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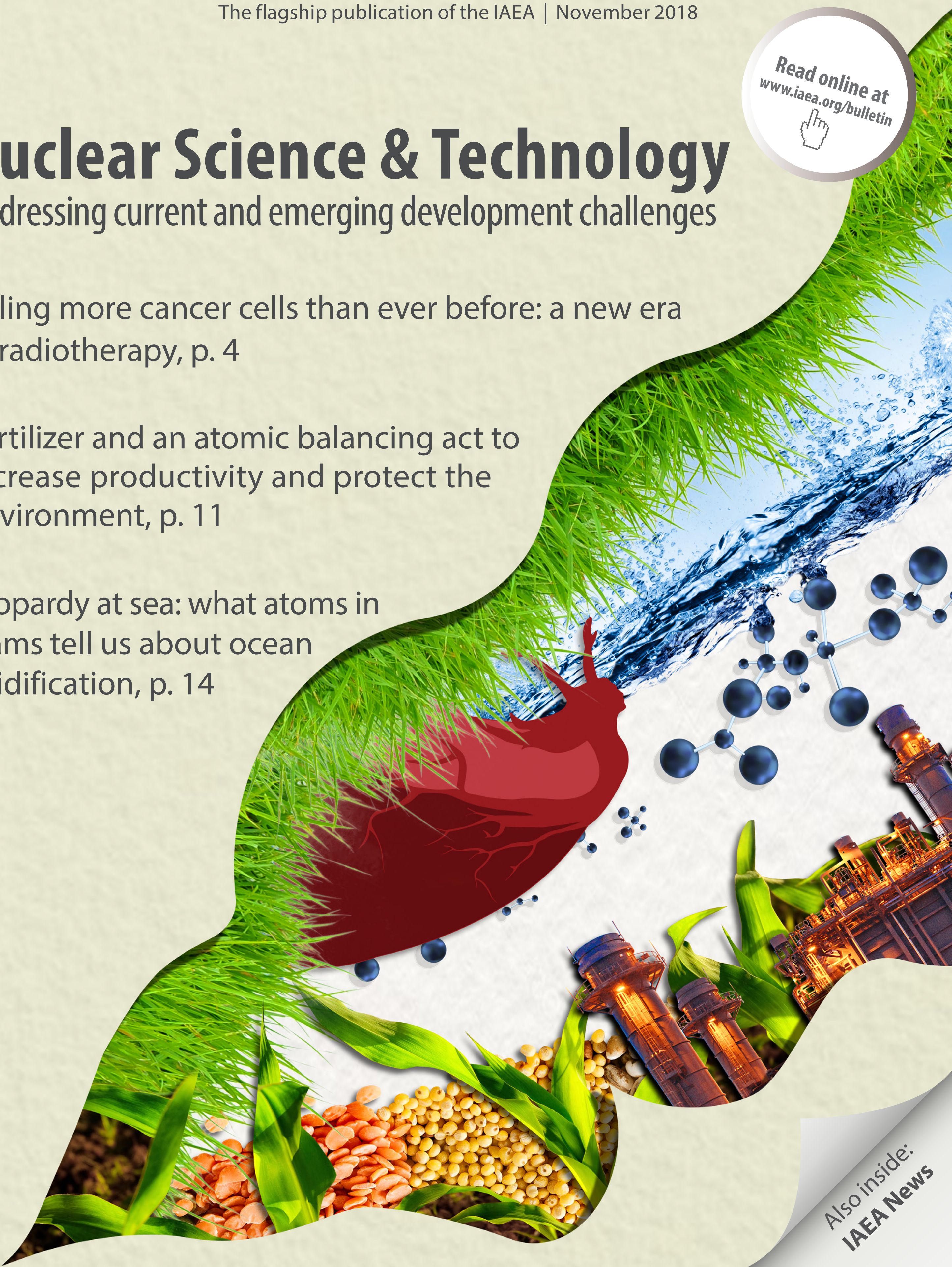
Nuclear Science & Technology

Addressing current and emerging development challenges

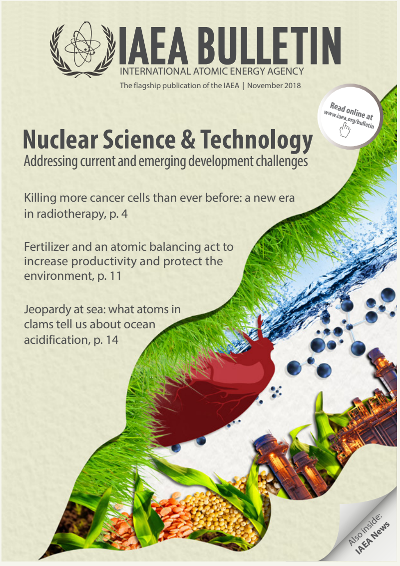
Killing more cancer cells than ever before: a new era in radiotherapy, p. 4

Fertilizer and an atomic balancing act to increase productivity and protect the environment, p. 11

Jeopardy at sea: what atoms in clams tell us about ocean acidification, p. 14



Also inside:
IAEA News



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Follow us on

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.

Advancing toward a sustainable future with nuclear science and technology

By Yukiya Amano, Director General, IAEA

Breakthroughs in computing, engineering and physics in recent decades have greatly increased the contribution of nuclear science and technology in areas as diverse as health care, energy and environmental protection. The growing versatility of nuclear applications is helping countries to tackle a host of existing and emerging challenges.

With its Atoms for Peace and Development mandate, the IAEA helps countries to take full advantage of nuclear science and technology to improve the lives of their people and care for the environment. The Agency is uniquely equipped to assist countries in building their capacity, knowledge and expertise, as well as in tapping into the latest developments in nuclear applications. The IAEA Ministerial Conference on Nuclear Science and Technology: Addressing Current and Emerging Development Challenges in November 2018 is part of our continuing efforts to bring together leading thinkers and decision-makers to assess the state of play today and consider what the future might bring.

In this edition of the *IAEA Bulletin*, you can gain an insight into some of the innovative ways in which nuclear science and technology are being used throughout the world.

Learn how the latest developments in radiotherapy are making cancer treatment more effective, safer and gentler on patients than ever before (page 4). Discover the ways in which isotopic techniques reveal valuable nutrition information to help counteract the rise in unhealthy lifestyles often associated with growing prosperity (page 6). Other isotopic techniques are helping farmers to optimize fertilizer use to boost food production for the world's growing population and to reduce the negative impact of fertilizer as an environmental contaminant and source of greenhouse gas emissions (page 11).

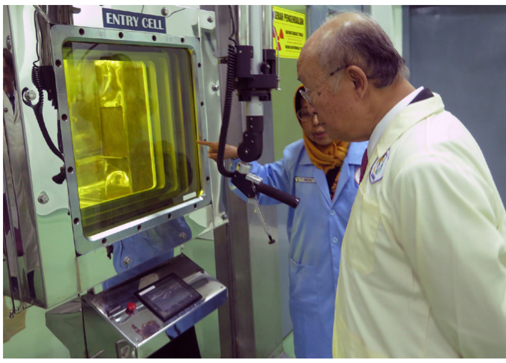
Many countries have turned to nuclear science to help them monitor, mitigate and adapt to climate change, widely seen as the biggest environmental challenge of our time. Experts at the IAEA's 2018 Scientific Forum agreed that solutions to the problems of climate change must include nuclear technology (page 17). This technology has also shed light on what is sometimes called 'the other CO_2 problem' — ocean acidification — and helped scientists to find ways to combat its effects on the oceans and on the livelihoods of coastal communities (page 14).

The impact of nuclear techniques has grown significantly over the years. They are being used in new and diverse fields, from space exploration to conserving valuable works of art and historical artefacts (page 9). To maintain this positive momentum, there is a need to educate and train new generations of nuclear specialists and ensure that knowledge is shared across disciplines. Our story of a young chemist in the Philippines illustrates how empowering a non-nuclear specialist to use nuclear techniques can bridge scientific gaps and break new ground in research (page 19). Countries increasingly recognize the need to increase the proportion of women working in nuclear sciences in order to ensure that we make the most of all the brightest minds in the world (page 21).

The IAEA is committed to supporting all countries in the peaceful use of nuclear applications in order to derive maximum benefit for their people.

"The IAEA helps countries to take full advantage of nuclear science and technology to improve the lives of their people and care for the environment."

—Yukiya Amano, Director General, IAEA



(Photos: C. Brady/IAEA)

Contents

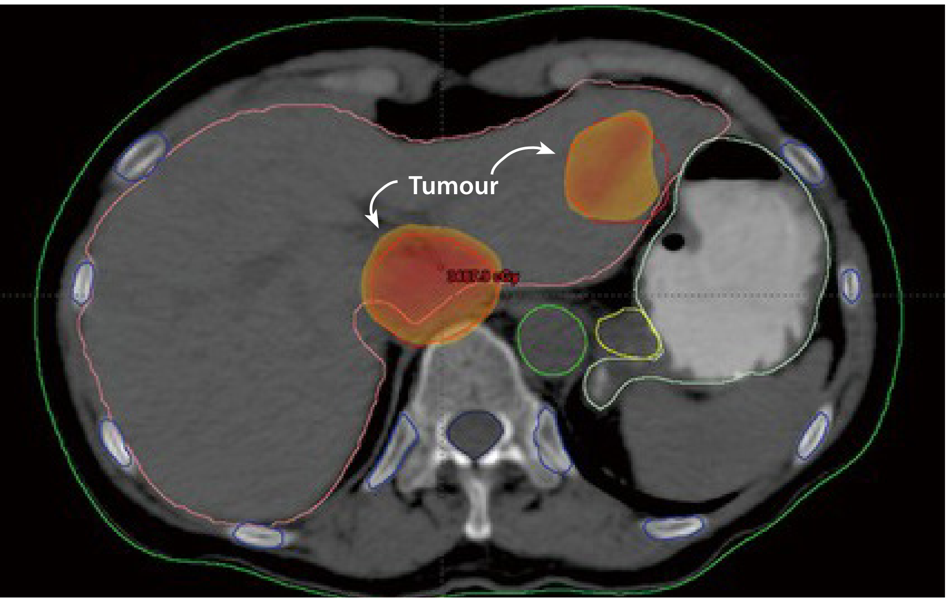
Nuclear Science and Technology Applications: Sustaining, Enabling, and Empowering

World View — The Way Forward

IAEA Updates

Killing more cancer cells than ever before: a new era in radiotherapy

By Nicole Jawerth



A case of liver cancer to be treated with an advanced radiotherapy method called stereotactic body radiation therapy.

(Photo: National Cancer Institute, Egypt)

Radiation revolutionized medicine when it was first used to treat cancer in 1901. Its use, however, has only been able to evolve as far as technical innovation has allowed. Now, thanks to progress in physics, technology and computing, radiation therapy is entering a new era of precision, effectiveness and safety, and the IAEA is helping to ensure advances in radiotherapy reach patients in all parts of the world.

"These advances can improve the quality of life for the patient during treatment. And for many types of cancer, improve targeting, reduce recurrence, and improve survival rates," said May Abdel-Wahab, Director of the IAEA's Human Health Division. "In addition, some of these new technologies, such as stereotactic body radiation therapy (SBRT), may complement new immunotherapy treatments by enhancing the immunogenicity of the cancer."

Over 14 million people worldwide are diagnosed with cancer each year. Around half of all cancer patients receive radiotherapy at some point during their treatment (see The Science box), and it is often used in combination with other methods, such as surgery and chemotherapy.

Many developing countries face challenges in keeping up with evolving technology and methods. Through IAEA support, countries across the world are setting up and receiving training in radiotherapy and safely transitioning to advanced techniques. "The IAEA works hard to help countries provide high-quality radiotherapy services, so that all patients can access and benefit from these life-saving tools and methods," Abdel-Wahab said.

The goal of radiotherapy

The goal of radiotherapy is to safely maximize the treatment of a tumour using radiation, while minimizing harm to the patient's nearby normal tissue and critical organs. To do that, specialists must first meticulously evaluate the tumour and plan treatment using diagnostic imaging and planning tools. They then use a radiation beam from a radiotherapy machine to safely hit a tumour with a carefully measured dose of radiation.

Higher doses of radiation can kill more cancer cells, but can also pose a greater risk to normal tissue nearby. "This is why ensuring precise tumour targeting and delivering accurate radiation doses is critical to safe and effective radiotherapy," Abdel-Wahab said. "Many of the advances we see in radiotherapy revolve around improving and refining these two elements."

More accurate plans for fighting cancer

Advances in imaging and treatment planning, for example, have made it possible for radiation oncologists to move from 2-D to 3-D radiotherapy techniques with relevant imaging and subsequent contouring (a process of taking images of and evaluating a tumour, defining where it ends and healthy tissue begins). A rise in automated planning tools is also helping radiation oncology specialists harness computing power to pinpoint tumours and plan out exactly how much radiation to use on which part of the tumour and from which angles.

But precision in treatment can only go as far as the quality of diagnostic images and a radiotherapy machine's capabilities. Previous generations of diagnostic imaging were less detailed, and the capabilities of radiotherapy technology were more limited. This meant that specialists were forced to use lower radiation doses over more sessions to keep patients safe, and sometimes depending on the patient's condition, rule out radiotherapy as a treatment option altogether.

This has changed with the advent of tools and procedures such as 3-D brachytherapy and image-guided radiation therapy, which use detailed imaging to help dynamically guide and adjust radiation during treatment. SBRT has also made it possible to provide highly precise treatment that delivers radiation from multiple directions and allows for significantly higher doses over shorter treatment times.

Surround and conquer a tumour

SBRT has taken control and precision to another level. What makes it unique is its use of 4-D images — height, width, depth, and, in some sites, motion — to plan and deliver very precise beams of radiation at a tumour from different angles. Each beam on its own has a lower radiation dose, which is safer and reduces the risk of side effects for normal tissue in its path. When the beams converge at the tumour, they expose the cancer cells to a greater combined dose of radiation. This generally means fewer sessions are needed to effectively treat a patient.

"For some types of cancers that are inoperable or cannot be effectively treated with conventional radiotherapy, SBRT is a new chance for survival," said Tarek Shouman, Head of Radiation Oncology at Egypt's National Cancer Institute (NCI), which has been working with the IAEA for over 20 years.

Shouman and the team at NCI, in part through IAEA support, are now using SBRT to treat early lung cancer and recurrent head and neck cancer, as well as a type of liver cancer called hepatocellular carcinoma (HCC), the most common cancer among men in Egypt.

For liver cancers like HCC, SBRT has radically improved radiation treatment options, Shouman explained. Liver cancer is now the third most common cause of cancer deaths in the world. For years, this form of cancer could not be effectively treated using radiation; conventional radiotherapy cannot safely deliver radiation doses high enough to treat a liver tumour because of risks to the surrounding healthy liver tissue. With SBRT, even very small liver tumours can be treated with higher doses of radiation while preserving healthy tissue.

Studies have shown that SBRT can reduce the number of treatments for HCC as well as other cancers, such as brain, lung, and head and neck, from about 30 to 35 treatments to around one to five. Over a two-year treatment period, SBRT has had success rates of 80 to 90% with certain cancers. This is similar to surgically removing a tumour, but poses fewer risks.

"SBRT is just one new approach in radiotherapy — the field is growing fast. We plan to continue working closely with the IAEA to help us stay at the forefront, while also expanding collaboration and support to other countries," Shouman said.

"SBRT is just one new approach in radiotherapy — the field is growing fast. We plan to continue working closely with the IAEA to help us stay at the forefront, while also expanding collaboration and support to other countries."

—Tarek Shouman, Head, Radiation Oncology, National Cancer Institute, Egypt

THE SCIENCE

Radiation therapy

Cancer occurs when cells in the body grow and divide abnormally and uncontrollably. Radiation therapy, or radiotherapy, involves a team of experts in radiation oncology, medical physics and radiation therapy technology using a radiotherapy machine to target ionizing radiation at cancer cells. Depending on the type and location of the cancer, the team may use external beams of radiation or radiation sources placed inside the patient's body. The radiation damages DNA in the cancer cells. As the cells are faulty, their DNA cannot be repaired, destroying the cells' ability to divide and grow and eventually causing them to die. Normal cells — which are also exposed to radiation during treatment — are better able to repair themselves because they are healthy, which increases their chances of survival during radiotherapy.

"Learning about body composition is very important because it is the right marker to measure body fat, and if you have the right marker you can know exactly what the situation is in the country."

—Noorjehan Joonus, Head, Biochemistry Services, Central Health Laboratory, Mauritius

(Photo: L. Viegas Assumpcao/IAEA)

A health policy with atomic precision in Mauritius

By Luciana Viegas Assumpcao

A gust of economic prosperity is sweeping through Mauritius, a bustling island nestled in the Indian Ocean. While mounting affluence has brought opportunity, it has also given rise to unhealthier habits. For many countries, growing wealth often means growing waistlines and the accompanying preventable diseases. To better understand the impact of nutrition on national health, countries like Mauritius are turning to nuclear techniques.

“There is growing interest in studying nutrition to better target health interventions and assess their impact,” said Cornelia Loechl, Head of the IAEA’s Nutrition Section. “Many countries, like Mauritius, now face a double burden — where undernutrition and micronutrient deficiencies coexist with overweight and obesity — increasing the risk of diet-related, non-communicable diseases.”

In the last few decades, the gross domestic product of Mauritius has tripled, thanks largely to tourism and the textile industry, and the country now boasts one of the highest income per capita in Africa. Comprehensive health care is free, and regional health centres service the majority of the population.

But a rise in fast food consumption, coupled with a decline in physical activity and increased life expectancy, have led to the country now having the highest rates of obesity and diabetes in Africa. Non-communicable diseases have soared, becoming responsible for 80% of deaths in 2016, with diabetes alone accounting for 24% of mortality, and cancer killing around 12%.

“The pattern of cancer in Mauritius is very different from that in mainland Africa,” said Shyam Manraj, Director of Laboratory Services and National Cancer Registry Coordinator at the Ministry of Health and Quality of Life. “The country has the highest rate of breast, colorectal and endometrial cancer in the continent. These types of cancer are commonly linked to diet.”

To tackle this growing burden, the authorities in Mauritius have decided to improve the

Results of body composition studies using isotopic techniques led the Government of Mauritius to place stricter controls on food sold in canteens, such as this one at the Baichoo Madhoo Government School.

(Photo: L. Viegas Assumpcao/IAEA)

monitoring of obesity and its impact. With the help of the IAEA, it has carried out several studies since 2009 to measure body composition using a stable isotope method called the deuterium dilution technique (see The Science box). These studies paint a more accurate picture than those using standard measurements, such as the body mass index (BMI).

“The deuterium dilution technique helps to determine the amount of body fat and fat-free mass,” said Loechl. “This is important because there are negative health consequences associated with a higher amount of body fat.”

The national Central Health Laboratory in Mauritius first started to look at the magnitude of obesity in children aged 6 to 13 to find out when they started to become overweight, and what health risks that could carry. The results showed that the BMI for that age group underestimated obesity and overweight in both boys and girls, and that chronic diseases were just around the corner for many young people. “We found an increase in insulin resistance, which means the children are predisposed to non-communicable diseases, especially diabetes,” said Noorjehan Joonus, Head of Biochemistry Services at the Central Health Laboratory, who is leading these studies.

“We communicated the results to the Ministries of Health and Education, and there has been an increase in physical education

Children in Mauritius drink deuterium-enriched water for a study to assess their body composition.
(Photo: L. Viegas Assumpcao /IAEA)

at schools," Joonus added. "They now have physical activity every day, rather than on a weekly basis."

In addition, the government has stepped up other measures: an existing tax on sugar was raised, and stricter controls were placed on food sold at schools. They also increased nutrition counselling in all regional health centres. "When you are in the phase of pre-diabetes it is reversible, but once you become diabetic it is irreversible, so we offer diet advice at an early stage," said Anju Gowreesunkur, a nutritionist at the Ministry of Health and Quality of Life.

Mauritius has since expanded studies to different population groups. Along with deuterium dilution, the laboratory has started to use dual-energy X-ray absorptiometry, or DXA, scans to study the link between body composition, insulin resistance, and breast and colorectal cancers. The DXA technique provides information on body fat distribution (see The Science box), which is important as fat around the organs (visceral fat) carries a greater risk of chronic diseases, such as diabetes.

"These studies are actually helping us to work out our cancer control programme," said Joonus. The country plans to set up a training course for the region on isotope applications for nutrition assessments at the University of Mauritius, in collaboration with the IAEA. "Learning about body composition is very important because it is the right marker to measure body fat, and if you have the right marker you can know exactly what the situation is in the country."

With better data, Mauritius plans to continue to improve its nutrition policies to prevent diseases, so that wealth and prosperity do not get in the way of the nation's health. "As we say, 'you are what you eat'. Research has continuously shown that diseases can be prevented or delayed by just eating the right food," Gowreesunkur said.

THE SCIENCE

Deuterium dilution and DXA

The **deuterium dilution** method works by drinking water with a known amount of deuterium, a stable isotope of hydrogen. An isotope is an atom of the same element (hydrogen, in this case) that has the same number of protons, but a different number of neutrons. Isotopes of an element have a different atomic weight, allowing researchers to trace them based on mass.

After a few hours, when the deuterium is fully mixed in with the water in the body, a saliva sample is taken as representative of the body's water content. The concentration of deuterium in the saliva can then be measured. Since the amount of deuterium consumed and the concentration of it in the body's water are both known, the body's total water content can be calculated. Once researchers know the total amount of body water, they can work out the proportions of fat and fat-free mass in the body, which is called body composition.

DXA, or **dual-energy X-ray absorptiometry**, is an imaging technique for assessing body fat distribution. Using a whole-body scanner, X-rays with two different energy levels are passed through the body. The two energy beams are absorbed differently by different body tissues. The DXA machine measures how much energy is absorbed by the different tissues and converts those measurements into images. By overlaying these images, the relative proportions of bone mineral, fat tissue and lean soft tissue can be visualized and calculated.

DXA was mainly designed to measure bone mineral density in adults to diagnose osteoporosis. However, the scanner can also measure body composition with a high degree of accuracy. The major advantage of DXA is that it measures regional fat deposition, which is where the body fat is situated. This is important because fat deposited around the organs (visceral fat) bears a greater health risk.

X-rays help to uncover who painted a centuries-old masterpiece in Albania

By Alejandra Silva

A portable X-ray fluorescence spectrometer helps scientists analyse a portrait of Saint George, one of Christianity's most famous saints.
(Photo: A. Silva/IAEA)

Albanian researchers have used X-rays to discover who painted a delicate, centuries-old masterpiece of Saint George, one of Christianity's most famous saints. Their methods included non-destructive testing (NDT) and non-destructive assay (NDA) involving X-rays, which are widely used to study materials and the quality of objects, from analysing cultural artefacts and biomedical samples like blood and hair, to finding cracks or cavities in oil pipes and aeroplane parts.

"Non-destructive testing and assay let us evaluate the integrity and physical properties of objects without damaging them, which is critical when dealing with old, often very fragile artefacts," said Elida Bylyku, Director of the Institute of Applied Nuclear Physics in Tirana, Albania. "X-rays also help us see the inner parts of an object and identify any cracks or flaws that may not otherwise be visible."

After recovering the portrait from an old church, researchers at the Institute of Applied Nuclear Physics worked with IAEA experts to study the portrait using NDT and NDA techniques. Their findings have helped conservationists at the National Museum of History in Tirana understand the painting's history and choose the right methods to restore the precious piece of art.

"Originally when we received the portrait, we thought it had been painted by an anonymous artist," said Bylyku. After checking the structural integrity of the piece using industrial radiography, the researchers used X-ray fluorescence analysis (XRF) to identify the materials used to create the icon (see The Science box). They compared these materials to those used by various artists during different time periods and their analysis led to a match.

"Thanks to X-ray fluorescence analysis we have now identified the colour pigments used in the portrait of Saint George, which helped us to discover that the icon was painted by the Çetiri brothers in the 18th century," said Bylyku. "This information is also key to restoring the piece in an authentic way."

The portrait of Saint George is one of thousands of cultural and archaeological treasures in the museum's collection. Many of the pieces have been recovered from historical sites and churches. They are often delicate and deteriorating, which makes them

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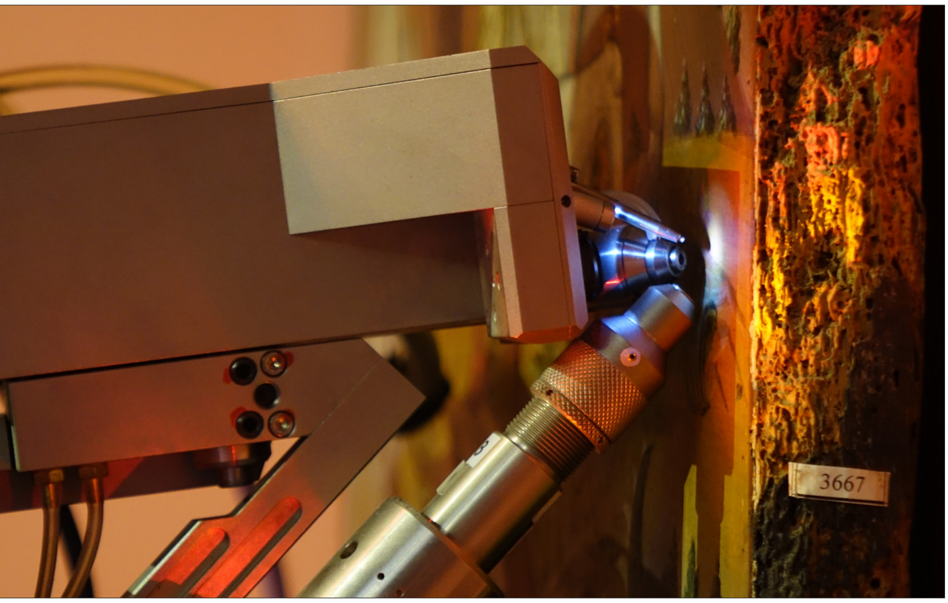


Beams of X-rays interact with the atoms in the portrait to reveal clues about its history and how it was created.

(Photo: A. Silva/IAEA)

precarious to handle. As NDT and NDA are both hands-off methods, they are often used by researchers to study such fragile objects.

Protecting cultural heritage worldwide

NDT and NDA can uncover valuable details in artwork and cultural artefacts that are undetectable to the naked eye. "Each piece contains a unique blend of elements and isotopes that carries information about the origin of the piece, from the techniques and materials used, to when and even where it was likely created," said Patrick Brisset, an industrial technologist at the IAEA. "While this information can be used to preserve pieces and discover the history surrounding their creation, it can also be used to identify forgeries."

Hundreds of specialists worldwide are working with the IAEA to use NDT and NDA to study and preserve cultural heritage and to identify forgeries. This can include receiving training and the necessary equipment and facilities to carry out these studies through IAEA coordinated research and technical cooperation projects. These projects are also an opportunity for specialists to share their expertise and knowledge, which helps to advance the field and preserve the history of human civilization.

"We are working together with the Institute of Applied Nuclear Physics because icons are one of the most important cultural heritage artefacts that we have. So, we are taking every possible step to make sure that they are being adequately analysed and preserved," said Arta Dollani, Director of the Institute of Cultural Monuments of Albania, which works closely with the National Museum of History to restore cultural artefacts.

THE SCIENCE

X-ray fluorescence and industrial radiography

X-ray fluorescence, or XRF, is a non-destructive assay method that detects the presence and measures the concentration of elements in virtually all types of material. Scientists normally use a small, portable device called an X-ray fluorescence spectrometer to bombard a sample of the test material with X-ray beams. The beams interact with the atoms in the sample, displacing the electrons from the inner shells of these atoms. When an electron is displaced, it leaves behind a vacancy that is then filled by an electron from the higher orbit. When an electron moves from a higher orbit to a lower one, a certain amount of energy is released as electromagnetic radiation. This radiation is in the form of X-rays, which can be detected by the spectrometer and is used to unequivocally identify the element they originated from. The method is accurate because the energy of the emitted X-rays is unique to each element. XRF is widely used in archaeometry to investigate the composition of pigments or metals used in manuscripts, paintings, coins, ceramics, and other artefacts.

Industrial radiography is a non-destructive testing method used to verify the internal structure and integrity of objects. It uses ionizing radiation, such as X-rays, to create an image of the internal structure of solid and hard materials. The radiation passes through the material, hitting an exposed film placed on the other side. The darkness of the film varies depending on the amount of radiation that reaches it through the object: materials with areas of reduced thickness, cracks or voids, or a lower material density, allow more radiation to pass through. These variations in the image can be used to find any flaws or cracks hidden inside the object.


(Photo: FAO)

Fertilizer and an atomic balancing act to increase productivity and protect the environment

By Nathalie Mikhailova

When it comes to fertilizer, balance is critical: with the right amount at the right time, crops can flourish to help feed the world's growing population, but too much can cripple plants, pollute soil and water, and perpetuate global warming. So how do you strike the right balance? One way is with the help of isotopic techniques to optimize fertilizer use and tackle its impact as an agro-contaminant and source of greenhouse gas emissions.

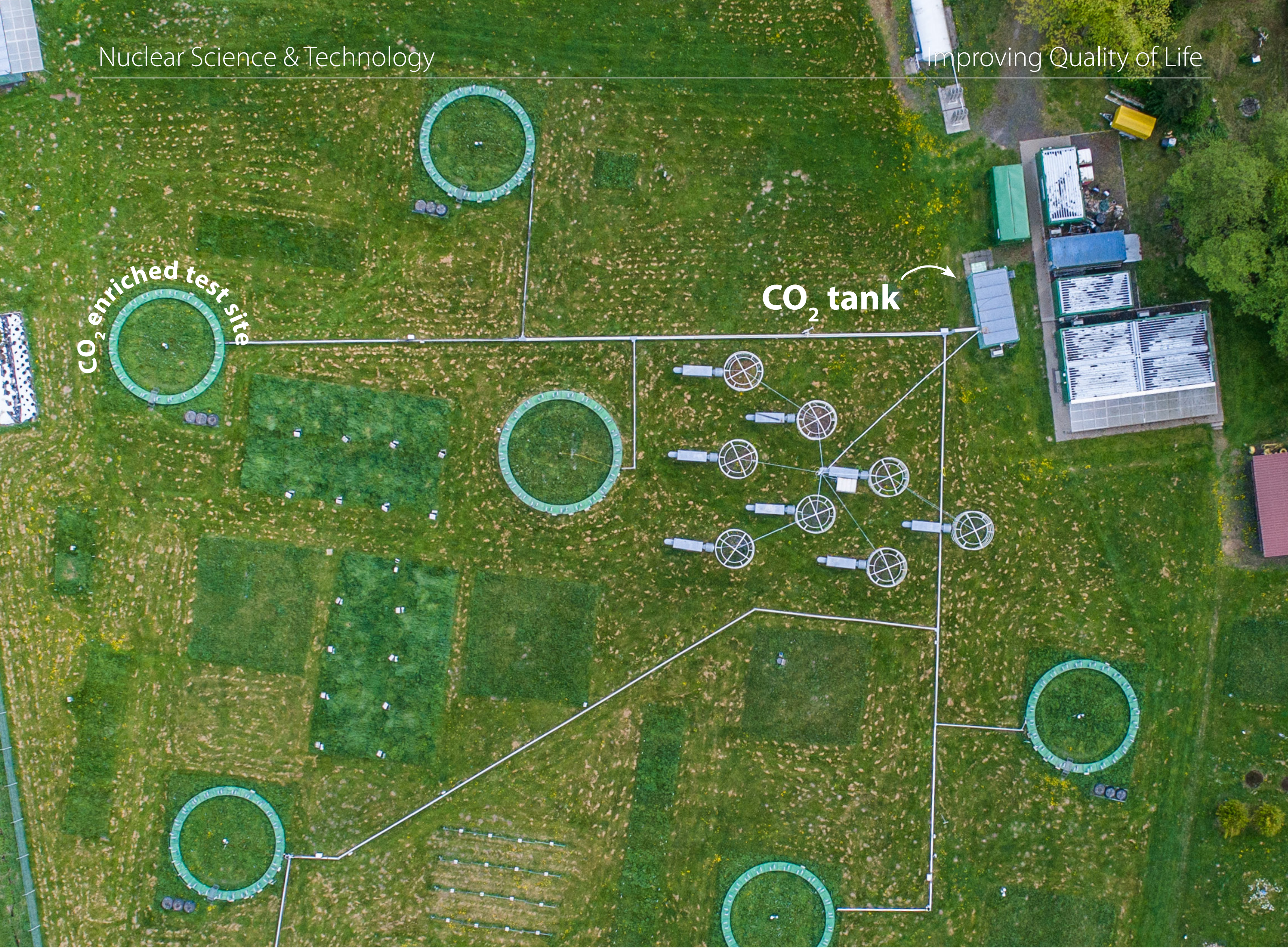
Helping farmers while cutting greenhouse gas emissions

"There are more mouths to feed worldwide than ever before, but the answer is not more fertilizer — the overuse of fertilizer is a big part of why the agriculture sector has gradually become one of the major sources of greenhouse gases over the last 70 years," said Christoph Müller, a soil and plant expert at the Institute of Plant Ecology, Justus Liebig University Giessen in Germany and at the School of Biology and Environmental Science at University College Dublin. In 2014, the agriculture sector, including forestry and other land use, accounted for 24% of global greenhouse gas emissions, according to the Food and Agriculture Organization of the United Nations (FAO).

"We need to protect the environment while helping farmers, but to do that, we first need a detailed understanding of how fertilizers interact with soil and crops, and at what point they release greenhouse gases," said Müller. "Nuclear techniques can help us get those details and find sustainable ways to grow more food while minimizing the environmental impact."

As plants and soil convert fertilizer into useful nutrients, some of the by-products are greenhouse gases: carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). With the right amount of fertilizer, plants thrive and minimal greenhouse gases are released.

> "Nuclear techniques can help us . . . find sustainable ways to grow more food while minimizing the environmental impact."
>
> *—Christoph Müller, soil and plant expert, Institute of Plant Ecology, Justus Liebig University Giessen, Germany*



The Free-Air CO_2 Enrichment (FACE) experiment pumps CO_2 enriched air into several test sites through rings of pipes to simulate atmospheric CO_2 conditions over typical grassland expected by the middle of this century.

(Photo: C. Müller/Justus Liebig University Giessen)

However, when there is too much fertilizer for plants to process and a surplus is left in the soil, it causes an exponential increase in emissions.

Müller and scientists from nine countries along with experts from the IAEA, in partnership with the FAO, are tracking isotopes to understand the link between fertilizer, crops, soil and greenhouse gas emissions (see The Science box). These techniques are also being used as part of a Free-Air CO_2 Enrichment (FACE) experiment, which is helping scientists to study how crop quality and fertilizer needs can be affected by the higher levels of CO_2 in the atmosphere associated with climate change. The findings of their isotopic studies will be used to develop guidelines to help reduce fertilizer use in agriculture, without compromising crop quality and yield.

Their research results have already revealed ways to optimize fertilizer use on an area of over 100 hectares with pasture and rice, maize and wheat crops: greenhouse gas emissions were reduced by 50% and crop yields increased by 10%.

“We have also seen in our FACE experiment that plants are growing more, but their quality is changing,” said Müller. FACE is a large-scale climate change facility under natural conditions. The test site in Giessen, Germany is one of the longest running studies of this kind simulating the atmospheric CO_2 conditions over typical grassland expected by the middle of this century.

Plants grown in these high CO_2 conditions become tougher and their protein content drops. As cows graze on these plants, their stomachs have to work harder and they have to eat more to extract enough nutrients to produce milk. This not only jeopardizes milk production but also causes the cows to emit more methane — a greenhouse gas 34 times more potent than CO_2.

Finding fertilizer in drinking water and beyond

Alongside contributing to greenhouse gas emissions, excess fertilizer is often washed away into rivers and streams by rain or melting snow, ending up in the ocean and drinking water supplies.

“Agro-contaminants can make water undrinkable and harm aquatic ecosystems and biodiversity,” said Lee Heng, Head of the Soil and Water Management and Crop Nutrition Section at the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. “The nutrients in fertilizer, for example, encourage algae growth, which lowers oxygen levels in water and harms fish and aquatic life.”

Fertilizers are one of several agricultural chemicals that contaminate the environment. Others include pesticides, salt from irrigation, sediments and drug residues from livestock. The use of these substances is rising as food producers seek ways to increase food production while combating the effects of climate change, said Heng.

Scientists from 15 countries are working with experts from the Joint FAO/IAEA Division to track multiple stable isotopes to analyse agro-contaminants, their origins, and movement (see The Science box).These techniques will form a toolkit for identifying agro-contaminant sources and developing innovative sustainable practices to counteract their overuse and impact on the environment.

For over 20 years, scientists have used single isotopes to identify agro-contaminants, but using one isotope at a time does not provide enough information to distinguish between different contaminants and their distinctive isotopic signatures.

“Analysing multiple isotopes allows for a more complete picture of the relative contribution of each chemical from each source, so scientists can know which approach to take to deal with contaminants in fields and across landscapes,” Heng said.

Algae grow in the Danube Delta by feeding on nutrients in fertilizer contaminating the water.

(Photo: Joint FAO/IAEA Division)

THE SCIENCE

Stable isotope techniques

Isotopes are atoms of the same element with the same number of protons, but a different number of neutrons, resulting in a different atomic weight. For example, nitrogen-15 has the same chemical behaviour as nitrogen-14, but has one more neutron, making it heavier. Scientists can use this to understand and trace how isotopes transform, as well as their flow paths and exchanges with plants, soil and water bodies.

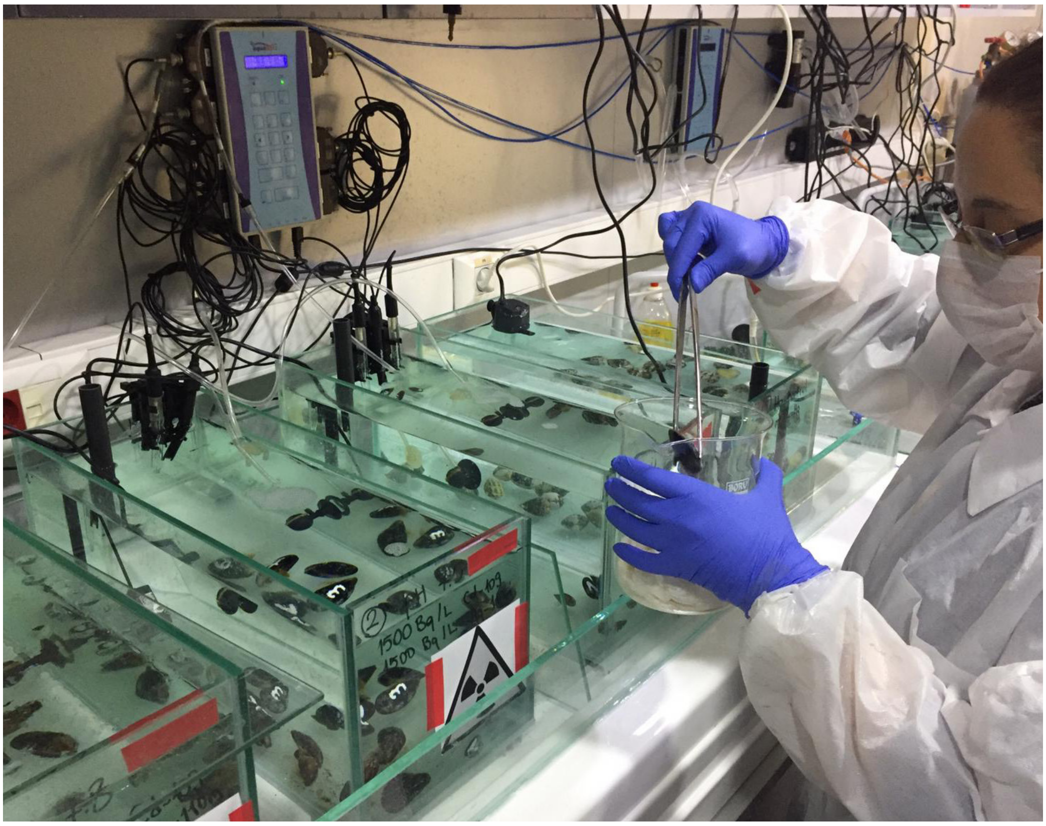
Scientists use nitrogen-15 and carbon-13 to trace the movement and origin of nitrous oxide, methane and carbon dioxide emissions in agriculture. By using fertilizers labelled with nitrogen-15 isotopes, scientists can track the isotopes and determine how effectively fertilizer is taken up by the crops and how much is leftover. Carbon-13 is tracked to determine the movement and origin of carbon dioxide and methane.

Multiple isotope analysis

Scientists use stable isotopes of carbon, hydrogen, nitrogen, oxygen, and sulphur to track agro-contaminants, including their origin and movement from soil to water bodies. These isotopes are used because fertilizers and pesticides contain nitrogen, sulphur and carbon, which are dissolved and transported by water, which contains oxygen and hydrogen isotopes. The isotopes are simultaneously measured to distinguish between the water and pollution cycles and to better understand where contaminants are coming from and where they are going.

Jeopardy at sea: what atoms in clams tell us about ocean acidification

By Laura Gil



For scientists worldwide, marine organisms like clams, corals and tiny marine snails are a window into how CO_2 emissions are affecting the ocean.
(Photo: M. Belivermiş/Istanbul University Radioecology Laboratory)

Clams and other molluscs are under threat. As oceans gradually acidify due to rising carbon dioxide (CO_2) emissions, some of these marine organisms will find it harder to build their shells or skeletons. This is bad news not only for the organisms themselves, but also for the people who rely on them.

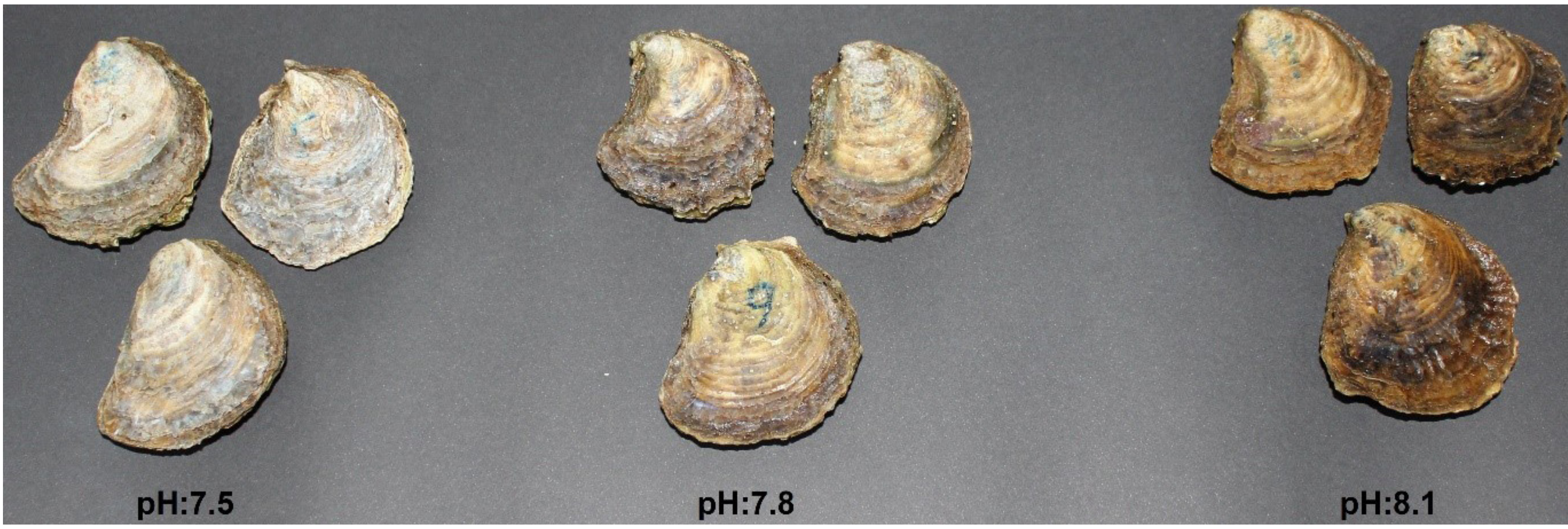
The good news? Scientists can use isotopic techniques to trace the atoms in these shell-building marine animals to better understand the impact of ocean acidification and climate change, which is a first step toward countering the problem.

> **"As ocean acidity levels increase, some organisms take up and accumulate more radionuclides or metals than others, grow more slowly, or need more food to survive. Nuclear techniques can trace all these effects."**
>
> *—Murat Belivermiş, scientist, Radioecology Laboratory, Istanbul University, Turkey*

"As ocean acidity levels increase, some organisms take up and accumulate more radionuclides or metals than others, grow more slowly, or need more food to survive. Nuclear techniques can trace all these effects," said Murat Belivermiş, a scientist at Istanbul University's radioecology laboratory who is using isotopic techniques to study the effects of climate change and ocean acidification on socially and economically important seafood. Belivermiş learned how to use nuclear and isotopic techniques during a fellowship in 2013 at the IAEA's Environment Laboratories in Monaco.

For scientists worldwide, marine organisms like clams, corals, and tiny marine snails are a window into how changing climate conditions are affecting the ocean. Increasing CO_2 emissions — the propelling force behind climate change — are also accelerating ocean acidification. Oceans absorb about one-fourth of the CO_2 that the world emits into the atmosphere, changing seawater chemistry and, in turn, some marine ecosystems and organisms.

Nuclear and isotopic techniques are powerful tools that scientists can use to study ocean acidification, which is sometimes referred to as the 'other CO_2 problem'. Radioactive isotopes such as calcium-45 can serve as precise tracers to examine, for instance, the growth rates of calcifying organisms (see The Science box on page 16). These include mussels and clams that build their shells out of calcium carbonate, a naturally occurring mineral found in the ocean. Ocean acidification makes it harder for clams and



Oyster shells are bleached rather than destroyed by changes in pH levels: pH 8.1 is ambient conditions; pH 7.8 is estimated value in year 2100; pH 7.5 is estimated value in year 2300.

(Photo: N. Sezer/Istanbul University Radioecology Laboratory)

mussels to find the material they need to build and maintain their calcium carbonate shells.

Using radiotracers, Belivermiş and his colleagues discovered that, when exposed to slightly acidified seawater conditions, clams absorbed twice as much cobalt than they would under balanced control conditions, while other marine organisms, such as oysters, have shown a higher level of resilience. This reveals that ocean acidification not only poses a risk to the clams themselves, but also to the people who eat them; cobalt is a heavy metal needed by the human body in minute quantities, but is toxic at elevated concentrations. This can have wider socioeconomic implications for coastal communities like those in Turkey that rely on seafood for local consumption as well as for export to European countries.

“The fishery industry, including many aquaculture growers in Turkey, rely on certain species like clams. So this kind of research could help growers adapt to the changing conditions, which in turn would also help protect the country’s fishery economy,” Belivermiş said.

Belivermiş and his colleague, Önder Kılıç, are now working to expand their collaboration with the IAEA to study the long-term effects of ocean acidification on the growth, nutritional value and health status of species used as seafood in Turkey, such as the Mediterranean mussel or mullet.

“Mussel species live for up to two years,” said Belivermiş. “In order for us to study the full life cycle of an organism, and to fully understand how it acclimates to acidified water, we need much longer experiments.”

Understanding the long-term effects of ocean acidification

Much work lies ahead in order to understand the long-term effects of ocean acidification worldwide. Studies on marine organisms often last weeks to months, but grasping the more realistic effects of the changing ocean over time requires multigenerational studies.

A four-year IAEA coordinated research project to be launched in 2019 will bring together scientists to advance the understanding of the effects of ocean acidification on marine organisms in the long term. The project will aim to fill data gaps on economically and socially important seafood species, as well as explore adaptation strategies for aquaculture and seafood industries.

It will also help scientists understand the long-term effects of ocean acidification on essential nutrients in seafood, such as unsaturated fatty acids that benefit the human cardiovascular system, and what impact this could have on human health. Scientists will use both conventional and nuclear and isotopic techniques to study seafood species providing these nutrients, including oysters, mussels, shrimp, lobster, and fish.

“The oceans are on the one hand fragile, but on the other hand quite resilient. We have seen that they can recover if they are managed well,” said David Osborn, Director of the IAEA Environment Laboratories. “What is important is that we recognize the threats we are putting on the oceans, their combined effect, and that we allocate resources to understanding those effects and addressing them in a proactive and effective way.”

THE SCIENCE

Isotopic techniques and the effects of ocean acidification on calcifying marine organisms

Ocean acidification comprises a series of changes to seawater chemistry, such as a decrease in seawater pH, reflecting a shift towards increased acidity. These changes are measurable: since the onset of the Industrial Revolution, the average ocean pH levels have decreased by 0.11 pH units, equivalent to an increase of roughly 30% in acidity.

While it is difficult to estimate the full impact that ocean acidification may have on marine life, what is known is that, below a certain pH level and a corresponding carbonate concentration, conditions become corrosive to calcium carbonate, a key building block used by many organisms to form shells and skeletons. This can hinder their ability to grow shells and bones, making them fragile and lowering their chances of survival. Some corals, tiny sea snails (pteropods), clams and mussels (bivalve molluscs) and calcifying phytoplankton appear to be particularly sensitive to these changes.

Scientists use nuclear and isotopic techniques to study the rates of biological processes in marine organisms, such as mussels, oysters and corals. They trace specific isotopes, such as calcium-45 (Ca-45) or carbon-14, to understand these processes. Isotopes are atoms of the same element containing the same number of protons, but a different number of neutrons, giving them a different atomic weight.

For instance, scientists can use the radiotracer Ca-45 to measure the quality and rate of calcification, determining how fast and how well shells and skeletons are constructed. To do this, they add a known amount of Ca-45 into a seawater-filled aquarium that also houses, for example, clams. By measuring how much radiolabelled calcium carbonate ($CaCO_3$) is taken up by these organisms over time, scientists can evaluate this calcification process. They use this information to carefully assess the impact of ocean acidification.

(Photo: N. Jawerth/IAEA)

Nuclear technology for combating climate change

Outcomes of the 2018 IAEA Scientific Forum

By Brianna Hartley

(Photo: F. Nassif/IAEA)

How to tackle climate change is at the centre of debates among policymakers and scientists alike, but one thing that experts across disciplines agreed on at the 2018 IAEA Scientific Forum was that nuclear technology *is* part of the solution.

"It is up to us to make the case for nuclear technology and communicate it widely," said Princess Sumaya bint El Hassan, President of the Royal Scientific Society of Jordan, at the opening session of the 2018 Scientific Forum on Nuclear Technology for Climate: Mitigation, Monitoring and Adaptation during the 62nd IAEA General Conference. "We must make the notion of nuclear technology for climate clear, accessible and palatable to all. It is our duty to ensure that the wider world is aware of this and the importance of nuclear technology in combating climate change is recognized."

During the Forum, held from 18 to 19 September 2018, thought leaders including economists, scientists and high-level officials from more than 20 countries discussed ways of expanding the use of nuclear technology for monitoring, mitigating and adapting to the impact of climate change.

Nuclear power can help limit greenhouse gas emissions

With energy production accounting for two-thirds of greenhouse gas emissions, presenters highlighted how nuclear power — a clean, reliable and affordable low-carbon energy source — can simultaneously reduce emissions while securing sufficient energy generation to drive economic growth.

"We need to build on science and facts, but we also need to use proven technologies right now," said Agneta Rising, Director General of the World Nuclear Association. "With nuclear energy, not only will you decarbonize, but you will grow your economy at the same time."

Along with these benefits, nuclear power nevertheless comes with certain challenges. Apart from financial and technical aspects, many nations say public acceptance is a major barrier, explained Malcolm Grimston, Senior Research Fellow at Imperial College London.

"Why is the safest large-scale energy source regarded as the most dangerous by significant numbers of people?" said Grimston. His presentation analysed how the nuclear

"We must make the notion of nuclear technology for climate clear, accessible and palatable to all."

—Princess Sumaya bint El Hassan, President, Royal Scientific Society, Jordan

(Photo: F. Nassif/IAEA)

industry communicates with the public and concluded that the industry should "treat this like a normal industry with normal issues" to improve public acceptance.

Accurate data on climate change

Collecting accurate data on climate change helps scientists and decision makers understand what issues they are dealing with and what action is needed to address it, explained presenters during the Forum's session focused on monitoring and measuring climate change.

"People want to take action. They want to know what emissions they can cut, where they can cut them, and, most importantly, if these actions have an impact," said Oksana Tarasova, Chief of the Environment and Research Division of the World Meteorological Organization.

Speakers during the session highlighted the versatility and precision of isotopic techniques for data collection: from identifying the origin of and measuring greenhouse gas emissions in the atmosphere and oceans, to studying freshwater and agricultural resources to make management more sustainable.

"This knowledge is important to provide better evidence for sound policy making, but many countries are not yet able to apply it," said Tarasova, calling for increased training in these methods.

Adapting to a changing environment

Climate change is wearing down the planet while unleashing more extreme environmental conditions, making it harder for people to grow food, conserve natural resources and fend off harmful insects. Its impact is felt across homes, ecosystems and economies worldwide. But, according to speakers in the Forum's session on the impact of climate change on health and food security, nuclear technology can help scientists find climate-smart ways to deal with these effects.

"We have to set up systems that are able to cope with different challenges," said Natalia Alekseeva, Team Leader for National Climate Change Action at the Food and Agriculture Organization of the United Nations (FAO). "For example, using nuclear techniques for new breeds of plants that are drought-resistant and consume less water or fertilizer and other chemicals helps to redesign agriculture systems in a way that is more robust and more sustainable."

Experts discussed how nuclear and isotopic techniques have helped preserve water and soil resources and control insect pests, as well as improve livestock production and health. They explained the ways in which nuclear technology has also helped in overcoming climate-related challenges to ensure food safety and boost food security, which in turn improves nutrition and health.

Nuclear technology cannot solve climate change issues on its own, said Ilmi Hewajulige, Senior Deputy Director and Principal Research Scientist at the Industrial Technology Institute at Sri Lanka's Ministry of Science and Research. "But we can use this technology as a tool to combat a lot of climate change issues."

Young Philippine chemist finds missing environmental data by turning to nuclear science

By Miklos Gaspar

Wilfren Clutario, a chemist, used nuclear science to study how the ocean handled pollution caused by a severe typhoon in 2013.
(Photo: M. Gaspar/IAEA)

When environmental chemist Wilfren Clutario wanted to understand the level of pollution in the ocean caused by the world's most severe typhoon to reach land, which claimed over 6000 lives and devastated two-thirds of Tacloban in 2013, he had a problem: there was no baseline data available.

"We could measure the concentration of nitrates and organic matter in the sea, but we did not know how much of it was natural and how much was the result of contamination by the typhoon," said Clutario. At the time, he was a researcher at Eastern Visayas State University using conventional techniques to measure the concentration of different compounds at sampling sites. The gusting winds of Typhoon Haiyan, which hit the city on 8 November 2013, caused tsunami-like waves that carried debris containing organic materials, contaminants and human and animal corpses from the land into the ocean.

Researchers and policymakers were unsure if the ocean would be able to cope with the volume of pollution that entered the ocean during the typhoon, which could have transformed the area into a dead zone lasting for decades. They needed to understand what was pollution and what was natural to know whether any measures were needed to assist the ocean in 'digesting' the debris so that it could return to its natural state of equilibrium, explained Clutario.

When Clutario presented his research problem at a conference in 2015, Raymond Sucgang, a senior researcher from the Philippine Nuclear Research Institute (PNRI) with expertise in the use of isotopic techniques to characterize water pollution, sat on the edge of his seat, eager to offer a solution to Clutario's dilemma. They have been working closely together ever since. "Ours is like a professional marriage made in heaven," Sucgang said.

Not only has Clutario learned how to use isotopic techniques to characterize the source of nitrogen and organic matter and its movement to the ocean (see The Science box), with help from the PNRI and the IAEA, in cooperation with the Food and Agriculture Organization of the United Nations, but he has also added the use of isotopic techniques to the curriculum at the Philippine Science High School — East Visayas Campus, where he teaches. He has since supervised several research projects by senior high school students on the use of these techniques in characterizing contamination in fresh water bodies in the area.

"When I watched the typhoon and the storm surge devastate my city and kill many people I knew, I did not know that a few years later, I would be using nuclear techniques to help Tacloban deal with the typhoon's aftermath."

—Wilfren Clutario, chemist, Eastern Visayas State University, Philippines

"We have no office in Tacloban, but we have Wilfren," Sucgang said. And indeed, on a sunny day in August 2018, one of the school's classrooms was filled with researchers from the city and the province who participated in a one-day PNRI workshop on the use of nuclear and isotopic techniques in a wide range of areas.

"Nuclear techniques can do so much, but most people, even in the scientific community, don't know it," said Clutario, who had participated in IAEA-led training courses in Australia and Malaysia to broaden his own knowledge of the subject. "When people, even researchers, hear the term 'nuclear', they only think about nuclear power, but there is so much more to it."

Spreading the use of nuclear applications in the scientific community is central to the mission of the PNRI, which looks to researchers like Clutario to assist, said Carlo A. Arcilla, Director of PNRI. "We are conducting workshops across the country to educate scientists."

Protecting the food chain

Clutario's research has revealed that relatively high concentrations of nitrogen in commercial and coastal areas were natural, while relatively lower concentrations in protected areas and neighbouring commercial fisheries could be traced back to biomass from land, such as cadavers.

"The nitrogen is the tracer, showing us where the pollution ended up," Clutario explained.

For the next step, the fish and sediment need to be studied to determine how much of these contaminants made it into the food chain. Checking the heavy metal concentration in fish is important because toxic substances may have entered the sea as part of the debris.

Clutario continues to take samples and PNRI offices near Manila analyse them using an isotope ratio mass spectrometer, a machine donated by the IAEA through its technical cooperation programme. These analyses will reveal whether the concentrations are decreasing and if this process is happening naturally. "There is a lot more to be done to better understand the ocean," he said

The catastrophic events in 2013 marked Clutario for life; and while history cannot be changed, he said he is glad he can help in the restoration work.

"When I watched the typhoon and the storm surge devastate my city and kill many people I knew, I did not know that a few years later, I would be using nuclear techniques to help Tacloban deal with the typhoon's aftermath."

THE SCIENCE

Stable isotope techniques

Isotopes are atoms of the same element with the same number of protons, but a different number of neutrons. While the chemical properties of all isotopes of one element are the same, their weight differs according to the number of neutrons they have. These weight differences enable scientists to distinguish them from each other when analysed using an isotope ratio mass spectrometer. Scientists can use this approach to identify the isotopic composition of a material.

For these studies on water pollution, researchers tracked stable isotopes of nitrogen and carbon. Species of different origins contain specific, unique levels of isotopes that reflect the food they eat and the environment they live in. Scientists can study this isotopic composition and use it like a fingerprint to identify the presence of different types of organic matter in their surroundings.

In the ocean, plants, like seaweed and seagrass, and stationary animals, like oysters, can tell scientists a lot about the current and past isotopic composition of the environment. Because these organisms do not move, as they take in food from seawater and grow, their isotopic composition develops to reflect the concentration levels of different substances in the ocean at that specific point in time. Therefore, researchers can measure the isotopic composition of these plants and animals to better understand the ocean's past.

Toward closing the gender gap in nuclear science

By Miklos Gaspar and Margot Dubertrand

Muhayatun Santoso, a senior researcher at Indonesia's National Nuclear Energy Agency (BATAN), has led ground-breaking research on air pollution across Indonesia.
(Photo: BATAN)

Women make up less than a quarter of the workforce in the nuclear sector worldwide, hurting not only diversity within the industry, but also competitiveness, experts have said. Many organizations, including the IAEA, are actively working to increase the share of women in all job categories.

"Although there are many talented and highly-skilled women within the nuclear industry, we are still vastly under-represented. There is still work to do," said Gwen Perry-Jones, Executive Director of Operations Development at the Wylfa Newydd nuclear power plant in the United Kingdom. "Diversity in the workplace benefits us all, and I fully support initiatives that encourage women to enter the industry and help them see routes to senior positions."

Women who have made it to leadership roles are making a significant contribution. Muhayatun Santoso, a senior researcher at Indonesia's National Nuclear Energy Agency (BATAN), has led ground-breaking research into the use of nuclear techniques to measure air pollution in many of Indonesia's cities. Her work contributed to Bandung, Indonesia's third largest city, receiving the ASEAN Environmentally Sustainable Cities Award in 2017.

"Air pollution is a major problem across urban areas in Indonesia, with a surge in industrial activity and traffic increasing the amount of toxic substances in the air," she said. "I am proud to be able to help my country tackle this major problem."

Agneta Rising, Director General of the World Nuclear Association, is a leading specialist on nuclear energy and the environment. While she was Vice President for the Environment at Vattenfall AB, Sweden's state-owned nuclear and hydropower operator, she headed a pan-European department focused on energy, environment, and sustainability. She is also the co-founder and former President of Women in Nuclear (WiN). During her presidency, WiN quadrupled in size.

"Women are essential to the strong development of the global nuclear sector. To be the most competitive, a business needs to have the best people working for it. The nuclear industry should have programmes to attract and recruit women, otherwise they would be missing out on the competitive advantage their talents could bring," said Rising. "When the workforce better reflects the diversity of society, including the representation of women, it also helps to build society's trust in nuclear technologies."

"The nuclear industry should have programmes to attract and recruit women, otherwise they would be missing out on the competitive advantage their talents could bring."

—Agneta Rising, Director General, World Nuclear Association

Philippine students do hands-on experiments to learn about nuclear science.
(Photo: M. Gaspar/IAEA)

At present, women make up only 22.4% of the workforce in the nuclear sector, according to data from the IAEA.

Women in Nuclear

The goal of WiN, a non-profit organization with 35,000 members in 109 countries, advocates for stronger roles for women in nuclear science and technology and to increase awareness of the importance of gender balance in historically male-dominated fields. It also promotes these areas to women making career choices.

"While there is a growing proportion of women in senior technical positions in every branch of nuclear science and technology, women are still under-represented," said Gabriele Voigt, President of WiN and former manager of nuclear facilities and laboratories in Germany and at the IAEA.

"Part of the problem is that too few young women study science, technology, engineering, and mathematics in secondary and higher education," she said. "Another issue is the omnipresent glass ceiling and bias — whether conscious or unconscious — that is difficult to confront in the work environment."

WiN is helping to change that by increasing girls' exposure to nuclear-related topics from a young age and by building a strong network of women and creating access to role models for the next generation. Some countries, including with the help of the IAEA, are introducing nuclear science to high school students with a particular emphasis on girls.

"Presenting science, and particularly nuclear science, to girls at an early age is the best way to achieve a higher proportion of female scientists in this field," said Micah Pacheco, regional science supervisor at the Philippines' Ministry of Education, under whose watch several schools in the Manila area have introduced nuclear science and technology education programmes. "Nuclear is fun — girls should see that!"

The IAEA's progress on gender parity

As of the end of 2017, the proportion of women in the professional and higher categories at the IAEA reached 29%, compared to 22.5% ten years earlier. Director General Yukiya Amano has stated that he would like to achieve gender parity at the most senior level by 2021.

"The Agency has taken concrete steps to improve the representation of women in the Secretariat through targeted recruitment efforts and awareness-raising activities, and we've seen improvement in the representation of women at the Agency," said Mary Alice Hayward, Deputy Director General and Head of the Department of Management at the IAEA. "But we are conscious of the challenges that remain. Gender equality in the workplace requires more than improving the statistics — it also means making sure the IAEA is a place where women want to work."

This includes creating a supportive environment, such as flexible working arrangements that enable staff members to combine work and family responsibilities, as well as special outreach campaigns to young women highlighting the benefits of working at the IAEA.

An example of success in reaching gender parity in senior roles at the IAEA was in the Division of Information Technology. While it is historically a male-dominated field, an active campaign and sourcing strategy resulted in targeted outreach to many qualified women candidates.

At the Office of Legal Affairs, the majority of professional staff are women.

"Not only do we have a female Director, two of the three Section Heads are also female, meaning 75% of the senior staff are women," said Director Peri Lynne Johnson. "Furthermore, we have 11 female lawyers and ten male lawyers, and we try to ensure parity among our interns."

Overcoming the Innovation Paradox and how the IAEA can help

Q&A with the World Bank Chief Economist for Equitable Growth

By Aleksandra Peeva

New technologies have the potential to boost a country's development, but a 2017 World Bank study suggests that many developing countries invest relatively little in realizing that technological potential.

Why?

To find out, we spoke to William F. Maloney, Chief Economist for Equitable Growth, Finance and Institutions at the World Bank Group and co-author of The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up. Maloney gave us his take on this innovation paradox and on how the IAEA could help countries maximize their technological potential.

Q: The results of your recent study show that developing countries are missing out on a huge opportunity by not investing enough in research and development (R&D). Why do you think that is and how can it be changed?

A: A common misperception is that innovation is a flow of great ideas but, in fact, innovation is the accumulation of knowledge. It is also important to mention that it is not just the newest technologies that developing countries can benefit from, but also mature, existing technologies, such as some nuclear techniques, that they can profit from enormously and need to be experimenting with.

"It is never about just providing a machine, but rather ensuring the presence of complementary factors, such as highly trained human capital."

—William F. Maloney, Chief Economist for Equitable Growth, Finance and Institutions, World Bank Group

But many factors can prevent countries and firms from getting the returns we think they could get when investing in technology. In the innovation paradox study, we present two explanations as to why there is not a greater adoption of technology.

The first is the absence of the complementary production factors necessary for innovation. These factors can include not having access to qualified personnel, necessary machinery, financing, or, one that we especially stress, managerial capabilities. This is critical, since managers who are not capable of organizing their plant floor or developing a long-term growth plan are often also incapable of identifying and implementing new technologies or undertaking R&D.

The second is information. People, governments and firms don't know what they don't know. One of the main resources that firms generally don't look for are managerial upgrading programmes, which are when an outside expert analyses a company's performance and suggests an improvement plan. These programmes have been proven to have a large impact on productivity and innovation. One of the reasons for this is that firms often vastly overestimate how well they do in terms of management quality and technological abilities compared to the best firms and therefore don't realize how much they can improve.

Q: Your research shows that governments and the private sector in developing countries need to work in tandem for R&D-focused initiatives to succeed. What role could international organizations such as the World Bank and the IAEA play?

A: The further away one gets from the technological frontier, the more complex the problems become; developing countries often suffer simultaneously from weak educational systems and poorly functioning financial markets and business climates, while also having governments that often do not function very well. This means many developing countries may find themselves in a trap where they don't have the capabilities to fix the things they need to fix in order to adopt technologies and take advantage of them to grow.

We often see people bringing business models from advanced countries to developing countries. However, these business models often don't work because the constraints are different in developing countries, and the models' incentives are designed for a different situation. For instance, an advanced country may have low rates of innovation because of standard problems, such as firms' inabilities to fully capture the fruits of their innovation effort. So, they focus on patent systems, public research institutes, tax write-offs or subsidies for R&D. However, developing countries may not have firms capable of carrying out an R&D project or the human capital to undertake it, which means that policies need to focus on these areas first.

International organizations like the World Bank and the IAEA can help strengthen governments, identify key barriers to innovation and adoption of technologies, and assist in creating adequate policies to reduce such problems. Over time, this will lead to more sophisticated innovation structures in developing countries.

Q: The IAEA is not a donor organization; our expertise lies in transferring knowledge and technology to Member States — developing countries in particular — which are crucial for long-term sustainable development. In this context, how could the IAEA best help countries find their way out of the innovation paradox?

A: Technology transfer is a critical ingredient for growth, and facilitating it will require addressing the issues I've talked about: providing information and capacity building. It is never about just providing a machine, but rather ensuring the presence of complementary factors, such as highly trained human capital. The IAEA has the technical know-how and the experts with the right scientific background to help train people to recognize opportunities for transferring technologies and develop the capabilities to transfer these technologies. This is critical for many developing countries with weak human capital, because if there are no capable engineers and scientists to identify where and how a technology can be applied, there won't be an idea transfer, even if the business environment is in reasonable shape.

Building connections with institutions outside the countries can ease the flow of information and increase countries' awareness of existing technologies. This is another critical area in which the IAEA could assist governments.

Nuclear science & technology: towards the 2030 Agenda for sustainable development in Malaysia

By Mohd Abdul Wahab Yusof

Nuclear activities in Malaysia began in 1897, when X-rays were first introduced to a hospital in Taiping, Perak. From this humble beginning, nuclear technology in Malaysia evolved and flourished with the establishment of PUSPATI (later Nuklear Malaysia) in 1973. The field became more active and dynamic when the Reaktor TRIGA PUSPATI, our first research reactor, was commissioned in 1982.

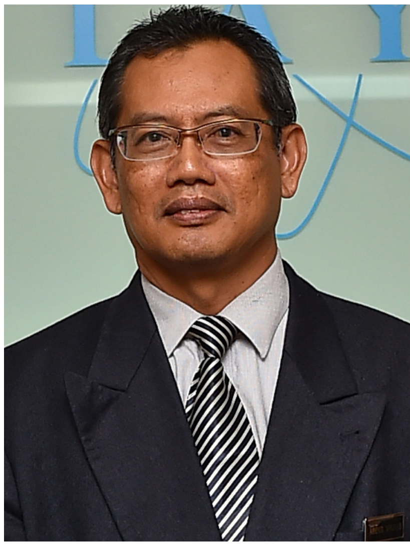
The peaceful uses of nuclear technology have had a positive impact on the nation's socioeconomic development by improving quality of life, enhancing social wellbeing and contributing to the gross domestic product (GDP). Building on a previous study, we are currently working on quantifying the value-added contribution that nuclear technology makes to the country's overall GDP and economic growth.

Malaysia aims to transform and modernize the food and agriculture industry into a high-income and sustainable sector. These efforts will include ensuring food security, improving productivity and overcoming the impact of climate change on the sustainability of agricultural practices. We are exploring the use of precision agriculture in managing and responding to various factors, such as weather patterns, soil condition and temperature. Developed using nuclear techniques, a new rice variety called NMR152 has been found to mitigate the effects of climate change by its ability to withstand periods of drought and flooding. The Gamma Greenhouse, which is the only facility for chronic mutagenesis activities in South-East Asia, can further support developments in climate-smart agriculture.

Industrial testing using nuclear technology has also contributed to the competitiveness of Malaysia's manufacturing sector by establishing an export niche in South-East Asia, offering non-destructive testing to manufacturers in neighbouring countries. Similarly, the field of radiation processing has produced numerous new materials and composites with desirable characteristics for the manufacture of, among others, medical devices, cables and biodegradable plastics. Currently, Nuklear Malaysia is collaborating with PROTON, a car manufacturer, to produce and test a radiation-induced cable insulation material, which can withstand high temperatures to enhance car safety. The designation of Nuklear Malaysia as an IAEA Collaborating Centre in the area of non-destructive testing and radiation processing is a recognition of Malaysia's achievements in these fields, as well as of the close and valuable cooperation between Malaysia and the IAEA in various activities in the region, including research, development and training.

Malaysia remains committed to achieving universal access to quality healthcare by strengthening efforts towards improving healthcare services, particularly in areas where radiation is used in medicine, such as radiology, radiotherapy and nuclear medicine. We will continue to promote and improve the use of radiation in medicine for social wellbeing. Nuclear techniques are critical for the early detection, diagnosis, treatment and care of cancer. The field of radiation medicine in Malaysia has expanded greatly since the 19th century, culminating in the establishment of the first cyclotron and positron emission tomography/computed tomography (PET/CT) facility in 2006, which marked the first step in the creation of the National Cancer Institute. Currently, more than 20 hospitals in Malaysia use nuclear technology in diagnosis or treatment.

For Malaysia to be continuously relevant among other countries in nuclear technology, we need to follow technology trends such as Industry 4.0, the Internet of Things, and national and international agendas, such as the 2030 Agenda and the Sustainable Development Goals. Sustainable development has been at the heart of Malaysia's developmental approach since the 1970s, with an emphasis on eradicating poverty, improving the wellbeing of the



Mohd Abdul Wahab Yusof, Director General, Malaysian Nuclear Agency people, providing universal access to education and caring for the environment. The 2030 Agenda, in the Malaysian context, is a mirror of our New Economic Model and the 11th Malaysia Plan.

So, what do we have to look forward to? In the future, fusion between nuclear and other technologies will be more widespread. I am convinced that nuclear technology will continue to expand, particularly through its convergence with emerging technologies, such as nanotechnology, biotechnology and information and communication technology. This is important for us, especially when faced with challenges such as technology acquisition, which may become more prominent in time and which may ensure further development and economic competitiveness, so that Malaysia can become a fully industrialized and high-income nation.

As part of our preparation to face future challenges, localization and development of home grown technology needs to be enhanced, so that products and services of the future are adaptive to current demands. Undoubtedly, nuclear science and technology have contributed to the nation's socioeconomic development by generating employment, creating opportunities for new businesses, enhancing human capital development and improving the quality of healthcare services. Its use has exposed Malaysia to advanced technology, leading to better products and service quality, and enhanced diagnosis and therapeutic capabilities in medicine, and it provides the agriculture sector with the means to produce new and better cultivars.

Malaysian scientists use nuclear techniques to breed new plants with desirable traits such as humidity tolerance and higher yields.
(Photo: M. Gaspar/IAEA)

Answering the call of a changing world: nuclear technology today and in the future

By Aldo Malavasi, Deputy Director General and
Head of the Nuclear Sciences and Applications Department, IAEA

Nuclear science and technology may operate on scales invisible to the naked eye, but the impact of this atomic work is evident in many spheres of life. It is boosting food security by helping farmers grow more food, conserve water and stave off insect pests. Doctors and other health professionals use it to care for patients and save lives. Other uses include ensuring the safety of products like car tyres and aeroplanes, as well as cleaning up environmental pollution and preserving cultural artefacts.

But as the world changes, development challenges evolve as well, calling for novel tools and methods. It is the task of the nuclear science community, including the IAEA, to answer this call.

Researchers worldwide work with IAEA experts and in IAEA laboratories to use nuclear and isotopic techniques to tackle new global challenges, such as climate change, addressing the growing nutritional and medical demands of an increasing global population and supporting the expansion of industrialization for development.

Some of the innovative work we are already seeing in nuclear science includes new ways to manage insect pests, such as disease-carrying mosquitoes, using the sterile insect technique, and novel plant varieties that can withstand new climate conditions while still providing high yields. Scientists are also exploring the growing plastic pollution problem and how to deal with plastic particles that are entering our food chain via the ocean. New methods are also being developed to monitor deadly diseases and viruses, such as Ebola, and creating new, irradiated vaccines to help both animals and humans.

As nuclear technology continues to advance, scientists are finding new ways to more precisely and effectively use radiation to diagnose and treat diseases like cancer, saving more lives and improving patients' quality of life. They are also breaking into new areas of medicine, such as neuropsychiatry and the use of molecular imaging for the early diagnosis of diseases like Alzheimer's.

Underlying this forward-looking research and development is the IAEA. The IAEA's Atoms for Peace and Development mandate reflects the broad scope and opportunity for nuclear science and technology to contribute to human wellbeing and sustainable development. The IAEA provides a platform for scientific collaboration, research and development and training across a broad spectrum of development areas, including food and agriculture, environmental protection, water management, industrial development and human health.

The benefits of nuclear science and technology touch all corners of the globe through the IAEA technical cooperation programme and coordinated research activities, which reach more than 145 countries every year, supported by the IAEA's 12 specialized laboratories in Austria and Monaco.

To help keep nuclear technology at the forefront of global development, several IAEA laboratories are undergoing a complete modernization, which will ensure they remain flexible and able to rapidly respond to emerging and emergency needs worldwide. A brand new Insect Pest Control Laboratory, completed in 2018, will further enhance the nuclear techniques essential to combating insect pests that can cripple crops and affect livestock and human populations. A Flexible Modular Laboratory, inaugurated in November 2018, houses three further laboratories that focus on the latest nuclear techniques linked to livestock production and health, including combating zoonotic diseases such as Ebola and Zika; food and environmental protection, which includes forensic techniques for tracing the origin of products to fight food fraud; and soil and water management and crop nutrition to preserve precious resources in agricultural production. In addition, a dosimetry bunker to house a new linear accelerator is under construction. The linear accelerator is expected to become operational in 2019 and will provide dosimetry services to help hospitals to safely calibrate and use radiation to care for patients.

The IAEA's partnerships are further amplifying the reach of nuclear science and technology. To mention just a few, a unique joint division was established with the Food and Agriculture Organization of the United Nations in 1964. In 1976, the IAEA and the World Health Organization began a formal partnership. Now the IAEA's Environment Laboratories in Monaco host the Ocean Acidification International Coordination Centre. The ALMERA worldwide laboratory network was also established in 1995 to support work measuring environmental radioactivity levels in the event of accidental or intentional release of radioactivity.

The IAEA's partnerships also include 31 IAEA Collaborating Centres around the world (see box). These centres work with the IAEA to pursue research and provide training in nuclear science, which allows for the efficient sharing of resources, knowledge and expertise between scientists and the IAEA. This network will grow as countries and the IAEA work together to identify new Collaborating Centres.

The IAEA's support and its unique global network of laboratories, Collaborating Centres and partnerships are helping pave the way forward. As countries' development needs continue to evolve, the IAEA's support will be there to help them access and benefit from the use of atoms for peace and development. And with the ongoing innovations and advances in technology, the unique tools that the atom gives us will continue to contribute to the wellbeing of humankind for many years to come.

Connecting scientists around the world

IAEA Collaborating Centres form a network that stretches across all continents: from Africa, Asia and Australia to Europe, the Middle East and North and South America. A Collaborating Centre is a scientific institute or organization that offers a unique facility and skill set in a distinct area related to nuclear technology, such as food irradiation, environmental radioactivity measurement, the health effects of radiation, non-destructive testing or water resource management.

Centres are chosen for their ability, capacity and readiness to directly contribute to specific IAEA projects and activities. They work with the IAEA on a mutually agreed plan to support and amplify the use of nuclear science and technology worldwide. The cooperation is designed to encourage original research and development, while also helping scientists to share knowledge, resources and expertise, prepare reference materials, validate methods and provide training. These activities in turn help countries, both with Centres and without, get access to scientific support to pursue their development objectives and meet their targets under the United Nations Sustainable Development Goals (SDGs).

"Through the Collaborating Centre network, Member States can assist the IAEA by undertaking original research and development and training relating to nuclear technologies. This encourages scientific studies and cooperation across Member States, making Collaborating Centres one of the IAEA's key cooperative mechanisms," said Sasha Damjanac, Head of the IAEA's Research Contracts Administration Section.

As of 2018, there were 31 active Collaborating Centres worldwide, with ongoing discussions in several countries to establish new Centres.

— By Sarah Kiehne

Winners of the IAEA crowdsourcing challenge for materials for fusion technology announced

A team of four scientists from the Max Planck Institute of Plasma Physics and the Max Planck Computing and Data Facility in Garching, Germany won the IAEA crowdsourcing challenge for visualization, analysis and simulation of materials to build fusion reactors in October 2018.

Nuclear fusion, the atomic reaction that powers the sun, has the potential to eventually provide an unlimited supply of affordable and clean carbon-free energy using hydrogen isotopes obtained from water and lithium. However, harnessing commercially viable fusion power presents serious technological challenges, such as protecting the wall and other components of the reactor vessel from extremely high temperatures and high-energy particles.

Fourteen research teams from ten countries submitted innovative analyses of simulations of reactor wall damage, which can be caused by high-energy neutrons released by a fusion reaction. The simulations were judged on their scientific benefit, the novelty of the algorithm itself or its use within the domain of material science, and the visualization's utility and expected impact.

"Some of the submissions were quite extraordinary; it was almost like organizing a local football event and then having a World Cup-winning team come," said Sergei Dudarev, Manager of the Materials Programme at the United Kingdom Atomic Energy Authority and one of the initiators of the challenge.

The winning team members — Udo von Toussaint, Javier Dominguez, Markus Rampp and Michele Compostella — applied an existing technique from machine learning and data science for the first time to identify and classify structures of defect in the simulated damaged crystals.

"This solution opens up a new and productive way to automatically categorize defect structures and hence deduce, in a quantitative way, the common factors and differences between materials," explained Arjan Koning, Head of the Nuclear Data Section at the IAEA. "In the context of the study of materials for the vacuum vessel of a nuclear fusion reactor such as ITER, it provides an effective means of measuring, classifying and visualizing the damage done to a particular material by the high-energy neutrons released by the fusion reactor. The search for a suitable material from which to construct the reactor vessel's first wall is a crucial step towards the construction of a viable fusion power plant."

The approach has several advantages over existing methods, including the following:

- new or unexpected defect types can automatically be identified and classified;
- it is based on a combination of robust and clear algorithms from data science;
- it can distinguish between genuine defects and the small, temporary distortions caused by thermal movement of the atoms; and
- it is fast enough to be applied during the evolution of the crystal's simulated damage over time to better understand how defects form, combine and, in some cases, eventually disappear as the atoms return to their initial positions on the crystal lattice.

Until now, defect identification and classification were very labour-intensive and time-consuming tasks and, therefore, were typically carried out only at the end of molecular simulations. This new algorithm can be applied during the simulation of the crystal defect at each stage, which can provide new insights into when certain types of defects occur and vanish. This gives much more information about the system, which up to now was hardly accessible, and allows the types of defects that are likely to remain for a long time to be distinguished from those that are not.

"We hope that our approach will tremendously accelerate the simulation analysis for molecular dynamics simulations," said von Toussaint. "Computing power is increasing and manual capabilities are limited. Anything that can be done by computer rather than by people speeds up scientific development."

The winners will make their code available on a cost-free, open-source basis to any interested party, he added. It could be used by other institutions and experts — mainly material scientists — to analyse the results of their simulations, particularly those relating to radiation damage in solids.

The IAEA is planning to build on the success of this challenge by developing a distributed computing application that can be downloaded by volunteers to run simulations of damage in materials for fusion, Koning said. This has the potential to greatly increase the speed at which new candidate materials for a fusion reactor can be explored and will further enhance scientists' understanding of the behaviour of these materials in such extreme conditions.

— By Christian Hill and Aleksandra Peeva

IAEA neutron activation e-learning course helps scientists in 40 countries

From helping to solve historical criminal cases to determining the cause of a disappearing beach in Jamaica or the air quality at your gym: neutron activation is an established method to find out the composition and origin of materials. An e-learning tool developed by the IAEA is now helping researchers in 40 countries to apply the method.

Neutron activation is a common type of analysis carried out in around half of the 238 operational research reactors worldwide, as well as in some accelerator-based neutron sources. The highly sensitive technique can reveal the concentration of a single atom in a million, without tampering with or destroying the material. Its precision offers advantages over other analytical methods, and it is particularly useful for bulk analyses and studying materials that are unique and need to remain intact.

The technique works by irradiating stable atoms with neutrons and subsequently measuring the decay, or radiation, of the elements in the sample. Scientists use the technique to find the chemical signature of plastics, metals, glass, soil and air particles, among others.

"The main fields of application of this method today are in environmental sciences, archaeology, cultural heritage and even forensics," said Nuno Pessoa Barradas, Research Reactor Specialist at the IAEA. "Researchers in these fields, however, do not necessarily have a background in nuclear physics, so they may not be able to use the technique to its full potential."

Building knowledge

In order to bridge this knowledge gap and to address a growing demand, the IAEA, through the technical cooperation project Networking for Nuclear Education, Training, and Outreach Programmes in Nuclear Science and Technology, designed an e-learning course on neutron activation analysis. Launched in late 2017, the tool caters to both newcomers and specialized advanced-level professionals.

In October 2018, the online training course reached a landmark target, with participants in 40 of the 52 countries with operating research reactors signing up for it in less than a year. Several institutes use the tool to educate staff and students, including at university level.

"We face frequent changes of employees and the training of new staff is quite time consuming, especially in such a specialized field," said Katalin Gméling from the Hungarian Centre for Energy Research. "The e-learning material offers a great collection of information to train newcomers and refresh the knowledge of senior staff."

Discovered in 1935 by Hungarian-born chemist George de Hevesy and German-Danish physicist Hilde Levi, neutron activation originally became a useful tool to measure the mass of rare earth elements.

In the past few decades, several other uses have been found for the method, including providing additional evidence for historical criminal cases. In 2013, neutron activation was used on a moustache hair to disprove the theory that Danish nobleman Tycho Brahe was killed by mercury poisoning. His valuable notes were inherited by his assistant, and prime suspect, mathematician and astronomer Johannes Kepler, who discovered planetary motion laws.

More recently, following the theft of an estimated five hundred truckloads of sand from the Coral Springs beach in Jamaica, local authorities teamed up with the International Centre for Environmental and Nuclear Sciences to apply neutron activation to test the origin of sand at suspected receptor beaches, providing additional evidence for the case.

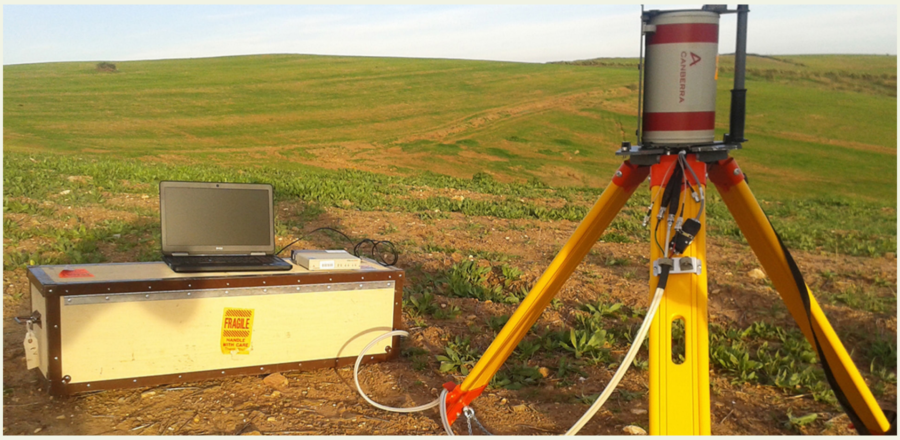
Today, neutron activation is also used to research and test indoor air quality (e.g. at schools and fitness centres) by helping to determine the quantity and origin of pollutants in the air.

The neutron activation analysis e-learning tool was reviewed at a workshop in September 2018 at the IAEA Headquarters in Vienna.

"The tool is intended to be a living book that can be constantly updated and extended as this field evolves to include different laboratory protocols and research areas," Barradas said. The launch of the first revision is planned for early 2019.

— By Luciana Viegas

Egypt and Senegal receive gamma detectors to help combat soil erosion



Experts in Egypt and Senegal will be better able to fight soil erosion thanks to two gamma spectroscopy detectors which were delivered in November 2018 through the IAEA's technical cooperation programme. The detectors will be used for soil erosion assessment in areas that have experienced severe land degradation, a phenomenon that jeopardizes agriculture in many regions of the world, including in arid and semi-arid lands in Africa.

Egypt and Senegal are both suffering from severe land degradation, with soil productivity in most of the northeast Nile Delta in Egypt, for instance, having decreased by more than 45% in the last 35 years, according to recent studies. Land degradation is the result of several factors, including overexploitation of land, unsustainable agricultural practices and extreme weather events, which have occurred more frequently in the last few decades. Soil erosion — a major type of land degradation caused by both human and environmental factors — can lead to the complete loss of the fertile topsoil, leaving the affected land unfit for agriculture.

Agriculture is an important economic sector in most African countries, accounting for approximately 12% of Egypt's gross domestic product (GDP) and 17% of Senegal's GDP. Low-input farming from subsistence farms run by families represents a significant component of this sector. It accounts for a high proportion of jobs, and provides livelihoods to subsistence farmers and their families. As this type of farming typically takes place on arid and semi-arid land with marginal agricultural potential, such as drylands and mountains, it is particularly susceptible to soil erosion.

The IAEA, in cooperation with the Food and Agriculture Organization of the United Nations (FAO), has been assisting countries for more than 20 years in combating land degradation by supporting the use of isotopic techniques to assess soil erosion.

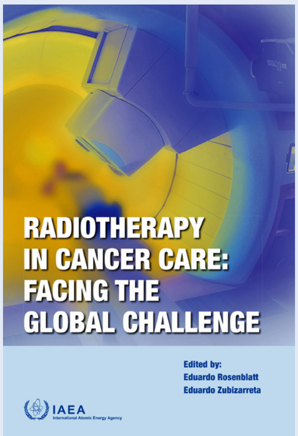
Fallout radionuclide tracers, such as caesium-137 (Cs-137), have been used extensively in assessing soil erosion and sedimentation. This radionuclide is present in the atmosphere from where it falls to the ground in precipitation and accumulates in the uppermost soil layer. During erosion, the topsoil is washed away, which can be measured as decreased levels of Cs-137. At the same time, where the eroded soil settles, increased levels of Cs-137 are seen.

The erosion assessment using Cs-137 has many advantages compared to traditional methods, said Emil Fulajtar, a soil scientist in the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. This method provides long-term mean erosion rates, while conventional methods provide mostly short-term data. Using this nuclear technique, there is therefore no need for long and resource-demanding monitoring programmes: soil redistribution can be assessed in a single sampling campaign. It also helps to determine the spatial distribution of erosion, which is essential input for soil conservation programmes aimed at sustainable land management and thereby food security.

The provision of gamma spectrometers, which are used to carry out the Cs-137 measurements, is part of an ongoing initiative by the Joint FAO/IAEA Division to help African countries enhance their capacity to control soil erosion; this also includes the training of scientists on the use of the Cs-137 method and the establishment of gamma spectroscopy capacities across the continent. Another three table-top gamma detectors — for Madagascar, Algeria and Zimbabwe — and three portable gamma detectors — for Morocco, Tunisia and Madagascar — have already been delivered.

"We will use the gamma detectors for the 'fingerprinting' of sedimentation in the Nile River to trace the origin of contamination from different sources, such as drainage from industrial and agricultural bodies located on the riverbank," said Mohamed Kassab, a lecturer at the Egyptian Atomic Energy Authority's Nuclear Research Centre. "We also plan to help other countries in Africa to build capacity in gamma measurements and analytical services."

— By Matt Fisher

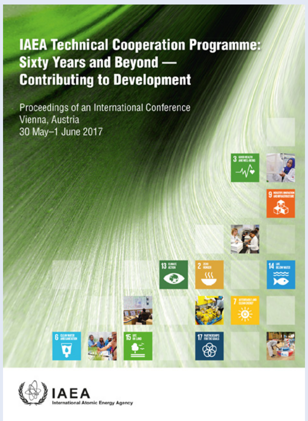


Radiotherapy in Cancer Care: Facing the Global Challenge

presents a comprehensive overview of the major topics and issues to be taken into consideration when planning a strategy to address the lack of radiotherapy resources worldwide, particularly in low and middle income countries. Radiotherapy is recognized as an essential tool in the cure and the palliation of cancer. Access to radiation treatment is currently limited in many countries and non-existent in some. This lack of radiotherapy resources exacerbates the burden of disease and underscores the continuing health care disparity among states. Closing this gap is an essential measure in addressing this global health equity problem. With contributions from leaders in the field, this publication provides an introduction to the achievements and issues of radiation therapy around the world as a method to treat cancer. Dedicated chapters focus on proton therapy, carbon ion radiotherapy, intraoperative radiotherapy, radiotherapy for children, HIV/AIDS-related malignancies as well as costing and quality management issues.

Non-serial Publications; ISBN: 978-92-0-115013-4; English edition; 62.00 euro; 2017

www-pub.iaea.org/books/iaeabooks/10627/Radiotherapy-in-Cancer-Care

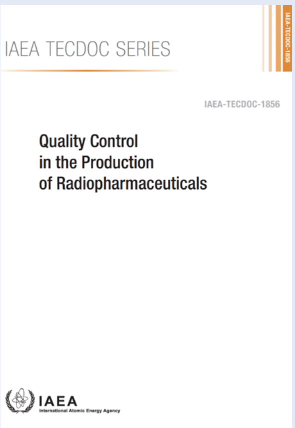


IAEA Technical Cooperation Programme: Sixty Years and Beyond — Contributing to Development

details how the IAEA Technical Cooperation programme has contributed to the establishment of national nuclear infrastructure and capabilities in Member States over six decades in support of their national development priorities. The publication also presents examples of successful partnerships and looks to the future regarding appropriate approaches and concrete measures that will help countries maximize their use of nuclear science and technology to achieve their development goals, including sustainable development goal targets. Key thematic areas covered include the application of nuclear science and technology in human health and nutrition, food and agriculture, water and the environment, radiation technology, energy and safety. Common issues relating to regional collaboration and networking are presented, as are the approaches the IAEA and Member States take to building lasting and mutually beneficial partnerships.

Proceedings Series; ISBN: 978-92-0-100318-8; English edition; 36.00 euros; 2018

www-pub.iaea.org/books/iaeabooks/12280/Technical-Cooperation-Programme



Quality Control in the Production of Radiopharmaceuticals

provides guidelines and best practices for the quality control of medical radioisotopes and radiopharmaceuticals. Advances have led to the production of new radiopharmaceuticals and availability of new production routes. Various new diagnostic agents in the field (such as Ga-68 radiopharmaceuticals and generators) as well as therapeutic agents (such as alpha emitters) have been added to the clinician's menu. It is essential that radiopharmaceuticals are prepared within a robust quality control system encompassing materials and personnel, with adequate documentation, and continuous review of ongoing results. This publication was written by a group of experts with experience across a range of radiopharmaceuticals and is intended to support professionals in the preparation of good quality and safe products to be used in nuclear medicine procedures.

IAEA TECDOC; ISBN: 978-92-0-107918-3; 18.00 euro; 2018

www-pub.iaea.org/books/IAEABooks/13422/Quality-Control-in-the-Production-of-Radiopharmaceuticals

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