The Safe, Secure and Sustainable Application of Nuclear Technology in Industry and Agriculture

Case study
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Summary

The peaceful applications of nuclear technology[1] contribute to our health and wellbeing on a daily basis. This is especially true for those of us living in developed countries with access to good health care, plentiful and safe food and water, and electricity that is reliable and affordable. If applied safely, securely and sustainably these applications can improve the lives of people all over the world. To this end it is important that the general public and policy makers understand the benefits and risks related to their use, and how these risks are managed and mitigated.[2]

The case study aims to:

a) Create awareness about the benefits of some of the peaceful applications of nuclear technology in industry and agriculture.
b) Provide a better understanding of the technologies available for their application and the related risks and benefits.
c) Describe the important role of the International Atomic Energy Agency (IAEA) in making these technologies available and supporting Member States to use them safely, securely and sustainably.
d) Identify key challenges and opportunities to expand the secure and sustainable use of radiation technologies in industry and for food safety and phytosanitary treatments.

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1 This case study addresses only non-power applications of nuclear technology.

2 This case study was developed with the support of the German Government

Introduction

Most of us are not aware of the many ways in which nuclear technology contributes to our quality of life. From the switch we flick to turn on the lights in the morning when we get out of bed and the fruit we eat for breakfast, to the drops we put in our eyes and the fish we eat for dinner, it is more than likely that nuclear technology contributed in one way or another. Apart from these every-day interactions, most people would also be surprised to learn that nuclear technology and its peaceful applications have tangible outcomes that improve the lives of people all over the world, contributing to socio-economic growth and development and to ending hunger and disease. As an example, they increase the yield of staple crops and the shelf life of produce, thereby improving income for the farmer and food vendor, and reducing food and nutrition insecurity. Radiation for cancer treatment and the sterilisation of medical devises improves health and combats disease, while the use of non-destructive testing can verify the safe operation of industrial installations and diagnose technical problems with equipment without interrupting operations, thereby improving efficiency and saving money.

Many of these applications rely on high-activity sealed radioactive sources.[3] The International Atomic Energy Agency (IAEA), established in 1957 to "accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world,"[4] provides crucial assistance to countries to use radioactive sources in a safe, secure and sustainable manner to improve the lives of people and the environment.

This case study describes only a few of the many applications of nuclear technology in industry and agriculture. It includes a discussion on access to radiation technologies in developing countries, explains their application in food safety, medical sterilisation and non-destructive testing in industrial use, and highlights the importance of nuclear security and the support provided by the IAEA in this regard. For more information on other applications in agriculture, the VCDNP case study "The Contribution of Innovative Technology to Sustainable Agriculture Development,"[5] published in November 2020, examines how nuclear science and technology is contributing to sustainable, climate-smart agricultural practices. The IAEA website also provides more information on non-power peaceful applications of nuclear technology.[6]

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3 The International Atomic Energy Agency (IAEA) defines a sealed radioactive source as, "radioactive materials [radioisotopes] firmly contained or bound within a suitable capsule or housing". Category 1 and 2 sources are categorised as high-activity sources by the IAEA. These are sources that if "not managed appropriately, as in the case of accidents, malicious use or orphan sources, may cause a range of deterministic health effects, including erythema, tissue burns, acute radiation sickness and death". See IAEA Nuclear Safety Guide No. RS-G-1.9, " Categorisation of Radioactive Sources." Available at https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1227_web.pdf.

4 IAEA Statute, Article II. Available at: https://www.iaea.org/about/statute.

5 Ingrid Kirsten, "The Contribution of Innovative Technology to Sustainable Agriculture Development Available," Vienna Center for Disarmament and Non-Proliferation, 12 November 2020. Available at https://vcdnp.org/wp-content/uploads/2020/11/Contribution-of-Innovative-Nuclear-Technology-to-Sustainable-Agriculture_final.pdf.

6 IAEA, Department of Science and Technologies. Available at: http//www.iaea.org/about/organizational-structure/department-of-nuclear-sciences-and-applications

The VCDNP organised a workshop[7] on the industrial uses of nuclear technology, including food safety, to which it invited developing country experts to discuss their experience of the benefits and challenges related to the use of these applications. This case study was inspired by the workshop and reflects not only the experiences of the workshop participants, but also draws on various international reports and guidance documents that have been published on this subject.

7 VCDNP Workshop on the Sustainable Use of Nuclear Technology in Industrial Applications and Food Safety, 12 May 2021. Available at: https://vcdnp.org/industrial_applications.

Access to Radiation Technology: The ongoing debate about the use of gamma technology versus alternative non-isotopic technologies

Ionising radiation[8] has been used for peaceful purposes since the dawn of the nuclear age in a variety of fields, including in industrial applications. Gamma radiation, X-ray, and electron beams (e-Beams) are examples of ionising radiation (hereafter referred to as radiation). Gamma rays are produced by high activity sealed radioactive sources (radioactive sources) inside radiological devices (gamma technologies). A sealed source typically contains either cobalt-60 (Co-60), iridium-192 (Ir-192) or cesium-137 (Cs-137) radioisotopes. Co 60 is most commonly used in medical device sterilisation, food irradiation, cancer therapy, plant mutation breeding, the eradication and control of pests, and industrial radiography. Devices that use electricity to produce e-Beams that directly irradiate objects or indirectly produce X-rays for irradiation are referred to as alternative or non-isotopic technologies.[9]

The terror attacks against the United States on 11 September 2001 brought worldwide attention to the dangers posed by non-State actors. Analysis of such events led to concerns regarding the security of radioactive sources and their potential use in a radiological dispersal device (RDD) commonly known as a "dirty bomb", which disperses radioactive material over a large area when combined with explosives, or a radiation exposure device (RED), which could be hidden in a public area to expose people to radiation. As a result, increasing the security of nuclear and other radioactive materials, including radioactive sources, became a focus of the international community.[10]

To reduce the risk posed by high-activity radioactive sources the US Energy Policy Act of 2005 included "the importance of developing and implementing alternative technologies in order to reduce the number of radiation sources in the United States." The US government, through its national laboratories, supports the installation of security cameras at sites that use high-activity radioactive sources, nationally and internationally, and encourages users of these sources to replace them with alternative technologies.[11]

8 The World Health Organization generally categorises energy emitted from a source as radiation. Examples include heat or light from the sun, microwaves from an oven, X rays from an X-ray tube and gamma rays from radioactive elements. Ionising radiation can remove electrons from the atoms, i.e. it can ionise atoms. For more information, see: https://www.who.int/news-room/q-a-detail/radiation-ionizing-radiation.

9 Non-Radioisotopic Alternative Technologies White Paper, Cybersecurity and Infrastructure Security Agency, U.S. Department of Homeland Security, September 2019. Available at: https://armscontrolcenter.org/wp-content/uploads/2019/10/Non-Radioisotopic-Alternative-Technologies-White-Paper1491.pdf

10 Ibid

11 Consensus Study Report on Radioactive Sources: Applications and Alternative Technologies, National Academies of Sciences, Engineering, and Medicine, 2021. Available at: https://doi.org/10.17226/26121.

Gamma technologies have been the mainstay in nuclear applications, especially in developing countries, as they are hardy, relatively easy to use and easy to maintain. Importantly they can be used in remote locations as they are not dependent on electricity to produce radiation. The radioactive sources must be protected during their use and storage, and when the sources are spent, they must be disposed of either through repatriation by the source provider or stored in a secure facility. Security concerns associated with radioactive sources and resultant challenges related to their transport, use, storage and disposal are making these sources more expensive and harder to come by for developing countries.

The US National Academies of Sciences, Engineering, and Medicine (National Academies) were tasked by Sandia National Laboratories with assessing the status of medical, research, sterilisation, and other commercial applications of radioactive sources and alternative (non-isotopic) technologies in the United States and internationally. It is envisaged that the findings of the study[12] and the related recommendations will support existing and future activities under the US National Nuclear Security Administration (NNSA) Office of Radiological Security programme to reduce the current use of high-activity radiological materials in these applications and promote alternative technologies. The National Academies report gives a comprehensive overview of radioactive sources and alternative technologies in each of these applications and is well worth reading. This case study reflects some of these recommendations which are pertinent to the question of improving and expanding access to radiation technologies, especially in developing countries.

The VCDNP also sought the views of Dr. Suresh Pillai, the Director of the National Center for Electron Beam Research (NCEBR) at Texas A&M University. The NCEBR is advancing e-Beam and X-ray technologies for environmental remediation, novel vaccines and therapies, and food safety and security through research, development, and training. These activities are conducted in collaboration with government agencies, the private sector, financial institutions, and equipment providers. The NCEBR is an IAEA Collaboration Center and partners with developing countries such as Pakistan and Mexico to improve their access to radiation technologies. Dr. Pillai describes the mission of the NCEBR as "harnessing e-Beam technology for cleaning, healing and shaping this world and beyond."

In terms of the availability of suitable non-isotopic alternatives to gamma technologies, the National Academies report notes that with the exception of blood irradiation, where X-ray technology is considered equivalent to Cs-137 irradiation, and e-Beam therapy where linear accelerator technology is considered superior to cobalt-60 teletherapy for cancer treatment, there are no broadly accepted replacement technologies for other applications. In some applications, such as industrial radiography, suitable replacement technologies have yet to be developed.[13]

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12 Ibid

13 Ibid

Dr. Pillai does not agree with this assessment.[14] He notes that e- Beam and X-ray technologies are suitable for food pasteurisation, medical device sterilisation and phytosanitary treatment and makes the point that Cobalt-60 is a legacy technology and therefore it will take some time for alternative technologies to completely replace gamma technology. He points out that the number of e-Beam and X ray facilities are increasing worldwide in comparison to gamma facilities and asserts that it is only a matter of time before there are alternative technologies that will be suitable for use in all applications and in all countries.

Currently there are however challenges related to the adoption of alternative technologies in developing countries, including medical linear accelerators (Linacs) used for cancer therapy. Compared to gamma technologies Linacs have higher maintenance costs, more infrastructure requirements, higher power demands, require more highly trained personnel to operate and maintain and are more dependent on a reliable and continuous supply of electricity.[15] Importantly the National Academies report recommends that efforts to reduce the use of high-activity radioactive sources globally and in developing countries should be driven by the examination of the local infrastructure and needs.

In Dr. Pillai's experience e-Beam and X-ray technologies are evolving rapidly. He is of the opinion that the private sector will drive innovation in this sector based on the needs of the users. Supply chains and end users of the technologies will also adapt to the specific requirements of the technology. He believes that in time these technologies will not only be adopted successfully in developing countries but also that alternative technologies are essential to expanding global access to nuclear technologies and to realising the full potential of peaceful uses.

The IAEA provides support to its Member States in the safe, secure and sustainable application of nuclear technologies and recognises that the selection of using either radioactive sources or alternative technologies for a given application is the prerogative of each country. To use nuclear technologies, a country must have a safety and security legislative and regulatory framework in place to protect humans, society and the environment from the harmful effects of radiation and from possible accidents and malicious acts involving radioactive sources. More information on the IAEA's support is provided later in this case study.

14 Interview with Dr. Suresh Pillai via Zoom on 7 June 2021.

15 National Academies Study Report and research conducted by the VCDNP.

Suresh Pillai takes former IAEA Director General Yukiya Amano on a tour of the National Centre for Electron Beam Research at Texas A&M AgriLife Research during his official visit to the US in 2014.

Photo: Conleth Brady / IAEA

Food Irradiation: How it Works and Why it's Important

The irradiation of food for safety and phytosanitary purposes began in the early 1920s. Food safety treatments have multiple benefits including, reducing the transmission of foodborne illnesses, extending the shelf life of products, preventing sprouting, and slowing the ripening process. Phytosanitary treatments protect domestic crops from invasive species carried across borders with imported food products. A broad range of pests can be transported across borders in fresh fruits and vegetables which, unless properly controlled, could spread and result in economic loss for the importing country. Likewise, the detection of an insect, like a fruit fly, in a produce container can lead to immediate import bans and have devastating financial consequences for the exporting country.[16]

16 Luciana Viegas, "Irradiation Secures Vietnam's Food Exports, IAEA, 27 November 2020. Available at: https://www.iaea.org/newscenter/news/irradiation-secures-viet-nams-fruit-exports.


Photo: Conleth Brady / IAEA

An example of a country that has benefited greatly from this application is Vietnam, where agriculture and fishery contribute significantly to its gross domestic product. Dr. Tran Minh Quynh of the Hanoi Irradiation Center at the Vietnam Atomic Energy Institute[17] notes that Vietnam, with support from the United Nations Food and Agricultural Organisation (FAO) and the IAEA, has been researching food irradiation since the late 1990s and today hosts 11 radiation facilities. Vietnam is able to irradiate a variety of food products for both domestic use and for export. Using primarily gamma technology, Vietnam in 2020 irradiated an average of 200 tonnes of fresh fruit per week.[18] Vietnam is planning to expand its exports of fresh fruits and, to this end, will need to increase its radiation facilities.

According to IAEA experts there are many countries interested in the irradiation of fresh fruits, but the challenge is having enough radiation facilities, as existing facilities are also used for medical sterilisation. The expectation is that alternative technologies and advances in these technologies could make these processes more economically viable and this would result in the establishment of an increased number of facilities globally.[19]

Dr. Tran notes that the rising cost of Co-60 is making it more difficult to sustain long-term use of gamma technology. This is a problem facing an increasing number of developing countries. However, switching entirely to non-isotopic alternatives brings its own challenges. While e-Beam technology processing is much quicker and has inherently fewer security concerns than gamma irradiation, e-Beams are less effective at irradiating bulky pallets, as the penetrating ability of electrons is less than that of gamma rays. Lack of access to spare parts and challenges related to the maintenance of e-Beam irradiators were also noted by Dr. Tran as disincentives to using these this technology. Bearing these limitations in mind, many countries with growing irradiation programmes use both source-based and non-isotopic methods.

17 VCDNP Workshop on the Sustainable Use of Nuclear Technology in Industrial Applications and Food Safety..

18 ""Five ways nuclear technology is improving agriculture and food security," Food and Agriculture Organization of the United Nations, 30 March 2021. Available at: http://www.fao.org/fao-stories/article/en/c/1390726/.

19 Luciana Viegas, "Irradiation Secures Viet Nam's Fruit Exports," IAEA, 27 November 2020. Available at: https://www.iaea.org/newscenter/news/irradiation-secures-viet-nams-fruit-exports

Dr. Pillai notes that bulky packaging does not have to be a problem when using e-Beams. Food can be repackaged to reduce the need for large penetration depth. He is also of the opinion that the private sector, as the main driver of the food irradiation industry, will favour alternative technologies as they make more commercial sense than gamma technologies given their efficiency and the costs related to the cradle to-grave management of radioactive sources.

According to the National Academies report, the biggest investor in food irradiation is China. The country is investing in e-Beam technologies with five to 10 new machines being installed each year during the past five years. The report however notes that adoption of food irradiation for safety purposes is stagnant in other parts of the world, including the United States and Japan, and is declining in Europe largely due to public perception that irradiated food is dangerous for consumption. Dr. Pillai however points out that the volume of irradiated mangoes and guavas are growing in the US and argues that the reason the volumes are not larger is due more to the fact that there isn't enough irradiation capacity in the US to meet the demand rather than lack of consumer acceptance. In his opinion the biggest challenge to food irradiation is that governmental regulations in some countries, including the US, have not kept up with the needs of the food industry. The acceptance of irradiated food by the retail industry is also critical in his view.

A cobalt 60 multipurpose irradiator at the Philippine Nuclear Research Institute

Photo: Lucille Abad / PNRI

The question whether irradiated foods are safe for consumption has been reviewed and evaluated by joint expert committees of the International Atomic Energy Agency (IAEA), the World Health Organisation (WHO), and the FAO. Their conclusion was that this process does not present any toxicological, microbiological, or nutritional hazard beyond those brought about by conventional food processing techniques.[20] This is in contrast to other methods, including chemical fumigation that leaves residues which could be harmful to people and the environment. Another benefit of this technology is that it can be applied to packaged foods, thus limiting the chances of re-infestation or re-contamination.

While customer acceptance and marketing remain an issue in Vietnam, the government made early efforts to mitigate this trend through public outreach in the media. Dr. Tran notes that ongoing efforts to educate the public on the safety of irradiated food is integral to the sustainable application of nuclear technologies.

Unfortunately, although the number of incidences of foodborne diseases disproportionally affects populations in developing countries, food irradiation in many of these countries remains a challenge. For example, in Africa, with the exception of Egypt and South Africa, the lack of resources and basic infrastructure cannot support food irradiation technologies at the scale necessary to be effective.[21] The support of the IAEA and its collaborating centres such as Texas A&M is essential to improving access by developing countries to the benefits of food irradiation technologies.

20 Kim Morehouse and Vanee Komolprasert, "Irradiation of Food and Packaging," American Chemical Society Symposium Series (accessed through the United States Food and Drug Administration, "Overview of Irradiation of Food and Packaging"), 2004. Available at: https://www.fda.gov/food/irradiation-food-packaging/overview-irradiation-food-and-packaging..

21 Consensus Study Report on Radioactive Sources: Applications and Alternative Technologies, National Academies of Sciences, Engineering, and Medicine, 2021.

Gamma irradiation is used to sterilize human tissues prior to transplant at a tissue bank at the Santa Casa de São Paulo Hospital in Brazil, in 2015.

Photo: IAEA

Medical Sterilisation: How it Works and Why it's Important

Radiation for sterilisation in the medical field has been used since the late 1950s and today more than 40 percent of single-use medical products are sterilised using this technique. These products (many of them lifesaving) include empty eyedroppers, bloodlines for kidney washing, petri dishes, blood collection tubes, empty gelatine capsules and personal protective equipment that is in dire need due to the COVID-19 pandemic. One of the key advantages of using radiation is that it allows already-packaged products to be sterilised. More than 160 gamma irradiation plants around the world are operating to sterilise medical devices. As with food irradiation the IAEA helps its Member States set up radiation facilities and provides guidelines for the use of these applications.[22]

The process of sterilising medical equipment is not significantly different from the one used to irradiate food. In fact, many of the facilities that irradiate food are also used to sterilise medical equipment. The object in question is placed in a sealed plastic bag

22 Medical sterilization, IAEA. Available at: https://www.iaea.org/topics/medical-sterilization

(or similar container) and irradiated with gamma radiation or e-Beams.[23] The radiation kills bacteria in the container, while leaving the container sealed until use. As with food irradiation the added benefit of this technology is that unlike chemical sterilisation it leaves no harmful residue behind in the product.

Jordan, a country with a growing medical industry, has become one of the foremost exporters of medical supplies in its region. As demand in the region grew, so did the need to efficiently sterilise higher volumes of medical products, such as empty eye droppers. Ethylene oxide, a chemical commonly used for sterilisation, could be fatal for patients that have enhanced sensitivity to it, which is why it should not be used to sterilise empty eyedroppers as it can leave a residue that combines with the eyedrops. Similarly, patients with kidney problems are especially sensitive to ethylene oxide, thus requiring a different method for sterilisation of kidney washing equipment.

Jordan uses a Co-60 irradiator for medical sterilisation, which it procured with the support of an IAEA technical cooperation project in 2000. Mohammad Etoom[24] of the Jordan Atomic Energy Commission (JAEC) notes that this has improved the level of healthcare in Jordan overall and increased its ability to compete in the export market on a global scale. Despite the benefits that gamma technology has brought to the Jordanian medical industry and export market, Jordan is experiencing some of the same barriers to the sustained use of this technology as Vietnam, namely increasing scarcity and costs of Co-60 sources.[25] In the near term the JAEC has solved the problem by entering into a partnership with a private company that will finance the replacement of its Co-60 sources. Jordan may have to explore options for transitioning to e-Beam technology in the coming years.

According to the National Academies report, full transition in the US to alternative technologies for sterilisation of medical products is not expected within the next decade. Gamma technology currently contributes 40 percent to the US medical sterilisation market, compared to 10 percent from e-Beam irradiation and 50 percent from ethylene oxide. All these major medical device sterilisation modalities are expected to contribute to the reliability of the market, which in the US and globally is growing from five to seven percent annually because of increasing demand, especially in 2020 as a result of the COVID-19 pandemic.[26]

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23 "Ask the Experts," Health Physics Society, 18 October 2004. Available at: https://hps.org/publicinformation/ate/q4004.html.

24 VCDNP Workshop on the Sustainable Use of Nuclear Technology in Industrial Applications and Food Safety, 12 May 2021. Available at: https://vcdnp.org/industrial_applications..

25 Co-60 sources used by the JAEA were replenished in the past with spent sources from teletherapy machines, as medical sterilisation requires a lower dose rate than cancer therapy. Jordan has however replaced all its source-based cancer therapy equipment with LINACs, as a result the JAEC must procured new sources.

26 Consensus Study Report on Radioactive Sources: Applications and Alternative Technologies, National Academies of Sciences, Engineering, and Medicine, 2021..

According to the report, the transition to non-isotopic alternatives will take some time as sterilisation using gamma rays from Co-60 has, over decades, resulted in extensive experience and data on the performance of materials, in comparison to the sparse information available for the same materials irradiated with e Beams and X-rays. Manufacturers considering adopting this technology would have to invest substantially to ensure sterilisation equivalency and absence of material alteration. The report also notes that US manufacturers would have to undergo significant facility modifications accompanied by high transition costs.

Medical supplies sterilized with gamma irradiation, Santa Casa de Sao Paulo hospital, Brazil. 13 May 2015.

Photo: Louise Potterton / IAEA

Sandia National Laboratories (Sandia) is currently examining the costs, benefits, and challenges associated with operating a gamma industrial irradiator facility compared to a non-isotopic irradiator replacement. At the conclusion of the study anticipated later this year, a report will be provided to the NNSA that will include guidance on a decision strategy to allow facilities to analyse and determine if alternative technologies may be a viable option. The report will also include lessons learned for future engagement on alternative technology adoption.[27] Dr. Pillai notes that there are no new gamma facilities being built for medical sterilisation in the US, however there are four new e-Beam and X ray facilities under construction, which in his opinion is an indication that US manufacturers have already made their decision.

Developing country manufacturers wishing to transition from gamma to e-Beam facilities in order to meet their medical sterilisation needs can benefit from the outcome of the Sandia report. Efforts to support developing countries in their transition from gamma to alternative technologies should also take these recommendations and lessons learned into account.

27 Ibid

Experts from VARANS and the Republic of Korea meet with licensees in Viet Nam to test a radioactive source tracking system at an equipment fabrication facility outside Hanoi. The tracking system allows licensees and the regulatory body to verify dose rate and position data of industrial radiography devices, increasing the level of protection of these sources and contributing to strengthened nuclear security for industry. Viet Nam, 1 November 2016.

Photo: Dean Calma / IAEA

Non-Destructive Testing: How it Works and Why it's Important

Although some may associate non-destructive testing (NDT) with nuclear verification, it is in fact a neutral term describing a technique with many different applications, a great number of them industrial. NDT is a technique used to test a piece of material or equipment to identify cracks or other defects. There are several NDT methods available, the most common of which include visual inspection, industrial radiography, ultrasonic testing, liquid penetrant inspection, magnetic particle inspection and eddy current testing.[28] As the name suggests, NDT does not damage or alter the inspected item in any way, so that the material or item can still be used.[29] In manufacturing, NDT can be used to monitor the quality of raw materials, the manufacturing process, or the finished product itself. NDT can also be used to verify the safe operation of industrial installations and diagnose technical problems with equipment without interrupting operation. The use of NDT results in increased safety and reliability of the product in operation and decreased cost by reducing waste. NDT can also facilitate the design of new products.[30]

28 Other non-destructive testing, IAEA. Available at: https://www.iaea.org/topics/other-non-destructive-testing

29 In contrast to NDT, other tests are destructive in nature and are therefore done on a limited number of samples ("lot sampling"), rather than on the materials or components actually being put into service.

30 Training Guidelines in Non-destructive Techniques, Manual for Ultrasonic Testing at Level 2, IAEA, 2018. Available at: http://www-pub.iaea.org/MTCD/Publications/PDF/TCS-67web.pdf.

At Vienna's Museum of Fine Arts in 2006, conservation scientists, trained at the IAEA, aim precise X-ray beams at the 16th century Italian golden table sculpture known as the Saliera. Non-destructive testing is used to study works of art.

Photo: IAEA

Industrial radiography is one of the most widely used NDT techniques, using X-ray or gamma radiation to see inside and inspect a wide variety of objects, for example concrete materials and components as well as various metallic welds in gas and water pipelines, storage tanks and structural elements. It can identify cracks or flaws that may not be otherwise visible to the naked eye and can be used to inspect insulation for corrosion. The radiation passes through the material or item being inspected and is recorded on an industrial photographic film or by a digital detector. For thinner or less dense materials such as aluminium, X-rays are commonly used, while for thicker or denser materials, Co-60 radiation is generally used due to its greater penetrating ability. Modern industrial radiography can use digital techniques to display high quality radiographic images almost instantly on a computer screen. This allows for a much shorter exposure time so that the images can be interpreted quickly. As NDT techniques do not require systems to be taken offline in order to work, efficiency of operations is not affected and, when used to troubleshoot problems within operations, NDT can contribute to faster diagnoses aiding in a quick return to full operational functionality. These characteristics have made industrial radiography a key tool for quality control, safety and reliability.

As there is such a large variety of potential applications of NDT, the IAEA has a long history of capacity building in this field, including helping countries to understand which methods can solve what problems and providing services to industries, training centres and national certifying bodies. According to the IAEA, this has led in many cases to national self-sufficiency in NDT.[31] Several countries that received support from the IAEA in this regard have gone on to support regional partners in the same way. The IAEA works with such countries to promote the peaceful uses of radiation technologies in industry, with the aim of having an immediate beneficial impact on the country's economy.

Morocco is one such country. Using NDT techniques to bolster its industrial complex, Morocco has also helped regional partners to benefit from NDT with the support of the IAEA. Dr. Rachad Alami of the Moroccan Centre National de l'Energie des Sciences et des Techniques Nucléaires (CNESTEN)[32] explains that, as an official IAEA Collaborating Centre, CNESTEN provides support to African countries, under an agreement between the IAEA and the African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA), to implement these techniques in their local industries. Under the AFRA programme Morocco cooperates directly with countries such as Angola, Cameroon, Egypt, Kenya and Senegal.

Dr. Alami estimates that for every euro spent on NDT, the radiotracers used for equipment diagnostics and other radiation applications has resulted in a return in efficiencies equivalent to at least 32 euros. This has allowed the Moroccan industry to thrive, for Morocco to act as a training and certification centre for regional partners, and for the creation of several dozen private companies acting as NDT offices in Morocco and abroad.

Morocco, and Dr. Alami specifically, has not experienced any of the challenges experienced in Vietnam and Jordan in replenishing its radioactive sources. It should be noted that there are currently no viable or cost-effective alternatives to gamma radiation for NDT. According to the National Academies report, the existing alternatives "do not offer enhancements in performance, or they produce data on material and structures that are not directly comparable to those produced by radioactive sources."[33]

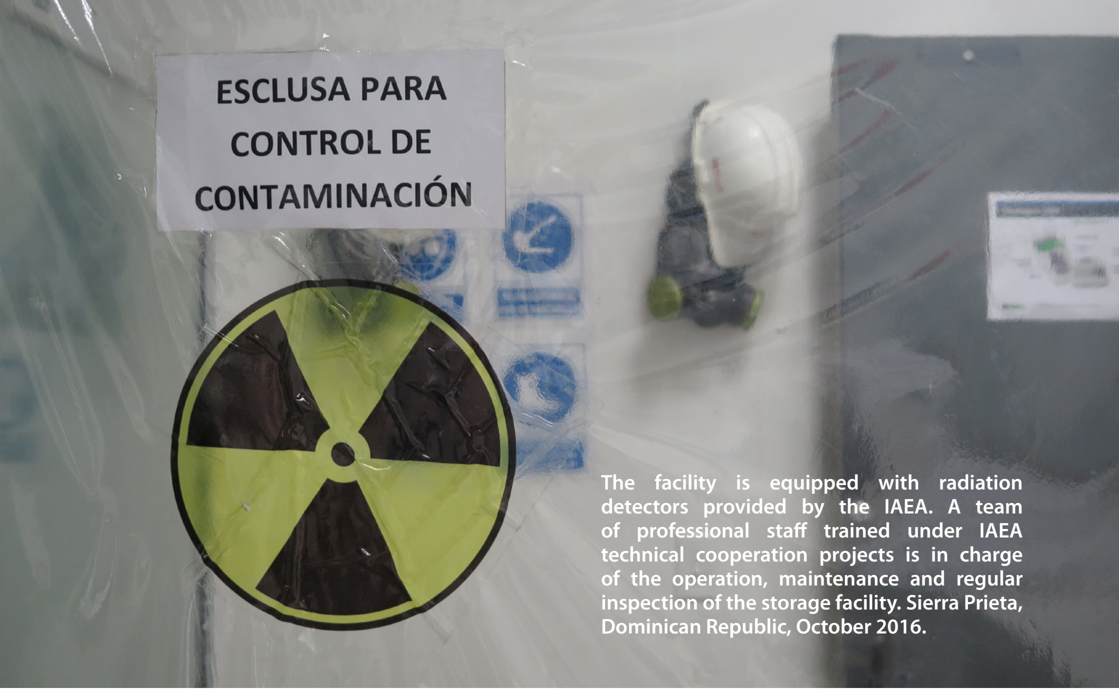
Specialists use gamma scanning techniques to perform diagnostic tests on equipment at an oil refinery in Morocco precisely, quickly and without service interruption.

Photo: Rachad Alami / CNESTEN

31 Other non-destructive testing, IAEA.

32 VCDNP Workshop on the Sustainable Use of Nuclear Technology in Industrial Applications and Food Safety, 12 May 2021. Available at: https://vcdnp.org/industrial_applications.

33 Consensus Study Report on Radioactive Sources: Applications and Alternative Technologies, National Academies of Sciences, Engineering, and Medicine, 2021..



The facility is equipped with radiation detectors provided by the IAEA. A team of professional staff trained under IAEA technical cooperation projects is in charge of the operation, maintenance and regular inspection of the storage facility. Sierra Prieta, Dominican Republic, October 2016.

Photo: Laura Gil-Martinez / IAEA

The Importance of Nuclear Security

All of the applications detailed in this study have positive impacts on socio-economic development including specific contributions to the UN Sustainable Development Goals. However, none of these activities would have been possible without the countries in question having safety and security legislative and regulatory frameworks in place and adhering to the IAEA safety standards and security guidance.

The IAEA assists its Member States, upon request, to enhance the security of radioactive materials in use and storage under the IAEA's programme on nuclear security. This assistance includes the development and publication of guidance documents under the IAEA's Nuclear Security Series[34], offering e-learning courses on nuclear security, conducting face-to-face practical trainings on various topics, and providing expert guidance through peer review missions and advisory services such as the International Physical Protection Advisory Service (IPPAS).[35] It also includes the delivery of technical assistance to support countries in meeting the provisions of relevant international instruments like the Code of Conduct on the Safety and Security of Radioactive Sources and its supplementary guidance.

34 Nuclear Security Series, IAEA. Available at: https://www.iaea.org/resources/nuclear-security-series

35 International Physical Protection Advisory Service (IPPAS), IAEA. Available at: https://www.iaea.org/services/review-missions/international-physical-protection-advisory-service-ippas.

IAEA experts visit medical sites in Cuba to review and assess the progress of an on-going project to upgrade physical protection systems for the security of radioactive sources. Cuba, November 2016.

Photo: Dean Calma / IAEA

The IAEA's Division of Nuclear Security also provides a technical backstop for nuclear security aspects of relevant IAEA initiatives, including projects under the IAEA Technical Cooperation programme. The Division works closely with the Division of Radiation, Transport and Waste Safety, and other organisational units of the IAEA, to implement joint activities aimed at supporting States' in the safe and secure application of nuclear technology such as Regulatory Infrastructure Development Projects.

The IAEA also assists its Member States in implementing safe and cost-effective technologies for recovering, conditioning and storing sealed radioactive sources. Direct assistance includes:

- Searching for potential orphan sources, as well as recovery and safe management of found sources.
- Recovering, characterising and conditioning of disused sealed radioactive sources, including radium sources.
- Completing national inventories of disused sealed radioactive sources, source characterisation and record-keeping.
- Providing assistance for the repatriation or recycling of high-activity disused sealed radioactive sources.

Conclusion:
Opportunities to Expand Access to Nuclear Technologies for Peaceful Purposes

The use of radiation for food safety and phytosanitary purposes, medical device sterilisation and to support industrial processes benefits people, society and the environment if used in a safe, secure and sustainable manner. Much more can and should be done to expand the use of radiation technologies, especially to those countries who need them the most.

The IAEA plays an essential role in providing access to these technologies. It assists its Member States in using nuclear science and technology for peaceful purposes and facilitates the transfer of such technology and knowledge in a sustainable manner. It plays a central role in strengthening the nuclear security framework globally and in coordinating international activities in the field of nuclear security, including by supporting States, upon request, to establish and maintain an effective nuclear security regime.

The following is a summary of the key opportunities to expanding access to nuclear technologies with a specific focus on the applications discussed in this case study.

- Gamma technology continues to play a central role in agriculture and industrial applications. Ongoing challenges related to their access could result in a "technology apartheid" as developing countries are generally more dependent on the use of these sources for applications requiring radiation. The IAEA, drawing on past experience and its central role in coordinating international cooperation on nuclear security, could facilitate efforts to address these challenges.

- In the long term, non-isotopic technologies are likely to provide a solution to the challenges related to radioactive sources. However, efforts to reduce the use of high-activity radioactive sources in developing countries should be driven by the examination of the local infrastructure.

- Efforts to facilitate the transition from gamma technology to e-Beam technology in developed countries should consider the challenges faced by developing country manufacturers and identify ways in which this transition can be supported in developing countries.
- More countries will benefit from the peaceful uses of nuclear science and technology as alternative technologies are developed that are less dependent on electricity, more affordable to procure, are easier to use, and are cheaper and less complicated to maintain. The private sector is the key driver behind this innovation however, national partnerships with the IAEA, research organisations, financial institutions and donor partners will be required to advance the development and use of these technologies globally.

- Regional cooperation is another factor that can support the expansion of the safe and secure application of nuclear technologies both in terms of human resource development and improving developing country access to radiation technologies.

- Fostering consumer awareness about the safety and security of these applications is an important aspect of the sustainable application of these technologies.

- Raising awareness with the public and policymakers about the benefits of the non-power applications of nuclear technology is essential if the full potential of peaceful uses is to be realised.