IAEA BULLETIN

INTERNATIONAL ATOMIC ENERGY AGENCY

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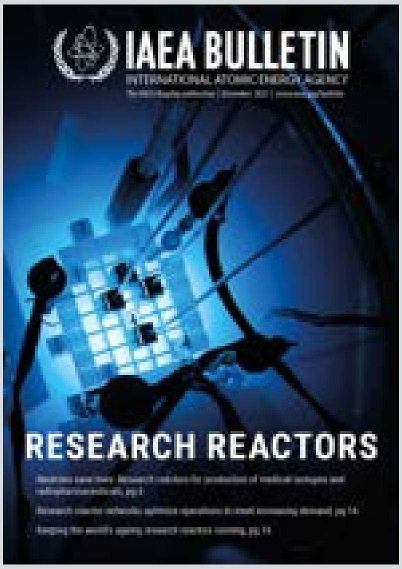
RESEARCH REACTORS



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

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

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

The IAEA safety standards provide the fundamental principles, requirements and recommendations to ensure nuclear safety 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.

Maximizing the versatility, longevity and impact of research reactors

By Rafael Mariano Grossi, Director General, IAEA

Research reactors are catalysts for scientific and technological advancement. They are integral to the fulfilment of the IAEA's mission to foster the peaceful uses of nuclear science and technology, serving as instruments for education, and research and development. Through their unique capabilities, research reactors play a pivotal role in advancing our understanding of nuclear physics, materials science and medicine. This in turn has further benefits for humankind, including, for example, the production of new radiopharmaceuticals.

More than 220 research reactors operate in 54 countries, and another 25 reactors are planned or under construction. Today's global fleet is ageing, with the majority of reactors having already operated for more than 50 years. This can be managed, and the IAEA is helping countries to develop and implement plans to refurbish and modernize reactors so that they can continue to operate safely and effectively.

Meanwhile, some nuclear newcomer countries are pursuing the development of their first research reactor facilities, which can serve as stepping stones towards future nuclear power programmes. In the nuclear domain, safety and security are paramount, and research reactors are no exception. The IAEA stands ready to support countries in fulfilling their national responsibilities to ensure the safety, security and the full optimization of their research reactors, from conception to decommissioning. It does this through coordinated research projects, expert missions, peer reviews, published guidance, planning tools and training. The IAEA is currently supporting more than 30 technical cooperation projects on research reactors, engaging countries from all over the world. These projects are as multifaceted as the uses of research reactors, ranging from enhancing the nuclear safety, utilization and operational performance of reactors, to developing a nuclear infrastructure for a country's first research reactor.

This edition of the *IAEA Bulletin* presents the versatility of research reactors and their profound impact on our lives and livelihoods. From medical treatments to the advancement of cutting edge materials and fuels, research reactors provide the groundwork for scientific progress and socio-economic development. As countries grapple with the urgent challenges of climate change and energy security, research reactors enable the development and testing of innovative energy solutions involving nuclear fission, as well as fusion energy. They are also routinely used to help identify sources of air pollution, support land management, produce radioisotopes for life-saving treatments and to evaluate the structural integrity of buildings.

With so many uses, nuclear research reactors are an important tool. The IAEA actively supports countries in making the most of them, with a resolve that everyone should be able to enjoy their wide-reaching benefits.

"From medical treatments to the advancement of cutting edge materials and fuels, research reactors provide the groundwork for scientific progress and socio-economic development."

— Rafael Mariano Grossi, Director General, IAEA

Photos: IAEA

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What are research reactors? How do they contribute to sustainable development?

By Joanne Liou and Xinwen Tang

Around **220** research reactors are in operation in **54** countries, and about **25** are under construction or are being planned.

More than one third of the nuclear reactors in operation around the world are used for research, educational purposes and the production of radioisotopes, rather than for power generation. Unlike nuclear power reactors designed to generate electricity, nuclear research reactors are primarily used to produce neutrons. Neutrons are uncharged subatomic particles used in various applications, such as the study of materials at the atomic level, the production of radioisotopes for medicine, industry and research, and the imaging of objects' internal structure.

Around 220 research reactors are in operation in 54 countries, and about 25 are under construction or are being planned. They play a key role in not only advancing nuclear technologies, but also improving many aspects of daily life by helping countries to realize sustainable development objectives. Research reactors come in a variety of sizes and designs. Often located at academic and research institutes, research reactors are smaller and operate at lower temperatures than conventional power reactors. The thermal power of most research reactors ranges from 0 to 100 megawatts (thermal) (MW(th)), in contrast to the 3000 MW(th) of a large nuclear power reactor. Accordingly, the amount of nuclear fuel used, and the volume of radioactive waste produced, is significantly lower for research reactors.

How are research reactors utilized?

Research reactors are designed and utilized for experiments, education and training, as well as the production of radioisotopes for medical and industrial applications. They provide a controlled environment to study and understand the behavior of materials, neutron interactions and radiation effects. Beyond supporting research across many disciplines, research reactors are pivotal for advancements in nuclear energy. As test beds for innovative reactor technologies, they offer a realistic setting for experimenting with materials and nuclear fuels. Research reactors also provide education and training opportunities for staff at nuclear facilities, radiation protection and regulatory personnel, as well as students and researchers.

How do research reactors support the United Nations Sustainable Development Goals?

The Sustainable Development Goals (SDGs) are a set of 17 objectives established in 2015 by the United Nations to tackle global challenges, such as in health, education and energy. Research reactors contribute to addressing several of the SDGs, including:

SDG 3: Research reactors are instrumental in medical imaging and cancer treatment. They produce radioisotopes utilized in 85 per cent of nuclear medicine procedures and are essential for the development of new radiopharmaceuticals, benefiting millions of people annually by enhancing diagnostic methods and treatments for various cancers. Rays of Hope, the IAEA's flagship cancer initiative, is helping countries to increase access to such life-saving treatments.

SDG 4 and **SDG 5:** As an educational and training tool, research reactors serve students of all genders. Workshops, trainings and missions supported by the IAEA, as well as the IAEA Marie Skłodowska-Curie Fellowship Programme and the Lise Meitner Programme, cultivate an inclusive workforce that contributes to and drives global scientific and technological innovation.

SDG 6: Research reactors play a key role in the development of radiation-based sterilization techniques for water treatment. Radiation processing in wastewater treatment is an effective method to eliminate harmful microorganisms, pathogens and other contaminants from water, making it safe for consumption and other uses.

SDG 7: Research reactors enable the development and testing of new energy technologies. Researchers can assess novel nuclear reactor concepts, fuels and materials to optimize nuclear power reactor designs for enhanced safety, efficiency and performance to help support a clean energy future. Atoms4NetZero is an IAEA initiative that supports countries' efforts to harness the power of nuclear energy in the transition to net zero. Research reactors are also used, with techniques such as neutron imaging, neutron scattering and neutron depth profiling, to study non-nuclear energy concepts such as hydrogen fuel cells and lithium-ion batteries.

SDG 8: Students, researchers and professionals in the nuclear field can gain practical experience and knowledge through trainings conducted with research reactors. Such trainings can prepare them for opportunities in the nuclear and related fields. Furthermore, research reactors are used to deliver products and services, such as for silicon doping, which introduces impurities into silicon to modify electrical properties for electronic devices.

SDG 9: Research reactors foster innovation in various areas, from electronics and construction materials for extreme conditions to medicine and more. Neutrons produced by research reactors are also valuable for non-destructive testing across various industries, ensuring the quality and safety of objects.

SDG 17: Working towards sustainable development is a collective effort, and many institutes and universities housing research reactors participate in collaborative projects and research activities. These enhance regional and international cooperation on and access to science, technology and innovation.

What is the role of the IAEA?

The IAEA supports countries in the efficient and sustainable use of research reactors so that they can fully reap the benefits of these nuclear facilities. The IAEA offers research reactor training courses and workshops, as well as published guidance, safety standards and e-learning courses. The IAEA's coordinated research projects foster international cooperation and networking among experts, while advancing science involving research reactors.

The IAEA's review missions for research reactors support new research reactor projects. They also assess countries' practices using IAEA guidance and standards to improve the operation, utilization, safety and maintenance of reactor facilities. Several IAEA technical cooperation projects also focus on strengthening countries' technical capabilities for operation and maintenance to improve research reactor safety, reliability and utilization.

An aerial view of the reactor core of the University of Missouri Research Reactor (MURR) in the United States of America. MURR produces radioisotopes used in life-saving treatments for liver, pancreatic, prostate and thyroid cancers.
(Photo: University of Missouri)

Neutrons save lives

Research reactors for production of medical isotopes and radiopharmaceuticals

By Amirreza Jalilian and Mary Albon

40 countries have research reactors capable of producing radioisotopes; of those, around **25** are actively producing radioisotopes for medical applications.

The efficient production of medical radioisotopes and the development of new radiopharmaceuticals are leading to better diagnoses and more effective therapies for many types of cancer and other diseases. As a result, the demand for radioisotopes, which are mainly produced using research reactors or accelerators, is continuing to grow, and the number of radiopharmaceuticals in clinical use is increasing rapidly.

"Medical radioisotopes and radiopharmaceuticals can be lifesaving when they are prepared and administered appropriately," said Melissa Denecke, Director of the IAEA Division of Physical and Chemical Sciences.

Medical radioisotopes are radioactive elements that, when attached to specific molecules in pharmaceutical formulations, emit radiation that is easily traceable, which makes them useful for medical diagnostics. They can also be used for therapeutic purposes, targeting tumour tissue to treat cancers, such as those of the prostate, breast or intestine.

Radiopharmaceuticals are drugs that combine a medical radioisotope with a biologically active molecule. Diagnostic radiopharmaceuticals containing radioisotopes that emit gamma radiation can target specific organs, tissues or cells. They are administered to patients through injection, inhalation or orally to produce images of the targeted organs or tissues using a non-invasive external camera that detects gamma rays. Therapeutic radiopharmaceuticals contain particle-emitting radioisotopes that accumulate in target tissues to kill cancerous cells.

Research reactors are the major source of medical radioisotope production, including molybdenum-99 (Mo-99), iodine-131 (I-131) and holmium-166 (Ho-166), among others. I-131, which is used to diagnose and treat thyroid cancer, was one of the earliest radioisotopes produced in a research reactor in the early 1940s. Although around 35 medical radioisotopes are produced, Mo-99 accounts for the major share. It is the parent isotope of technetium-99m (Tc-99m), which is used in about 85 per cent of nuclear medicine procedures worldwide for the diagnosis of cancers and heart, brain and bone diseases — that is up to 50 million nuclear medicine procedures per year.

Lutetium-177 (Lu-177) is another important research reactor-based radioisotope. "Lu-177 is the mainstay for the production of therapeutic radiopharmaceuticals used to treat people with bone pain and prostate, stomach and intestinal cancers," said Renata

A research reactor core irradiating a target for medical radioisotope production at Reed College in the United States of America.
(Photo: D. McCullough/Flickr)

Mikołajczak, a researcher at Radioisotope Centre POLATOM at Poland's National Centre for Nuclear Research. "At least 20 new drugs using Lu-177 are in the pipeline worldwide."

In May 2023, the IAEA launched a coordinated research project to develop new radiopharmaceuticals for cancer therapy using Lu-177. "Recent developments in Lu-177-based radiotherapeutics have transformed treatment management for neuroendocrine tumours and prostate cancers — with better outcomes for patients," said Aruna Korde, an IAEA radiopharmaceutical scientist. "However, gaps remain in our understanding of the biological behaviour of Lu-177-labelled therapeutic radiopharmaceuticals," she added. The coordinated research project aims to identify and address factors that may limit the efficacy of these radiotherapeutics. It will develop and carry out the preclinical evaluation of Lu-177 radiopharmaceuticals to assess their potential for targeting some of the major cancers. It will also provide guidelines for radiolabelling and for the quality, safety and efficacy evaluation of Lu-177-based radiopharmaceuticals.

Radioisotope production

Forty countries have research reactors capable of producing radioisotopes; of those, around 25 are actively producing radioisotopes for medical applications. In most cases, radioisotopes are produced for the domestic market. A smaller number of countries export radioisotopes to the regional or world market, and a select number of countries export in large quantities. The IAEA provides knowledge and expertise to countries around the world on how to use research reactors to develop and manufacture these crucial tools for diagnosis and treatment. Research reactors provide a safe and stable source of important isotopes for medical applications, including radiopharmaceuticals, but also radioisotope therapeutic sources, like brachytherapy, and the sterilization of medical devices.

Demand continues to grow. "There is still a long way to go to meet the increasing demand for research reactor-based radioisotopes," said Bernard Ponsard, Radioisotopes Project Manager at the Belgian Nuclear Research Centre, known as SCK CEN.

The IAEA supports countries in the production of radioisotopes using research reactors not only for medical uses, but also for industrial and research and development purposes. It develops guidance publications, convenes technical meetings for the exchange of information and know-how, organizes coordinated research projects involving research institutions in multiple countries, and promotes capacity building through training activities, scientific visits and fellowships. Through its technical cooperation programme, the IAEA also supports individual countries and promotes regional and interregional projects.

"The IAEA is building and nurturing a community of professionals around the globe who are able to produce radioisotopes and safe, high-quality radiopharmaceuticals," Denecke said. "Our ultimate goal is to help increase global production of these essential tools for nuclear medicine and bridge gaps in access in some regions, so that vulnerable people with cancer and other life-threatening diseases can receive the care they need."

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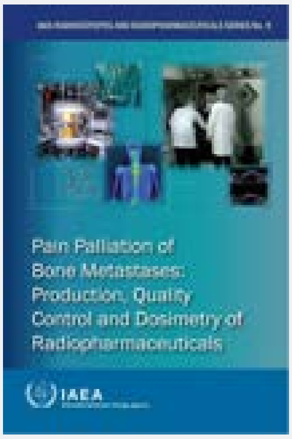
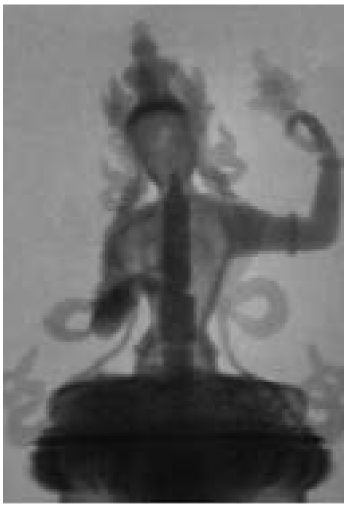


Two recent IAEA publications address the production and clinical use of radiopharmaceuticals for treating joint pain in people with rheumatoid arthritis and haemophilia, and for reducing pain associated with advanced bone metastases. These treatments can improve the quality of life of people with these conditions.

Advances in neutron imaging create opportunities for low power research reactors

By Mary Albon



The neutron imaging system at the Czech Technical University in Prague (CTU) revealed an axis mundi (a symbol of the connection between the physical and spiritual worlds) inside a Tibetan Bon statue of Chamma.

(Photos: L. Sklenka/CTU)

Neutron imaging is a non-invasive technique for examining internal structures that is carried out using research reactors or accelerator-based neutron sources. “It is an amazing tool, with endless possibilities for scientific and industrial research and development, as well as for forensics and the study of cultural artefacts,” said Molly-Kate Gavello, Associate Project Officer at the IAEA. Neutron imaging can be used to test motors, shock absorbers and turbine blades. It can show how water moves within a living plant, or examine the inside of a fossilized dinosaur skull filled with ferrous rock.

Although neutron imaging has been in use since the 1950s, two dimensional (2D), film-based images were the main format until the 1990s. With the advent of digital technologies, including sophisticated digital cameras, neutron imaging now utilizes computed tomography (CT), which uses hundreds of images taken from different angles to create a highly detailed three dimensional (3D) image.

Until recently, neutron imaging with CT, or 3D imaging, was not feasible for low flux neutron sources, such as low power research reactors, for both technical and financial reasons.

High-quality images at low power

This changed in 2021, when Jana Matoušková, a PhD student at the Czech Technical University in Prague (CTU), and her supervisor Lubomír Sklenka demonstrated the capability to perform neutron imaging with CT at 500 watts (W) of research reactor power.

The breakthrough followed two developments. First, low-cost, high-quality astronomy cameras had become available in the previous decade. Second, researchers at the Heinz Maier-Leibnitz Research Neutron Source (FRM II) at the Technical University of Munich, Germany, had realized the potential of these new cameras, and in 2016 they presented the first mini facility for neutron tomography, including for low power reactors. Led by Burkhard Schillinger, the team developed and built a low-cost, high-quality neutron imaging system with a 3D printed detector housing and a downscaled version of the professional control software used at the Advanced Neutron Tomography and Radiography Experimental System (ANTARES) imaging facility at the FRM II research reactor. The image quality of the new detectors matched that of the state-of-the-art system usually employed at the ANTARES facility.

Matoušková wanted to test neutron imaging with low power neutron sources, such as the CTU’s 500 W VR-1 training reactor — by comparison, the 20 megawatt FRM II reactor has 40 000 times more power and therefore produces 40 000 times more neutrons than the CTU reactor. This would prove to be challenging, since she was unable to access the CTU facilities for experiments due to COVID-19 restrictions.

Sklenka contacted Schillinger for advice on replicating the low-cost system that FRM II had developed, and Schillinger advised Matoušková in video calls and supplied her with information on the system’s design and where to source the necessary parts. Step by step, she built a neutron imaging system in her own home and tested it with visible light.

Once the COVID-19 restrictions had been lifted, Matoušková installed her system at the CTU reactor and successfully generated the CTU’s first digital neutron 2D image, followed by a neutron CT with a 12-hour exposure at 500 W. This means that results can be obtained within one day and with significantly less power — the power of research reactors where the technique is also used ranges from hundreds of kilowatts to tens of megawatts.

Matoušková is now refining the CTU's neutron imaging system as part of her PhD studies. The system is mainly being used for educational purposes, but also for carrying out research, for example, to examine cultural artefacts in collaboration with the National Gallery in Prague.

Sharing technology and expertise

FRM II and the CTU's experience has demonstrated that a mini facility could be used at any neutron source, including extremely low power research reactors. Schillinger said that his team is ready to provide the design plans and software for free and to help with installation and set-up internationally.

With parts made by a 3D printer, software downscaled to fit on a laptop and a drop in prices for astrophotography cameras, the whole package can be assembled for under €5000 and can be transported easily. In 2022, Schillinger and Aaron Craft, a research scientist at the Idaho National Laboratory in the United States of America, led an IAEA expert mission to install a digital neutron imaging system at the Chilean Nuclear Energy Commission's RECH-1 research reactor. Schillinger brought the components in a suitcase, and the system was set up within two days.

"The IAEA plays a key role in making this technology available for low power research reactors," Schillinger said. "With the new sensitive detectors, it opens an entire new field of application for those reactors, which do not provide enough neutrons for complex neutron scattering experiments. Neutron imaging makes them more accessible for education, research and collaboration with museums."

The IAEA supports technical cooperation with research reactors, including expert missions and equipment procurement. It also publishes guidebooks on neutron imaging, provides regional training and is expanding its e-learning opportunities. The IAEA also enabled Matoušková to spend four months at the RA-6 research reactor in Argentina to help install and test a low-cost neutron imaging system in 2022.

A similar dual neutron–X-ray system has been installed and commissioned at the IAEA's Neutron Science Facility in Seibersdorf, Austria, where it is being used for training.

"With the new sensitive detectors, it opens an entire new field of application for those reactors, which do not provide enough neutrons for complex neutron scattering experiments."

– Burkhard Schillinger, Instrument Scientist, Technical University of Munich

Lubomír Sklenka, Jana Matoušková and Burkhard Schillinger at the research reactor facility of the Czech Technical University in Prague.

(Photo: Technical University of Munich)

What is neutron imaging?

Neutron imaging is a non-invasive method for examining the internal structures and composition of opaque objects. It is based on principles similar to those of X-ray imaging. However, in contrast to X-rays, which are absorbed by dense materials such as metals, neutron beams penetrate most metals and rock, and they are attenuated by some light elements, such as boron, carbon, hydrogen and lithium. Neutrons can also help visualize magnetic fields, as well as strain in technological and structural materials.

New IAEA peer review service helps countries maximize the power and utility of research reactors

By Emma Midgley

Research reactors are versatile tools. While they are not used to generate electricity, some are contributing to the development of innovative clean energy solutions, while others are providing life-saving radioisotopes and revealing new facts about cultural heritage. Many research reactors are used to their full capacity, but some are underutilized. To help countries harness the full potential of their research reactors in a sustainable and effective way, the IAEA has launched the Integrated Research Reactor Utilization Review (IRRUR).

"Many research reactors were built in the 1950s and 1960s to address an immediate need at that time. Today, the potential of research reactors is better understood, and new applications are being developed for both new and old reactors," said Nuno Pessoa Barradas, Research Reactor Specialist at the IAEA.

The inaugural IRRUR was carried out jointly with an Operation and Maintenance Assessment for Research Reactors (OMARR) mission in 2022 at the 5 megawatt (MW) pool-type RECH-1 research reactor at the La Reina Nuclear Research Centre in Santiago, Chile, following a pilot review mission in Italy in 2019. The IRRUR team of international experts had brought a range of scientific, managerial and operational backgrounds related to research reactor utilization and applications.

"Nuclear science and technologies contribute to national development goals in health, environment, water and agricultural resources, energy, mining and industry, among others," said Luis Huerta, Executive Director of the Chilean Nuclear Energy Commission. "These IAEA missions, with the objective of an exhaustive review of the Chilean nuclear reactor RECH-1, provided an analysis of our capabilities and capacities, in order to improve operation and maintenance and to expand the use and applications of our nuclear facility, especially for new research and development initiatives."

Experts from Argentina, Belgium, the United States of America and the IAEA, as well as an observer from Peru, joined the five-day mission. The team found opportunities for the expanded utilization of the reactor, such as partnering with stakeholders in medical isotope production to plan for future needs.

A team of IAEA and international experts completed an Integrated Research Reactor Utilization Review mission at the Idaho National Laboratory (INL) in June 2023.
(Photo: INL)

The team also recommended that the facility develop an outreach strategy to increase its user community.

Since the mission, a neutron imaging system at the Chilean reactor has been installed, with the assistance of the IAEA, thereby opening new lines of research at the reactor. Neutron imaging is a non-destructive way of imaging objects, similar to X-ray radiography. It can be used to examine nuclear fuels, electronic components and engine turbine blades, as well as to characterize fuel cells and geological samples.

Supporting clean energy solutions

The importance of research reactors for research and development, including research into nuclear fission and fusion reactor materials, was noted at two consecutive IRRUR missions in the United States of America in 2023. International teams of experts visited the Idaho National Laboratory (INL) and the Nuclear Reactor Laboratory at the Massachusetts Institute of Technology (MIT).

The INL research reactor is mainly utilized for research on neutron radiography and other non-destructive techniques, and for neutron irradiations, which explore how nuclear fuel and structural materials react to normal and extreme conditions. The MIT reactor carries out irradiations, which complement the work of the INL and other United States nuclear research facilities, and supports research in both nuclear fission and fusion materials development.

The mission found that the INL could improve some digital neutron capabilities to enhance its research into innovative nuclear energy solutions, while MIT could benefit from engaging more productively with the global nuclear science and technology community. In addition, the mission recommended that the Nuclear Reactor Laboratory at MIT revitalize its ageing infrastructure, in order to improve reliable reactor utilization and provide a more attractive environment for outside users, students and staff.

Ron Crone, Associate Laboratory Director of the Materials and Fuels Complex at the INL and a member of the IRRUR team on the MIT mission, said he believed that MIT's Nuclear Reactor Laboratory had the potential to become a "world-leading" facility for the custom irradiation of nuclear fuels and materials. "With additional infrastructure investment and more external engagement, I believe it will support important research into innovative energy solutions involving nuclear fission, as well as nuclear fusion, for the coming decades," he said.

IRRUR review missions are carried out upon request and can either be directed at all the activities of a research reactor or limited to specific facility mission areas. The reviews are based on IAEA guidance on the strategic planning for and utilization of research reactors, and on international best practices.

The IAEA published IRRUR guidelines in 2023, which provides information on the preparation, implementation and reporting of IRRUR missions, as well as information on self-assessments for operating organizations of research reactor facilities. In 2020, the IAEA also launched an e-learning course on strategic planning for enhancing the utilization of research reactors.

IRRUR missions

2019: Italy (pilot)

2022: Chile, Peru, South Africa

2023: Islamic Republic of Iran, USA (two missions)

2024: Canada (planned)

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– Nuno Pessoa Barradas, Research Reactor Specialist, IAEA

Supporting African scientists to harness the power of research reactors for socio-economic development

By Omar Yusuf

Africa now has **11** research reactors in **8** countries, namely Algeria, the Democratic Republic of the Congo, Egypt, Ghana, Libya, Morocco, Nigeria and South Africa.

The first uranium deposits in Africa were discovered in 1915 in the village of Shinkolobwe, located in the south of today's Democratic Republic of the Congo. Approximately four decades later, in 1958, Africa's nuclear science and technology story would begin, with the first criticality of the Democratic Republic of the Congo's TRICO I research reactor, the first such reactor built in the region, at the University of Kinshasa. Egypt and South Africa followed the Democratic Republic of the Congo's example soon after, commissioning reactors in 1958 and 1965, respectively. Research reactors have played a vital role in the continent's socio-economic development ever since.

Africa now has 11 research reactors in 8 countries, namely Algeria, the Democratic Republic of the Congo, Egypt, Ghana, Libya, Morocco, Nigeria and South Africa. These facilities have a thermal power of up to 22 megawatts and are routinely used for numerous applications, including to support sustainable land management among African farmers, to produce radioisotopes for life-saving cancer treatments and for probing the structural integrity of buildings and industrial equipment, and to identify sources of industrial air pollution.

Although around ten African countries are presently considering nuclear power generation, many others consider the deployment of research reactors to be a stepping stone towards future power programmes, since this will enable the build-up of a contingent of trained personnel with relevant capabilities.

Some countries without research reactors — including Ethiopia, Kenya, the Niger, Rwanda, Senegal, Uganda, the United Republic of Tanzania and Zambia — are now considering, or planning for, the construction of research reactor facilities and have already targeted specific applications and products or services for delivery.

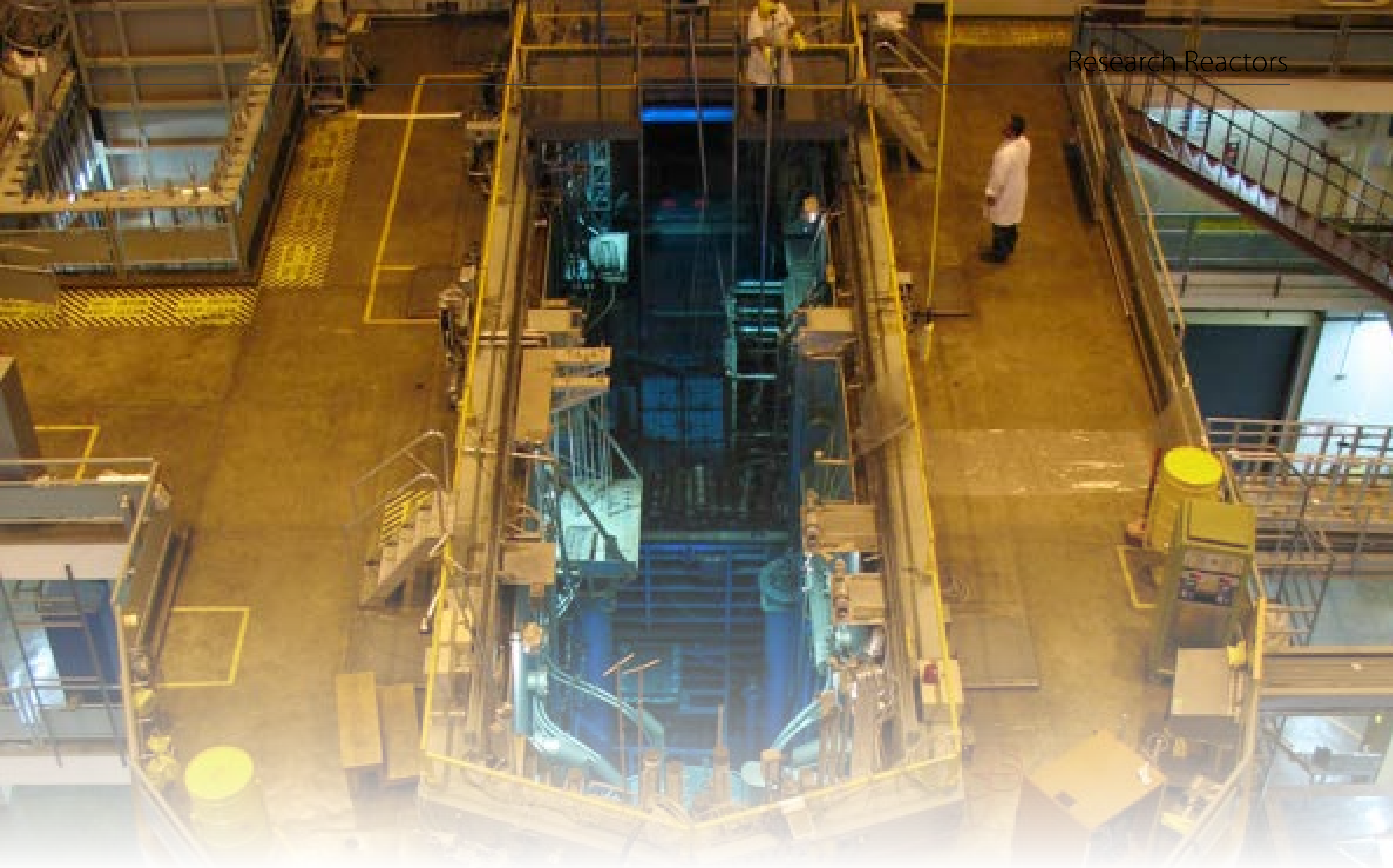
Training the next generation of research reactor professionals

The need for radiation services provided by research reactors and, consequently, for young professionals capable of delivering them, has intensified in recent years. As a result, the IAEA is supporting African countries to develop strategic plans for the construction and use of new research reactors.

For example, through an ongoing regional technical cooperation (TC) project, experts from several African countries attended an IAEA workshop in June 2023 to learn how to prepare strategic plans for the construction of new research reactors. These business-facing plans are designed to provide both justification for a facility's construction and detailed recommendations for use of the reactor, including specific radiation services or products for industrial, medical and scientific use. Under the guidance of IAEA experts, the participating scientists were subsequently asked to propose corresponding financial and policy plans to ensure the safety and sustainability of the proposed research reactor.

Throughout the week-long training workshop, presentations and practical sessions were provided by IAEA specialists to attending scientists from Ethiopia, Kenya, the Niger, Rwanda, Senegal, Uganda, the United Republic of Tanzania and Zambia.

Complementarily, in order to support capacity building in the areas most closely associated with the operation of research reactors, the IAEA launched the IAEA-designated International Centre based on Research Reactor (ICERR) initiative, a scheme which identifies facilities capable of accommodating the training and research needs of countries without routine access to research reactors. In May 2023, the third iteration of the IAEA's Research Reactor School in the Africa Region was held at the most recently recognized



ICERR, Morocco's National Centre for Nuclear Energy, Sciences and Technology (CNESTEN), which operates the MA-R1 research reactor.

Designed to provide intensive training in reactor physics, as well as the safe operation and utilization of research reactors, the third Research Reactor School in the Africa Region provided the 13 attending engineers and physicists with the opportunity to witness the real-time operation of a research reactor. Specifically, the attendees were able to study how experts at CNESTEN produce medical radioisotopes and conduct neutron activation analysis. "The school was highly educative, informative, engaging and valuable," said Yahaya Musa, who works in medical physics at the Centre for Energy Research and Training in Zaria, Nigeria. "The programme enhanced my research reactor operation and experiments knowledge and developed my skills in these areas."

Supporting the safety, operation and utilization of reactors

While newcomer countries are pursuing the development of new research reactor facilities, existing reactors on the African continent could also benefit from improved operational safety standards, more effective business planning, and the closer association of research reactor services with persisting national development challenges.

This is the aim of another ongoing IAEA TC project — channelled through the African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA) — that is prioritizing the improved safety and strategic operation of Africa's fleet of research reactors. From the preparation of safety documents to the implementation of periodic safety reviews and emergency preparedness arrangements, scientific visits have helped the project's participating countries — all of which presently operate research reactors — to identify how best to improve their compliance with the relevant IAEA safety standards and guidance.

Senior African scientists have also visited research reactor institutions in the Czech Republic, France, Germany, Jamaica, Malaysia, the Netherlands and Thailand to observe and study how their counterparts abroad apply the IAEA's safety standards, ageing management guidance and utilization programmes at their facilities. These site visits and knowledge exchanges are aimed at enhancing regional capacities; improving the utilization of research reactors for socio-economic development and ensuring their operational safety.

South Africa's SAFARI-1 research reactor has been in operation since 1965. It is one of the world's five largest producers of the medical radioisotope molybdenum-99.

(Photo: South African Nuclear Energy Corporation)

Research reactor networks optimize operations to meet increasing demand

By Melissa Evans

Nuclear research reactors are important scientific hubs for the nuclear community that house training sessions and experiments and provide valuable products and services, including the production of radioisotopes for medical, agricultural and industrial use. Increasing demand is being placed on the more than 200 operational research reactors around the world, and the IAEA is helping research reactor staff to meet this demand by forging networks to foster collaboration with the goal of optimizing operations.

The Regional Network of Research Reactors and Related Institutions in Latin America and the Caribbean (RIALC) launched in 2023, with the support of the IAEA. RIALC, which was formed at the regional level and based on shared regional challenges, comprises 9 countries with 16 operational research reactors. By joining forces, each country benefits from the pool of experts and capabilities of the other research reactors in the network. This allows each research reactor facility to focus on the area where it has the competitive advantage, while ensuring that regional demands are better met and that services are more efficient. The network evaluated its stock of research reactors to identify national and regional priorities, as well as the specialties of each reactor. Intercomparison exercises are also being undertaken to help standardize future endeavours.

"The countries all agreed to work in an integrated and harmonized manner, as a single block, for nuclear technological development. The level of development achieved by various countries is quite different, but this is precisely the added value that RIALC has — showing the paths already taken in the region to allow countries to demonstrate their available infrastructure and resources," explained Mario Mallaupoma, RIALC Coordinator and President of the Peruvian Institute of Nuclear Energy. "RIALC was founded not only on the desire to support each other as countries in the region, but to assume a true commitment on the part of decision makers to promote the achievement of the objectives of sustainable development in the region and to improve the quality of life of the population."

"The level of development achieved by various countries is quite different, but this is precisely the added value that RIALC has — showing the paths already taken in the region to allow countries to demonstrate their available infrastructure and resources."

– Mario Mallaupoma, RIALC Coordinator and President of the Peruvian Institute of Nuclear Energy

RIALC has been working on five thematic areas: education and training; operation and ageing; reactor applications such as geochronology; neutron imaging and neutron activation analysis; and radioisotope production.

Since RIALC's launch in February 2023, the Chilean Nuclear Energy Commission has hosted technical experts from Peru to discuss neutron activation analysis — a non-destructive testing application for determining trace elements that is often conducted at research reactors due to their neutron flux capabilities. Mallaupoma said that "Peru has a 10 megawatt research reactor, making it the one with the highest power in the region and the one that can produce the greatest neutron flux. Peru will promote and encourage the greater use of our research reactor to develop research work, as well as actions to produce goods and services jointly with the other countries of the Latin American and Caribbean region."

A new Spanish language e-learning course, Strategic Planning for National Nuclear Institutions, was launched at the IAEA's 67th General Conference in September 2023, complementing the English language course on the same subject. The course has been tailored to the Latin American and the Caribbean region, specifically with two in-depth case studies provided by the RIALC representatives from Argentina and Chile. It is based on the 2017 IAEA publication entitled Strategic Planning for Research Reactors (IAEA Nuclear Energy Series No. NG-T-3.16) and concentrates on the operational management of research reactors. Participants in the course learn how to prioritize demands for different types

of services to ensure the effectiveness and sustainability of research reactors. This builds on the IAEA's history of supporting research reactors in strategic planning activities. Since 2014, the IAEA has provided expert advice on 95 strategic plans associated with 63 reactors, in response to countries' requests.

The RIALC Network follows in the footsteps of earlier research reactor networks that have been founded with the support of the IAEA, including both regional and technical networks. The Eastern European Research Reactor Initiative (EERRI) was formed in 2008. Similar to RIALC, it aims to bolster regional training efforts, as well as to optimize services. It is made up of seven countries — Austria, the Czech Republic, Hungary, Poland, Romania, Serbia and Slovenia — and activities are hosted by participating institutions. The EERRI has hosted 18 editions of a six-week training course for young professionals in the nuclear field, supported by the IAEA. It includes technical lectures, site visits and practical exercises at EERRI research reactor facilities to prepare the next generation of research reactor staff.

The sharing of technical expertise forms the basis for another IAEA-supported research reactor network — the Global TRIGA Research Reactor Network (GTRRN). TRIGA (Training, Research, Isotopes, General Atomics) reactors are all designed and function in a similar fashion, and there are more than 30 currently in operation worldwide. The GTRRN was launched in November 2013 to help TRIGA research reactor operators in 15 countries to address common issues, such as TRIGA's low enriched uranium fuel, which is increasingly difficult to obtain and to dispose of after use. "The GTRRN is a preeminent resource on TRIGA research reactors, and the network members use it to share information and to help each other — for instance, to source spare parts needed for experiments, since sometimes it can be a challenge to find potential suppliers," said Nuno Pessoa Barradas, Research Reactor Specialist at the IAEA.

The IAEA helps countries to improve research reactor services. As research reactors are unique scientific institutions, bespoke networks supported by the IAEA create a platform for research reactor experts from around the world to solve shared challenges and to realize the full potential of their institutions through collaboration.

At the research reactor facility of the Technical University of Vienna, the Eastern European Research Reactor Initiative hosts training courses to help students build practical skills.
(Photo: IAEA)

Keeping the world's ageing research reactors running

By Emma Midgley

More than 220 research reactors are in operation, and they provide essential services such as the production of medical radioisotopes and enable scientific research in agriculture and industry. However, these facilities are ageing — the majority of the world's fleet of research reactors has been operating for more than 50 years. Operators and regulators, with the help of the IAEA, are focused on refurbishing and modernizing these reactors so that they can continue to deliver goods and services while operating safely and securely.

"In many countries, there are no replacements for these older research reactors and no plans for new ones," said Ruben Mazzi, Technical Lead for Research Reactor Operation and Maintenance at the IAEA. "We help countries to take the steps to keep these reactors running. Each reactor is different and ages differently. Resources and services provided by the IAEA in support of the global fleet are important for ageing management."

The IAEA initiated its Research Reactor Safety Enhancement Plan in 2001, in anticipation of an increasingly ageing fleet of research reactors. 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 and regulations regarding the safety of research reactors. As part of the plan, countries are working with the support of the IAEA to implement systematic ageing management programmes.

The IAEA has developed complementary activities to help countries manage their ageing research reactors. It has developed and continues to update safety standards and technical guidelines, while also conducting peer reviews and advisory services, and organizing technical meetings, workshops and training courses.

The IAEA adapted the methodology of Safety Aspects of Long Term Operation (SALTO) for nuclear power plants to apply to research reactors and completed the first

During an Operation and Maintenance Assessment for Research Reactors mission at the MARIA research reactor in Poland in 2022, experts discussed the quality assurance and management systems, operating and maintenance practices, and the ageing management programme.
(Photo: National Centre for Nuclear Research, Poland)

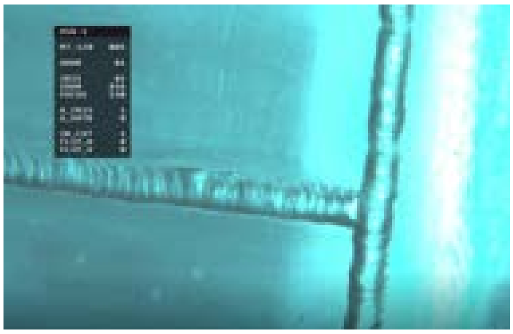
SALTO mission for a research reactor in 2017 at the Belgian Reactor 2 (BR2) research reactor in Belgium. SALTO missions assess a facility's procedures and practices based on the IAEA safety standards and provide recommendations for further improving safety and effectiveness of modernization and refurbishment projects of such facilities. "In addition to systems and components, refurbishment and modernization also apply to implementing safety upgrades to bring the reactor facility in accordance with up-to-date IAEA safety standards," said Amgad Shokr, Head of the IAEA's Research Reactor Safety Section.

A regular examination of a reactor facility's structures, systems and components (SSCs) for potential degradation is necessary to assess ageing effects on safety and operation, or to avoid costly repairs. Operating organizations carry out routine maintenance and periodic testing programmes to assure the continuing capability of SSCs to perform their intended functions and to ensure that the reactor functions within operational limits and conditions. In some cases, these examinations require special techniques and additional resources that may not be available to all operating organizations.

The IAEA, upon request, supports countries by providing the needed equipment or expert advice to enable the operator to conduct specific inspection activities through in-service inspections (ISIs). ISIs assess the status of components that are important

Visual examination and non-destructive testing are used to assess the safety and operating conditions of a reactor facility's structures, systems and components, including the reactor core support and grid.

(Photos: R. Mazzi/IAEA)



HD radiation resistant underwater cameras are used to inspect and monitor welds of research reactor tanks.
(Photos: R. Mazzi/IAEA)

for the safety and operation of reactors. Specialized equipment can monitor structural defects and damage to a reactor's physical infrastructure. These examinations identify cracks, other defects or weaknesses in structures at an early stage and over time in a reactor's concrete and metal parts using radiation resistant underwater cameras and other specialized tools.

The IAEA plans to release a new publication provisionally entitled *Guidelines for Non-Destructive Examination, In-Service Inspection and On-Line Monitoring Programme for Research Reactors* in 2024.

Strengthening sustainability

Another peer review mission that supports countries in managing reactor ageing is the Operation and Maintenance Assessment for Research Reactors (OMARR). OMARR missions are focused on the operational and maintenance aspects that need to be addressed throughout a research reactor's lifetime, from commissioning to decommissioning. Through OMARR missions, countries can strengthen the sustainability and reliability of a research reactor and optimize utilization of human and financial resources, considering IAEA standards, international good practices and national regulations.

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. Since 2012, OMARR and pre-OMARR missions have been completed or are ongoing in Bangladesh, Chile, the Democratic Republic of the Congo, Indonesia, Italy, the Islamic Republic of Iran, Poland, Portugal, Thailand, the United States of America and Uzbekistan.

Sammy Malaka, General Manager of Reactor Operations at the South African Nuclear Energy Corporation, participated as an expert on the 2018 pre-OMARR and the 2023 ISI missions at the TRICO II research reactor in the Democratic Republic of the Congo. TRICO II has been in extended shutdown since 2004, and there are now plans to restart the reactor and resume its activities for scientific research, training, radioisotope production and material characterization.

"The success of both missions will enable the TRICO II facility to establish minimum

What is research reactor ageing?

There are two kinds of ageing related to research reactors.

Physical ageing is the degradation of the physical condition of the reactor's systems and components. Over time, exposure to aggressive environments and operating conditions, such as irradiation, corrosive agents and vibration, degrades some of the materials and components.

Obsolescence is another type of ageing, in which the technology used for computers, instrumentation and control systems becomes outdated, or safety regulations change and become obsolete.

SSCs to support the programme of restarting the reactor and its long term operation," Malaka said. "In particular, we emphasized the importance of initiating an ageing management programme to manage ageing SSCs and to track and monitor upgrades, modernization or replacement projects, as this can be beneficial to the facility in the long term following a successful restart programme."

In May 2023, an OMARR mission supported by experts from Australia and the Czech Republic was conducted at the Thai Research Reactor-1/Modification-1 (TRR-1/M1) in Thailand, which is used for radioisotope production, research and development, and education and training. "The suggestions from the OMARR mission were helpful to establish and implement systematic and effective maintenance and ageing management programmes for TRR-1/M1 to enhance operation and effective utilization of the reactor," said Kanokrat Tiyapun, Reactor Manager at the Thailand Institute of Nuclear Technology. "This is key for the sustainable development of nuclear capacity — technological expertise and human resources — and infrastructure required for future nuclear programmes in Thailand."

Review missions and advisory services

The IAEA offers more than 30 peer review and advisory services to help countries strengthen and enhance their nuclear-related practices. Peer reviews, which are organized upon request, are led by the IAEA and supported by teams of international experts. They assess the country's national infrastructure and current practices considering IAEA guidance, safety standards and international good practices. These services, often referred to as 'missions', focus on an array of specialties, from nuclear safety to the health sector.

The IAEA provides several peer review missions to assist countries in the safe, secure, reliable and sustainable use of their research reactors. The IAEA peer reviews specific to research reactors are the Integrated Nuclear Infrastructure Review for Research Reactors (INIR-RR), the Integrated Research Reactor Utilization Review (IRRUR), the Integrated Safety Assessment of Research Reactors (INSARR) and the Operation and Maintenance Assessment for Research Reactors (OMARR). The International Physical Protection Advisory Service (IPPAS) related to nuclear security and the Safety Aspects of Long Term Operation (SALTO) cover research reactors, as well as nuclear power plants.

IAEA mission team experts and Research Centre Řež (CVŘ) staff discuss recommendations of the Integrated Safety Assessment of Research Reactors review in the control room of LVR-15 research reactor in Řež, Czech Republic, in 2023.
(Photo: CVŘ)

Planning human resources for research reactor programmes

By Sara Kouchehbagh

> "The results from the model will be used as a support document to communicate with decision makers on human resource requirements, competency and the capacity of the country to meet the requirements of a new research reactor programme."
>
> *– Kanokrat Tiyapun, Reactor Manager, Thailand Institute of Nuclear Technology*

For countries looking to introduce or expand a research reactor programme, developing a human resource management (HRM) strategy is typically a box to check before embarking on what is a significant investment. The IAEA supports countries on HRM through modelling tools, educational resources, publications and peer review services.

The nuclear industry requires a high standard of quality when it comes to planning human resources, including for research reactor programmes, and it relies on a well-trained workforce for safety and sustainability. That workforce is facing several challenges, including the retirement of qualified personnel and issues related to the retainment of talent. Countries and organizations need to recognize the importance of establishing and implementing an HRM strategy to increase the number of qualified personnel in the long term — and to retain them.

"The management of human resources is the pillar of successful project development," said Cheikh Niane, Technical Coordinator of Senegal's first research reactor project and General Secretary of the Ministry of Petroleum and Energy. "We should define what is the state of our workforce to support a nuclear programme in the country, and what should be our recruitment pool."

Senegal is one of several countries planning its first research reactor. In December 2022, a new IAEA training service was piloted in Senegal covering the IAEA's Human Resource Modelling Tool for New Research Reactor Programmes, which has been developed using a Nuclear Power Human Resources (NPHR) modelling tool, provided to the IAEA by the United States of America in 2011, as a basis. The NPHR helps countries to understand their workforce requirements and the flow of human resources when they are planning to start a nuclear power programme.

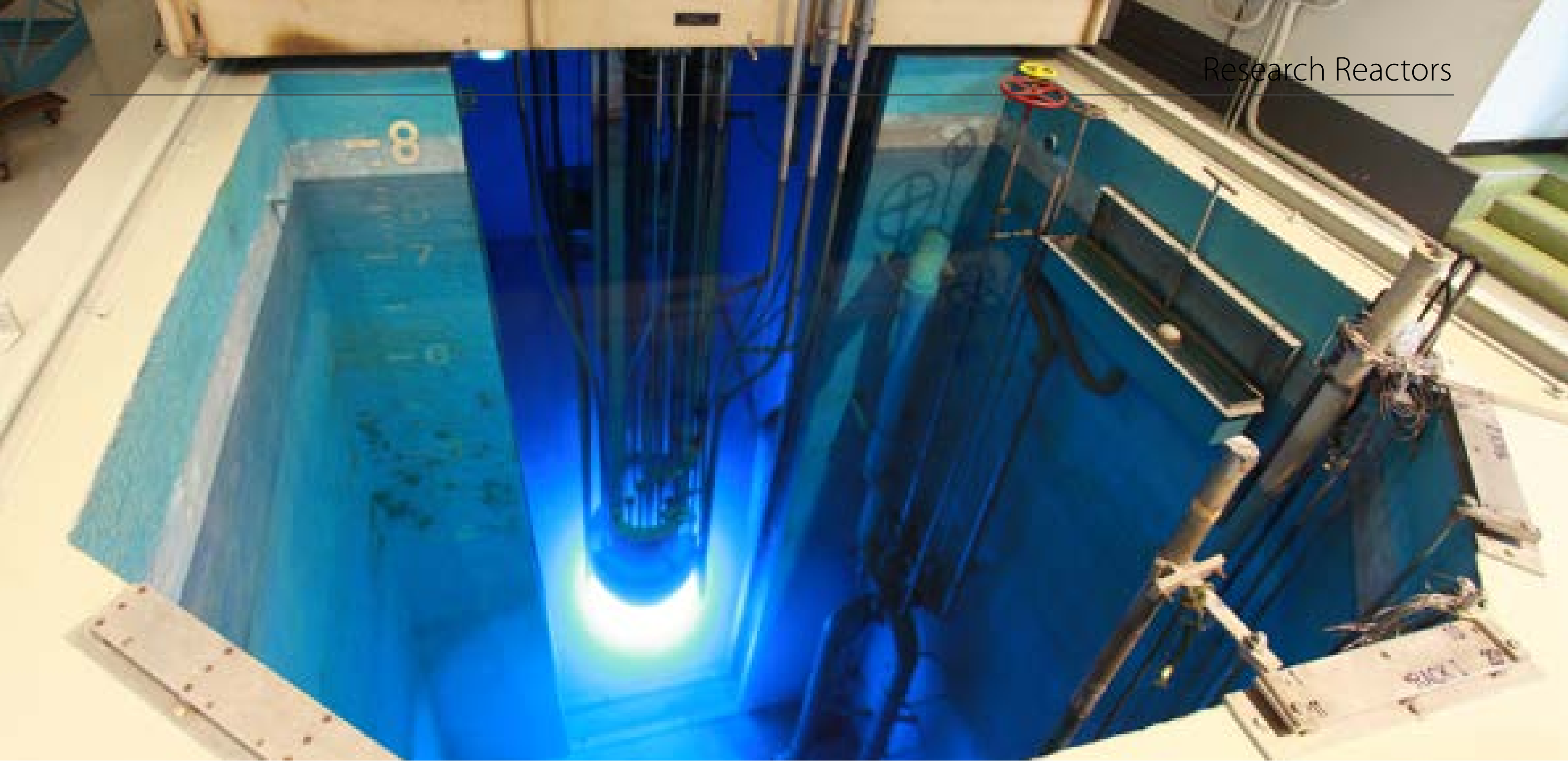
The new tool for research reactor programmes supports countries to better understand human resource requirements and the need for coherent national workforce development in this field. The workshop in Senegal included a demonstration of the human resource model, the installation and configuration of the tool on participants' computers, and training on basic skills in using dynamic modelling and exercises. It also covered good practices for workforce planning, safety and managing human resource data.

In April 2023, a similar training session was held in Thailand, which has one operational and two planned research reactors, in order to inform personnel on the use of the modelling tool and to provide feedback on Thailand's workforce plan. In addition, the session provided information on IAEA guidance and collaboration on how best to adapt the NPHR modelling tool for research reactors in the future.

"Human resource development is an important component in developing infrastructure for a new research reactor, according to the IAEA Milestones Approach," said Kanokrat Tiyapun, Reactor Manager at the Thailand Institute of Nuclear Technology. "The results from the model will be used as a support document to communicate with decision makers on human resource requirements, competency and the capacity of the country to meet the requirements of a new research reactor programme."

More resources for the workforce

The IAEA also provides free online educational materials on human resource development, including online modules and publications. A newly released publication, entitled Managing Human Resources in the Field of Nuclear Energy (IAEA Nuclear Energy Series No. NG-G-2.1 (Rev. 1)), provides guidance for decision makers and senior managers responsible for the development of competent and sustainable staff. The publication covers key elements of HRM — such as workforce planning,



training and development, and performance management — that need to be integrated into a country's management strategy. The publication provides clear markers for producing effective HRM, which can be ideal for senior managers, human resource professionals and line managers. The publication is also useful for newly embarking countries, as well as those seeking to optimize their current nuclear programme.

In addition to readily available materials, the IAEA Milestones Approach has supported nuclear newcomers in the development of their nuclear power programmes with a phased approach that is applicable to research reactor programmes. When a country chooses to pursue the development of a research reactor through the Milestones Approach, they start by reporting justifications on the need for a research reactor, ultimately leading them to the construction and commissioning of a new reactor, provided that all requirements are met along the way.

Human resource development is one of the 19 infrastructure elements — among developing a regulatory body and legal framework and ensuring nuclear safety and security — that are part of the Milestones Approach. It can be addressed through an Integrated Nuclear Infrastructure Review for Research Reactors (INIR-RR) mission, which helps countries to determine the status of their national nuclear infrastructure and to identify further development needs to support the project, from planning all the way to decommissioning.

"The availability of adequate human resources is key for any project," said Petr Chakrov, Head of the IAEA's Research Reactor Section. "The development of these resources is a complex, dynamic process, and our new modelling tool helps countries to plan human resources for their research reactor programmes in a more comprehensive and realistic way."

TRR-1/M1 is a TRIGA Mark III research reactor operated by the Thailand Institute of Nuclear Technology (TINT) in Bangkok, Thailand.

(Photo: TINT)

Supporting women in nuclear

In 2020, the IAEA launched the Marie Skłodowska-Curie Fellowship Programme to support the next generation of women nuclear professionals by offering scholarships for master's degree in nuclear-related fields. A new IAEA initiative launched in March 2023, the Lise Meitner Programme, offers early- and mid-career women multiweek training visits to nuclear facilities.

The IAEA Marie Skłodowska-Curie FELLOWSHIP PROGRAMME

The IAEA Lise Meitner PROGRAMME

Swift and effective

A new approach to updating IAEA Safety Guides

By Wolfgang Picot

Research reactors are essential for advancing nuclear science, conducting experiments and producing vital isotopes for medical and other purposes. The IAEA's Safety Guides on research reactors play an indispensable role in ensuring the safety of these facilities. The Safety Guides are one of three sets of publications that comprise the IAEA Safety Standards Series. The Series consists of:

1. **Safety Fundamentals**, which establish the fundamental safety objectives and the principles of protection and safety in language that is understandable to non-expert readers;

2. **General Safety Requirements (GSRs)** and **Specific Safety Requirements (SSRs)**, which set out the requirements that must be met to ensure the protection of people and the environment, both now and in the future, and to help countries establish their national regulatory frameworks; and

3. **General Safety Guides (GSGs)** and **Specific Safety Guides (SSGs)**, which present international good practices and increasingly reflect best practices and provide recommendations and guidance on how to comply with the SSRs.

Due to the highly technical nature of the Safety Guides, updating them is a meticulous process. Knowledge is gathered and integrated into the Guides from varied experiences of using nuclear technologies around the world. Drafts produced by the IAEA are reviewed by multiple Safety Standards Committees. The drafts are also shared with participating countries for comments and further input before being endorsed by the Commission on Safety Standards.

Typically, such revisions span several years owing to their complexity and the need to carefully consider advancements in nuclear and radiological research, development and safety practices.

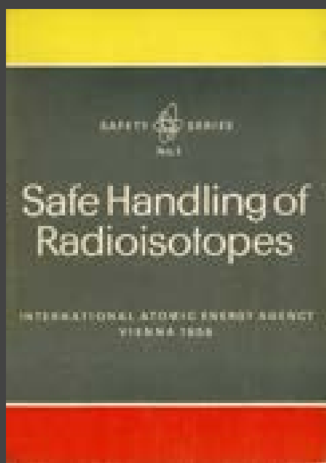
However, the IAEA took a new approach in the latest update of 11 Safety Guides on research reactors. By updating them simultaneously, the IAEA accelerated the process, and the publication cycle was completed within 12 months, from 2022 to 2023.

"Revising the research reactor Safety Guides all together as a batch through a dedicated process made it much easier for participating countries to harmonize their review of the content of the safety standards and provide

65 YEARS of IAEA SAFETY STANDARDS

The IAEA looks back on a long history of safety standards, with the first on *Safe Handling of Radioisotopes* (IAEA Safety Series No. 1) issued in 1958, just one year after the IAEA's establishment. It was also the first publication of the IAEA.

Today, most users access the Safety Standards Series on the IAEA website (www.iaea.org), where they are available for free.



timely feedback," said David Sears, Senior Nuclear Safety Officer at the IAEA, who led the project.

Finalizing such a complex project within a short period represents a significant achievement. "Given the tight timeline, this project required strong cooperation within the IAEA, intense focus and a concentrated effort from experts, country representatives and the IAEA's technical editors," Sears said. "This would not have been possible without the commitment and dedication of everyone involved."

The SSR publication for research reactors, *Safety of Research Reactors* (IAEA Safety Standards Series No. SSR-3), was updated in 2016. It covers all requirements for safe research reactor operations, from management and regulatory supervision to site evaluation, design, construction, operation, utilization, modification and decommissioning. Additionally, it incorporates relevant lessons learned from the Fukushima Daiichi nuclear accident and insights from countries' experiences and feedback.

The recent update concerned the 11 SSGs, which provide guidance and present best practices on how to fulfil the SSR-3 requirements. In contrast to SSR-3, which provides an overview of all relevant issues in one volume, the SSGs deal with specific technical topics such as maintenance, periodic testing and inspection, core management and fuel handling, operational limits and conditions, instrumentation control, and ageing management.

"Updating the safety standards for research reactors is quite difficult because there is such a tremendous variety of them," said Onne Wouters, Reactor Manager of the High Flux Reactor (HFR) at the Nuclear Research and Consultancy Group (NRG) in the Netherlands. "The IAEA Safety Guides are relevant for all facilities, from the smallest critical assemblies to large research reactors such as the HFR."

Many research reactors have received upgrades with electronic equipment, and others are being modified for new applications, expanding their intended purposes. As many research reactors are several decades old, ageing management is also increasingly important. "With new electronic technologies and ageing reactors, we have to improve and adapt continuously," Wouters said. "It is essential that the Safety Guides keep reflecting these changes."

The IAEA safety standards are not legally binding for countries, and they apply them at their discretion. Many countries that use IAEA safety standards adopt them within their national regulations.

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– Onne Wouters, Reactor Manager of the High Flux Reactor (HFR), Nuclear Research and Consultancy Group, Netherlands

The IAEA recently updated 11 Safety Guides on research reactors.

Securing Egypt's research reactors against nuclear security threats

By Vasiliki Tafili

The implementation of nuclear security measures in all types of nuclear facilities, including research reactors, ensures protection against malicious acts and other criminal or intentional unauthorized acts that may have radiological consequences or lead to other adverse situations. The IAEA's International Physical Protection Advisory Service (IPPAS) provides peer advice on the physical protection of nuclear and other radioactive material and associated facilities and activities, including nuclear research reactors, upon request.

When Egypt received an IPPAS mission in 2005, and an additional experts' mission in 2014, the independent assessment of the status of the nuclear security regime identified a need to upgrade the physical protection systems in the country's nuclear research reactors.

In response to IPPAS recommendations, and with the aim of enhancing the nuclear security of its research reactors, known as the ETRR-1 and the ETRR-2, Egypt developed an Integrated Nuclear Security Sustainability Plan (INSSP), which is a tailored IAEA mechanism to identify and prioritize countries' national nuclear security needs.

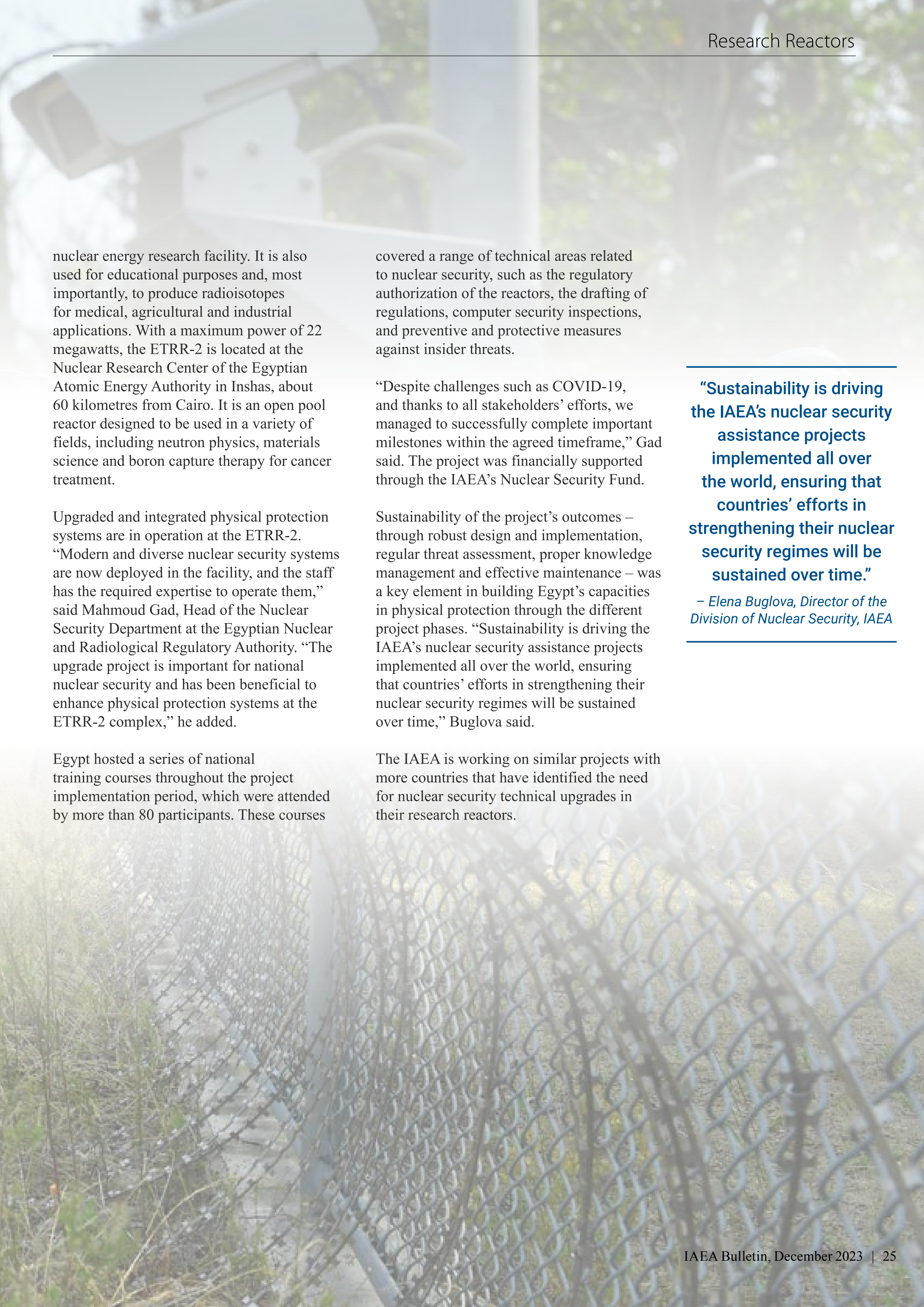
Physical protection upgrade

Egypt's INSSP includes a physical protection upgrade project that prioritizes the nuclear security systems, protecting the two research reactors against sabotage, theft or any other unlawful taking of nuclear material, and mitigating or minimizing the radiological consequences of such malicious acts. The first two implementation phases of the project were carried out from 2015 to 2020, while the last phase is ongoing.

"The complementarity of the different assistance tools included in the IAEA's nuclear security programme is clearly evident in the case of the specific project implementation in Egypt," said Elena Buglova, Director of the IAEA's Division of Nuclear Security. "The starting point of the cooperation with Egypt was an IPPAS mission; however, the project implementation required the broad technical and financial support for the development of new regulations, technical capacity building and, of course, the upgrade of the physical protection systems in the research reactors complex."

While the ETRR-1 is in long-term shutdown, the ETRR-2 complex serves as the national

Physical protection systems are vital for the nuclear security of nuclear power plants and research reactors.
(Photos: D. Calma/IAEA)



nuclear energy research facility. It is also used for educational purposes and, most importantly, to produce radioisotopes for medical, agricultural and industrial applications. With a maximum power of 22 megawatts, the ETRR-2 is located at the Nuclear Research Center of the Egyptian Atomic Energy Authority in Inshas, about 60 kilometres from Cairo. It is an open pool reactor designed to be used in a variety of fields, including neutron physics, materials science and boron capture therapy for cancer treatment.

Upgraded and integrated physical protection systems are in operation at the ETRR-2. “Modern and diverse nuclear security systems are now deployed in the facility, and the staff has the required expertise to operate them,” said Mahmoud Gad, Head of the Nuclear Security Department at the Egyptian Nuclear and Radiological Regulatory Authority. “The upgrade project is important for national nuclear security and has been beneficial to enhance physical protection systems at the ETRR-2 complex,” he added.

Egypt hosted a series of national training courses throughout the project implementation period, which were attended by more than 80 participants. These courses covered a range of technical areas related to nuclear security, such as the regulatory authorization of the reactors, the drafting of regulations, computer security inspections, and preventive and protective measures against insider threats.

“Despite challenges such as COVID-19, and thanks to all stakeholders’ efforts, we managed to successfully complete important milestones within the agreed timeframe,” Gad said. The project was financially supported through the IAEA’s Nuclear Security Fund.

Sustainability of the project’s outcomes – through robust design and implementation, regular threat assessment, proper knowledge management and effective maintenance – was a key element in building Egypt’s capacities in physical protection through the different project phases. “Sustainability is driving the IAEA’s nuclear security assistance projects implemented all over the world, ensuring that countries’ efforts in strengthening their nuclear security regimes will be sustained over time,” Buglova said.

The IAEA is working on similar projects with more countries that have identified the need for nuclear security technical upgrades in their research reactors.

“Sustainability is driving the IAEA’s nuclear security assistance projects implemented all over the world, ensuring that countries’ efforts in strengthening their nuclear security regimes will be sustained over time.”

– Elena Buglova, Director of the Division of Nuclear Security, IAEA

New IAEA tools help countries decide on research reactor spent fuel management

By Sara Kouchehbagh

Medical isotope production, education, research, training, materials testing — the uses and benefits of research reactors are many and varied. However, a key challenge for countries that operate these powerful tools, or have plans to do so, is spent fuel management, particularly the associated infrastructure and costs.

New IAEA tools are making that task easier, and the IAEA has developed workshops that utilize these tools to aid countries in their decision making processes.

BRIDE (Back-end Research Reactor Integrated Decision-making Evaluation), based on a customized Excel spreadsheet, allows countries to quantitatively compare available technologies and determine the best strategy for their situation. FERREX (Fuel Cycle Cost Estimation for Research Reactors in Excel) can then provide them with detailed cost estimates for the chosen strategy. Both are freely available upon request.

The IAEA has developed tutorials that include examples of these tools' applications and piloted a workshop on BRIDE in Malaysia in 2022. FERREX was discussed as a post-workshop activity.

"Proper disposal of nuclear spent fuel is crucial for ensuring safety, and BRIDE has provided valuable insights on making informed decisions regarding the final repository," said Julia Abdul Karim of the Malaysian Nuclear Agency (MNA), which operates the TRIGA PUSPATI research reactor, the country's only nuclear reactor. "From my perspective, the BRIDE tool is particularly useful for countries like Malaysia, aiding in strategic planning for the future management of its nuclear spent fuel."

After 40 years of operating the TRIGA PUSPATI, Malaysia is putting in place an ageing management strategy and plan to handle its spent fuel. During the workshop in November 2022, MNA presented seven scenarios for the participants to consider. The participants then conducted a pilot application of BRIDE, which included a cost comparison for each activity to help determine the

Malaysia's TRIGA PUSPATI research reactor has been in operation since 1982.
(Photo: Malaysian Nuclear Agency)

preferred option. For Malaysia, the next step is to develop a strategic plan for spent fuel disposition based on the workshop's results, which will be reviewed by the Malaysian Government and technical communities.

"This workshop allowed us to help Malaysia sort through many options for disposition of their residual nuclear materials," said John Dewes, who led the workshop and is a nuclear engineer at the IAEA. "We not only scrutinized the life cycle costs of each option, but also considered the non-economic aspects, such as environmental impact, the availability of human resources, legal and regulatory readiness, and political and public support. It is very complex to think about all these factors at once, but the BRIDE tool methodically assesses each aspect and then combines the results."

Fuel cycle of a research reactor

As of October 2023, there were 224 research reactors operating in 54 countries, with another 25 planned or under construction. A research reactor's fuel cycle is like that of most nuclear power reactors, starting with fuel fabrication and ending with spent fuel management and disposal. Similar to a power reactor, the fuel cycle of a research reactor includes the temporary storage, as well as the reprocessing or disposal of spent fuel declared as waste. Ultimately, it is up to each country to decide on the best method for its spent fuel management.

The IAEA provides scenarios tailored to meet a country's needs based on their circumstances. The recent publication Research Reactor Spent Fuel Management: Options and Support to Decision Making (IAEA Nuclear Energy Series No. NF-T-3.9), a direct output of several coordinated research projects, provides additional information about the available strategies for research reactor spent fuel management, and presents the decision methodology to assist those deciding between several options.

The publication helps to identify the preferred approach depending on a country's specific situation and presents the IAEA decision support framework tools to consider. Additionally, examples of the technologies that are currently used by some countries are provided. The publication also provides information about BRIDE and FERREX, along with case studies and tutorials to assist users.

"These IAEA tools and workshops serve to facilitate an educational process that allows a country to reach their own conclusion on what is best for them," Dewes said. "Countries like Malaysia can then identify the best solution themselves, while also getting vital buy-in from all relevant stakeholders."

"Proper disposal of nuclear spent fuel is crucial for ensuring safety, and BRIDE has provided valuable insights on making informed decisions regarding the final repository."

– Julia Abdul Karim, Malaysian Nuclear Agency

Brazil's experience

Research reactors for the benefit of society

By José Augusto Perrotta

José Augusto Perrotta
has been working in the field of nuclear reactor technology since 1978. Perrotta joined the Nuclear and Energy Research Institute (IPEN) of Brazil's National Commission for Nuclear Energy in 1983 and retired from IPEN in June 2022. He is an emeritus researcher at IPEN.

During his career at IPEN, he performed several technical, management and coordination roles, including serving as Head of the Nuclear Reactor Core Engineering Division, Head of the Nuclear Engineering Center, Coordinator of the Fuel Cell and Hydrogen Program, and Technical Coordinator of the Brazilian Multipurpose Reactor Enterprise.

The importance of research reactors to the world can be exemplified using the idea that science, technology, innovation and society are inextricably linked. Scientific research and discoveries lead to the development of new technology, thereby feeding innovation, which eventually benefits society in terms of health, energy, agriculture, industry and economic development. This is particularly true of research reactors.

One way in which people directly experience the benefits of research reactors is through access to nuclear medicine, which is used to treat and diagnose cancer and cardiovascular disease. Annually, Brazil carries out two million procedures involving nuclear medicine, which is dependent on radioisotope production in research reactors. This became apparent in 2009, when the world's largest supplier of medical isotopes, the National Research Universal reactor in Canada, shut down. Brazil, along with many other countries, was significantly affected by the global supply shortage of molybdenum-99 (Mo-99), which is used for diagnostic imaging, that followed. Brazilian nuclear medicine uses five per cent of the world's supply of Mo-99. However, Brazil had become dependent on other countries for supplies of this isotope.

Following this supply crisis, the decision was made to start constructing a new Brazilian multipurpose research reactor in the city of Iperó, about 120 kilometres outside São Paulo. It is one of around 25 new research reactors currently being planned or under construction around the world. The new reactor is designed to produce radioisotopes for medical and industrial applications; it will also be used for fuel and material irradiation testing to support the Brazilian nuclear energy programme, and to provide neutron beams for scientific and applied research and innovation.

Many people in Brazil — and beyond — will benefit from research reactors, whether because they need radiopharmaceuticals or owing to the increased knowledge and technological skills developed for human welfare and the betterment of our society.

Brazil is not heavily reliant on nuclear for its energy needs, deriving much of its electricity from hydropower, wind and biogas. Nonetheless, Brazil has been a pioneer in nuclear technology research since the 1950s. Brazil was the first country in the Southern Hemisphere to inaugurate a nuclear research reactor — the IEA-R1, a 2 megawatt pool-type reactor. This reactor started operation in 1957 in what is now known as the Nuclear and Energy Research Institute (IPEN) in São Paulo, and is still in use today, producing radioisotopes for use in medicine and scientific research. In 1960, the 200 kilowatt IPR-1 TRIGA research reactor began operation in Belo Horizonte; in 1965, the 500 watt Argonauta research reactor began operation at the Institute of Nuclear Engineering in Rio de Janeiro; and, in 1988,

the IPEN/MB-01 critical facility began operation in São Paulo.

These research reactors acted as catalysts to the development of Brazil's nuclear technology research centres because of the reactors' multidisciplinary applications across different fields, from health to engineering. As these research reactors are situated within an academic environment, university students and researchers have access to them for carrying out research and for specialized training. Over the past decades, Brazil's research reactors have enabled its scientists and engineers to conduct scientific and technological research in many areas, including research on materials for use in nuclear power reactors and the application of neutrons in industry, agriculture and the environment. Other research areas include nuclear fuel cycle possibilities for both uranium and thorium, and their various compounds; nuclear fuel development; research into the treatment and storage of radioactive waste; nuclear metrology; and the design of nuclear reactors and other nuclear and radiation facilities.

With research reactors serving as a foundation for the country's nuclear endeavours, Brazil is involved in many exciting new developments in the nuclear sector. There is research into areas such as fusion, the utilization of high-intensity lasers, microreactors for space exploration and small modular reactors (SMRs). Brazil developed low enriched uranium fuel for use in SMRs and research reactors. Hydrogen and fuel cells have also been developed in researching clean energy solutions.

Brazil adheres to the IAEA's Code of Conduct on the Safety of Research Reactors and is well organized at a national level with respect to nuclear safety, with a new independent nuclear regulatory authority and engaged operating organizations. In this respect, the IAEA plays a very relevant role, since the services it provides, such as IAEA safety standards and Technical Documents, workshops, training courses, symposiums, technical cooperation and review missions, enable Brazil to create an environment with a strong culture of safety and security at its nuclear facilities.

While IPEN continues to provide great research and development capacity, its graduate degree programme in nuclear technology at the University of São Paulo is key to creating Brazil's next generation of nuclear technology professionals. So far, more than 3300 students have graduated from master's and doctoral degree programmes at the university, and IPEN has, annually, around 1000 students pursuing a degree at various levels. The nuclear technology programme is popular with both men and women, with women making up 46 per cent of students in 2022. Despite these achievements, however, human resources remain one of our greatest challenges in terms of the future of research reactors and the nuclear field in general, as the needs are greater than the available resources. We must attract more young people to nuclear professions. Without people, we cannot achieve anything.

"Many people in Brazil — and beyond — will benefit from research reactors, whether because they need radiopharmaceuticals or owing to the increased knowledge and technological skills developed for human welfare and the betterment of our society."

– José Augusto Perrotta, Emeritus Researcher, Nuclear and Energy Research Institute, Brazil

IAEA and FAO launch ‘Atoms4Food’ to expand use of nuclear techniques for global food security

The Atoms4Food initiative, launched by the IAEA and the FAO, will support countries to use innovative nuclear techniques in different ways to strengthen food security. (Photo: K. Laffan/IAEA)

The IAEA and the Food and Agriculture Organization of the United Nations (FAO) launched the ‘Atoms4Food’ initiative at the World Food Forum on 18 October 2023 in Rome, in order to help boost food security and tackle growing hunger around the world.

Atoms4Food will support countries to use innovative nuclear techniques in enhancing agricultural productivity, reducing food losses, ensuring food safety, improving nutrition and adapting to the challenges of climate change.

“We find ourselves in an unprecedented time, where hunger and malnutrition are on the rise, posing a threat to humanity,” IAEA Director General Rafael Mariano Grossi and FAO Director General Qu Dongyu said in a joint statement. “The Atoms4Food initiative seeks to provide Member States with ground-breaking solutions tailored to their specific needs and circumstances, by harnessing the advantages of nuclear techniques along with other advanced technologies.”

The world faces vast food security and nutrition challenges. In 2022, between 691 and 783 million people faced hunger and 3.1 billion could not afford a healthy diet — over 40 per cent of the global population. At the same time, obesity is becoming more prevalent in every region of the world.

“Increasing climate extremes will cause more crops to fail, as global food demand rises. We need to use every tool we have to grow more food,” said Director General Grossi. “Nuclear science offers incredible, innovative tools to grow stronger, healthier, safer crops and to protect the food we need to live.”

Atoms4Food builds on the almost 60 years of experience that the IAEA and the FAO have jointly developed in supporting countries to use nuclear and isotope technology solutions to enhance food security, as well as nutrition and food safety.

Nuclear techniques can be used in different ways to strengthen food security. They are used to speed up the natural process of plant mutation in order to develop crops that better withstand diseases and climatic shifts. Nuclear and isotopic techniques can also be used to assess nutrient use and water use in soil, diagnose and characterize disease pathogens in animals, trace sources of contamination in water and study various forms of malnutrition. The nuclear sterile insect technique targets insect populations, reducing the use of insecticides for both crops and livestock. The irradiation of food can ensure that food is safe from pathogens and increases its shelf life to aid food security.

Tailor-made research will form the core of this initiative, focusing on the specific needs of countries through concrete innovations and solutions.

— By Sinead Harvey

IAEA training centre for nuclear security to build expertise in countering nuclear terrorism

The IAEA has opened a unique nuclear security training centre, the first international facility of its type, to support the growing efforts to tackle global nuclear terrorism.

The IAEA Nuclear Security Training and Demonstration Centre opened in October 2023. (Photo: K. Laffan/IAEA)

IAEA Director General Rafael Mariano Grossi officially opened the IAEA Nuclear Security Training and Demonstration Centre (NSTDC) on 3 October 2023, during a ceremony at the IAEA's Seibersdorf laboratories in Austria, attended by representatives from 45 countries and territories.

The centre will provide more than 2000 square metres of specialized technical infrastructure and equipment for course participants to learn about the physical protection of nuclear and other radioactive material, as well as the detection of and response to criminal acts involving nuclear material and facilities.

"Nuclear security is one of the most important areas of our work to make sure that nuclear material never falls into the wrong hands," Mr Grossi said. "The international nuclear security centre of excellence is where experts on nuclear security and the physical protection of nuclear material from all over the world will be trained to hone their skills."

Requests to the IAEA for training in nuclear security have increased in recent years as more countries embark on nuclear power programmes, and following the 2016 entry into force of the Amendment of the Convention on the Physical Protection of Nuclear Material (CPPNM) — the only legally binding international instrument in the area of the physical protection of nuclear material.

Over two floors, the new centre contains simulated environments, virtual reality tools and advanced software. It will provide hands-on practice on nuclear security systems for the physical protection of nuclear facilities, information and computer security, nuclear forensics, major public events and other areas of work related to nuclear security.

"We are giving countries the tools to do nuclear better, safer and in a secure way," added Director General Grossi.

The centre welcomed the first trainees in October for a course on security management of radioactive material, one of the 23 training courses and workshops offered.

"By building this new centre, the IAEA can offer unique training activities to address existing gaps using specialized up-to-date equipment, computer-based simulation tools and advanced training methods," said Elena Buglova, Director of the IAEA Division of Nuclear Security.

The centre is part of a multi-purpose building that was constructed with over €18 million in extra-budgetary funding by 15 donors, as well as in-kind contributions, bolstering the capabilities of the IAEA to respond to countries' needs in capacity building for nuclear security.

— By Sinead Harvey

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