a thin strip of foam, which has been pre-soaked in an acid solution that traps ammonia, placed inside the bottle and runs from the mouth at the top down to a small plastic cup anchored to the soil with three metal prongs. The chamber is placed alongside the plants or livestock area to be monitored, and the foam is removed every 24 hours and taken to the laboratory for analysis.

This unique and simple device and instructions on how to use it were created by scientists from the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Embrapa and the Agronomic Institute of Paraná (IAPAR) in Brazil.

"This device could help us understand ammonia losses and move toward climate-smart solutions that leave enough nitrogen to boost plant productivity, especially in less fertile and nitrogen-deficient soil, which can have a major impact on food production," said Mohammad Zaman, a soil scientist and plant nutritionist in the Joint FAO/IAEA Division.

The device can be used on its own to precisely measure ammonia losses, as well as in combination with agricultural practices designed to reduce greenhouse gas emissions and their impact on the environment. These practices include drip irrigation systems, co-application of fertilizers with nitrogen process inhibitors and crop rotation involving nitrogen-fixing legumes.

Simple, yet reliable

Given the tool's simplicity, the reliability of its results raised a major cause for concern. To test the reliability, the scientists used an isotopic technique that involves adding nitrogen-15 to fertilizer (see The Science) as a way of tracking, measuring and comparing the amount of ammonia captured by the plastic chamber versus the amount released, which was measured by using the nitrogen mass balance method to check the amount of nitrogen in the soil over time. As ammonia is a compound containing nitrogen, the nitrogen-15 method allowed scientists to track the ammonia losses.

The results of the tests showed that the chamber was a reliable and suitable method for tracking ammonia emissions from organic and synthetic fertilizers used for annual and perennial crops, as well as from livestock excretion. "This method is highly efficient and precise in measuring and monitoring ammonia in comparison to the traditional closed-chamber method," Urquiaga said.

Experts in six countries — Brazil, Chile, Costa Rica, Ethiopia, Iran and Pakistan — have already started using the tool. The tool is expected to become more widely used, said Zaman, particularly after the project's results are published in a special edition of a peer-reviewed international scientific journal. Moreover, there is a plan to recommend to the Intergovernmental Panel on Climate Change (IPCC) to include the tool as a method to be used in agricultural systems worldwide, especially in developing countries.

THE SCIENCE

Nitrogen plays an important role in plant growth and photosynthesis — the process through which plants use sunlight to synthesize nutrients from carbon dioxide and water. Nitrogen is often added to soil in the form of fertilizer. By using fertilizers labelled with nitrogen-15 stable isotopes — atoms with extra neutrons as compared with 'normal' nitrogen — scientists can track the pathway and determine how efficiently the crops are absorbing the fertilizer, as well as track the different nitrogen losses involving ammonia. This technique also helps to determine the optimal amount of fertilizer that should be used.

— By Nicole Jawerth and Elisa Mattar

IAEA Member States get access to radioactive source transport container, thanks to US contribution

IAEA Deputy Director General Mikhail Chudakov and U.S. Department of Energy Undersecretary for Nuclear Security Lisa E. Gordon-Hagerty cutting the ribbon in front of a 1:10 model of the container for the transport of disused sealed radioactive sources, donated by the U.S. to the IAEA for use in other countries.

(Photo: S. Krikorian/IAEA)

The IAEA will now have access to a new container to transport disused sealed radioactive sources (DSRSs) thanks to a contribution from the United States Department of Energy's National Nuclear Security Administration (DOE/NNSA). The contribution was announced during a ceremony at the 63rd IAEA General Conference.

The container, a 435-B Type B(U) model, was designed for the domestic and international transport of various types of radioactive sources and devices. It is certified to transport both very high activity sources, such as teletherapy sources and irradiators, and sources with somewhat less activity, such as those used for industrial gamma radiography and high or medium dose rate brachytherapy.

The container's delivery was marked by a ribbon-cutting ceremony at the IAEA's Headquarters in Vienna.

"One of the major expenses associated with source removals from a Member State is the transport cost, as well as the leasing of an authorized transport container," said Mikhail Chudakov, IAEA Deputy Director General and Head of the Department of Nuclear Energy. "As the IAEA will now have direct access to a licensed container, we will be able to provide a more effective method for the safe and secure transport of DSRSs from users' premises to an authorized recipient for further management."

Radioactive sources, which are used for a variety of applications in areas such as medicine, industry, research and agriculture, must be managed properly, not only while they are in use but also once they have reached the end of their useful life. This usually involves transporting them to a location away from their place of use.

DSRS management options include interim and long term storage, recycling, repatriation and final disposal. Transport is also an important step in DSRS management. For the removal of these sources from a country to an authorized facility, they must be properly transported.

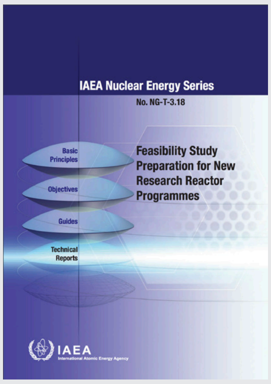
"The IAEA having access to this certified shipping container will facilitate the IAEA's support to ensure the safe and secure management of our DSRSs," said Marinko Zeljko, Director of the State Regulatory Agency for Radiation and Nuclear Safety in Bosnia and Herzegovina

Transporting these sources for end-of-life management has been a challenge in many countries due to a lack of suitable containers that are specially licensed for transporting DSRSs. With this 435-B container now available, the IAEA can assist the organizations in charge to transport DSRSs more efficiently.

"Making the 435-B container available further strengthens the cooperation between the USA and the IAEA, and I hope it is taken as a symbol of our long-term commitment to the IAEA's efforts to advance the proper end-of-life management of radioactive sources," said DOE Under Secretary for Nuclear Security and NNSA Administrator Lisa E. Gordon-Hagerty. "These efforts will not only strengthen global security but will also promote public health and safety."

Since 2014, the IAEA has supported the removal of more than 60 high activity DSRSs from over 15 Member States. Numerous missions for the consolidation and conditioning of lower activity DSRSs have resulted in thousands of DSRSs being placed in safe and secure storage. In 2018, the IAEA helped five South American countries remove 27 DSRSs in what was the largest such project it had ever facilitated.

— By Matt Fisher

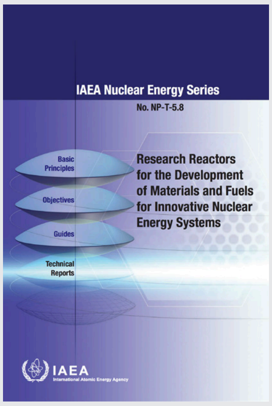


Feasibility Study Preparation for New Research Reactor Programmes

describes the various elements to be included in a comprehensive, robust and logically structured feasibility study report for a new research reactor project. It provides guidance for the main supporting organization or team of a new research reactor to enable them to undertake an authoritative and comprehensive feasibility study that could be submitted to decision makers for their review in order to support proposals and endorse an action plan for construction of such a facility. It includes considerations of justification for a new research reactor, associated key nuclear infrastructure issues, cost-benefit analysis and risk management that would have to be addressed prior to authorizations for the establishment of a new research reactor. Addressing these issues will help Member States to develop a comprehensive understanding of all the roles, obligations and commitments involved in establishing and operating a research reactor and ensure that these are met during all phases of the project life cycle. The publication also includes a generic template for preparing a feasibility study report and provides some examples and lessons learned from individual Member States in preparing such studies.

IAEA Nuclear Energy Series NG-T-3.18; ISBN: 978-92-0-104518-8; English Edition; 30.00 euro; 2018

www.iaea.org/publications/12306/feasibility-study

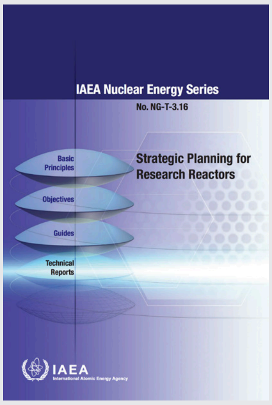


Research Reactors for the Development of Materials and Fuels for Innovative Nuclear Energy Systems

presents an overview of research reactor capabilities and capacities in the development of fuels and materials for innovative nuclear reactors, such as GenIV reactors. The compendium provides comprehensive information on the potential for materials and fuel testing research of 30 research reactors, both operational and in development. This information includes their power levels, mode of operation, current status, availability and historical overview of their utilization. The publication is intended to foster wider access to information on existing research reactors with capacity for advanced material testing research and thus ensure their increased utilization in this particular domain. It is expected that it can also serve as a supporting tool for the establishment of regional and international networking through research reactor coalitions and IAEA designated international centres based on research reactors.

IAEA Nuclear Energy Series NP-T-5.8; ISBN: 978-92-0-100816-9; English Edition; 32.00 euro; 2017

www.iaea.org/publications/10984/research-reactors-for-the-development-of-materials-and-fuels



Strategic Planning for Research Reactors

is a revision of IAEA-TECDOC-1212 which primarily focused on enhancing the utilization of existing research reactors. This updated version also provides guidance on how to develop and implement a strategic plan for a new research reactor project and will be of particular interest for organizations which are preparing a feasibility study to establish such a new facility. This publication will enable managers to determine more accurately the actual and potential capabilities of an existing reactor, or the intended purpose and type of a new facility. At the same time, management will be able to match these capabilities to stakeholders/users' needs and establish the strategy of meeting such needs. In addition, several annexes are presented, including some examples as clarification to the main text and ready-to-use templates as assistance to the team drafting a strategic plan.

IAEA Nuclear Energy Series NG-T-3.16; ISBN: 978-92-0-101317-0; English Edition; 38.00 euro; 2017

www.iaea.org/publications/10988/strategic-planning-for-research-reactors

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