IAEA BULLETIN

INTERNATIONAL ATOMIC ENERGY AGENCY

The flagship publication of the IAEA | March 2017

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Radiation Technology

the industrial revolution behind the scenes

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IAEA BULLETIN
is produced by the
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and Communication (OPIC)
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IAEA BULLETIN is available online at
www.iaea.org/bulletin

Cover: IAEA

IAEA

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

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

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

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

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

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

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

Radiation technology for a more prosperous and sustainable future

By Yukiya Amano, Director General, IAEA

Nuclear science and technology have a great deal to contribute to industrial development and economic growth. Their many benefits include improved materials, more effective industrial processes and a cleaner environment, contributing to the achievement of several of the United Nations Sustainable Development Goals, including goal 9 that aims at promoting industry, innovation and infrastructure. The IAEA helps its 168 Member States to improve their capabilities in the use of radiation science and technology in order to improve the quality of life of their people.

Radiation technology offers versatile tools that have an important role to play in support of sustainable development. It is often more cost-effective and environmentally friendly than traditional alternatives, requiring less energy and generating less waste. This is important for all countries, but particularly for those with limited resources.

This edition of the *IAEA Bulletin* highlights some of the ways in which radiation science and technology are being put to effective use throughout the world. You can read about how China, one of the world's leading textile producers, is using radiation technology to clean up wastewater from textile dyeing to make it safer for reuse (page 8), and how Brazil is using it to fight invasive insect pests to protect its cultural heritage (page 16).

Companies throughout the world are using nuclear techniques for quality control of products, processes and structures to boost production and strengthen safety. In Chile, these tools are helping the mining sector to remain competitive (page 14). In Morocco, specialists use radiation to detect and correct flaws and inconsistences in products and production processes (page 12), while in Myanmar, nuclear techniques are leading to increased efficiencies in the oil and gas sector, shipyards, railways and even amusement parks (page 6).

Many scientists and experts work together through IAEA coordinated research activities and scientific meetings to further improve radiation technologies and widen their use. This scientific work results in innovative solutions for tackling global challenges. A good example is the development of new biodegradable, 'active' packaging material to combat plastic pollution (page 10). IAEA Collaborating Centres play a key role in moving these scientific solutions outside laboratories and into industry and daily life (page 20). As a result of the work of the IAEA, many scientists gain the experience they need to become a source of expertise and guidance to other countries in how to apply radiation tools (page 18).

Science and technology are essential for development. If countries are to fully embrace the potential benefits of nuclear technology, a strong radiological safety and security framework is essential. The IAEA is committed to helping countries train and certify professionals and establish the necessary safety and security systems to ensure that these innovative technologies continue to be used for the benefit of humankind.

"Radiation technology offers versatile tools that have an important role to play in support of sustainable development."

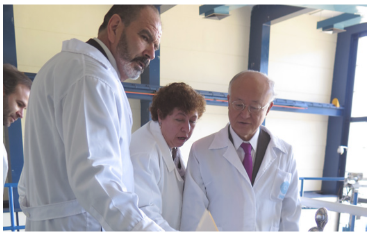
— Yukiya Amano, Director General, IAEA

(Photo: R. Murphy/IAEA)

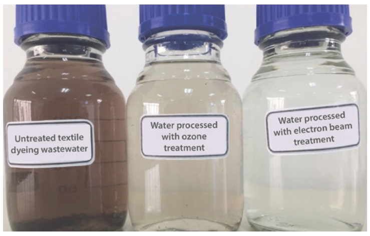
(Photo: C. Brady/IAEA)

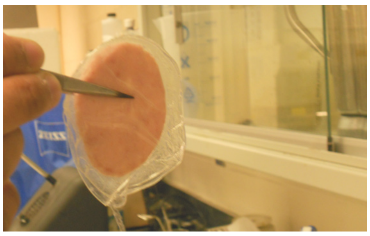
(Photo: C. Brady/IAEA)

Foreword



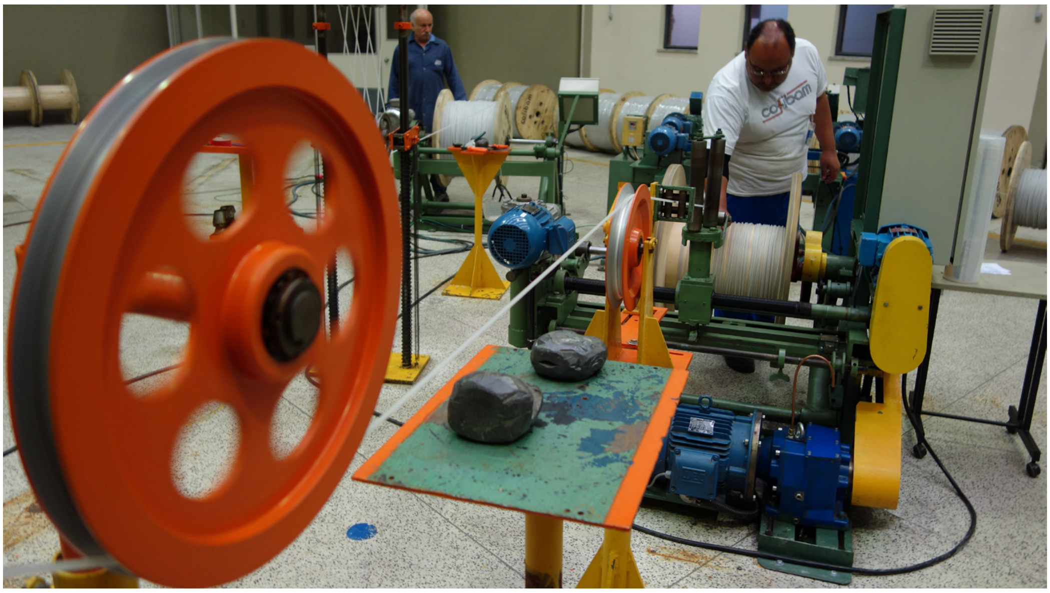
Radiation Science & Technology





A look at radiation science and technology

By Nicole Jawerth



Wires and cables can be made stronger and more resistant to harsh chemicals and extreme temperatures, such as fire, with the help of radiation technology.
(Photo: L. Potterton/IAEA)

Smartphones, car tyres and bandages: these are just a few of the everyday products that are made safer, more reliable, or more effective with radiation technology. Beyond these products, this technology is also a tool for safety checks, cleaning up water and air pollutants, and even improving food production and preservation, among others. Through advances in research and innovation in radiation science, this technology's global impact on daily life and sustainable development continues to grow.

"Look at farmers in India, who have arms full of vegetables because of fertilizers made from irradiated sewage sludge. Or admire thousands of beautiful art pieces and cultural relics in Brazil that have been saved from insects and mould thanks to radiation," said João Osso, Head of the IAEA's Radioisotope Products and Radiation Technology Section. "The potential benefits of radiation are vast."

"Radiation technologies can help to alleviate emerging environmental challenges, and help us ensure a sustainable future, particularly in low and middle income countries. As these tools continue to develop and evolve, there will be new possibilities for how we can use them."

— João Osso, Head, Radioisotope Products and Radiation Technology Section, IAEA

Scientists have been studying radiation (see The Science box) and its chemical effects for decades. These studies have resulted in a range of tools and methods that take advantage of these effects and apply them in a variety of areas, from agriculture and industry to environmental protection to safety and security. Compared to many conventional methods, techniques involving radiation are often quicker, more cost-effective and environmentally friendly.

Non-destructive testing (NDT), for example, is a quality control method used in industry to detect leaks, cracks and other structural inconsistences in products, building structures and machines. It works by passing radiation, like X-rays, through the material so that it can be detected using specialized devices. These devices produce images of what is happening inside the material. Read more about this on pages 6 and 12.

Radiotracers are another family of tools often used to improve the productivity of sectors such as the mineral processing and metals extraction industry. Specialists inject key radioisotopes into a fluid or a mixture containing a substance, where these atoms latch on to the molecules of the substance. Using special scanning machines, specialists can track the radioisotopes to take measurements and understand different characteristics of the substance and how it moves inside a system. Read more about this on page 14.

New materials for a more sustainable future

Radiation science research has also led to new ways of restructuring and linking molecules to create new materials, many of which are more sustainable, effective and eco-friendly. These new materials are made from irradiated organic compounds and polymers, such as proteins from milk,

Radiation technology can be used to inspect the internal components of a process or piece of equipment without interrupting production.
(Photo: A. Rachad/CNESTEN)

leftover materials from plants, or cellulose from natural sources such as trees and crustacean shells. In some cases, these compounds are combined with fibres from other natural sources, such as wood, to improve durability. This has resulted in, among other things, new building materials, improved gels for healing wounds and eco-friendly food packaging material. Read more about this on pages 10 and 18.

Using the same radiation tools, but at different energy levels, scientists can modify how cells and molecules behave so as to treat unwanted contaminants or infestations. At certain dose levels, the radiation can change key components inside the cells to inhibit their reproduction or break down molecules to make them easier to treat. Read more about this on pages 8 and 16.

"Radiation technologies can help to alleviate emerging environmental challenges, and help us ensure a sustainable future, particularly in low and middle income countries," said Osso. "As these tools continue to develop and evolve, there will be new possibilities for how we can use them."

THE SCIENCE

What is radiation?

Radiation is a form of energy, like heat and light from the sun. There are two types of radiation: ionizing radiation and non-ionizing radiation. Ionizing radiation is usually what people mean when they talk about radiation.

Ionizing radiation comes from atoms that are unstable and are in the transformation process towards becoming stable — this process is called radioactivity. It can also come from the acceleration of particles by an electromagnetic field. There are several types of ionizing radiation: alpha particles, beta particles and gamma rays, as well as accelerated particles and waves called electrons, protons and X-rays. There are also sub-atomic particles like neutrons or charged ions that serve as a source for radiation applications.

Scientists can use ionizing radiation, combined with special tools, to determine different characteristics of substances or, when used at a high enough dose, to modify the substances. For example, a special camera is used to detect radiation as it passes through an object, which results in an image outlining what is happening inside of the object.

Myanmar uses nuclear techniques to improve industrial processes

By Miklos Gaspar

A researcher at Myanmar's Department of Atomic Energy is testing equipment to be used for non-destructive testing at the country's oil refinery.
(Photo: M. Gaspar/IAEA)

Experts are rolling out the use of nuclear technology in industrial testing across Myanmar, following successful implementation of the technique in the oil and gas sector.

"NDT inspections, including those using nuclear applications, are crucial for quality control in a variety of industrial fields in Myanmar."

— Ingyin Phyu, NDT researcher, Department of Atomic Energy, Myanmar

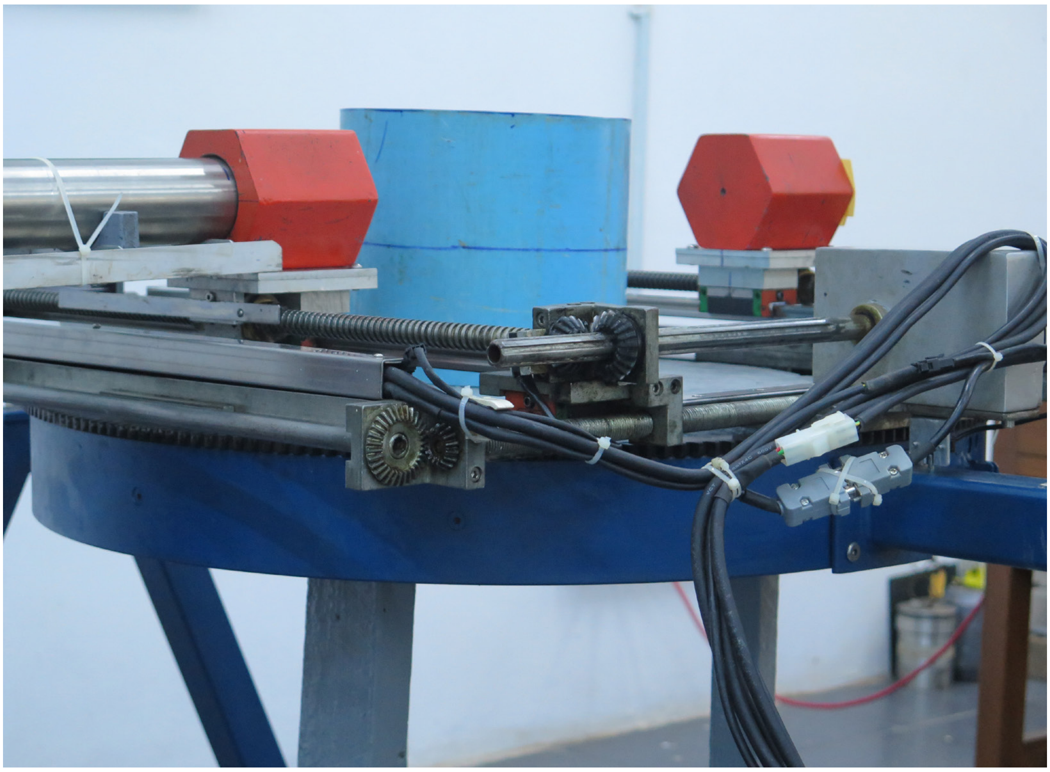
Non-destructive testing (NDT) using nuclear techniques involves ionizing radiation to test the quality of materials and products (see The Science box). The technique used in Myanmar is called gamma process tomography and is based on the differential absorption in different materials of gamma rays emitted from a radioactive source. Since 2013, the IAEA has helped Myanmar's Department of Atomic Energy to purchase the necessary equipment and build the expertise of its staff in using the technique. Department of Atomic Energy experts regularly perform NDT in the Thanlyin oil refinery near Yangon to inspect the quality of the pipes and of the products flowing through them.

"Nuclear science and technology play a major role in bringing innovation and efficiency to industrial processes," said Meera Venkatesh, Director of the Division of Physical and Chemical Sciences at the IAEA. "Myanmar provides a great example of how low-income countries, too, can take advantage of this technology."

Oil pipes, boilers, pressure vessels, buildings, aircraft equipment and ships are just some of the products being quality tested using this technique around the world, and Myanmar's Department of Atomic Energy is taking steps to spread its use, said Ingyin Phyu, the scientist in charge of the Department's NDT laboratory. "NDT inspections, including those using nuclear applications, are crucial for quality control in a variety of industrial fields in Myanmar," she said.

Technical staff of Myanmar Railways, Myanmar Shipyards, Yangon Technological University and private companies have recently received training in the use of the technique and have already begun to employ it in a wide range of activities, including on construction sites, in dockyards, on locomotives and at the country's largest amusement park.

"The use of NDT is greatly enhancing the shipbuilding and ship repair sector," said



This NDT device emits radiation from the radioactive source (left). The radioactive particles react with the substance in the light blue pipe in the middle. The detector on the other side of the pipe measures radiation. This measurement provides information about the quality and quantity of the material going through the pipe.
(Photo: M. Gaspar/IAEA)

U Myint Zaw, Deputy General Manager and senior NDT inspector at Myanmar Shipyards. “It is essential for the improvement of our industrial processes and products and we use it extensively for quality control.”

In 2017, the IAEA developed a new project to use NDT to support the preparation and recovery of civil infrastructure after natural disasters for countries in Asia and the Pacific. This project builds on experience gained following the devastating earthquake in Nepal in April 2015, when NDT was used in the aftermath to test the integrity of critical buildings such as hospitals, schools and historical attractions.

THE SCIENCE

Non-destructive testing

Industrial testing using nuclear technology involves using ionizing radiation — along with other methods — to test the quality of materials, without causing any damage to them or leaving behind any radioactive residue. This technique is called non-destructive testing (NDT).

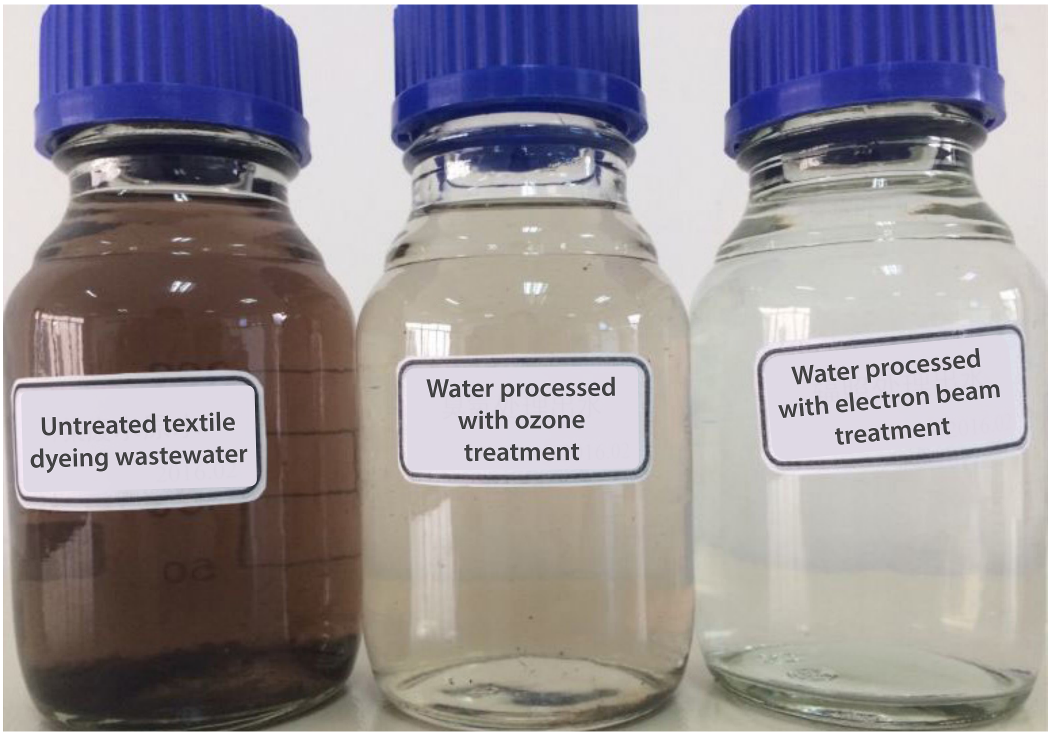
NDT methods include radiography — a type of radiation technology — and gamma tomography, which is based on the differential absorption in different materials of gamma rays emitted from a radioactive source. Measuring the rays that pass through the material without being absorbed allows the make-up and structure of the material to be determined. These techniques are able to identify structural defects that cannot be discovered through traditional testing methods.

Industrial radiography is used to inspect, for example, concrete and a wide variety of welds, such as those in gas and water pipelines, storage tanks and structural elements. It can identify cracks or flaws that may not otherwise be visible.

Other commonly used NDT methods include:
- ultrasonic radiography, which uses mechanical vibrations similar to sound waves;
- liquid penetrant inspection, which can locate surface-breaking defects in non-porous materials;
- magnetic particle inspection, which can detect surface and slightly subsurface discontinuities in ferromagnetic materials; and
- eddy current testing, which uses electromagnetic induction to detect flaws in conductive materials.

China's first wastewater plant using radiation opens

By Miklos Gaspar



A side by side comparison of wastewater after it has been treated using electron beam technology and other methods.
(Photo: Nuclear and Energy Technology Institute, Tsinghua University)

China has inaugurated its first facility that uses electron beams to treat industrial wastewater, ushering in a new era of radiation technology for the world's leading textile producer.

> "Electron beam technology was the clear winner as both the more ecological and more effective option."
> — *Jianlong Wang, Deputy Director, Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing*

Textile dyeing accounts for a fifth of all industrial wastewater pollution generated worldwide. Although several industrialized countries have used radiation to treat some of the effluent from textile dyeing plants, the relocation of much of the industry to developing countries in Asia in recent years has meant that a lot of the wastewater goes untreated.

"Despite advances in conventional wastewater treatment technology in recent years, radiation remains the only technology that can treat the most stubborn colourants in wastewater," said Sunil Sabharwal, a radiation processing specialist at the IAEA. "The problem is that the technology exists in developed countries, while most of the need is now in the developing world."

To bridge the knowledge gap, the IAEA ran a coordinated research project on this technology, including its transfer to several countries, mostly facilitated in Asia. Chinese researchers, for instance, have benefited from the advice of experts from Hungary, the Republic of Korea and Poland in the adoption of the technology and the construction of the plant, said Jianlong Wang, Deputy Director of the Institute of Nuclear and New Energy Technology at Tsinghua University in Beijing and the principal researcher behind the project.

The new plant in Jinhua city, 300 kilometres south of Shanghai, will treat 1500 cubic metres of wastewater per day using radiation technology (see The Science box), which is around a sixth of the plant's output. "If everything goes smoothly, we will be able to roll out the technology to the rest of the plant and eventually to other plants across the country," said Wang.

Before opting for radiation technology using electron beams, Chinese researchers had conducted extensive feasibility experiments using the effluent from the plant, comparing electron beam technology with other methods. "Electron beam technology was the clear winner as both the more ecological and more effective option," Wang explained.

Electron beam technology is used to clean industrial wastewater at a textile dyeing facility in Jinhua city.
(Photo: Nuclear and Energy Technology Institute, Tsinghua University)

Other countries with significant textile manufacturing industries, such as Bangladesh, India and Sri Lanka, are also considering introducing the technology with IAEA assistance, said Sabharwal. India is already using gamma irradiation to treat municipal sewage sludge, he added.

Chinese researchers are also considering using electron beam technology to treat residues from pharmaceutical plants that produce antibiotics. These residues are currently handled as hazardous waste because they contain antibiotics and antibiotic resistance genes that cannot be destroyed using conventional technologies, such as composting or oxidation. However, research has revealed that electron beam technology can effectively decompose the residual antibiotics and antibiotic resistance genes, Wang explained. The establishment of a demonstration plant at an industrial scale is planned for late 2017, he added.

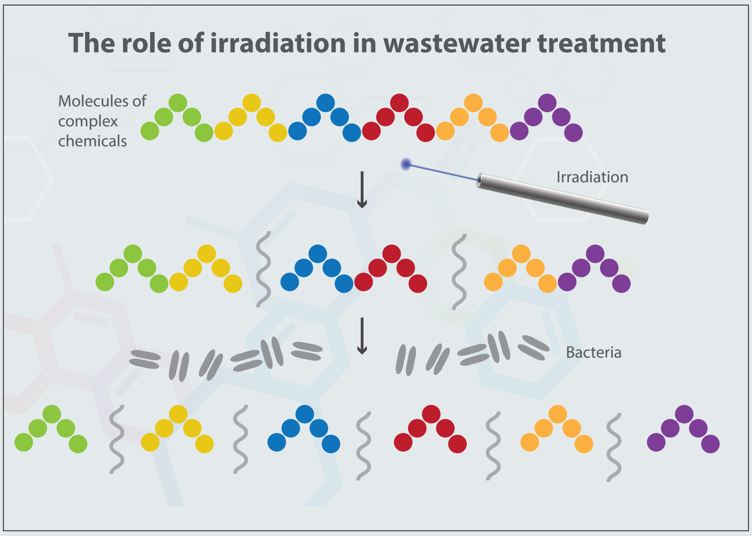
THE SCIENCE

Compounds too long for bacteria

Bacteria are the workhorses of wastewater treatment: they digest and break down pollutants.

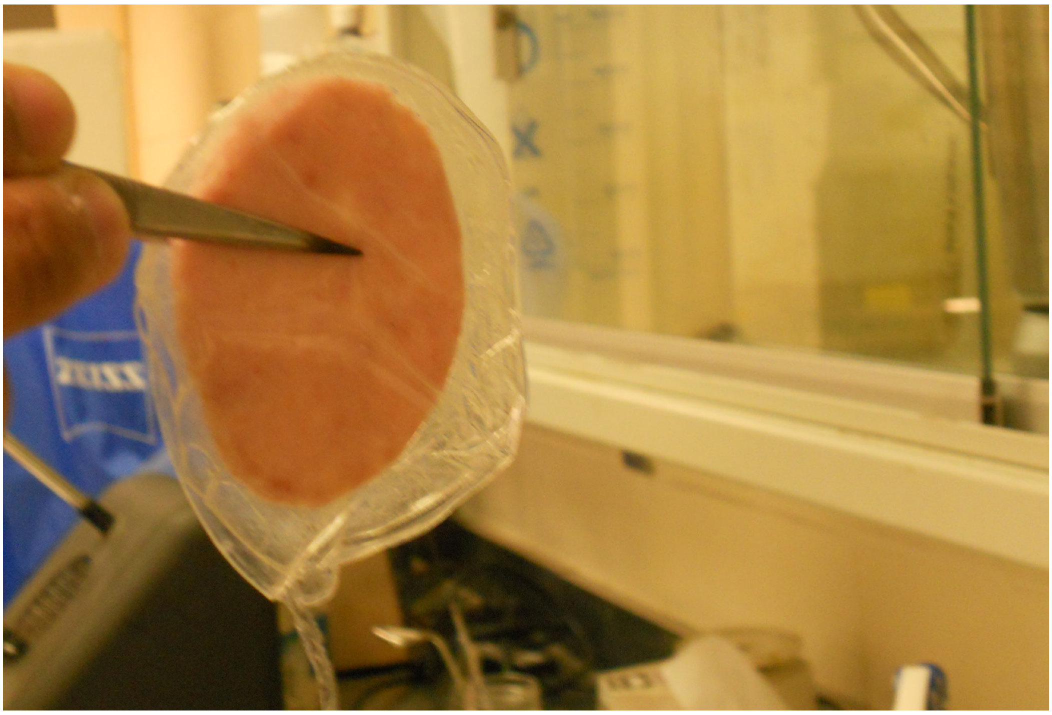
Wastewater from textile dyeing, however, contains molecules that cannot be treated with bacteria. The compounds used to colour textiles have large, long and complex molecule chains. Wastewater from the industry can contain more than 70 complex chemicals that do not easily degrade.

By irradiating the effluent using electron beams, scientists can break these complex chemicals into smaller molecules, which can then be treated and removed using normal biological processes, such as breakdown by bacteria. Irradiation is done using short lived reactive radicals that can interact with a wide range of pollutants and break them down.



Canada pursues better, more eco-friendly food packaging from irradiated nanofibres

By Aabha Dixit



Active packaging for ready to eat meat products based on crosslinked chitosan containing nanocellulose and antimicrobial agent.
(Photo: A. Khan/CIC)

Across the globe, discarded food packaging is polluting public spaces and pushing already overloaded landfills to the brink. Recognizing the harm that this leftover packaging does to the environment and the limitations associated with recycling it, Canada is pursuing research into biodegradable, eco-friendly food packaging developed using radiation technology.

"The race to develop biodegradable packing material or eco-friendly 'active' food packaging is gathering momentum," said Monique Lacroix, Director of the Research Laboratories in Sciences Applied to Food (RESALA) and researcher at the Canadian Irradiation Centre (CIC). "Packaging based on natural polymers can help address the challenges of non-biodegradable food wraps and help reduce a major source of environmental pollution."

For over 15 years, scientists at RESALA and CIC have been using their training with the IAEA to research and develop biodegradable, 'active' packaging materials. They do this by taking raw renewable materials such as starch or proteins and combining them with nanocellulose, which is a natural polymer that contains nano-sized cellulose fibres and then irradiating them (see The Science box). This combination leads to materials with improved properties compared to conventional materials in terms of durability, biodegradability and better water resistance.

"Irradiating natural polymers to make new materials is a promising avenue to further enhance product safety and contribute to the environmental goal of reducing food packaging waste."

— Monique Lacroix, Director, Research Laboratories in Sciences Applied to Food, Canada

"These polymers are not naturally very sturdy, but when you add nanocellulose and subject it to radiation, the polymers become tough and offer more reliable, sturdy coverage and protection of food," explained Lacroix. "Then when we add specific bioactive materials such as essential oils from thyme, the packaging is considered 'active' because these additions actively help to extend the shelf life of food and assure food safety."

A growing reliance on plastic

Production of plastic has surged over the past 50 years, from 15 million tonnes in 1964 to 311 million tonnes in 2014, with packaging accounting for around 26% of the total volume of plastics used worldwide, according to a 2016 World Economic Forum report on the future of plastics. The report projects that production will double in the next 20 years, as reliance on plastic grows. In Canada, for example, 9 to 15 billion plastic packages are used each year.

Most packaging material is made of materials like paperboard coated with wax and plastic because of their wide availability, relatively low cost, durability and strength. However, these packaging materials are often not biodegradable, and recycling them tends to be technologically impractical and economically unviable, due to contamination by food stuff and biological substances.

Global research for more eco-friendly material

Radiation processing is an attractive option for the food packaging industry worldwide. To build their skills and knowledge in this area, many researchers are turning to IAEA-supported projects as an avenue for collaborating with and learning from experts like the scientists at RESALA and CIC. Among these is an IAEA project that began in 2013 and has brought together scientists from 14 countries: Algeria, Bangladesh, Brazil, Canada, Egypt, Italy, Malaysia, the Philippines, Poland, Romania, Thailand, Turkey, the United Kingdom and the United States. They are now sharing ideas and strengthening their skills in developing advanced packaging material for food products using radiation technology.

"Global research is focusing more and more on eco-friendly packaging material in response to new regulations where governments are making industries responsible for their use of plastic, including paying for the waste being generated because of plastic packaging," Lacroix said. "Irradiating natural polymers to make new materials is a promising avenue to further enhance product safety and contribute to the environmental goal of reducing food packaging waste."

Cobalt-60 gamma irradiators are used to treat and sterilize materials for use in products such as packaging.

(Photo: Nordion/Canada)

THE SCIENCE

Irradiating polymers and nanocomposites

Scientists expose natural polymers and nanocomposites to gamma radiation, X-rays or electron beams to create materials that are more stable, sealable, biodegradable and recyclable. These natural polymers include proteins, such as soya, zein, caseinate, as well as polysaccharides, such as chitosan, algae and potato extracts. These are then combined with nanocellulose — an organic, natural polymer that comes from plant matter, such as wood, and comprises nano-sized cellulose fibrils. The nanocellulose provides reinforcement to make materials sturdier.

For example, scientists often use a group of milk proteins called caseins to create these new materials. There are four types of caseins: each has its own distinct molecules, but they have similar structures and compositions. These proteins can be dissolved in water and then irradiated with gamma rays. The resulting solution is then dried on a surface, which forms a free-standing solid film that can be shaped for packaging purposes. The film is stronger and more durable than conventional plastic, and when nanocellulose is added to the film and then irradiated, the film has better water resistance, which makes it particularly effective for protecting packaged food from moisture and bacteria that can compromise food safety.

Boosting quality while saving costs: Morocco beefs up its industry with radiation technology

By May Fawaz-Huber

A CNESTEN specialist gamma scanning a 75 metre vacuum-packed bed distillation column at a refinery in Morocco.
(Photo: R. Alami/CNESTEN)

Small, nearly invisible cracks are no longer the costly threat they once were for Moroccan industrial operators. Equipped with highly sensitive and precise radiation technology, operators are now uncovering flaws before they compromise production — which has helped to boost production quality and save millions of dollars in maintenance and repair costs.

"Maintenance and repair costs were very high, and this was harming competitiveness. Now, nuclear techniques are being used to detect problems and improve production quality."

— Rachad Alami, Head, Industrial Applications Division at the National Centre for Nuclear Energy, Sciences and Technology, Morocco

"Industrial operators used to run their facilities until unexpected breakdowns forced them to shut down for very long periods of time," said Rachad Alami, Head of the Industrial Applications Division at the National Centre for Nuclear Energy, Sciences and Technology in Morocco (CNESTEN). "Maintenance and repair costs were very high, and this was harming competitiveness. Now nuclear techniques are used to detect problems and improve production quality."

Moroccan industrial operators have worked with CNESTEN specialists trained by the IAEA in using non-destructive testing (see The Science box on page 7) to inspect industrial equipment and conduct quality assurance tests. In Morocco, these techniques, which represent more than 98%of the technical controls carried out on industrial plants worldwide, have been applied in diverse branches of industry, including the petrochemical, phosphates production and processing, metal, transport, food and cement sectors.

Over the past three decades, Moroccan industry has benefited greatly from radiation technology, Alami said. While accurate figures on the savings generated by the application of nuclear technology are hard to come by, industrial operators in Morocco agree that the minimum benefit ratio for the use of nuclear techniques is 32:1 — which means that for every euro spent on non-destructive testing (NDT), radiotracers and other radiation applications, operators saw a return of at least 32 euros.

Gamma scanning helps restore petrochemical refinery operations

Conventional methods are often not precise or sensitive enough to get to the root of a problem. In 2015, engineers at a petrochemical refinery used conventional techniques to look for the reason behind a nearly 90% drop in the operation capacity of a furfural production unit (furfural is a solvent used in the manufacture of many industrial products). They could not find the source of the problem and decided they needed to dismantle the entire unit, which would halt production for weeks.

Before dismantling the unit, they decided to try a radiation technique called gamma scanning (See The Science box) to get a better idea of what was happening inside the unit and find the source of the problem. Within hours, they had identified the problem, replaced the damaged portion of the unit and restored it to full operating capacity.

“Gamma scanning was the only technique able to detect the problem and to locate it precisely,” Alami said. “It was much cheaper to use this technique — which costs 5000 euros — than to sustain the huge loss that would have resulted had we dismantled the entire unit.”

Promoting radiation technology in Morocco and Africa

Specialists in Morocco are now using their decades of experience to support countries around Africa in using NDT, sealed radioactive sources and radioactive tracers.

“Since the 1990s, Morocco has taken a leadership role in the application of radiation technologies thanks to the commitment of CNESTEN and support from France and the IAEA,” said Patrick Brisset, an industrial technologist at the IAEA.

Central to Morocco’s collaboration in the region is the IAEA-supported African Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology (AFRA). The AFRA programme has helped establish direct cooperation between Morocco and countries such as Angola, Cameroon, Egypt, Ethiopia, Ghana, Senegal, Sudan, Tunisia, Tanzania and Zimbabwe. As a result of this cooperation, a number of these countries have been able to implement nuclear and nuclear-related techniques in their own local industries.

“Industrialization is really taking off in many countries on the African continent. The IAEA works with countries like Morocco to promote the peaceful use of radiation technologies in industry with the aim of having an immediate impact on the countries’ economies,” Brisset said.

The IAEA, in part through its technical cooperation programme, continues to stimulate the use of these technologies and to support collaboration. Morocco has been working in industrial projects involving radiation technology with the Democratic Republic of the Congo, Egypt, Kenya, Sudan and Zimbabwe.

THE SCIENCE

Radiographic testing and gamma scanning

Radiographic testing represents the largest non-destructive testing (NDT) technique on the market and is considered to be the reference method for all other complementary techniques (read more about NDT on page 7). It is mainly based on gamma rays from radioactive sources or X-rays from X-ray generators. Sometimes beta rays can also be used for low density, low thickness materials. When radiation is sent through a piece of material, specialists can use a special device that detects the radiation and creates an image. The higher the density or thickness of the material, the less radiation gets through, which results in less black on the image. Specialists evaluate these images to determine different characteristics of the material.

Gamma scanning is a technique used to carry out an internal inspection of any process or equipment without interrupting production. A collimated beam of penetrating rays is allowed to pass through the shell of a vessel, gets modified by the vessel internals and then comes out of the other side to reach a detector. By measuring the intensity of the transmitted radiation, valuable information can be obtained about the densities of the materials present inside the vessel. The higher the density or thickness of the material, the less radiation gets through. This leads to a simple and efficient method, a so-called ‘scan profile’ of the inspected component, which specialists can use to identify flaws or inconsistences.

Chile stays ahead in the race for scarce minerals with radiation technology

By Jeremy Li

A mining facility in Chile that processes raw copper. Chile is the world's largest producer of coppper.
(Photo: F. Diaz/Trazado Nuclear e Ingenieria Ltda.)

Competition is heating up in the multibillion dollar global race for high-grade minerals and metals as known resources grow scarce and demand increases for their use in all kinds of everyday products, from mobile phones to pots and pans. For countries like Chile, radiation technology is key to keeping a competitive edge.

> "Radiation technology offers a hard-to-beat advantage over other techniques. These tools have become a critical part of how we are growing our most important national industry and keeping our foothold as a global exporter."
>
> *—Francisco J. Diaz Vargas, principal manager, Trazado Nuclear e Ingenieria, Chile*

"Radiation technology offers a hard-to-beat advantage over other techniques," said Francisco J. Diaz Vargas, principal manager of Trazado Nuclear e Ingenieria, a Chilean organization that consults on mineral and metal extraction processes for mining companies. "These tools have become a critical part of how we are growing our most important national industry and keeping our foothold as a global exporter."

Thanks to its rich mineral reserves, Chile's vibrant mining industry contributes about 9% of the country's gross domestic product (GDP) and represents about half of Chile's total exports. Chile is the world's largest producer of copper, which is exported for use in alloys, buildings and electrical equipment, among other things. Chile's mines are also a major source of molybdenum, a chemical element that plays a critical role in over 80% of nuclear medicine procedures.

To keep their national industry thriving and help meet growing export demands, Chilean mining companies have been working with the IAEA to use radiotracers and nucleonic gauges (see The Science box) to help them streamline their production and mining processes and become more efficient in detecting and measuring mineral and metal concentrations. Compared to traditional techniques, radiation technology does a better job of improving the quality of products, optimizing processes, and saving energy, Diaz Vargas said.

"In many instances, it's simply not practical to use traditional tracer techniques because they involve large equipment that is too bulky to move around and use in the field. Radiotracers are more portable," explained Diaz Vargas. "They are also more accurate and faster than traditional techniques, which means we can save time and money because we have an accurate idea of how much we can expect to extract and process."

Using such innovative techniques is essential to staying ahead in an increasingly competitive global market and ensuring a steady supply of metals and minerals, said Patrick Dominique M. Brisset, an industrial technologist at the IAEA.

More than 2.7 billion metric tonnes of metals and minerals are extracted from natural reserves in the ground and used each year, according to the British Geological Survey's

World Mineral Statistics. These minerals and metals are used in a huge number of products, from machinery to electronics to household goods and automotive parts. In computers alone, more than 60 different kinds of metal are used in making the exterior casing, circuit boards and computer chips.

As the global population grows and the overall standard of living goes up, the demand for products using these materials is rising too. However, the challenge of finding easily-extractable minerals and metals combined with the long mining process — normally 10 to 15 years from discovery of a deposit to the start of extraction — is making it more difficult to accommodate the ever-growing demand.

"The demand is getting more and more difficult to meet because, globally, sources of high-grade metals and minerals are getting exhausted and harder to find, so countries have to find new ways to keep up," Brisset said.

Through IAEA support, specialists from around the world are building knowledge and skills in using nuclear techniques in the mining, metallurgy and mineral processing industries. They are also working closely with experts from countries like Chile that have developed years of expertise through their well-established mining practices and infrastructures.

"The industry is growing fast. If radiation techniques are developed and implemented on a massive scale, we are potentially looking at annual global economic savings of upwards of US $19 billion from the more efficient extraction and production processes and less reliance on human resources," Brisset said.

THE SCIENCE

Radioactive tracers and nucleonic gauges

Radioactive tracers are a family of analytical tools that can provide data to investigate and optimize the various steps involved in the mining and processing of minerals. They are based on radioactive isotopes that are injected into a mixture or fluid that latch onto molecules of a target substance, such as metals and minerals, and move in a similar way to those substances. Special devices, such as scintillators, are then used to detect the radiation being emitted from the tracers. Imaging tools, such as single photon emission computed tomography (SPECT) or positron emission tomography (PET), are also used. These devices produce images that reveal the concentration of mineral and metals — the higher the concentration of a substance in a mixture, the more radiotracers appear in the image. The radiotracer method can also be used to determine the real-time movement of water, oil or pollutants underground and to also map out the flow patterns inside of a system.

Nucleonic measurement and control systems, popularly known as **nucleonic gauges**, use special detection devices and radiation sources to emit gamma radiation or X-rays for measuring and controlling different variables of a product or equipment, such as its thickness, density and composition.

A nucleonic gauge works by passing radiation through a material to reach a special detector device on the other side. The detector picks up on variations in the amount of radiation coming through the material: when material is thinner, has a lower density or a lower concentration level, more radiation passes through it, and vice versa. The variations detected in this way can be used to determine and measure relevant characteristics. In many cases, these gauges can operate without direct contact and can pass through opaque walls or materials. They play a vital role in the production and maintenance of materials and structures without causing them damage or leaving behind any radioactive residue.

Culture meets nuclear in Brazil

By Laura Gil

Scientists use radiation techniques to treat cultural artefacts like this damaged book and help improve their durability.

(Photo: Institute of Brazilian Studies — IEB/USP)

Art conservationists and nuclear scientists may make an unlikely team, but in Brazil these specialists have joined forces to harness nuclear technology to preserve more than 20 000 cultural artefacts.

“By merging these two worlds together, we are preserving our heritage and uncovering details about our past in a way we had never done before,” said Pablo Vasquez, researcher and manager of the multipurpose gamma irradiation facility at the Nuclear and Energy Research Institute (IPEN) in São Paulo. “Radiation technology has become an essential part of our conservation process.”

The multi-disciplinary group at IPEN has worked with the IAEA for more than 15 years to use radiation techniques to treat, analyze and preserve cultural artefacts ranging from art pieces to old military paraphernalia to public document archives (see The Science box). Among these are well-known pieces from artists such as Anatol Wladyslaw and Wassily Kandinsky, as well as modern Brazilian painters such as Tarsila do Amaral, Anita Malfatti, Di Cavalcanti, Clóvis Graciano, Candido Portinari and Alfredo Volpi.

From medical devices to cultural heritage

The team repurposed the IPEN irradiation facility that was originally used for sterilization of medical devices, so that it could also use gamma irradiation on historical objects to disinfect them, fight mould and insect infestations, and help improve the durability of these artefacts.

This technique helps to protect artefacts from the effects of the country’s climate, Vasquez explained. “The problem in Brazil is the weather, the humidity and natural disasters. We have a larger amount of fungi and termites than other countries do, and these can be destructive to books, paintings, wooden pieces, furniture, sculptures and modern art.”

Using gamma radiation is a much less invasive way to disinfect pieces than using conventional methods, explained Sunil Sabharwal, a radiation processing specialist at the IAEA. “Using gamma rays is a better alternative because it is done at room temperature using no additional substances, unlike conventional decontamination methods that often involve heat or chemicals that can alter material,” he said.

Uncovering clues buried in artefacts

Before treating a piece, the team analyzes it using various nuclear and conventional techniques including radiography, X-ray fluorescence and X-ray diffraction (see The Science box). This process uncovers details buried in the pieces, such as the kind of pigment or metals the artist used. This helps the team identify the most appropriate preservation method.

“By merging these two worlds together, we are preserving our heritage and uncovering details about our past in a way we had never done before.”

— Pablo Vasquez, Manager, Nuclear and Energy Research Institute, Brazil

Scientists used these analytical techniques to study a pre-Hispanic canvas from the collections of the Palace of the State Government of São Paulo. They took measurements that helped them determine the kind of paint the artist used and uncover details of how the piece of art had previously been restored. They also found hidden drawings under the original painting.

A hub of knowledge

Today the IPEN team's decades of experience is a main source of knowledge for many experts in the region and around the world. In 2016, IPEN staff were involved in the first ever training course on this topic for Latin American experts. Organized by the IAEA, the course brought together conservators, restorers, museologists, librarians, curators and radiologists from ten countries in the region to learn about the different applications of radiation technologies in cultural heritage.

IPEN now has a long list of requests for support. Its staff work on objects from different countries and regularly train foreign scientists and cultural experts.

Many objects from the Afro Brazil Museum in São Paulo, Brazil, have been treated with gamma irradiation at the Nuclear and Energy Research Institute (IPEN).

(Photo: L. Potterton/IAEA)

An interesting project in the pipeline, said Vasquez, is the possibility of bringing three mummies that have been attacked by insects and fungi to the institute for treatment from Ecuador. The IAEA is supporting this project with expertise and training.

"I am glad that experts and international organizations are placing more and more importance on preserving cultural heritage because our heritage is what represents the identity of our people," Vasquez said. "We must continue to work to protect it."

THE SCIENCE

Gamma irradiation and X-ray diffraction (XRD)

Gamma radiation, also known as gamma rays, refers to electromagnetic radiation of an extremely high frequency. It is emitted as high energy photons, an elementary particle with wave-like properties. A chemical element called cobalt-60 is a commonly used source of gamma radiation.

Gamma rays are a type of ionizing radiation. At the dose levels used to protect cultural artefacts, this type of ionizing radiation inhibits reproduction of microbes at room temperature without any physical contact. The high frequency, high energy electromagnetic waves interact with the critical components of cells. And at these dose levels, they can alter the DNA so as to inhibit the reproduction of cells.

This process of inhibiting cell reproduction helps to kill off unwanted insect and mould infestations. At the right dose levels, it can also be used to reinforce and consolidate the resins that specialists use to cover the porous materials of artefacts to protect them and give them a second life.

X-ray diffraction is a non-destructive, highly sensitive technique that relies on X-rays to uncover information about crystalline materials. Crystalline materials are solid materials, such as glass and silicon, whose constituents are arranged in a highly ordered microscopic structure. The technique is beneficial in that it can be used in very small samples of many different types of crystalline materials.

Scientists expose a crystalline material to X-rays, and as the X-rays interact with the atoms of the crystals in the material, they scatter and produce an interference effect called a diffraction pattern. This pattern can provide information on the structure of the crystal or the identity of a crystalline substance, which helps scientists characterize and exactly identify the crystalline structure of an object.

Creating safer, cleaner materials through nuclear processing

By Andrew Green

This bandage has a hydrogel sheet that promotes wound healing and is easier and less painful to remove.
(Photo: S. Henriques/IAEA)

From water filters and lampshades to the soles of shoes and medical bandages, an increasing number of consumer products are now being manufactured with new materials produced using nuclear techniques.

"New developments in the processing of certain polymers are improving productivity and leading to a reduced burden on the environment," said Masao Tamada, Director General of the Takasaki Advanced Radiation Research Institute in the Nuclear Science Research Sector at the Japan Atomic Energy Agency and a renowned expert in the field.

"New developments in the processing of certain polymers are improving productivity and leading to a reduced burden on the environment."

— Masao Tamada, Director General, Takasaki Advanced Radiation Research Institute, Japan

The IAEA provides a platform for cooperation in this area, by supporting experienced experts such as Tamada to train professionals from other countries in the development of these specialized plastic and gel-based materials.

Leading an IAEA regional training course in Malaysia in August 2016, Tamada taught advanced methods of radiation grafting for environmental and industrial applications to participants from Bangladesh, China, India, Indonesia, Malaysia, Myanmar, Pakistan, the Philippines, the Republic of South Korea, Sri Lanka, Thailand and Viet Nam. In an earlier IAEA workshop, Tamada prepared a protocol for specialized methods in radiation grafting, which is now accessible online.

New medical applications of radiation-processed polymers

By using radiation, such as gamma rays, X-rays, accelerated electrons or ion beams, polymers such as plastics or gel-based materials can be modified or strengthened to create new and more resistant bond formations (see The Science box). Strengthening and improving polymers with radiation is a technique that has been used for decades to produce commercial products such as heat-resistant parts in car engines and heat-shrinkable tubes, foam sheets and tyres.

New developments in the radiation processing industry are leading to more novel and innovative uses of irradiated polymers, such as hydrogel sheets for use in medicine to manage burns and wounds, as well as in radiotherapy to treat cancer.

"Hydrogel sheets with high water concentration, which are created by using radiation to cross-link materials, enable wounds to heal faster than if the sheets were dry," explained Tamada. "Only by using irradiation to cross-link polymers are we able to produce such elastic hydrogels with high water concentration."

The same clear and transparent gels can be used in radiotherapy to help measure and maintain safe and effective doses of radiation, an area known as dosimetry. The hydrogel sheets can be used to identify simultaneously both radiation levels and the areas exposed to radiation, which may vary from patient to patient. This is helpful to know when preparing radiotherapy sessions, noted Tamada.

"The sheets can also be removed with less pain than conventional medical gauze, and because they are transparent, medical hydrogels allow continuous monitoring of the healing process," said Tamada.

Hydrogel bandages created using radiation can be used to treat burns and wounds.
(Photo: S. Henriques/IAEA)

THE SCIENCE

Cross-linking polymers with radiation

Plastic and gel-based materials are formed using polymer chains that are cross-linked and sterilized using gamma radiation or electron beams. The polymers are mixed in water, put into moulds or tubes, packaged, sealed and then cross-linked and sterilized through exposure to radiation. Radiation cross-linking techniques are also much safer than chemical techniques. No impurities are created because no chemicals are used. The radiation can break down chemical bonds and create new ones that change the chemical, physical, and biological properties of a material without additional chemical processing and without making the material radioactive. This makes it possible to redesign polymers at the molecular level to serve a specific purpose.

In the case of hydrogels, the cross-linking results in the polymers connecting to form a gel. The gel formed is strong, pliable and transparent. Hydrogels for wound dressings contain 70–95% water and are biocompatible. They do not stick to the wound; they keep the wound moist to aid recovery, absorb the excreta and are also easy to store and use.

The cross-linked polymers inside this white wound dressing have been formed into a gel that contains 70-95% water and is biocompatible.
(Photo: S. Henriques/IAEA)

Building momentum in radiation science through collaboration

By Nicole Jawerth

The diverse ways radiation is used today are the result of one scientist's research and expertise building on and feeding into that of another, and together these results translating into innovative, practical applications that touch people's everyday lives. One way scientists connect today is through IAEA Collaborating Centres.

To get a glimpse into the work of an IAEA Collaborating Centre in radiation science and technology, Suresh Pillai, Director of the National Center for Electron Beam Research and a professor of microbiology and molecular biology at the Texas A&M University answered a few questions for the IAEA Bulletin about his centre and its designation as an IAEA Collaborating Centre. He explained how their work contributes to the use of electron beam technology for food, health and environmental applications, and how it functions as a platform for researchers from about ten countries. He also talks about the future and some of the innovative research being done at his centre.

Q: What does it mean to be a designated IAEA Collaborating Centre?

A: We have worked on the development and commercialization of electron beam technologies for the past 15 years. We do not-for-profit work, and our services equate to around US $1–2 million worth of electron beam activities each year, both commercially as a model for industry to adopt and for research and development (R&D).

Being an IAEA Collaborating Centre is one way for us to move beyond merely publishing high-quality research towards ensuring our work has global ramifications. We maintain a strong connection with the IAEA and take part in its technical and coordinated research projects. These help us to connect our expertise with the people on the ground who might need it. They also allow us to establish strong connections with other scientists around the world, helping us to stay at the forefront of what is happening in the field and to keep an overview of where it is headed.

"Being an IAEA Collaborating Centre is one way for us to move beyond merely publishing high-quality research towards ensuring our work has global ramifications."

—Suresh Pillai, Director, National Center for Electron Beam Research, Texas A&M University, USA

Q: What does your institute do as a Collaborating Centre?

A: Our mandate is broad. Our work is primarily focused on three areas: raising awareness to encourage a greater understanding and use of electron beam technology; providing guidance and expertise to countries, companies, entities, and individuals to help them adopt and commercialize this technology; and continuing to push the proverbial envelope in research to add value to products and people's lives.

We do this by hosting IAEA-sponsored visiting scientists, travelling to other countries involved in IAEA projects to provide expertise, and organizing workshops involving IAEA-sponsored participants, including at our annual, one-of-a-kind hands-on electron beam technology workshop, where scientists actually work with the technology and learn how to use it.

One of the projects we have recently worked on was through an IAEA technical cooperation project for Latin America. We worked with a small industrial group in Mexico who built the first commercial electron beam facility in Tijuana, which just opened in February 2017. In the span of two to three years, we educated them in all the nuances of the technology, in everything from training people, all the way to building a sustainable business. We helped them set up collaborations with other local institutes. In this project, the IAEA helped provide guidance to officials and facilitate connections between experts around Latin America and in Mexico.

Q: What are electron beams and how does your institute use them?

A: Electron beams are streams of highly energetic electrons, which are produced with specialized equipment such as linear accelerators.We use electron beams to conduct research that can be used to clean, heal, feed and shape the world and beyond.

For cleaning, we use it for environmental remediation research, whether for wastewater treatment, drinking water treatment, or water reuse. For healing, we do research to formulate advanced vaccines and sterilize advanced pharmaceuticals and medical devices. For feeding, we use it in research to enhance food quality, safety and security, including food defence where this technology is used to decontaminate deliberately contaminated food. For 'shaping', we perform research on how to use the beams to make advanced materials that range from traditional polymers to very advanced nanomaterials and nanocomposites. This shaping also involves developing commercial applications and doing advanced R&D, including in space, through our close work with the National Aeronautics and Space Administration (NASA) on advanced applications for electron beam technology for manned and unmanned space missions.

Q: What are the advantages of using electron beams instead of other methods?

A: Electron beams are one of the cheapest and most organic approaches to creating free radicals. Electron beams don't require us to introduce chemicals or heat to effect changes in materials as other methods do, and they have a much lower carbon footprint. Also, other ionizing radiation technologies don't have the same simple switch-on, switch-off dimension.

Because they do not rely on a radioactive source and because they are able to be switched on and off, electron beams allow us to continue to develop radiation-based applications without having to fear any sort of nuclear proliferation, theft or nuclear exposure. This is very important in the security-conscious world in which we now live.

Q: What is one of the coolest things your institute is working on?

A: There are two areas I am really interested in. One is the development of vaccines for human and animal health. All the research we're doing on infectious diseases tells us that we are only scratching the surface of the potential for high value vaccines with this technology. We now know we can create very high value, high potency vaccines for different infectious diseases in humans and animals. That is very exciting for us.

The other area is in environmental remediation. Be it chemical pollutants in groundwater or municipal waste, we know that compared to other technologies out there today, electron beam technology will be a change agent. A change agent comes with a lot of challenges, but as you know, it is capable of flipping the entire industry on its head. How we look at waste would be to no longer call it a wastewater treatment plant, but instead something like a "resource recovery facility", where the connotation of waste is taken away and instead every drop of water that leaves a home or an industry is looked at as something that can be mined for energy and other resources.

Radiation technology for development: How the IAEA helps

By Meera Venkatesh, Director of the Division of Physical and Chemical Sciences, IAEA

Radiation, when used wisely and with the right safety precautions, can work wonders for our lives and the environment, making our world a safer, healthier and more secure place to live. If you look around, you will see ways radiation has touched your life too — from the energy shining from the sun to the hygienic food on your plate. Here at the IAEA, we work with countries around the world to help spread the peaceful use of radiation technology for the benefit of all.

There are many different tools and approaches a country can use to meet its development goals and challenges, and for many countries radiation technology is increasingly becoming part of the solution. Indeed, it is recognized as one of the most environmentally friendly and cost-effective options. Its many applications make it well suited for the diverse work required for achieving the United Nations Sustainable Development Goals (SDGs) and their comprehensive set of targets, which range from health and the environment to industry and infrastructure.

(Photo: N. Jawerth/IAEA)

Radiation can be used to break down living cells to treat diseases like cancer, fight harmful pathogens in food and sterilize surgical tools and medical supplies. Radiation can enable us to destroy pollutants in water, in the air and in the ground before they contaminate the environment. Other waste materials, such as bagasse — the fibrous matter from the sugar industry — or the shells of seafood such as prawns, can be tackled by using radiation technology to convert them into biodegradable and more eco-friendly materials, such as food packaging or high-quality nutrients used for farming. Radiation can also be used to join up and link molecules to make stronger, more sustainable cables and wires and create high performance materials and coatings that we use in our homes and cars and in industries worldwide.

We can even use radiation to help us 'see' the 'invisible' interiors of buildings and machinery to ensure they are still structurally sound and safe, especially after natural disasters. Every time you go to the airport you see an example of radiation technology in action, as officers scan people and baggage to ensure security. These are just a few examples highlighting how diverse the use of radiation technology can be.

To tap into the potential of radiation technology and science, countries require highly skilled professionals and the right equipment. Through IAEA support, many countries are able to get the necessary training and education courses, expert guidance and equipment they need to adopt this technology. Hundreds of scientists from institutes and organizations in both developed and developing countries also work together through IAEA coordinated research projects that advance scientific research.

These projects often result in significant practical applications, many of which are then also included in the work done through the IAEA's technical cooperation programme to transfer nuclear technology to where it is needed. This comprehensive support is


(Photo: L. Potterton/IAEA)

important for many countries, particularly for low and middle income countries that face resource constraints.

A platform for research, innovation and progress

The many uses of radiation technology stem from decades of research and development in radiation science, but as with any area of science, this work is not done in isolation. Collaboration is a vital way for countries to exchange ideas and make the most of this technology. Through IAEA meetings, events and conferences, such as the International Conference on Applications of Radiation Science and Technology (ICARST), being held from 24 to 28 April 2017, scientists, experts and industry specialists are able to connect with one another and learn from each other's experiences. These connections are a key ingredient to making advances in the field, identifying best practices and finding new and innovative ways to apply these powerful tools.

It is in part through strong partnerships between academia and industry that research in radiation science and technology can move out beyond the walls of laboratories and into factories and businesses worldwide.

The IAEA helps to facilitate strategic and public–private partnerships through national, regional and global initiatives. When scientists and experts team up with industry specialists, technology can be scaled up and, in many cases, commercialized. The result is that the benefits of radiation technology now reach people everywhere through the products used on a daily basis.

Use safely and securely

While radiation technology can help open many doors to a better future, these doors can only open when this technology is used safely and securely. Building a system of safety and security goes hand in hand with adopting radiation technology. Many countries work with IAEA support to build a system of regulations and policies that reflect internationally agreed safety and security standards. They also draw on the IAEA's support to establish appropriate quality regulations and get the necessary training and certification for personnel. In the hands of well-trained professionals working in a safe and secure manner, radiation technologies have tremendous potential to help in improving the lives of people and boosting the industrialization and development of countries worldwide.

IAEA Briefs: new series for policymakers

The IAEA has launched a new publication series — IAEA Briefs — to inform decision makers about how they can best make use of its services to enhance capacity and support development. Launched in autumn 2016, IAEA Briefs cover a wide range of topics relating to the applications of nuclear science and technology and also offer recommendations for consideration to IAEA Member States.

The Briefs also cover region-specific issues. The IAEA Brief *Enhancing Patient Care In Africa Through Safe Medical Imaging* highlights the importance of having well-qualified medical physicists in Africa to handle high-tech medical imaging equipment such as multi-slice helical computed tomography (CT) scanners.

Another IAEA Brief, *Detecting and Treating Cervical Cancer Using Diagnostic Imaging Techniques and Radiotherapy,* focuses on the IAEA's support to Member States in Latin America and the Caribbean, and how nuclear medicine and radiation therapy can offer rapid diagnosis and effective treatment for various types of cancer, including cervical cancer. The document details IAEA assistance available to Member States to enhance their national cancer care programmes for cervical cancer through training, expert assistance, fellowships and the procurement of equipment.

The third in the IAEA Brief series, *Using Nuclear Techniques to Assess Breastfeeding Practices for Better Nutrition and Health,* draws attention to the use of stable isotope techniques to help evaluate activities to improve infant and young child feeding practices. The Brief provides information about various IAEA projects in Member States to help them acquire competencies in applying these techniques, which can provide accurate and objective data on breastfeeding practices.

The IAEA plans to continue adding to its collection of Briefs and Factsheets.

IAEA Factsheets

The IAEA is also updating its collection of factsheets and has included new information of interest. The factsheets highlight the IAEA's multi-dimensional work in the peaceful applications of nuclear technology in energy, health, industry, food and agriculture, nuclear safety and security, and safeguards and verification. For example, under the theme of nuclear safety and security, factsheets are available on a range of areas, including computer and information security, the Convention on the Physical Protection of Nuclear Material and its Amendment, and nuclear forensics.

Another factsheet explaining the IAEA's support and activities to fight disease-transmitting mosquitoes can be found under the health theme, entitled: *The Zika Virus Mosquitoes: How can the sterile insect technique help?*

Access the IAEA Briefs and the collection of factsheets online, here: iaea.org/publications/factsheets

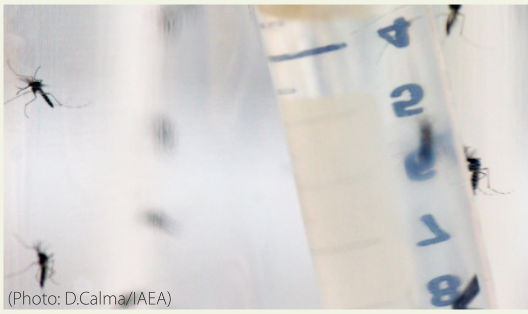
— By Aabha Dixit

New method advances research on controlling mosquitoes using nuclear techniques

A pioneering method unveiled in December 2016 for separating male and female mosquitoes could be a major step towards using the nuclear-based sterile insect technique (SIT) to control the insects that transmit diseases such as Zika, dengue and chikunguya.

SIT involves using ionizing radiation to sterilize mass-reared insects of the target pest and then releasing them into nature where they mate with wild insects, resulting in no offspring and, over time, reducing the overall insect population. SIT has been employed successfully in over 40 countries against agricultural pests such as fruit flies, tsetse flies, screwworm and moth pests, and research on its application against Aedes mosquitoes has intensified in the wake of the Zika crisis last year. The IAEA, in partnership with the Food and Agriculture Organization of the United Nations (FAO), is spearheading global research in the development and application of SIT, including against Aedes mosquitoes.

The main challenge facing researchers in scaling up the use of SIT against various species of mosquitoes has been the lack of a reliable method to remove females from among the mosquitoes that are released. Eliminating females before release is crucial to the use of SIT against mosquitoes, because it is the bites by female mosquitoes that transfer diseases.


(Photo: D.Calma/IAEA)

In countries where the use of SIT against Aedes mosquitoes is being tested or where testing is planned, such as Brazil, China and Mexico, a manual method is used to separate males from females. Female pupae — in the lifecycle of the insect, this is the stage between larvae and adult — are larger than male pupae, offering a way to distinguish and remove females before release. However, this method is very labour-intensive and is therefore not practical for upscaling to the tens of millions of mosquitoes that would be required in order to use SIT at the a larger scale needed to protect cities from disease transmission, said Rui Cardoso-Pereira, an SIT expert at the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

Finding alternative methods for what insiders call the ‘sexing’ of mosquitoes is the focus of an ongoing five-year coordinated research project that began in 2013 under the auspices of the Joint FAO/IAEA Division, with the participation of experts from 13 countries.

No optical illusion

Researchers at TRAGSA, the Spanish government’s institution focusing on environmental sciences and services, have now built the prototype of a device capable of differentiating male and female mosquitoes using via artificial vision technology and then eliminating the females using laser beams. The device consists of a rotating disk to distribute the mass-reared pupae, which are than analysed using software that can distinguish the sexes based on size, explained Ignacio Plá Mora of TRAGSA’s Pest Control Department.

The preliminary results of the tests conducted have shown that 99.7% of the females were eliminated, while up to 80% of the males survived and could be released, Plá Mora said. “The results achieved are highly satisfactory compared to those obtained by the manual methods that are currently used,” he said.

While the prototype can process a million Aedes males a day, it still does not quite scale up to the level of industrial production required at a regional scale. However, it will be satisfactory for projects targeting individual towns or villages, particularly in countries where the labour costs associated with manual sorting of mosquito pupae are prohibitive, said Cardoso-Pereira. Further research to perfect the method is ongoing, in order to eliminate fewer males and to scale it up further.

TRAGSA’s participation in the coordinated research project has helped it in the development of the new method. “When top experts in an area work together, everyone’s research accelerates,” Cardoso-Pereira said.

— By Miklos Gaspar

Armenia’s physics research legacy saved through pixels

More than 1000 destroyed research papers on high-energy physics and astrophysics have been recovered in Armenia thanks to digital copies saved at the IAEA’s International Nuclear Information System (INIS).

For over 25 years, thousands of research papers held by the library of the inadequately-funded Yerevan Physics Institute (YerPhI) were locked away in dusty storage rooms. They had become so dirty that it was impossible for them to be cleaned without causing damage.

“In the 60s, 70s and 80s we distributed our research papers to all large laboratories and transferred them to the IAEA,” said Ashot Chilingarian, Director of YerPhI. “Fortunately, INIS had digitized and preserved all the archives, which are now accessible to us in digital form. They have been literally saved.”

In May 2016, after YerPhI was granted the status of National Laboratory, its management asked the IAEA for help to reconstruct the old archives. IAEA staff provided YerPhI with the research papers in digital form and helped them to set up a digital scientific repository. Through the repository, the team has made all the recovered research papers available online at ivenio.yerphi.am.

Scientists at YerPhI conduct research in the fields of high-energy physics and astrophysics and collaborate with international partners using the world’s biggest accelerators and cosmic ray detectors, Chilingarian said. They have been collaborating in international experiments since the 1980s. Today YerPhI publishes approximately 30% of Armenia’s research papers and plans to add all new research publications to the repository.

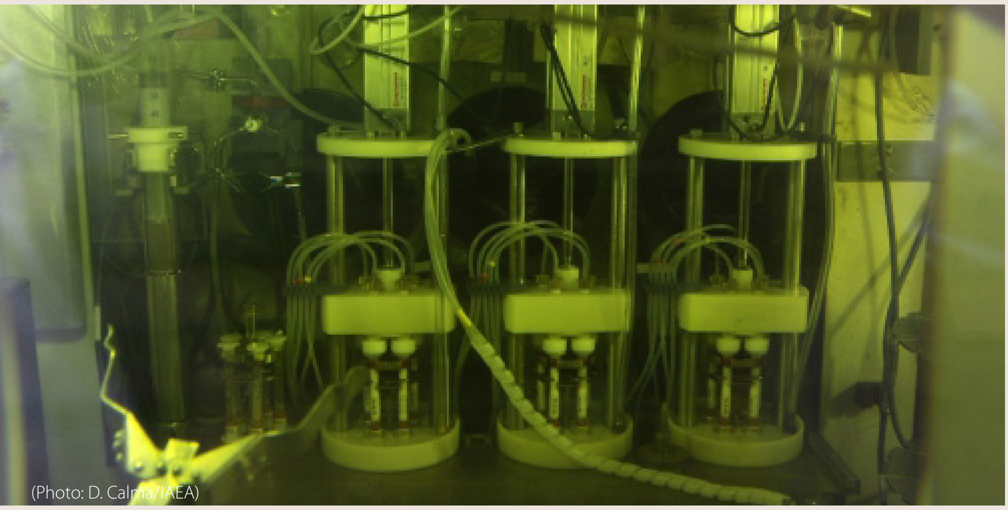
“The project has not only allowed YerPhI to acquire and reuse the lost scientific information, but has also introduced modern technologies to support the operation of Armenia’s research facilities,” said Zaven Hakopov, INIS coordinator at the IAEA. Based on Armenia’s example, the IAEA plans to assist more countries to create national nuclear information repositories to stimulate research and development, he added.

(Photo: YerPhI)

INIS is operated by the IAEA and hosts one of the world’s largest collections of published information on nuclear science and technology. It contains four million bibliographic records accessed by over two million users worldwide every year. Through INIS, the IAEA is able to gather nuclear data, information and knowledge resources on the peaceful use of nuclear energy and makes this available to its Member States, contributing to advancing research and development and helping countries achieve the United Nations Sustainable Development Goals.

— By Laura Gil

Alternative technology could boost production of Mo-99



(Photo: D. Calma/IAEA)

An alternative method for producing molybdenum-99 (Mo-99) could help to increase supply of this key isotope that is used to provide essential health care to millions of patients worldwide, revealed a paper published in the *Journal of Radioanalytical and Nuclear Chemistry* that was based on IAEA-supported research and co-authored by an IAEA expert.

As the major research reactors that supply Mo-99 age and cease production, the alternative method discussed in the paper offers a simplified way to diversify production and help ensure continued supplies of Mo-99 so that nuclear medicine services are not interrupted.

Troubles in the past

In 2009, reactors producing Mo-99 in Canada and the Netherlands were temporarily shut down for necessary repairs and maintenance. This caused major disruption in health care services worldwide, leading to cancelled medical scans and postponed operations, and in some cases requiring medical professionals to revert back to using old, less effective techniques. Although supply conditions have since improved, health officials and scientists have been looking into alternatives to address what the US National Academies of Sciences, Engineering and Medicine 2016 report, *Molybdenum-99 for Medical Imaging,* called 'supply vulnerabilities'.

"This disruption was really a wake-up call that something needed to be changed in how we are producing Mo-99," said Danas Ridikas, Research Reactor Specialist at the IAEA and co-author of the paper. "Diversification of how and where Mo-99 is produced, increased efficiency in the way the isotope is used, and devising a business model to recover production costs have all become essential to ensuring a continued, stable and economically viable supply of Mo-99."

Mo-99 is the parent isotope of technetium-99m (Tc-99m), the most widely used radionuclide for medical imaging. Because Tc-99m is unstable and decays quickly, its more stable parent isotope is produced and transported to hospitals.

With one research reactor in Canada ceasing production in October 2016, and another large producer in the Netherlands scheduled to go offline by 2024, finding alternative production methods is becoming increasingly critical, Ridikas explained. Producing Mo-99 by irradiating natural or enriched molybdenum is one of the lesser-used yet viable alternatives for fulfilling domestic needs, in particular for countries with research reactor facilities, he said.

Irradiating molybdenum

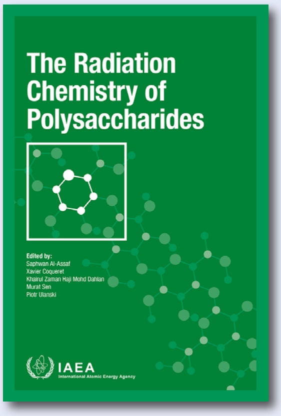
This technique, already in use in Chile, India, Kazakhstan, Peru, Russia and Uzbekistan, involves a simpler production process and generates less radioactive waste than the traditional method of producing Mo-99 through fission from uranium. It can also allow better use to be made of research reactors. Several countries, including Jordan, Mexico and Morocco, are considering implementing the technique.

While the new method shows potential, experts are still evaluating its efficiency. In December 2015, an IAEA workshop on the subject brought together experts from 15 research reactor facilities in 12 countries to explore the method and its feasibility. Experiments to irradiate natural molybdenum targets, carried out in several research reactors with IAEA support, clearly showed that when Mo-99 was obtained through irradiation there was less Mo-99 produced per gram of material irradiated than was the case with the fission method. However, the amount obtained should still be sufficient to meet local needs in several countries.

Although irradiating enriched molybdenum would yield a higher ratio of Mo-99, it would require a more expensive raw material, so using natural molybdenum, despite the lower yield, may be preferable, Ridikas explained. "The cost-effectiveness of irradiation and processing, compared to the fission method, still needs to be determined."

The lessons learned from the workshop and data on the approximate production capacities of the reactors formed the basis of a paper published by Ridikas and several other scientists in the *Journal of Radioanalytical and Nuclear Chemistry*. They also serve as a platform for continued research. A related workshop on irradiated target processing and preparation of technetium-99m generators, based on Mo-99 production by neutron capture, will be organized by the IAEA in 2017 in Kazakhstan.

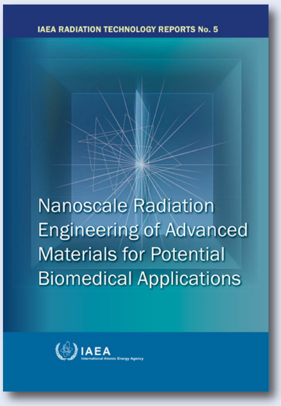
— By Jeremy Li



The Radiation Chemistry of Polysaccharides

provides the background and compiles the most recent research findings and details activities relating to the development of radiation processed products made of natural polymers. Successes clearly indicate that the radiation processing of natural polymers has emerged as an exciting area where the unique characteristics of these polymeric materials can be exploited for a variety of practical applications in agriculture, healthcare, industry and the environment.

Non-serial Publications; ISBN:978-92-0-101516-7; English Edition; 75.00 euro; 2016
www-pub.iaea.org/books/iaeabooks/10843/Poly



Nanoscale Radiation Engineering of Advanced Materials for Potential Biomedical Applications

presents the results of an IAEA coordinated research project on nanoscale radiation engineering of advanced materials for potential biomedical applications, summarizing the achievements of the participating institutions.

IAEA Radiation Technology Reports No. 5; ISBN:978-92-0-101815-1; English Edition; 49.00 euro; 2015
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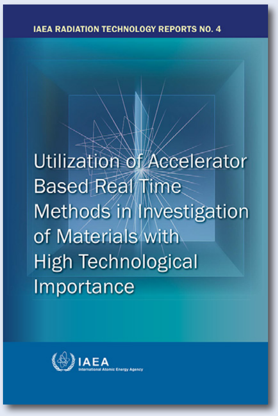
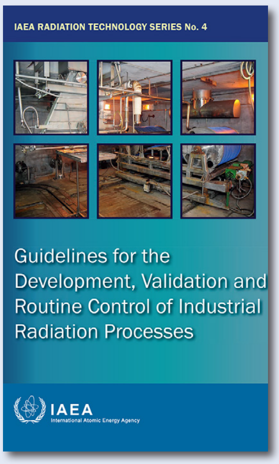


Utilization of Accelerator Based Real Time Methods in Investigation of Materials with High Technological Importance

presents the state of the art in the development and application of various accelerator based real time techniques to materials investigation. It reports examples of multidisciplinary scientific topics and challenges where application of accelerator based methods would bring significant benefits in terms of research data and further understanding of the scientific issues. The research activities that can profit from real time material characterizations using synchrotron radiation, neutron, ion and electron beams, and simultaneous combinations of different techniques are also briefly discussed. A recurrent theme emerging from the presented papers is that further work is needed to develop more robust and longer working life materials for energy applications.

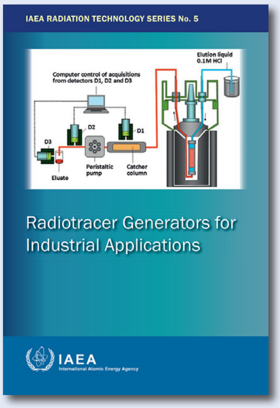
IAEA Radiation Technology Reports No. 4; ISBN:978-92-0-102314-8; English Edition; 37.00 euro; 2015
www-pub.iaea.org/books/IAEABooks/10490/RTM



Guidelines for Development, Validation and Routine Control of Industrial Radiation Processes

provides guidance that has been developed based on requests from Member States to provide guidance on fulfilling the requirements of the International Standard for Development, Validation and Routine Control for a Radiation Process, published by the International Organization for Standardization (ISO). While the ISO standard was developed for the sterilization of healthcare products, the present guidelines are generalized and are therefore relevant to any radiation process. This is possible since the principles involved in regulating a radiation process for achieving quality products are generally the same for any product or application. In several places, additional information has been included to provide insight into the radiation process that could help irradiator operators and their quality managers to provide better services to their customers.

IAEA Radiation Technology Series No. 4; ISBN:978-92-0-135710-6; English Edition; 29.00 euro; 2013
www-pub.iaea.org/books/IAEABooks/8676/Industrial



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IAEA Radiation Technology Series No. 5; ISBN:978-92-0-135410-5; English Edition; 34.00 euro; 2013
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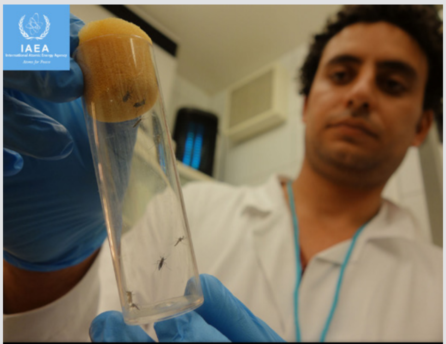

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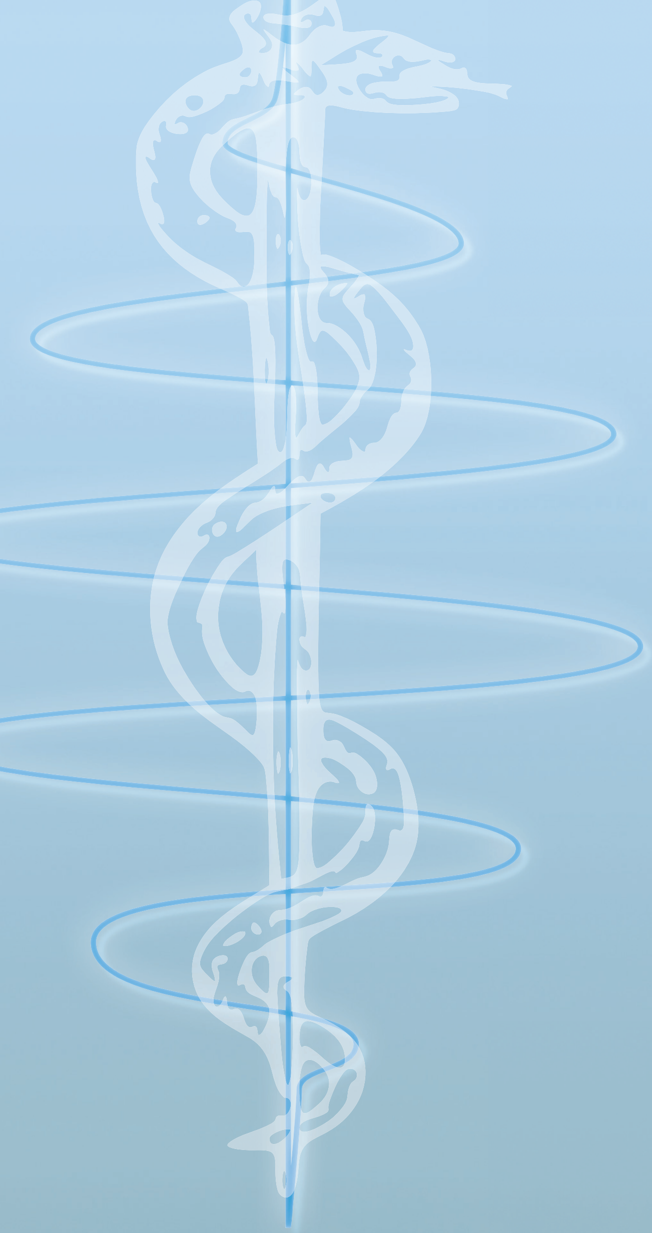

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