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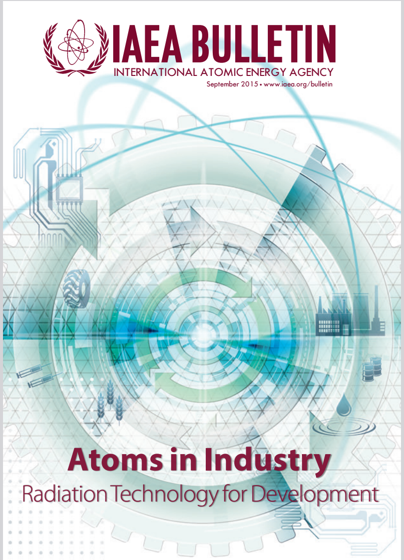
Atoms in Industry

Radiation Technology for Development



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is produced by the
Office of Public Information
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International Atomic Energy Agency
PO Box 100, 1400 Vienna, Austria
Phone: (43-1) 2600-21270
Fax: (43-1) 2600-29610
iaeabulletin@iaea.org

Editor: Miklos Gaspar
Managing Editor: Aabha Dixit
Contributing Editor: Nicole Jawerth
Design & Production: Ritu Kenn

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IAEA

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

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

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

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

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

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

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

Atoms in industry: radiation technology supports development

By Yukiya Amano, Director General, IAEA

Cutting-edge industrial technologies underpin the success of strong economies, in developed and developing countries alike. Nuclear science and technology, in particular, can make a major contribution to economic growth and competitiveness, and have an important role to play in support of sustainable development. The IAEA helps to make nuclear science and technology available to enable countries to pursue wider development objectives in areas including human health, agriculture, natural resource management and environmental protection. This edition of the *IAEA Bulletin* highlights some of the ways in which the technology is being put to effective use in industry.

Radiation technologies are part of our everyday lives. Buildings, pipes, medical devices and car parts are just some of the items treated and tested with radiation in a controlled and safe manner during manufacturing. Such procedures increase product quality and safety, benefiting both manufacturers and consumers. As the articles in this issue of the *Bulletin* demonstrate, radiation technologies often offer a more environmentally friendly approach than traditional alternatives, requiring less energy and generating less waste.

As their populations grow, low and middle income countries need to find ways to step up their industrial development to boost production and meet consumer demand in sustainable ways. Nuclear technologies can help make these processes more cost effective, as well as safer for the environment, and lead to better products that will ultimately benefit society.

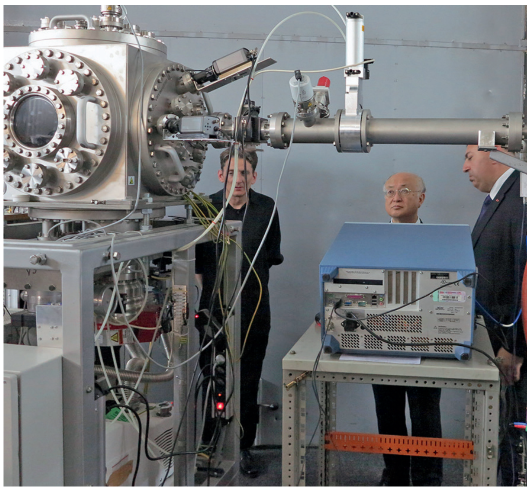
Making radiation technologies available to Member States and assisting them in the peaceful use of these technologies are an important part of the IAEA's work. Through technical cooperation projects, coordinated research activities and scientific meetings, hundreds of scientists and experts from all over the world work together to further improve radiation technologies and make them accessible to industry. In the last few years, this technical cooperation has also stimulated South–South cooperation among developing countries: Malaysia helps Sudan in non-destructive testing techniques, and Viet Nam transfers radiotracer technology to Angola, to name just two examples covered in this issue.

This year's IAEA Scientific Forum showcases some of these technologies and brings together leading experts to discuss the latest trends and best practices. I invite you to follow the proceedings in person in Vienna, or online via www.iaea.org/scientificforum.

"Radiation technologies often offer a more environmentally friendly approach than traditional alternatives, requiring less energy and generating less waste."

— Yukiya Amano, Director General, IAEA

(Photos: C. Brady/IAEA)



Atoms in industry can make a difference: The IAEA Scientific Forum

By Luciana Viegas

Industry has become indispensable to modern life. As the world travels further and faster, cities sprawl into large conglomerates, trade crosses barriers, and friendships are held together by the invisible strings of the Internet, it is hard to imagine a world untouched by large-scale industrial products and processing.

This year's Scientific Forum will focus on the uses of radiation technologies in industry, and how they are applied to control the quality of the products we use in our daily lives, such as car tyres and cables, enhance the durability of a variety of materials, and even sanitize wastewater. Leading experts, academics and industrial representatives will meet in Vienna, Austria, from 15 to 16 September 2015 on the margins of the IAEA General Conference to review the multitude of benefits these techniques offer, particularly in the context of sustainable development.

The Forum will include high-level panel discussions on the following topics:

Battling the bugs

Starting off with the health sector, the Scientific Forum will review how radiation can kill germs to ensure that sterile medical equipment is available for life-saving procedures, help produce more effective vaccines, or make tissue grafts safe for transplants.

Linking the chains

This session will explore how polymers — large synthetic and natural molecules composed of many repeated sub-units — can be made more stable, heat resistant and durable through the use of radiation. These versatile materials are present in many everyday items: for example, around 90 per cent of all materials used to build cars, aeroplanes and computers worldwide contain cross-linked polymers. Such techniques also benefit the medical and cosmetic industries, and even the agricultural sector through products that help plants to grow faster.

Solutions for pollution

Ever-expanding cities and large-scale industry can lead to increasing pollution. This session will look at how radiation techniques have been employed successfully to treat persistent industrial pollutants and to identify contaminating pathways. Several countries have used radiation techniques in assessing and studying environmental processes and in the treatment of wastewater and flue gases, and the Forum will highlight examples in these promising areas.

Tracing the pathways

Radiotracers and nucleonic gauges play an important role in increasing productivity and ensuring quality and reliability of industrial processes and production systems. Experts in this session will share their experiences and discuss how these technologies benefit the petrochemical and mining industries, among others.

Bolstering safety and quality

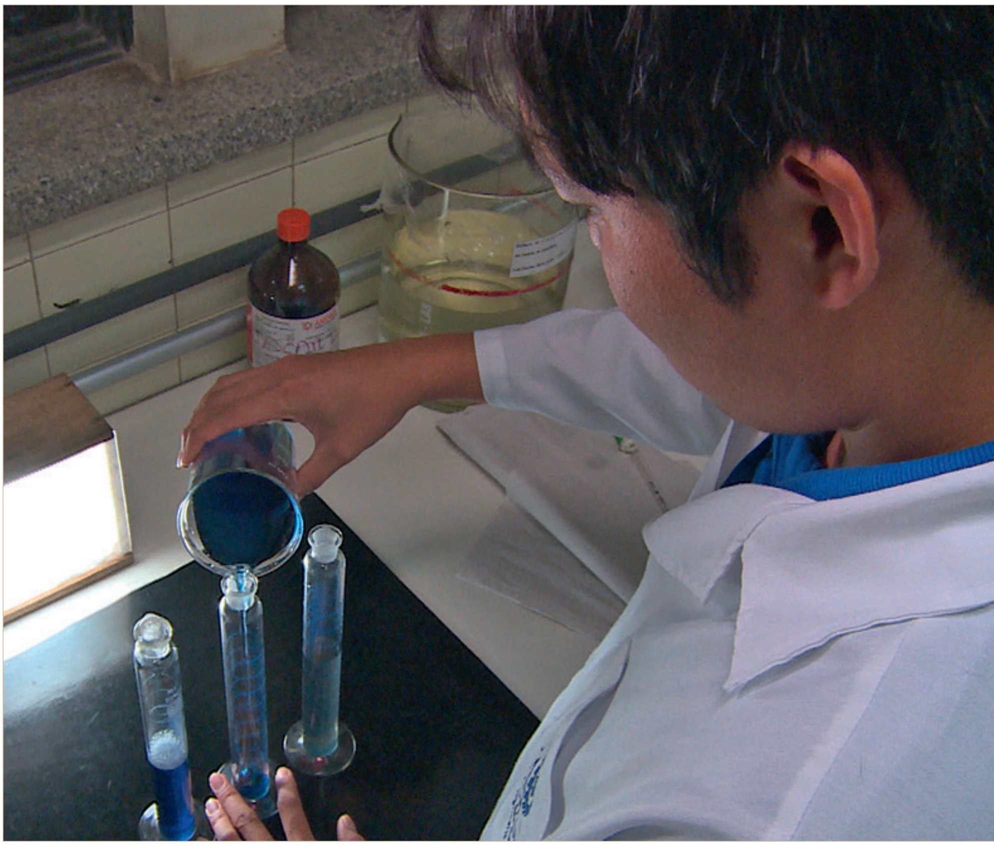
Non-destructive testing (NDT) techniques, including nuclear techniques, are applied extensively in manufacturing and civil engineering. NDT is a quality control tool used to examine the integrity of components, machinery, buildings and structures to ensure their safety and quality. The Forum will explore examples of the application of NDT techniques and share best practices in creating a qualified workforce to carry out NDT testing effectively, which could be vital in many cases, for example when there is a need to quickly test public civil structures for hidden cracks and flaws.

Rays of hope

Radiation technology offers great opportunities for the future of industry, and the Forum's last session will focus on new developments, including in the areas of nanoscale engineering, health, food and agriculture, as well as in the protection and preservation of cultural heritage.

The Forum will conclude with an open discussion about the added value of nuclear techniques in support of development efforts, and offer a chance for countries to share their experiences and hear more about the IAEA's services in this area.

For more information and the latest agenda, see https://www.iaea.org/about/policy/gc/gc59/scientific-forum. The page will be regularly updated throughout the event to provide summaries of the sessions.



(Photos: IAEA)

Better health care: Ghana uses radiation technology to sterilize medical items

By Aabha Dixit

> "Our country recognized the immense potential and usefulness of the technology of radiation processing for development in a number of fields, including in the medical sector to enhance health care. That is why Ghana was eager to have such technology available."
>
> *— Abraham Adu-Gyamfi, Manager, Radiation Technology Centre, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission*

Infections acquired from improperly sterilized equipment are recognized as a major impediment to safe health care delivery, with consequences that are often deadly for patients. Radiation technology plays a major role in many countries in making medical equipment safer. "The use of nuclear applications, such as exposing medical items to gamma radiation, helps Ghana protect its people from avoidable sicknesses that can occur if items like syringes are not properly sterilized," said Abraham Adu-Gyamfi, Manager of the Radiation Technology Centre of the Ghana Atomic Energy Commission's Biotechnology and Nuclear Agriculture Research Institute in Accra.

"Our country recognized the immense potential and usefulness of the technology of radiation processing for development in a number of fields, including in the medical sector to enhance health care. That is why Ghana was eager to have such technology available," Adu-Gyamfi said. Radiation technology has improved the hygienic quality of medical items, he explained, particularly items made of plastics, which are difficult to sterilize with heat and other conventional methods (see box).

Abraham Adu-Gyamfi (center) and technicians at the gamma irradiation facility.
(Photo: Ghana Radiation Technology Centre)

Short exposure eliminates viruses and bacteria

With the support of the IAEA, Ghana is working to improve its health care systems by ensuring safe medical supplies using modern nuclear science and technology, said Sunil Sabharwal, a radiation processing specialist at the IAEA. Gamma radiation plays a crucial role in providing sterilized packaged medical items quickly, effectively and affordably, he said.

Sterilization reduces the presence of microorganisms, such as fungi, bacteria, viruses and other potential pathogens. High energy radiation is now recognized as the most effective method of sterilizing medical items, said Sabharwal. It is a "clean and efficient process" as it does not leave any residue on the device after treatment. The gamma rays can penetrate all parts of the material uniformly, even in closed package products, with minimal temperature rise, he said. The items can be used instantly following sterilization, without any quarantine period.

Improving the hygienic quality of medical items using gamma radiation

The Ghana Atomic Energy Commission (GAEC) provides irradiation services to 15 hospitals/clinics and four companies using a cobalt-60 (^{60}Co) irradiator. Irradiated items include:

- single-use medical items such as gauze, syringes, cotton wool, sutures, syringe needles;
- catheters, infusion sets and fluids;
- surgical clothing (gowns, caps, footwear) and sheets;
- tissue grafts;
- reusable hospital equipment, for example surgical equipment such as scalpels, scissors, and bowls; and
- pharmaceutical items.

Support extended to neighbouring countries

The gamma irradiation facility located in GAEC also offers assistance to other West African countries including Nigeria, Côte d'Ivoire and Niger by providing irradiation services and training. The countries are also cooperating in several other areas, such as raising awareness of the technology among the general public and government officials, Adu-Gyamfi said.

These efforts have also helped to remove misconceptions about the use of nuclear technology in general, he added.

Knowing a country's needs

Ghana has benefitted from IAEA project assistance since 1970. It received the first and only ^{60}Co irradiation facility in 1994. IAEA experts have trained Ghanaian scientists, operators and technicians on the safe and secure use of the ^{60}Co irradiator. "Transferring knowledge and providing training on implementation of international standards for validation, process control and routine monitoring in the radiation sterilization of health care products requires a well thought out and tailor-made plan, suitable for a country's requirements," said Sabharwal.

The irradiation facility was upgraded in 2010 and underwent further implementation of IAEA quality control requirements in 2012. These steps have ensured that all international standards and procedures have been met for its safe operation, said Adu-Gyamfi.

Sterilized items ready for distribution.

(Photo: Ghana Radiation Technology Centre)

To make a difference to patients throughout the country, Adu-Gyamfi and his colleagues work with hospitals nationwide. "Technical capacities are built at the national level with the IAEA's support, but what we have to do is to carry forward the knowledge and skills acquired to help our people at the local level."

THE SCIENCE

Sterilizing medical items using gamma radiation

Gamma radiation, also known as gamma rays, refers to electromagnetic radiation of an extremely high frequency. Gamma radiation is very effective in preventing the growth of microorganisms, such as viruses and bacteria. It does so by damaging DNA molecules in the cells of such microorganisms, which prevents cell division.

These high energy electromagnetic waves can easily pass through the sealed plastic packaging of medical equipment such as syringes, infusion sets and similar items.

Gamma radiation is emitted by a radioisotope, usually cobalt-60 (^{60}Co) or caesium-137 (^{137}Cs). As long as the irradiated equipment remains in a sealed plastic pack, it will be free of viruses and bacteria. The gamma irradiation process does not create residuals or impart radioactivity to processed items.

Jelly-like bandage helps heal wounds: Egypt develops hydrogels using irradiated polymers

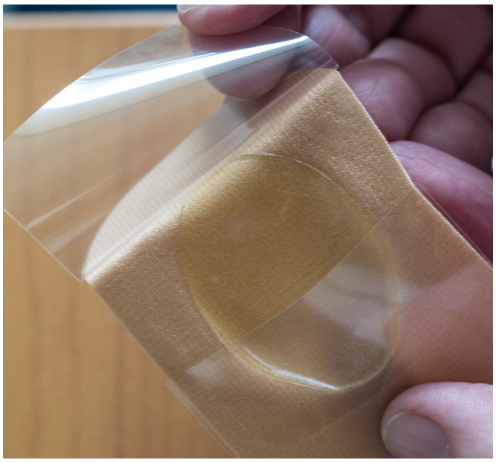
By Aabha Dixit

"Egypt is a beneficiary of IAEA assistance. An electron beam unit at the National Centre for Radiation Research and Technology is currently being upgraded to meet the growing demand for hydrogel production."

— El-Sayed A. Hegazy, Professor Emeritus and former Chairman of the National Centre for Radiation Research and Technology, Egypt

Patients suffering from burn injuries, skin ulcers and bed sores can find relief using unique jelly-like materials — hydrogels — that are playing an increasingly vital role in the healing process of such wounds. Nuclear technology has been crucial in developing hydrogels that form an important part of treating wounds in many low and middle income countries including Egypt.

The exceptional gel bandage is fast becoming ubiquitous to 'cool' wounds and reduce the painful effects of burns and other injuries. The wounds of diabetic patients have healed much faster and better than with traditional bandages, said El-Sayed A. Hegazy, Professor Emeritus and former Chairman of the National Centre for Radiation Research and Technology (NCRRT) of Egypt, the only facility in the country to develop hydrogels.



A hydrogel bandage can be used on wounds.
(Photo: S. Henriques/IAEA)

"Hydrogel has a very pleasant effect and relieves pain. It reduces the degree of tissue damage caused by the injury, and is transparent, so the doctor can monitor the wound. It reduces the time of recovery by half, but the most important effect is that it helps in the regeneration of new skin, which is scar-free," he explained.

Nuclear derived hydrogels are safe for humans

The science behind making hydrogels is complex but well understood, said Ghada Adel Mahmoud, professor of radiation chemistry at the Centre. "Hydrogels are formed using polymer chains that are crossed-linked and sterilized using gamma radiation or electron beams," she said. The polymers are mixed in water, put into moulds or tubes, packaged, sealed and then cross-linked and sterilized by exposure to radiation. This results in the polymers connecting to form a gel. The gel formed is strong, pliable and transparent.

Hydrogels for wound dressing contain 70–95 per cent water and are biocompatible, added Agnes Safrany, radiation chemist at the IAEA. They do not stick to the wound; they keep the wound moist for recovery, absorb its excretions and are also easy to store and use, she said.

Hydrogels also play a crucial role in delivering medication to the right place in the human body without causing harm elsewhere. They are used as a barrier applied to oral medications to either protect the stomach mucosa from gastric irritant drugs or to protect acid-labile drugs from the harsh environment of the stomach. Research in this area is ongoing, explained Mahmoud.

Researchers are considering using nano-hydrogels for chemotherapy treatment as well, because they go directly through the bloodstream to the tumour without having an impact on the rest of the body, Safrany said.

Advanced nuclear applications benefit the health sector

The IAEA has supported a number of countries through specific tailor-made projects to raise awareness, and train scientists and technicians to develop hydrogels using nuclear technology. "Egypt is a beneficiary of such assistance. An electron beam unit at the NCRRT is currently being upgraded to meet the growing demand for hydrogel production," said Hegazy.

A hydrogel bandage being used on a patient.

(Photo: S. Henriques/IAEA)

The nuclear techniques used to create hydrogels have been around for over 30 years and their production is simple and cost-effective, said Mahmoud.

The IAEA supported the establishment of a laboratory to assess the use of polymers in the development of hydrogels. The research includes examining the features of the polymers, such as their strength, how much they swell, the amount of drug required and its release when used in a hydrogel, as well as potential toxicity and long-term stability.

After the laboratory's investigations, the NCRRT applied for and received a licence for the preparation of hydrogels as wound dressings, and for their distribution from Egypt's Ministry of Health, Hegazy added.

Egypt has also transferred the knowledge and experience it has gained from the IAEA to other countries in the region. Hydrogels have been a life-saver for many patients suffering from serious burn wounds, and more countries should use them, he explained further.

The NCRRT is part of the Egyptian Atomic Energy Authority, the country's leading institution in promoting the peaceful applications of nuclear science and technology in practically all aspects of human life in the country.

With the IAEA's assistance, development of radiation processed products from natural polymers such as chitin (including chitosan, which is derived from chitin and is used for health care applications, see box, page 11) has significantly broadened the use of nuclear technology in the medical sector of Egypt.

The many uses of hydrogel wound dressings

Hydrogel wound dressings produced by radiation technology have the following medical advantages:

- form efficient barriers against bacteria, and also against excessive loss of body fluids;
- allow the diffusion of oxygen to the wound;
- are soft and elastic, but mechanically strong;
- have good adhesion to both the wound and the healthy skin, but without excessive sticking;
- are transparent, keeping the wound visible for health professionals;
- enable easy treatment of the wound with drugs;
- absorb liquid produced by the body in response to tissue damage and bacterial toxins;
- do not incite allergic reactions;
- soothe pain and provide optimal wound healing; and
- are sterile and easy to use.

(Source: mitr.p.lodz.pl/biomat/old_site/dress.html)

Super crops created from irradiated natural polymers in Viet Nam

By Sasha Henriques

"Oligochitosan protects plants from fungal and bacterial infection, and stops the spread of the Tobacco Mosaic Virus."

— Nguyen Quoc Hien, Vinatom Research and Development Centre for Radiation Technology, Viet Nam

Looking to increase yield and eliminate disease, farmers in Viet Nam are now feeding their plants oligochitosan [O-LEE-GO-KITE-O-SAN] and oligoalginate [O-LEE-GO-AL-GI-NATE], substances made from irradiated natural polymers.

And it's working.

Oligochitosan and oligoalginate come from shrimp shells and brown seaweed, respectively. These, and other natural polymers such as sago starch, cassava starch and palm oil, are exposed to precise doses of radiation in controlled environments, which changes their molecular structures and gives them plant-enhancing properties. The resulting products are not radioactive, and are biodegradable and non-toxic.

The polymer chitosan (above) is found in shrimp shells. It is used to make sprays and additives that prevent and cure plant diseases and promote plant growth.
(Photo: S. Henriques/IAEA)

Oligochitosan, a bright yellow liquid produced by the Viet Nam Atomic Energy Institute (Vinatom), has almost eliminated the use of harmful fungicides in agriculture across the country, said Nguyen Quoc Hien, of the Vinatom Research and Development Centre for Radiation Technology. "It protects plants from fungal and bacterial infection, suppressing diseases. And it also stops the spread of the Tobacco Mosaic Virus, a disease which infects well over 350 different species of plants, not just tobacco."

Plants treated with oligoalginate, which has the deep brown colour of molasses, grow quicker and up to 56 per cent bigger than untreated plants, Hien said. One teardrop's worth of liquid oligochitosan dissolved in one litre of water can be used to prevent diseases in plants and significantly increase the rate at which they grow.

The widespread use of non-toxic products like oligochitosan, which leave no harmful residue behind, is ultimately better for consumers, and opens up greater possibilities for national agricultural exports. Oligochitosan can even extend the shelf life of fruits like mangoes and oranges, keeping them firm and attractive to consumers for longer periods. Oligochitosan and its associated products like Gold Nano and Silver Nano, which are made from the same base polymers but with the addition of gold or silver particles before irradiation, are used in a number of other ways. They can be added to the feed of farmed fish, chicken and shrimp to improve the animals' immune systems, survival chances, and propensity for weight gain. They can also be used to clean up water in aquaculture and kill bacteria where infection is already present.

Super water absorbents

Cassava starch is another natural polymer used to create products that improve agricultural productivity. The edible root cassava is the base material used to make super water absorbents (SWAs), which can take up an incredible amount of moisture and release it slowly over time to the roots of nearby plants. SWAs look and feel a lot like large sugar crystals, but when they encounter and absorb water (or liquid fertilizer) they expand: one grain becoming as large as the average little fingernail.

SWAs processed by radiation are particularly useful for agriculture in dry areas where there is little rain, or where there are frequent periods of drought.

Placed in the soil near plants' roots, 1 kg of SWA crystals can absorb and hold 200 litres of water from rainfall and irrigation. The slow release of water and/or fertilizer to plants reduces waste, reduces pollution of waterways, and saves farmers money. After nine months, SWA crystals disintegrate, leaving no residue and no harmful after-effects on the surrounding environment.

In Vietnam, SWAs produced by the Vinatom are used on rubber plantations and in home gardens, and are also exported to Australia, where they are used in large-scale farming of high-value cash crops. These farmers use 30–60 kg of SWA per hectare.

Nguyen Van Dong sells super water absorbents in his chain of supermarkets across Viet Nam. He also uses SWA to reduce the amount of time and water given to his rooftop garden. (Photo: S. Henriques/IAEA)

THE SCIENCE

What's a natural polymer?

Natural polymers are large molecules made up of long chains of repeated blocks of atoms. They are found throughout nature: the cellulose in plants and trees, and the starch in bread, corn and potatoes are polymers; the shells of shrimps, crabs and other crustaceans, and seaweed, all contain polymers.

These and other natural polymers are the perfect building blocks from which to develop new materials because they are abundant, inexpensive, biodegradable, locally available and renewable. They also have some remarkable inherent properties. Chitin, for example, is naturally waterproof and hard, yet flexible.

Products made from natural polymers are used in medicine, agriculture, environmental protection, cosmetics, and a variety of industrial applications.

Benefits of using radiation on natural polymers

Radiation processing is used to break chemical bonds and create new ones, making it possible to redesign natural polymers at the molecular level to serve a specific purpose.

This process, during which natural polymer-based materials are exposed to ionizing radiation, can change the chemical, physical and biological properties of the material without the need for additional chemical processing, and without making the material itself radioactive.

Radiation processing has several advantages over conventional chemical methods for developing and manufacturing new materials and products. It's simpler and faster, more precise, and much cleaner because it changes the molecular structure of materials without requiring chemical catalysts or extreme physical conditions such as high temperatures and immense pressures; it neither uses toxic chemicals nor generates noxious fumes, explained Agnes Safrany, a radiation chemist at the IAEA.

The IAEA is working with Member States around the world to promote the adoption, manufacture and use of non-toxic, biodegradable polymers derived from plants and animals.

Electron beams help Poland's coal-driven power industry clean up its air

By Nicole Jawerth

"Electron beam accelerators are a multi-pollutant treatment technology; no other technologies can provide similar results."

— Lech Sobolewski, Chief Engineer, Pomorzany Power Plant, Poland

Radiation technology is expected to play an increasing role in Poland and other countries in cleaning up air pollution to meet regulatory requirements and to protect the environment.

An IAEA-supported project in Poland has helped the country to build a full-scale electron beam accelerator facility to treat flue gases from coal-driven power plants, leading to a significant reduction in emissions of sulfur dioxide, nitrogen oxides and polycyclic aromatic hydrocarbons, which threaten human health, damage the environment and can lead to economic losses. Acidic pollutants in the air can also drift to other countries through acid rain.

Following the results achieved in treating flue gases, or combustion exhaust gases, produced by power plants in Poland, other countries are now working with the IAEA to draw on the Polish experience and develop the skills they need to adopt and benefit from this electron-harnessing tool.

"Poland is producing 90% of its electricity from coal combustion. So air pollution is a big problem, and Poland has to meet regulations regarding air pollution control," said Lech Sobolewski, Chief Engineer in charge of construction and operation of the electron beam cleaning installation, built with IAEA support, at the Pomorzany Power Plant. "This is important as the European Union will introduce more strict regulations in 2016."

Limiting emissions

Poland and the IAEA teamed up to develop a model project in 1992 to evaluate the effectiveness of electron beam accelerators — machines that produce beams of electron radiation — for cleaning flue gases (see box). Following the success of this model, Poland, the IAEA, and its partners constructed a full-scale plant in 2002 with 15 times the capacity of the pilot plant. This electron beam treatment facility efficiently removes up to 95% of sulfur dioxide (SO_2) and 70% of nitrogen oxides (NO_x) present in flue gases, allowing the coal-fired power plant to meet emission limits. The by-product of the process is a high quality fertilizer used in agriculture.

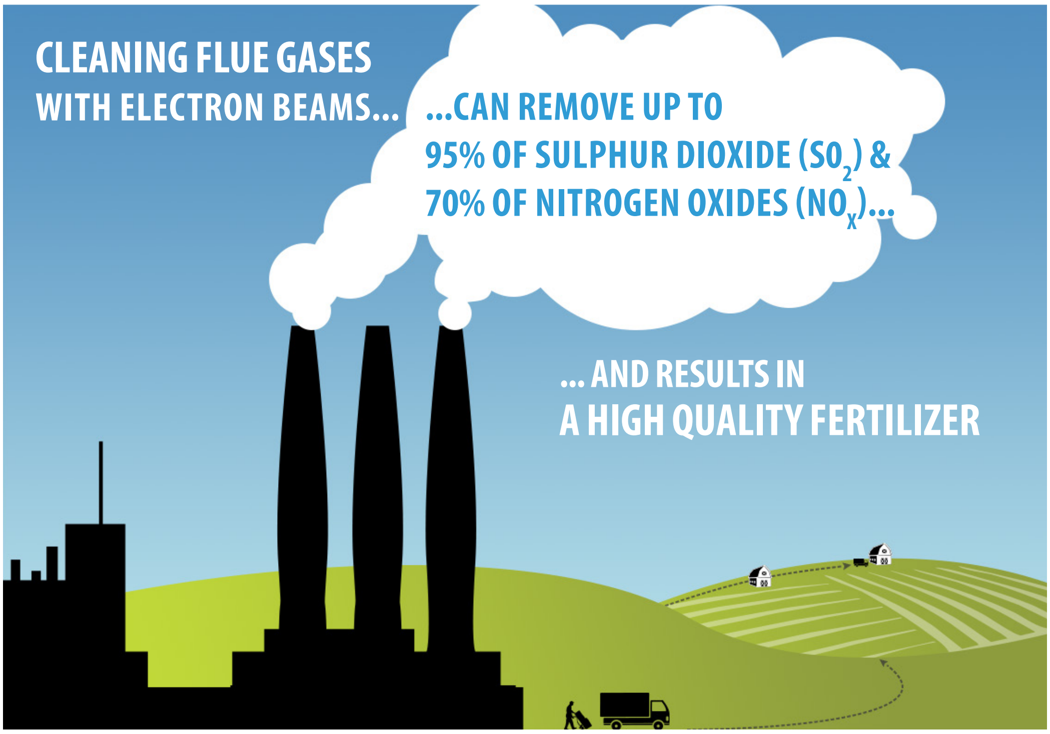
"Electron beam accelerators are a multi-pollutant treatment technology; no other technologies can provide similar results," said Sobolewski. Traditional technologies using various chemical and physical processes have a similar efficiency in removing both NO_x and SO_2 pollutants, but require the construction of two separate installations; consume large amounts of water; use a toxic, metal-doped catalyst; and produce a significant amount of waste that needs to be stored and treated.

"Conventional technology is generally more costly to install and operate, and requires special methods to dispose of the waste or to use the waste for other purposes," said Andrzej Chmielewski, Director General of the Institute of Nuclear Chemistry and Technology in Poland. "Electron beam accelerators are a proven, green technology that works. However, the accelerators are huge, high power units, which is a challenge. So we need to keep working to develop more reliable units that are easier to maintain. The IAEA can play an important role in developing such equipment through its scientific and technical support."

Slow to catch on, but effective

The use of electrons to treat flue gases is not a new concept. The technology was first developed in Japan in the 1970s, but its slow emergence at industrial scale meant many older coal power plants were fitted with other, more costly cleaning devices. However, despite the initially slow industrial-level progress, several countries are now actively pursuing this technology to reap its benefits.

Poland's pilot and full-scale industrial projects are a source of guidance and knowledge other countries draw on through IAEA coordinated research projects and



technical cooperation projects, publications, and scientific visits. “So far, more than 30 fellows have been trained and more than 150 persons have participated in scientific visits and technical meetings. The experiences gained are now being applied to their own power plants to reduce emissions and to make their plants more environmentally friendly,” said Sobolewski.

Pilot plants have been constructed in Bulgaria, China, Malaysia, South Korea, Russia and Turkey. Brazil, Chile, the Philippines and Ukraine are also looking into technology transfers, while heavy oil combustion systems in Saudi Arabia and Denmark have undergone preliminary laboratory tests.

“The introduction of this new technology has an important impact on the power industry in how it develops monitoring and pollution control systems,” said Sobolewski. Now that the electron beam has been proven to work in harsh industrial conditions, countries like Russia and South Korea, are developing new and bigger accelerators, he added. “These trends for using accelerators are still being disseminated all over the world.”

THE SCIENCE

Electron beam dry scrubbing

Before flue gases — the combustion exhaust gases produced by power plants — escape through the chimney of a power plant, they are sent through a “cleaning” process called electron beam dry scrubbing.

In this process, the gases are cooled to between 70°C and 90°C with a spray of water and then diverted into a reaction chamber. There the wet gases are exposed to low energy electron radiation from an accelerator, which acts similarly to the tubes found in old television sets. Ammonia is then added to neutralize the SO_2 and NO_x, causing them to change chemical form and become solid aerosols. A high efficiency machine gathers and filters these sticky particles, converting them into high quality fertilizer. The remaining “cleaned” gases leave through the chimney.

Though radiation is used to treat the gases, there is no residual radiation in the cleaned gas or the fertilizer by-product.

Radiation technology helps China's industries make water cleaner

By Nicole Jawerth

"China is taking a multipronged approach to wastewater treatment, collaborating with a variety of private and public sector partners, including the IAEA, to develop expertise in radiation technology in combination with other methods."

— Kenneth Hsiao, President, Jiangsu Dasheng Electron Accelerator Device Co., Ltd., China

China is pursuing the use of radiation technology as part of its wastewater treatment methods to further efforts to manage industrial waste in an environmentally friendly way.

"Treating the water that comes from our industries is very important, so we have been doing this for a long time. Now we want to become better at making our water cleaner," said Jianlong Wang, Vice-President of the Institute of Nuclear and New Energy Technology (INET) at Tsinghua University in Beijing. "We are receiving a lot of support from the IAEA to use electron beam based technologies to help us get rid of various water pollutants that the other methods cannot do on their own."

Electron beam accelerators are machines that produce beams of electron radiation that can be used for cleaning wastewater, among other things (see box). Wastewater is water that has been adversely affected by its use in human activities, such as for industrial or agricultural purposes.

The electron beam scanning box is where wastewater can be irradiated by high energy electron beams.
(Photo: INET/Dasheng)

Industrial wastewater can contain a variety of chemicals, including pesticides, organic material, chemicals and dyes. These can be harmful and, in some cases, very toxic. Before releasing this water or reusing it, it must be treated to minimize the amount of these containments to prevent them from spreading to surface and groundwater resources.

For decades, China has been cleaning its wastewater using conventional treatment methods that involve physical processes and chemicals. To meet its tightening policies on energy saving and environmental conservation, China is now working to expand the use of radiation technology to remove harmful containments like, among others, cyanide, oils and greases, and dyes, from the leftover water, said Shijun He, Associate Professor at INET.

Conventional processes are difficult, inefficient and expensive to use alone, added Sunil Sabharwal, radiation processing specialist at the IAEA.

"Electron beam accelerators can be a very efficient and cost effective way to treat wastewater," said Sabharwal. Different types of contaminants need different treatment methods, and combining radiation technology with other methods can eliminate a spectrum of contaminants and more effectively break down organic matter, while leaving no secondary pollution and requiring very few or no additional chemicals, he explained.

Collaboration across sectors

"China is taking a multipronged approach to wastewater treatment, collaborating with a variety of private and public sector partners, including the IAEA, to develop expertise in radiation technology in combination with other methods," said Kenneth Hsiao, President of Jiangsu Dasheng Electron Accelerator Device Co., Ltd. in Jiangsu, China.

With the IAEA, China is focusing on ways to use electron beam irradiation to target specific types of pollutants and demonstrate the effectiveness of these radiation tools for adoption on a wider, larger scale in the future, explained Massoud Malek, an IAEA programme management officer working with China.

Water is ejected as it is treated to remove harmful contaminants and unwanted colours and odours.
(Photo: INET/Dasheng)

"The IAEA has been supporting China in developing electron beam irradiation to treat wastewater, remove certain contaminants, and help to ensure water resources stay clean and safe," said Malek.

From one country to another

Water is not bound by borders so international cooperation and effective national level treatment methods are essential, said Malek. "If contaminated wastewater reaches a surface or groundwater source, the contaminants can spread to other places through shared water resources and rain. So it is important that the water is made clean before it's released."

Studies like the IAEA projects in China can help further research and development of these technologies and show other countries how they can take up and use them. In this case they provide industries with appropriate means of cleaning up the results of their activities and further strengthen environmental protection efforts.

"So far there have been few projects like this, so China's project with the IAEA can be a source of expertise and knowledge for other countries and industries to adopt these tools for their own use," said Malek. "As more industries refine their wastewater treatment methods, the cleaner that water gets, helping us to protect the environment, people and our water resources worldwide."

THE SCIENCE

Treating wastewater using electron beam accelerators

The beams of high energy electrons produced by electron beam accelerators can be used to treat wastewater by minimizing harmful contaminants and removing unwanted colours and odours.

During the treatment process, the water is passed through a chamber that is exposed to ionizing radiation from the accelerator. This leads to chemical reactions in the contaminants, causing them to decompose into more manageable and easier to treat fragments. The water is then passed through biodegradation treatment that degrades these components further before the treated water is released or reused. This method does not make the water radioactive or leave any radiation behind.

Mapping it out: Tracer technology and the search for oil

By Joe Rollwagen

> **"A tracer tells you exactly what it sees, thereby optimizing the process."**
>
> *— Tor Bjørnstad, Chief Scientist, Institute for Energy Technology, Kjeller, Norway*

A typical oil rig in the North Sea where radiotracers may be used to map the sea bed.

(Photo: M. Bengtsson/wikimedia.org/CC BY 3.0)

Ever since oil was first found off the shores of Norway in the 1970s, the country's economy has seen tremendous growth. To maintain the efficiency of production for the long term, Norway has made extensive use of nuclear techniques.

Nuclear tracers are used to help optimize oil production by mapping underwater oil fields. According to Tor Bjørnstad, Chief Scientist at the Institute for Energy Technology in Kjeller, Norway before the use of nuclear tracers scientists relied on seismic mapping, which delivered less precise data.

"A tracer tells you exactly what it sees, thereby optimizing the process," Bjørnstad said.

At present, the institute employs tracer technology in more than 30 different wells, while collecting samples from hundreds more.

Understanding the oil fields

Small quantities of radioactive material are mixed into the water or gas that is pumped down oil wells — around 5 ml for water-based tracers. Soil samples are then gathered from wells in the area, and if the tracer is picked up in multiple samples, it indicates that the wells are connected, drawing oil from the same reservoir (see box). Wells in which no radiotracer is found are separated by fault lines under the seabed. Understanding the extent of various oil fields is crucial in determining how to extract oil more economically.

Constructing a well costs upwards of 500 million kroner (US $62.5 million). Therefore, it has been a tremendous advantage to employ tracer technology, which is precise and causes minimal environmental impact, Bjørnstad explained.

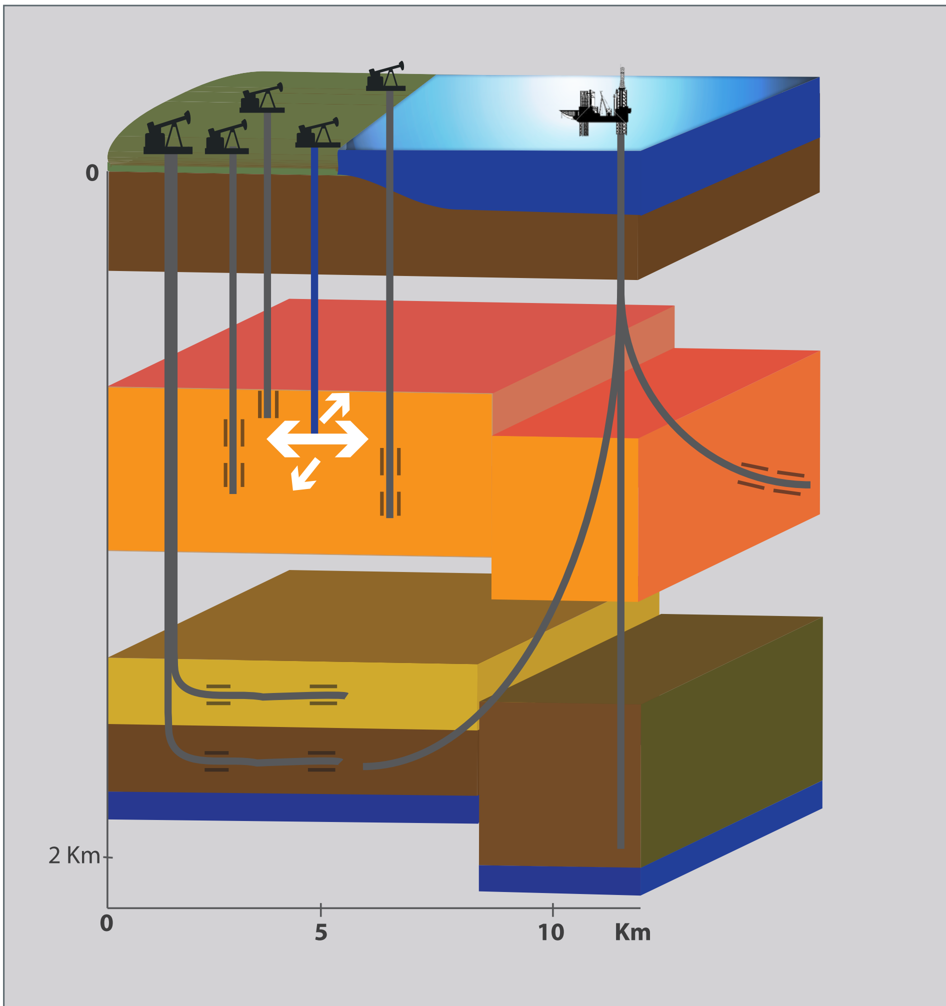
Minimizing environmental impact

Meeting regulations and national safety standards, as well as international environmental standards, is a constant goal of the Institute for Energy Technology, Bjørnstad said. The sheer size of the oceans in comparison with the tiny amount of radioactive material used within tracers ensures that there is a negligible threat to the natural environment.

The Institute has helped many emerging oil producers to employ this method. The IAEA has also facilitated technology sharing both independently and alongside the Institute. The IAEA and the Institute help other countries obtain the necessary equipment to use the technique, and also set up courses, meetings and coordinated research projects that provide learning opportunities to Member States.

In Viet Nam, for instance, the IAEA has helped to build the local knowhow needed to employ tracer technologies in oil exploration. “Before the projects [with the IAEA], tracer technologies for oil fields were not available in Viet Nam. The oil producer companies had to call in services from other countries,” said Quang Nguyen Huu, Director of the Centre for Applications of Nuclear Techniques in Industry.

Viet Nam has a fractured basement oil field off its coast, where cracks and breaks occur on the seafloor due to the shifting of tectonic plates. This complex geology requires a tailored approach. With the help of IAEA-led training sessions, Viet Nam has been able to modify the tracer technology to suit the seabed’s complex geology, Nguyen Huu said. Furthermore, Viet Nam has been able to export its services to countries such as Kuwait, Angola and Malaysia, he added.



Principle of tracer injection method for interwell communications

(Source: Application of Radiotracer Techniques for Interwell Studies, IAEA, 2012)

THE SCIENCE

Interwell tracer testing

Tracer applications can be found in almost any phase of oil field development. Interwell tracer technology is an important reservoir engineering tool for the recovery of oil.

This type of testing is also used in geothermal reservoirs to gain a better understanding of reservoir geology and to optimize production and reinjection programmes. The main purpose of conducting interwell tracer tests in oil and geothermal reservoirs is to monitor the quality and quantity of the injected fluid connections between injection and production wells, as well as to monitor the similarities and differences between wells and reservoirs.

The tracer is added into injection fluid via an injection well and observed in the surrounding production wells (see figure above). How the tracer responds helps to chart the flow pattern to provide a better understanding of the reservoir. This knowledge is important in optimizing oil recovery. Most of the information given by the tracer cannot be obtained through other techniques.

Keeping ports accessible: Brazil is saving "millions" in dredging costs thanks to nuclear techniques

By Rodolfo Quevenco

"In the same way as a heart surgeon can investigate major blood vessels, or a radiologist can track organic functions of the human metabolism by using medical tracers, radiotracers allow us to assess the hydrodynamic behaviour and main pathways of sediment movement in coastal areas."

— Jefferson Vianna Bandeira, senior researcher, National Nuclear Energy Commission of Brazil

With a coastline of over 8500 kilometres, 90 per cent of Brazil's total exports and imports pass through its ports.

Many of the country's major ports and harbours were built over 100 years ago. Keeping shipping lanes open and enabling these ports to accommodate larger vessels with ever bigger loads requires constant dredging, often at high cost.

Over the years, the use of nuclear techniques to study sediment build-up and transport across major ports and harbours (see box) has saved Brazil millions of dollars in dredging costs, said Jefferson Vianna Bandeira, a senior researcher in the Environment Department of the National Nuclear Energy Commission of Brazil.

With IAEA assistance, Bandeira and a team of scientists have been using radiotracers to map sediment movements that affect Brazil's major ports since the 1960s.

Radiotracer techniques can help economize dredging operations that keep harbours deep enough to accommodate larger ships with bigger loads.

(Photo: A. Hardacre/Flickr.com/CC BY 2.0).

Initially, a major focus was to assess the behaviour of sediments dredged from the harbour area of Port Santos after they were dumped. Port Santos, near Sao Paulo, is one of Latin America's largest and busiest ports, currently serving various Brazilian states and handling 28 per cent of the country's foreign trade.

The dumping site has been moved several times in order to minimize the flow of sediments back into the bay system. The use of radiotracers has enabled port engineers to find optimal locations as close to the port as possible.

"In the studies performed in the seventies at Sepetiba Bay, Rio de Janeiro State, for the construction of Ilha da Madeira harbour, we have probably 'economized' over 100 000 kilometres of dredging travel distance," Bandeira said. This has resulted in savings of millions of dollars to Brazilian port authorities, he added.

From port to sea: modelling sediment and water movement using radiotracers

Years of radiotracer investigations at the Port of Santos and other ports in Brazil have also given Bandeira's team extensive knowledge of the dynamics of sediment transport and movement patterns in changing conditions. In the process, they have been able to use mathematical models and accurate data sets of sediment transport and flow patterns that are continually being used in coastal engineering activities.

"We are like surgeons and specialists," said Bandeira, in describing the work he and his colleagues do. "In the same way as a heart surgeon can investigate major blood vessels, or a radiologist can track organic functions of the human metabolism by using medical tracers, radiotracers allow us to assess the hydrodynamic behaviour and main pathways of sediment movement in coastal areas."

This intimate knowledge has been put to good use many times over. For example, in the sediment studies carried out along the coastal shore of what would become known as the Port of Suape, radiotracer labelling

revealed low bottom sediment transport rates in summer as well as winter. This information was essential in determining the ideal location for the port and indicated that there would be no need for significant maintenance dredging offshore. These studies were performed simultaneously with oceanographic measurements in the nearshore (wave, wind, currents and tide). Suape has since developed into the most important port complex in north-eastern Brazil.

Fighting coastal erosion

Coastlines and seabeds are dynamic regions with sediments undergoing periods of erosion, transport, sedimentation and consolidation. The main causes of erosion of beaches include storms; but human activities, such as dredging of stream mouths, and construction of seawalls and jetties, also disrupt the natural flow of sediment.

"Nuclear techniques are the most useful and efficient methods to assess erosion and movement of silt and sediments in coastal areas," said Patrick Brisset, an industrial technologist at the IAEA. "Such techniques have been and are used in many countries for coastal engineering; many more are just starting to use the technology in support of their development plans."

Through the IAEA's technical cooperation programme, many of Brazil's scientists have received training, Brisset explained. At the same time, many IAEA experts have gone to Brazil to perform sediment transport studies and teach various technicians. Brazilian experts are also now extending help and support to other Member States, including Venezuela, Uruguay and Niger, in projects involving radiotracer applications for sediment studies.

Understanding the dynamics of sediment movement can help identify the best location of dumping sites for dredged sediment, so as to avoid unwanted pollution of nearby beaches. (Photo: R. Quevenco/IAEA)

THE SCIENCE

Advantages of using radiotracers to study sediment transport

Most of the world's population lives on coasts or in coastal regions, so understanding the dynamics of sediment transport in these areas is of vital importance to many countries.

Radiotracer techniques are an effective method of investigating sediment dynamics, as they can provide real-time, accurate assessment of where, how and why sediments move. A common procedure involves the introduction of small quantities of a radioisotope (for example, gold-198 or iridium-192) into the sediment samples to be measured, dropping them at key sampling points, and then monitoring their movement using scintillation detectors towed by boats.

Tracer techniques are also often employed to validate the results of other techniques used to assess sediment behaviour, for example bathymetric surveys, or mathematical and physical models. There is also a growing trend towards analysing radiotracer experiments using computational fluid dynamics, a branch of fluid mechanics that uses numerical analysis and algorithms to analyse fluid flows. This is expected to lead to more reliable models and better validation of results.

X-rays for industry: Non-destructive testing helps Malaysia's competitiveness

By Brian Plonsky

"The Malaysian example shows that it is possible to build an internationally recognized testing system from scratch."

— Patrick Brisset, industrial technologist, IAEA

Technicians inspecting a PETRONAS pipe using NDT methods in order to test the quality of the pipeline.
(Photo: A. Nassir Ibrahim/Madani NDT Training Centre)

Industrial testing using nuclear technology has contributed to the competitiveness of Malaysia's manufacturing sector, industry players have said. The country has also built itself an export niche in South-East Asia, offering non-destructive testing (NDT) with nuclear devices to manufacturers in neighbouring countries.

"The fact that we can get NDT services of a good quality level at a very reasonable price allows us to spend more money on inspection, and thus improve our competitiveness as well as the level of safety of our plant," said Zamaludin Ali, senior engineer at oil company PETRONAS. Before the development of a local NDT industry and accreditation system for testing services, PETRONAS and other companies in Malaysia had to rely on foreign NDT providers, or local companies hiring operators certified abroad, he explained.

NDT using nuclear techniques involves the use of ionizing radiation to test the quality of finished products. It is based on the same principle as X-rays used in hospitals (see box). Oil pipes, boilers, pressure vessels, aircraft equipment and ships are among the products whose quality is tested with the technique.

The IAEA has played an important role in helping Malaysia to establish accredited training agencies and a certification system, and to promote NDT technologies such as radiographic testing. As a result of this long-standing partnership, over 50 companies in Malaysia, employing more than 2000 technicians, are certified to carry out NDT testing.

Building local expertise

It all began in the 1980s, when Abdul Nassir Ibrahim, a junior official with Malaysian Nuclear Energy at the time, first attended a series of IAEA training courses on NDT. With support from his Government and assistance from the IAEA, he helped set up the National NDT Certification Board, from which he retired last year. Nassir Ibrahim is currently managing the Madani NDT Training Centre near Kuala Lumpur.

Companies in the oil and gas sector account for around 70 per cent of all NDT inspection business in Malaysia, Nassir Ibrahim explained. Power plants, shipyards and the aviation industry are other important clients that benefit from this technology. The cost of local inspections is about one fifth of the cost of hiring inspectors and using technology from overseas, he said.

The IAEA helped to develop local expertise in the early years by supplying equipment and organizing training courses and scientific visits, explained Patrick Brisset, an industrial technologist at the IAEA. “Seeing the advances and success in Malaysia, we regularly call upon Malaysian experts to help the IAEA to set up training and certification centres in other countries,” he said.

Malaysia’s training system and National NDT Certification Scheme have become a reference point for many countries: Nassir Ibrahim and his colleagues regularly conduct training courses in Sudan, which has adopted Malaysia’s certification scheme. Prospective inspectors from the Philippines, Yemen and Sri Lanka also come to Malaysia for training and certification, Nassir Ibrahim said.

In Malaysia, local NDT services cost one fifth of imported services.

The success of Malaysia’s NDT training programme can serve as a model and inspiration for other countries that wish to develop a domestic NDT certification programme, Brisset said. “The Malaysian example illustrates that it is possible to build an internationally recognized testing system from scratch and that the IAEA can help in the process.”

THE SCIENCE

Non-destructive testing

Art restoration in London, munitions manufacturing in Argentina, bridge construction in New York, and the oil and gas industry in Malaysia may appear to have very little in common. What connects them all is a quality control method using radiation, known as non-destructive testing (NDT).

The most important NDT technique on the market and the one most widely used in Malaysia is radiographic testing, which is based on the differential absorption of X-rays and gamma rays emitted from an X-ray machine and a radiographic source, respectively.

Radiographic testing works by using ionizing radiation (including X-rays or gamma rays) to create an image of the internal structure of solid and hard materials, such as steel or concrete. The radiation passes through the material and exposes a film placed on the other side of the material. The film’s darkness varies with the amount of radiation reaching it through the test object: materials with areas of reduced thickness or lower material density allow more radiation to pass through. These variations in the darkness of the image can be used to determine the thickness or composition of a material, and also reveal any flaws or discontinuities inside it.

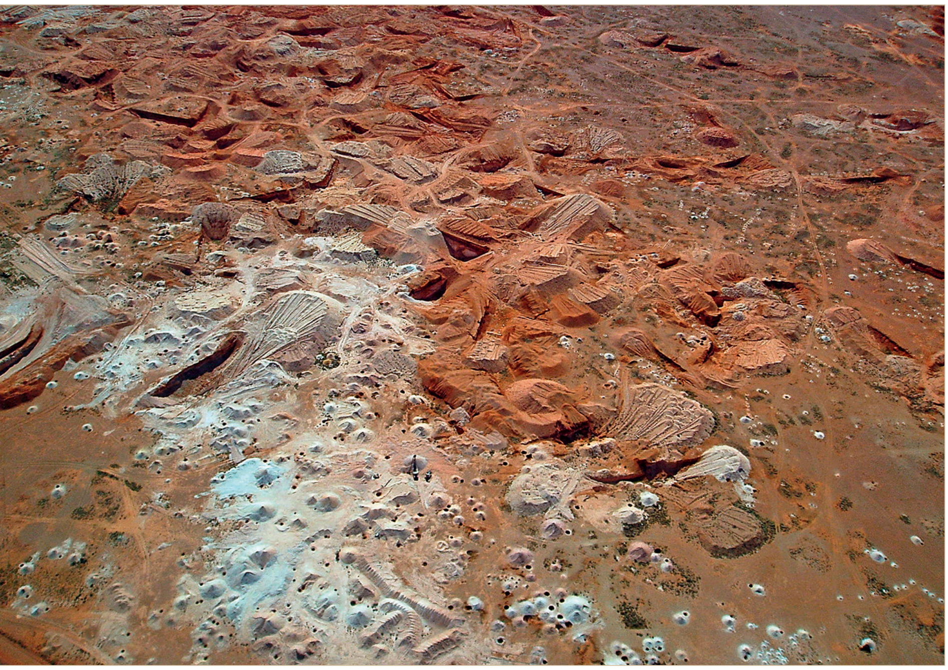
Radiographic testing plays a vital role in the production and maintenance of materials and structures, without causing any damage to them or leaving any radioactive residue. It is used to determine and improve quality, and thus ensure safety. Specific uses include flaw detection and evaluation, dimensional measurement, leak detection, structural characterization, stress and dynamic response measurement, structural integrity analysis, and material sorting, such as determining the conductivity and chemical composition of materials.

Profitable mining with the help of radiation technology

By Rodolfo Quevenco

> **"We need new technology that will enable us to mine material more selectively and not waste water and energy on very low grade ore."**
>
> *— Nick Cutmore, Research Programme Director, Commonwealth Scientific and Industrial Research Organisation, Australia*

During the boom years of the 2000s, the global mining industry expanded quickly, with many countries and companies investing large amounts of money in efforts to increase production and satisfy a rapidly growing global economy hungry for natural resources. Now, with lower commodity prices, decreasing ore quality and higher production costs, keeping these mines open means streamlining operations and improving productivity. Radiotracers and nucleonic gauges are among the techniques that enable the industry to achieve this increased efficiency.



Aerial view of the Coober Pedy opal mine in Australia.
(Photo: G. Sharp/Flickr.com/CC BY 2.0)

The industry is well aware of these issues. "The big challenge that the mining industry faces today is that there is less water; energy is getting more expensive; and the actual grade of ore is lower and lower," said Nick Cutmore, Research Programme Director at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), a leading scientific agency in Australia that pioneers research and development work on the application of nuclear techniques to the mining industry. "So we need new technology that will enable us to mine material more selectively and not waste water and energy on very low grade ore."

"The bottom line is simple: it's all about keeping the good rocks and getting rid of the bad rocks before you waste energy and water processing them," he said.

In mining operations, it is important to analyse bulk ore — from 1000 to 10 000 tonnes per hour — as it is moved on a conveyor belt. For quick and accurate analysis, engineers need a way of looking into the ore to identify the elements it contains and measure the amounts. Nuclear techniques are "absolutely best suited" for this type of analysis, Cutmore said.

"Neutrons or high energy X-rays or gamma rays are very penetrating and are able to analyse large amounts of material quite accurately where other approaches will fail," he said.

Radiotracers and nucleonic gauges are used by mining industries to improve the quality of products, optimize processes, and save energy and materials, said Patrick Brisset, an industrial technologist at the IAEA. "Today, many mining companies have also recognized the high socio-economic benefits of radioisotope technology."

Nuclear magnifying glass

CSIRO is pioneering development of the use of nuclear-based techniques for, among other things, drilling, mineral sorting and real-time sensing and analysis. It has developed a new analyser that combines X-ray fluorescence and X-ray diffraction to provide rapid characterization of minerals at parts per billion levels. The technique can detect down to a level of about a hundred parts per billion for key elements, measuring valuable metals such as gold, silver, uranium and the platinum group elements, and important contaminants such as lead, mercury and arsenic, at levels of a few grams per tonne or less.

CSIRO has also recently developed a method of gamma activation analysis that uses high energy X-rays to measure ore samples in an automated system without the need for laborious sample preparation or access to a nuclear reactor to conduct neutron activation analysis. This technique is particularly effective in detecting the gold content of various types of samples (see box).

Cooperation with the IAEA: Sharing technology

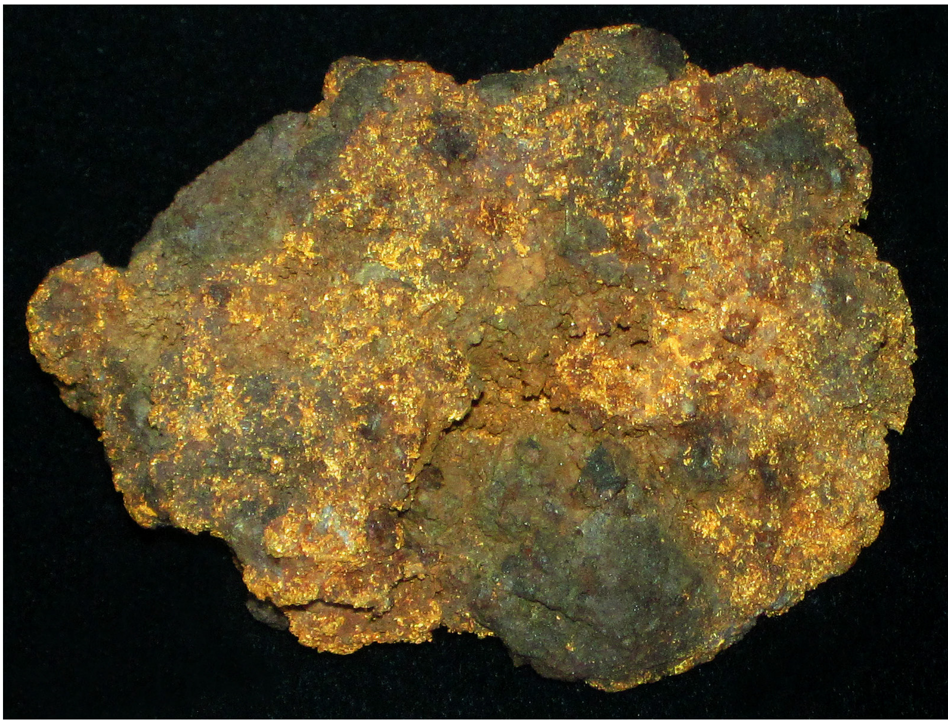
CSIRO is participating in an IAEA coordinated research project on the development of radiometric methods in exploration and mining of minerals and metals — sharing its technology with scientists from around the world.

In fact, Australia's cooperation with the IAEA on the use of neutrons, X-rays and radiotracers dates back to the 1980s when this technology was new.

As one of the top five mining countries in the world, Australia leads in several areas of nuclear applications used by the industry. Many of these applications are quite mature technologies, with a successful history of field and commercial use.

Australia's participation in the IAEA's coordinated research project is mainly focused on the transfer of technology to other countries, Cutmore said.

IAEA coordinated research projects provide a mechanism for bringing researchers from institutions in both developed and developing countries together to collaborate on a specific research topic, and to exchange and transfer knowledge in the use of nuclear techniques for various peaceful applications.



Gold ore in matrix.

(Photo: J. St. John/Flickr.com/CC BY 2.0)

"We want to make other countries aware of the technologies and knowledge we have developed, so that they are fully informed of what is available to the minerals industry in those areas," Cutmore said. "Our desire is to see this technology benefit some other Member States that could in the medium to long term utilize it to better exploit resources for the economic prosperity of their countries."

THE SCIENCE

Extracting every ounce of gold

World production of gold is worth billions of dollars annually, and the high price of gold is mostly a result of the high cost of mining it. Gold is mined commercially at gram-per-tonne levels, and few analytical techniques have the sensitivity to accurately measure metals at these ultra-low levels.

Gamma activation analysis uses high-powered X-rays to excite specific elements in the ore, activating any trace of gold in the sample. The technique applies to gold in any chemical or physical form, and can be used to measure the gold content of solids, slurries or liquids. Combining the latest developments in high power X-ray sources and radiation detectors with advanced computer modelling enables the analyser developed by CSIRO to detect gold at levels nearly ten times lower than is possible using other techniques. It can also detect very low levels in extremely small samples.

‘Fragile old man’: Mexico and France save a 2000-year-old sculpture using nuclear techniques

By Aabha Dixit

> **“In spite of its unstable condition, the experts from the Mexican–French team felt that there was hope that advanced nuclear techniques could possibly save the 2000-year-old fragile old man.”**
>
> *— Alejandra Alonso-Olvera, senior restorer, Department of Conservation, National Institute of Anthropology and History, Mexico*

During an excavation in 2001 in Becán, a Maya civilization site located in Campeche State in south-eastern Mexico, a 2000-year-old wooden sculpture was unearthed causing a buzz in Mexico’s archaeological community. The wooden statue was tucked away deep beneath a collapsed tomb. It was the first ever wooden object found that could be reliably dated to the early classical Mayan period, but was slowly decaying, with many fragments broken off.

With the help of nuclear technology, and assistance from France, scientists have revived it to its previous glory. The statue is now on display at the Campeche museum, along with other objects of Mayan art.

Left: The ‘fragile old man’ prior to gamma ray irradiation.

Right: The preservation has saved the ancient sculpture.

(Photos: courtsey of Quoc-Khôi Tran, ARC-Nucléart)

The irradiation treatment using gamma rays was carried out at the National Institute for Nuclear Research’s irradiation facility near Mexico City. This technology — using gamma polymerization technology on archaeological wooden objects (see box) — was a ‘first’ for Mexico’s conservation efforts. The conservation process for this unique find has provided Mexico with the necessary expertise on a state-of-the-art technology that can conserve aged artefacts of historical relevance.

After careful examination, the wooden artefact was identified as a male. Several areas of the sculpted body were heavily eroded, and fragments were missing. The ankles and feet of the sculpted character were particularly fragile because of their narrow shape, making these areas extremely weak for supporting the total mass load, said Alejandra Alonso-Olvera, senior restorer at the Department of Conservation, National Institute of Anthropology and History, who was involved in the restoration project.

“In spite of its unstable condition, caused by context disturbance, ageing, mechanical abrasion and biological decay, the experts from the Mexican–French team felt that there was hope that advanced nuclear techniques could possibly save the 2000-year-old fragile old man,” she added.

What did he look like?

Explaining the characteristics of the ancient Maya sculpture, Alonso-Olvera said that it had been carved out of a single wooden block, with a height of 21.5 cm and a width at its base of 17.5 cm. The sculpture had no facial features and the lower parts of the arms were missing, she added. A closer examination of the sculpture revealed that there were illustrations on several parts of the body, and that the base had been painted.

The Mexicans contacted the Atelier Régional de Conservation Nucléart institute (ARC-Nucléart) in Grenoble, France, part of the French Atomic Energy Commission, to seek scientific and technical assistance in restoring the old sculpture. ARC-Nucléart is renowned for its pioneering efforts in conservation and protection of ancient artefacts using gamma irradiation processes.

“It was an outstanding collaborative research opportunity for both institutions,” said Quoc-Khôi Tran, a senior expert in the field of gamma irradiation at ARC-Nucléart, which provided training in conservation and restoration methods using gamma irradiation processes to experts from Mexico.

Microscopic observations through laboratory investigations were initially undertaken only at the base level of the delicate artefact. “Touching the main sculptured piece was too tricky due to its fragile state,” said Alonso-Olvera. This study was necessary to assess the type of wood, the colour, the extent of damage by biological organisms as well as moisture content.

Preparing the support frame for the Maya sculpture for the resin impregnation.

From left to right: the Mexican technical team, Alejandra Alonso-Olvera and Quoc-Khôi Tran

(Photo: courtsey of Quoc-Khôi Tran, ARC-Nucléart)

Fighting fungi

These investigations determined that the wood was a tropical hardwood — ziricote — that is native to the Yucatan Peninsula. Ziricote is naturally resistant to fungi or attack by other wood-destroying microorganisms, she added. However, during the investigations, the presence of hyphae, a form of fungus that grows within the cells of the wood, was noticed, Alonso-Olvera explained.

The archeologists decided to subject the wooden figurine to gamma radiation polymerization treatment, which would kill the fungus and protect the sculpture from any further deterioration. This method would stabilize the wood through the use of a radiation-curing consolidant, and also restore the colour.

The irradiation treatment using gamma rays emitted by cobalt-60 sources was applied at relatively low dose rates in order to keep the temperature within the wood under control (at around 40–50°C) during the polymerization process. The gamma ray dose rates had to be carefully monitored each time to ensure proper consolidation of the wood, Tran explained.

Close collaboration between Mexican and French specialists was critical to the success of this project, said Alonso-Olvera.

The IAEA, in collaboration with ARC-Nucléart, supports Member States in using irradiation technology for the preservation of historical items. In addition, a number of IAEA training courses are conducted to widen awareness of the use of nuclear science and techniques, and to build irradiation preservation capacities that can help save distinctive archaeological items that help to explain the course of a country’s history.

THE SCIENCE

Conserving degraded wooden artefacts using gamma radiation polymerization treatment

The use of gamma radiation polymerization for consolidation of degraded wooden artefacts is based on the principle that certain liquid resins (such as unsaturated polyester or acrylic resins) can be in-situ polymerized into solid polymers inside the pores of wood through exposure to radiation, thereby strengthening the structure of the wood.

First, through a thorough cleaning of the surface, any solid particles that cover the artefact are removed using soft brushes. In the next step, regular diffusion of a liquid polymerizable resin within the structure of the wood is achieved by a vacuum and pressure process also known as pressure impregnation.

The impregnation process involves filling the pores of wood with a material that on in-situ polymerization by gamma radiation will strengthen the structure of the wood without causing it to contract or come apart. The consolidated wooden artefact is therefore much less sensitive to variations in humidity levels than untreated wood. After irradiation, other restoration procedures, such as gluing, reconstruction and filling gaps, are used to restore the artefact.

When tiny things have a huge impact

Ionizing radiation as a tool for nanoscale engineering

By Sasha Henriques

> "Nanoparticles and nanostructures are not entirely new. Rather, it's humans' ability to work, measure and manipulate at the nano-scale that is new."
>
> *— Wanvimol Pasanphan, Assistant Professor at the Centre for Radiation Processing for Polymer Modification and Nanotechnology, Kasetsart University, Thailand*

More than a dozen IAEA Member States are now using ionizing radiation to produce nanoparticles for use in agriculture, medicine, cosmetics and industrial applications, while others are researching ways to create their own products and processes. Below, Wanvimol Pasanphan, Assistant Professor at the Centre for Radiation Processing for Polymer Modification and Nanotechnology, Kasetsart University, Thailand, explains the basics of nanoparticles and talks about the exciting possibilities.

How small is a nanoparticle?

Nanoparticles are extremely tiny man-made structures that are measured in nanometres. One nanometre is one billionth of a metre.

Wanvimol Pasanphan explains molecular design of nanoparticles to students at the Centre for Radiation Processing for Polymer Modification and Nanotechnology, Kasetsart University, Thailand, where she is an Assistant Professor.

(Photo: T. Piroonpan)

In more everyday terms, a nanometre is 100 000 times smaller than the diameter of a single hair. Things in nanoscale can't be seen with the naked eye. Instead, researchers need to use very powerful microscopes.

Nanoparticles and nanostructures are not entirely new. Rather, it's humans' ability to work, measure and manipulate at the nano-scale that is new.

What are nanoparticles used for and how are they made?

Nanoparticles can be used in agriculture, medicine, cosmetics and industry. Due to their nanoscaled size, they are excellent storage, transportation, penetration and distribution devices, carrying and delivering medicines, fertilizers, bioactive compounds, etc. to specific places within an organism or structure.

Nanoparticles can be made from inorganic compounds and natural and synthetic polymers. Depending on how the nanoparticle will be used, it can be fabricated into various structures. For example, core-shell polymer nanoparticles are composed of three components: an outer shell (a polymer that provides stability to the chemicals that make up the inner shell); an inner shell (that can be made of water-resistant molecules); and the central core, which contains antimicrobial agents or anticancer drugs (see Figure 1). Nanoparticles with such a structure may be used for fruit coatings that prevent the growth of fungi, such as *Sphaceloma ampelinum*, a dark red mould that often appears on grapes.

What are the possible medical applications of this technology?

Nanoparticles can be designed to only release their contents at a certain time (or over a set period of time) and in a certain place. For example, researchers are working on nanoparticles that when coupled to radiopharmaceuticals (or created from radiopharmaceuticals themselves) travel only to cancer cells and nowhere else, and are able to get inside those cells to release the necessary medication.

Twelve Member States — Argentina, Brazil, Egypt, Iran, Italy, Malaysia, Mexico, Pakistan, Singapore, Poland, Thailand and the USA — are involved in an IAEA coordinated research project to use nanoparticles to create targeted drugs for cancer treatment. These

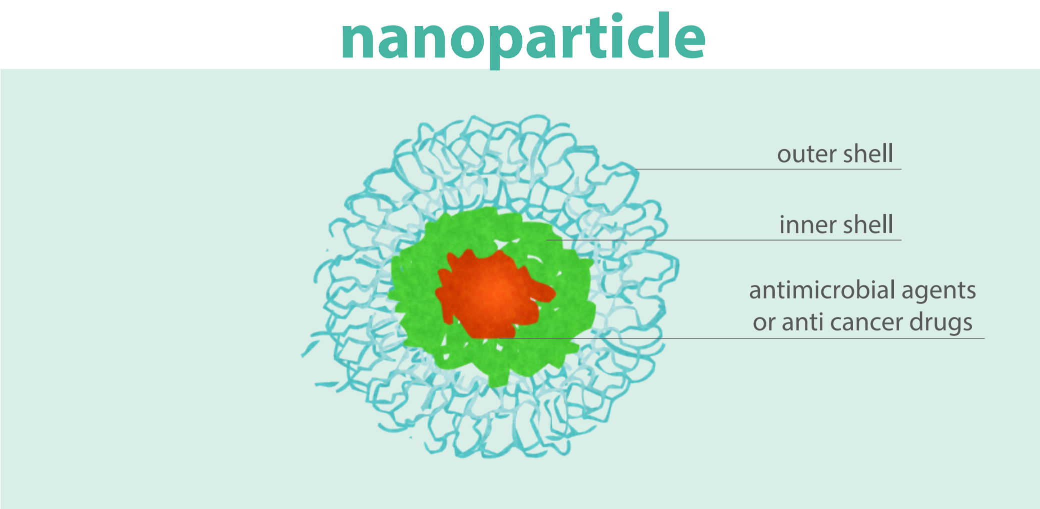


Fig. 1: Core-shell polymer nanoparticles are composed of three components: an outer shell (a polymer that provides stability to the chemicals that make up the inner shell); an inner shell (that can be made of water-resistant molecules); and the central core, which contains antimicrobial agents or anticancer drugs.

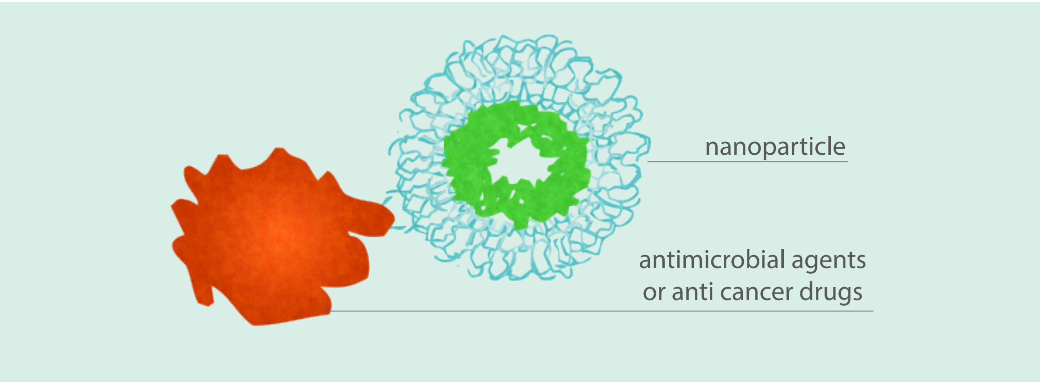


Fig. 2: This core-shell polymer nanoparticle has the antimicrobial agents or anticancer drugs outside the outer shell (a polymer that provides stability to the chemicals that make up the inner shell) and the inner shell (that can be made of water-resistant molecules).

nano-pharmaceuticals would be able not only to penetrate cancer cells more easily than other types of pharmaceuticals but also remain within the tumour mass longer than other drugs. If successful, this could revolutionize cancer treatment by decreasing the possibility of healthy cells — and by extension, the patient — being damaged by drugs designed to destroy cancerous cells. These nanoparticles can be structured similarly to what I've talked about before or they can look completely different. For example, some researchers are using nanoparticles that look more like the one shown in Figure 2.

What does radiation have to do with nanoparticles?

Ionizing radiation used in a highly controlled environment by trained professionals is a quick and effective tool that can be used to modify and/or combine the materials that will create nanoparticles. It is a clean, low temperature process, and sometimes the preparation and sterilization of a nanoparticle product can be done in a single step.

It's important to note that the nanoparticles that are created are not themselves radioactive.

(For more about natural polymers' interaction with ionizing radiation, see the Science Box on Page 11).

How is the IAEA involved?

The IAEA promotes the use of radiation processing of natural polymers such as those used to create nanoparticles, partly by helping Member States acquire and develop expertise in the use of ionizing radiation for medical, industrial and commercial purposes. And for the last 30 years, the IAEA has been providing interested countries with training (workshops, expert visits, fellowships) in this area, and has organized collaborative multi-country research projects exploring the limits of radiation technology for polymer and nanoparticle manipulation.

(Photos: IAEA)

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