iia White Paper

Uses and Applications of Radiation Processing

INTERNATIONAL
IRRADIATION
ASSOCIATION

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Foreword

This report highlights the importance and global economic, social and environmental benefits that arise from radiation processing.

The document is intended to give a non-technical introduction to the significant uses of radiation processing and summarises how they are applied throughout various regions of the world. In some instances, regional application reflects the need to find solutions to challenges, but the most dynamic, economically successful and environmentally engaged economies have integrated all of the beneficial uses of radiation processing with scientific research and commercial application. Radiation processing, or 'irradiation', is ubiquitous and an important component of a modern successful economy.

The document was initiated by the International Irradiation Association and includes contributions from independent groups and associations that have their own regional insight. All contributors are engaged in the support and enhancement of the safe and beneficial use of irradiation technology.

We hope that readers find this publication enlightening and interesting.

The International Irradiation Association would like to thank the following organisations for their support and regional input:

- American Nuclear Society (ANS, USA)
- Asociación Latinoamericana de Tecnologías de la Irradiación (ALATI, Latin America)
- Canadian Nuclear Isotope Council (CNIC, Canada)
- China Isotope & Radiation Association (CIRA, China)
- National Association for Application of Radioisotopes and Radiation in Industry (NAARRI, India)
- Panel on Gamma & Electron Irradiation (UK)

Further details about these organisations can be found at the end of this document.

More information about the International Irradiation Association can be found at **iiaglobal.com**

We welcome your feedback on this document and iia can be contacted at **info@iiaglobal.com**

Introduction

Radiation processing is the intentional exposure of products and materials to ionising radiation for beneficial purposes. The uses and applications deliver significant social, economic and environmental benefits worldwide.

Though largely unknown by the public, radiation processing or 'irradiation' touches everyone's life. If you suffer an injury or illness, then it is highly likely that you will be treated with wound care products or other medical supplies that have been sterilised by irradiation. Most vehicles contain wires and cables that have been treated with radiation to keep you safe during your journey. Radiation processing helps to make food safer, protects crops and helps secure international trade of plant products. Environmental applications of irradiation such as the treatment of flue gas, waste water and biowaste might soon provide new ways of improving the quality of air and water and keeping us safe.

This document summarises the uses and importance of radiation processing and highlights how these technologies have a positive impact on the daily lives of the world's population. The regional summaries provide an insight into how radiation processing delivers benefits to different parts of the world.

The important contributions made by radiation processing

Through its wide range of applications, radiation processing helps to keep us safe and healthy, supports our economies and helps to protect the global environment.

SOCIAL

Provides protection against disease and illness

Makes our everyday products safer to use

ECONOMIC

A critical process for some of the world largest industries

Creates trade, employment and protects livelihoods

ENVIRONMENTAL

Cleaner air and water and reduced use of harmful chemicals

Re-use of waste for useful purposes

Research into radiation processing continues to develop applications that will provide more benefits for future generations.

Some of the regional applications of radiation processing are detailed in the later chapters.

Summary of uses of radiation processing

Radiation processing is routinely used in a vast array of diverse and beneficial applications. This summary highlights some of the important uses that improve our lives.

LARGE SCALE COMMERCIAL USE

These are uses of irradiation that can be found at industrial sites around the world. High volumes of product and material are processed on a commercial scale.

Sterilisation of medical products, laboratory and cleanroom consumables

Radiation processing is used to sterilise over 40% of single use medical supplies so that patients have a lower risk of infection during surgery or medical treatment. Demand continues to grow with an increasing global population, greater access to healthcare and extended life expectancy. Products sterilised with irradiation range from simple gauze dressings to complex medical devices containing drugs and therapeutics. Products include surgical gloves, wound care products, implants such as hip joints, pre-filled syringes and blood collection tubes. Irradiation also helps medical and scientific manufacturing and research. Laboratory and cleanroom consumables such as petri dishes or protective equipment are also sterilised with irradiation.

Improvement of polymers

Irradiation of polymers results in a variety of reactions including crosslinking, polymerisation, grafting or degradation. These reactions will result in changes in the characteristics and performance of synthetic polymers that will make them, for example, more resistant to high temperatures, wear and chemicals, or easier to process further. These polymers can then be used safely in demanding conditions that they would otherwise not be able to withstand.

Modification of polymer products is the largest volume application of irradiation. They are used in a huge range of high-performance products and materials. Examples include: insulation for wires and cables used in the automotive, rail or aerospace industry; pipes and tubing used in water and gas supply; foams, heat-shrinkables films or tubes, moulded parts and composite materials used in construction and in many other industries.

Sterilisation of packaging

Many different types of packaging material are decontaminated or sterilised using radiation processing. Irradiation ensures that packaging is free from microorganisms that could otherwise contaminate the product that they will contain. The food and drink industry uses irradiation to treat cartons, bottles, bags, lids and caps because the technology leaves no residues. The pharmaceutical, medical and cosmetics industries also use radiation processing of packaging to ensure the safety of their products.

Pharmaceutical, cosmetic and food ingredients

Good Manufacturing Practises require the use of microbiologically clean ingredients to ensure the quality and safety of final products. The food industry uses irradiated spices, herbs and dehydrated vegetables for this purpose and to ensure optimal aromatic quality. A wide range of ingredients used in the pharmaceutical and cosmetic manufacturing are also irradiated to replace or reduce the need for chemical preservatives.

SUBSTANTIAL COMMERCIAL USE

These are uses of irradiation that are carried out on a more regional commercial or semi-commercial basis. Some uses are well-established and other are now seeing growth.

Food irradiation

Many international organisations have confirmed that food treated by irradiation poses no toxicological, microbiological or nutritional problem. The many applications include sprouting inhibition (bulbs and tubers), inactivation of parasites (meat, fresh-cut salads), insect control (pulses, cereals, dry fish), inactivation of pathogenic bacteria such as Salmonella or E. coli (seafood, meat and poultry whether refrigerated or frozen) and shelf-life extension (ready-to-eat meals, some fruit and vegetables). Food irradiation thus contributes to food safety by reducing foodborne poisoning and to food security by reducing post-harvest losses. The extent to which food irradiation is used greatly varies from one country to another due to the lack of harmonisation in food irradiation regulations.

Summary of uses of radiation processing

Phytosanitary treatment

Phytosanitary measures are used in the international trade of fresh commodities to prevent spread of non-native insects that could cause huge losses for the agriculture of the importing countries. Increasingly, irradiation is being used as one of the phytosanitary methods to replace banned or controversial pesticides such as fenthion or to provide fresh products of a better quality than when treated with alternative phytosanitary measures such as cold or heat treatment.

Treatment of waste water

Radiation processing is used to clean industrial waste water from the textile industry. Textile dyeing accounts for a fifth of all industrial wastewater pollution generated worldwide. Beside its chemical cleansing effects, irradiation also has the capability to dissociate biologically active organic pollutants.

Wood plastic composites

It is possible to make wooden flooring more resistant to abrasion and wear by injecting liquid monomers into the wood and solidifying them by radiation polymerisation. The same technique is used to consolidate wooden artifacts.

Improvement of microelectronics

Radiation hardening is the process of making electronic components and circuits resistant to damage or malfunction caused by high levels of ionising radiation in outer space and high-altitude flights, and within nuclear reactors and particle accelerators.

Colouration of gemstones

Some gemstones are irradiated to change their colour in order to give them a higher commercial value. Topaz is the most irradiated as it turns from orange to blue after exposure to radiation.

COMMON USE IN INSTITUTES AND LABORATORIES AROUND THE WORLD

These are uses of irradiation that are common but carried out by specialised organisations for the benefits that the use of irradiation provides to the community rather than for commercial purposes.

Blood components irradiation

Irradiation of blood components is almost exclusively used to prevent graft versus host disease (TA-GvHD) that is a rare but usually fatal complication of blood transfusions. This disease occurs when a patient is incapable of mounting an immune response against lymphocytes, a type of white blood cell, in the transfused blood that attack the patient's tissues. Irradiation damages the DNA of the blood components and thus stops them attacking the patient.

Tissue banks

Tissue substitutes are required in several clinical conditions for treatment of injured and diseased tissues. Tissues such as bone, skin, amniotic membrane and other soft tissues obtained from a human donor can be used for repair or reconstruction of the injured part of the body and constitute an excellent alternative to autografts. However, major concern with the use of allografts is the risk of infectious disease transmission. Sterilisation of tissue allografts by irradiation is widely used to make them safe for clinical use.

Sterile Insect Technique

The Sterile Insect Technique (SIT) involves the mass rearing and sterilisation by irradiation of male insect pests. When these insects are released there is no offspring when they mate with wild females, which results in a decline of the pest population. This process has been successfully used to control fruit flies that cause major losses in fruit and vegetable production and prevent exports; tsetse flies that feed on blood and transmit parasites; and screwworm flies that cause bacterial infections.

Preservation of cultural heritage

Many artefacts (wooden objects, parchments, textiles and leather artefacts) are under attack from insects, fungi and bacteria while stored in religious buildings, museums and archives. Irradiation can kill these organisms with minimal effect on wood, paints, pigments and varnishes. Most famously, irradiation was used to disinfect the mummy of pharaoh Ramses II in 1977.

Induced mutation for plant improvement

Very low doses of irradiation accelerate the frequency of mutations in plant materials. The changes that result can be selected to develop new crop varieties with improved characteristics such as higher productivity, resistance to draught, salt or diseases, or better nutritional quality. Irradiation thus contributes to food security and better nutrition.

NEW POTENTIAL USES UNDER DEVELOPMENT

These are uses of irradiation that are being developed or currently applied at a low level but might emerge as important applications in the future.

Treatment of gaseous effluents

Irradiation of flue gas from coal fired power plants removes high levels, typically 85-90%, of nitrogen and sulphur oxide pollutants. The technology can also be applied to municipal waste incinerators. Radiation processing is used to reduce pollution and improve the safety of gaseous and liquid effluents and solid waste.

Treatment of solid waste

Sewage sludge in liquid or solid form can be treated with irradiation to prevent microbes and viruses spreading into the environment before it is sent for safe disposal. The treated product can be used as organic fertiliser.

Treatment of hazardous biowaste

Research has demonstrated that irradiation is effective to render biowaste from hospitals or leftovers from international flight catering safe before disposal. While the economic feasibility still needs to be established, the increased sensitivity to virus spread might change the perspective.

Introduction to radiation processing technologies

Over that last 70 years the radiation processing industry has developed various technologies that are now well established to irradiate materials and product safely and efficiently.

The general principle is to expose products to the radiation field in a controlled manner, typically on a continuous conveyor system that carries the product into a concrete bunker for irradiation. The concrete bunker ensures that personnel are shielded from the radiation at every stage of the process.

Some developing applications, such as the treatment of gas or liquids, will have a different system of applying the irradiation but the concept of passing the material by a source of radiation remains unchanged. Low energy and laboratory scale irradiation systems generally comprise a shield that is a component of the machine.

The largest difference is with the sources of radiation that fall into three categories: gamma, electron beam (e-beam) and X-ray. Details of these three technologies can be found in factsheets available from the International Irradiation Association website iiaglobal.com

The radiation processing industry, regardless of technology, must comply with stringent regulations and has an exemplary safety record.

Image showing radioactive Cobalt-60 used within a gamma radiation processing facility.

Image courtesy of STERIS AST steris-ast.com

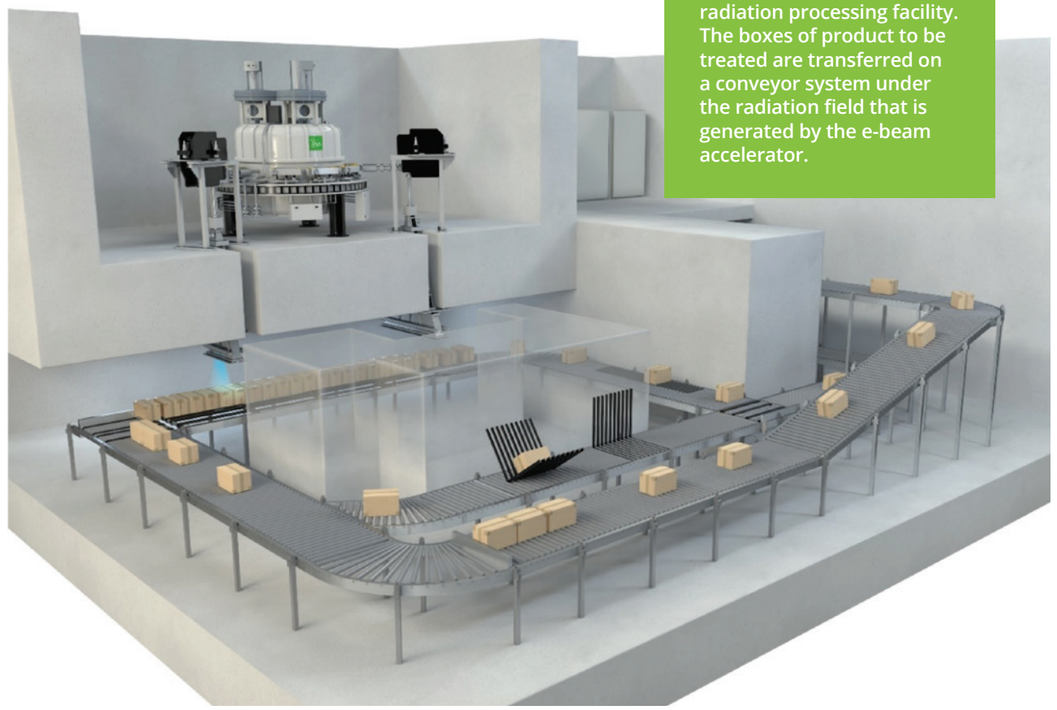


Image showing an e-beam radiation processing facility. The boxes of product to be treated are transferred on a conveyor system under the radiation field that is generated by the e-beam accelerator.

Image courtesy of IBA Industrial www.iba-industrial.com

Radiation processing is very well established in China and its population has benefited significantly from various irradiation applications for many years.

The initial focus of irradiation in China was applications in food preservation, agriculture and modification of polymers used in industry. Today, China has the world's largest number of gamma irradiators and accelerators in operation and its activities within the field are broad, continue to develop and have an important economic impact. China is also at the forefront of innovation and the development of new applications that make an import positive contribution to the environment.

More than 110 commercial scale gamma irradiators are in operation in China and these are used for most of the traditional high-volume processing applications such as sterilisation of medical devices. China is by far the country that treats the largest volume and variety of foods with irradiation. Approximately one million tons of food are irradiated annually(1) including spices, garlic, meat and fish products.

Additionally, over 600 electron accelerators are in operation for radiation processing in China. These machines are mainly used for polymer modification, particularly the cross linking of wires and cables, but also for disinfection, sterilisation and increasingly food irradiation. China is the world's largest producer of accelerators and this is an area of fast growth with innovations in X-ray and low energy beam applications.

Both gamma and electron irradiation technologies are used to enable the distribution of safe food products, to make critical patient wellbeing possible and to contribute to the production of safe and durable material and products. All these irradiation applications have far reaching and positive benefits for the population of China.

China is also the largest user and international supplier of electron accelerators used for large scale security screening of cargo. Over 900 inspection systems are used in various Chinese ports to inspect large shipping containers and vehicles to ensure the safety of goods being imported and exported.

China is a producer of Cobalt-60 used in radiation processing and is home to suppliers of gamma irradiators. These products are used domestically and are exported to overseas markets where they make a positive economic impact on these organisations, their supply chain and their employees.

China used irradiation to good effect in their response to the COVID-19 pandemic. The pandemic resulted in a shortage of necessary personal protective equipment (PPE) so the Chinese Government introduced emergency rules allowing the use of irradiation to sterilise medical disposable protective clothing. By mid-2020, nearly 80 Chinese companies had used gamma and e-beam irradiation to sterilise 1.1 billion pieces of medical disposable protective clothing, 3 million pieces of isolation clothing, more than 10 million pairs of medical gloves and a large volume of other medical equipment required for the fight against COVID-19. The fast cycle time of irradiation, compared with EtO gas sterilisation that would normally have been used, won precious time and enabled the early treatment of many patients.

On 5th June 2020, 'World Environment Day', seven e-beam irradiators commenced operation in China for the treatment of industrial wastewater. This is the world's largest such facility with an irradiation treatment capacity of 30,000,000 litres of wastewater per day. The irradiation treatment has several environmental chemistry and cleansing benefits resulting in up to 70% re-use of the wastewater which can annually save 4,500,000,000 litres of water and reduce chemical oxygen demand by 1,000 tons.

Electron beam irradiation technology is particularly suitable for the treatment of wastewater from printing, dyeing, paper and chemical industries. In China the technology is being expanded into other applications such as the management of antibiotic bacterial residues, disinfection and sterilisation of hospital wastewater, preservation of agricultural products and the treatment of medical waste, landfill leachate and pharmaceutical wastewater. This will result in further environmental benefits through pollution control and re-use.

China has embraced radiation processing to support the wellbeing of its population and economy. Development continues through scientific research and commercial collaboration initiatives which ensure that China takes full advantage of the beneficial uses of irradiation technologies to strengthen its economy, improve the lives of its people and to reduce pollution thereby helping the environment.

(1) The Business and Science of Radiation processing in 2019, International Irradiation Association, September 2019

Europe

All European countries benefit from radiation processing. Irradiation technologies are a major contributor to the wellbeing of its population and the ability of its manufactures to produce safe high-quality products.

Gamma, e-beam and X-ray are all used in Europe and the region has a long history of innovation leading to new applications that result in significant social, economic and environmental benefits.

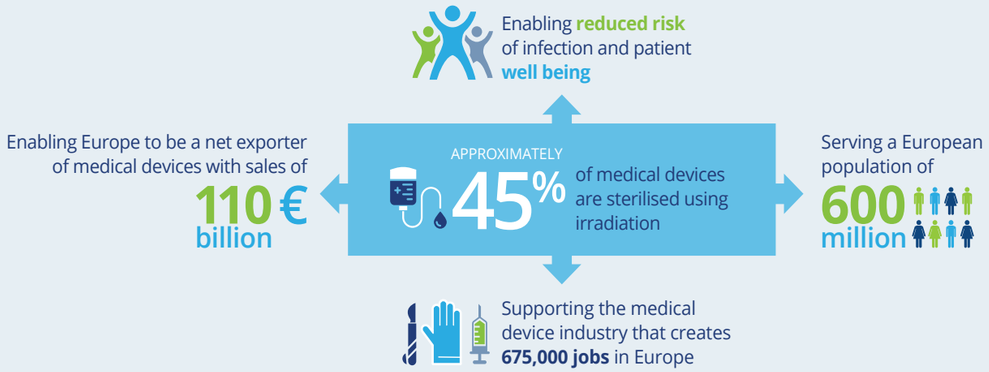
The largest application of gamma irradiation in Europe is the sterilisation of medical devices. With an aging population of about 600 million (excluding European Russia) and a high health expenditure per capita, European demand for medical devices is extremely high. In addition to the important health benefit of patients receiving treatment with reduced risk of infection, there is also an important economic contribution with the medical device industry providing €110 billion in sales and 675,000 jobs in Europe[1]. The EU is a net exporter in this sector[1] with some medical device manufacturers choosing to locate their irradiation sterilisation facilities in Europe.

Radiation processing using e-beam is widely used throughout Europe, particularly for the modification and improvement of plastics that can then be used in major industries including automotive, wire and cable, and electronics. Sterilisation of medical devices using e-beam irradiation is currently more widely adopted in Europe than in other parts of the world. Low energy e-beam is increasingly being used in Europe to reduce the bioburden on the surface of packaging material that can then enter cleanroom manufacturing facilities used in medical product manufacturing. The world's first X-ray irradiator commissioned for sterilisation of medical devices was supplied by a European manufacturer and is still in use by a European irradiation service provider.

Some of Europe's cultural heritage is also protected by irradiation. Many artefacts under attack from insects and microorganisms are preserved by disinfestation using irradiation as a safe alternative to fumigation or the use of liquid chemicals.

European research continues to develop important new irradiation applications resulting in, for example: more durable heart valves; pathogen resistant cereal grain; the recycling of polymer waste; and the treatment of wastewater, sludge and gas effluents. Much of this research has progressed to pilot plants and commercial realisation that benefits people worldwide.

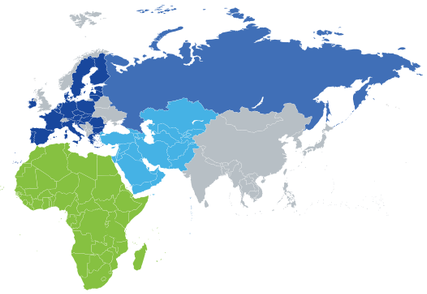
Europe leads the way in many areas of radiation processing. It is the home of the International Atomic Energy Agency, a centre of excellence for radiation processing, and some of the largest users and suppliers of radiation processing technology. European demand for radiation processing continues to grow and the people and economies of the region continue to benefit from its important socio-economic contributions.



(1) https://ec.europa.eu/growth/sectors/medical-devices_en

Middle East & Africa, and Russia

MIDDLE EAST & AFRICA



The number of commercial radiation processing facilities in this region that sterilise medical devices and treat food is relatively small. However, irradiation and nuclear techniques are used to some extent for the benefit of the region.

The Sterile Insect Technique (SIT) has been introduced to Africa to help control insect pests. The benefits of using the technology include: a significant reduction in crop and livestock production losses; protection of the horticultural and livestock industries through prevention of pest introductions; providing conditions for commodity exports to high value markets without quarantine restrictions; protecting and creating jobs; significant reduction in production and human health costs; and environmental protection through a reduced use of insecticides[1].

SIT promises also to be effective in combatting malaria-transmitting mosquitoes and the diseases they carry[2]. There were an estimated 228 million cases of malaria in 2018, and the estimated number of malaria deaths stood at 405,000. In 2018, the WHO African Region was home to 93% of malaria cases and 94% of malaria deaths[3].

Other irradiation and nuclear techniques are employed in the region to address issues of poor soil fertility in drought prone areas that result in low crop yield. These technologies have enabled the production of drought and heat tolerant crops and improved the use of water resulting in increased crop yields, self-sufficiency and much improved farmer livelihoods.

RUSSIA

Russia has a long history of researching irradiation technology and there are several organisations that operate facilities and produce e-beam equipment that is supplied locally and internationally. In recent years, the commercialisation of radiation processing, particularly using e-beam, has developed rapidly with investment in new facilities and applications.

Most standard applications are undertaken, including the treatment of polymers, cable, electronics and packaging. The demand for irradiation sterilisation of medical devices and pharmaceutical products is growing with the need to meet international standards and the requirements of foreign companies that manufacture in Russia. Herbs and spices are also treated and the use of irradiation technology for treating other foods is under development.

Russia is also a major supplier of Cobalt-60 that is used in radiation processing. Large volumes of this material are exported, supporting employment, the economy and helping industry meet medical device sterilisation needs internationally.

(1) International Atomic Energy Agency, Sterile insect technique, https://www.iaea.org/topics/sterile-insect-technique
(2) International Atomic Energy Agency, Nuclear technology and applications/ Health/Infectious diseases/Malaria, https://www.iaea.org/topics/malaria
(3) World Health Organisation, Health topics, Malaria, https://www.who.int/health-topics/malaria#tab=tab_1

Japan and South Korea both have a long history of developing and growing applications of irradiation. Today irradiation technology is used to support their major industries, particularly the automobile and electronics industries, by enabling the production of robust products at reduced cost without the use of chemicals. The technology generates several billion USD revenue annually, provides large scale employment and is expected to grow as demand from industry increases.

JAPAN

Commercial applications of radiation processing have been developed in Japan since the 1950s and the country continues to be in the forefront of innovation in radiation chemistry. Irradiation applications rapidly expanded into new areas of crosslinking plastic foams and rubber tyre components in support of the Japanese automotive industry. There are now over 300 accelerators performing commercial scale polymer modification by irradiation in Japan.

Sterilisation of medical devices using irradiation is well established with Japanese manufacturers constructing in-house gamma irradiators to enable them to meet demand. Since 2000, several medical device manufacturers have started to adopt electron accelerators to meet their irradiation needs.

In Japan new applications continue to be developed such as radiation degradation of PTFE for making ultra-fine powders and the use of inline low energy electrons for the sterilisation of packaging in aseptic processing.

SOUTH KOREA

Electron accelerators were introduced into South Korea during the 1970s, firstly for research and later for insulated wire and cable production. There are currently over 60 electron accelerators in commercial use in South Korean industries, mainly for purposes such as, productions of wires, cables, thermo-shrinkable materials, foam sheets, coating, curing of materials, sterilisation of medical products and environmental protection.

The demand for irradiation crosslinking of wire and cable has grown steadily in South Korea since 1985. Major markets include wiring for vehicles and process control instruments that require superior performance and mechanical properties. Irradiation has the benefit that it does not require the use of peroxide or heat.

The tyre industry benefits from irradiation by pre-curing components prior to assembly of the tyre. The irradiation does not add significant improvement in physical properties of the final tyre but the process does simplify manufacturing and reduced material costs.

Irradiation is widely used in South Korea in the production of foam products. Irradiation increases the viscosity of the molten polymer material making it more difficult for the gaseous products from the foaming agent to escape from the melt. This results in large volume expansion and a uniform foam size.

The first South Korean gamma irradiator was installed as a training facility and to demonstrate the sterilisation of medical products. The technology is now used more widely in South Korea for the commercial sterilisation of medical products such as surgical gloves, needles, bandages and blood bags. There is a growing demand for medical product sterilisation as well as the treatment of traditional medicinal herbs and food products and the qualification of equipment to be used in nuclear power plants.

Latin America

Latin America benefits from locally sterilised medical devices that have been treated with irradiation along with pharmaceutical, veterinary, agricultural and polymer products. The treatment of food products is a highly important irradiation application in the region.

Latin America makes up 23% of the world's arable land and is responsible for 13% of global agricultural production and 16% of global agricultural exports. Approximately 25 commercial scale or semi-commercial irradiators operate in Latin America and play a significant role in ensuring the safety and sustainability of these agricultural food products and supporting the economy by enabling trade and export.

Latin America is one of the leading food producing regions but it is geographically large, has a population of approximately 650 million people and is having to deal with major social challenges including extreme poverty and hunger. There are significant issues with distribution and access to food, particularly for the rural population. Shelf life extension and improved safety of food products through irradiation treatment has had a significant social impact and made an important contribution to addressing these issues and reducing food waste.

Phytosanitary irradiation is an important process that enables food products to be exported from Latin America. Mexico is leading the way with the irradiation of large volumes of fruit such as mangoes, various citrus fruits, guava and peppers. After irradiation, these fruits can be exported to the USA without alternative treatment such as harmful gas treatment or other post-harvest quarantine measures. In addition to the environmental benefit, this process enables trade that is economically important and has a positive social impact for farmers, employment and the surrounding industries.

The Sterile Insect Technique (SIT) has been adopted and highly effective in Latin America in reducing the mosquito population that spreads Dengue, Zika and Chikungunya diseases.

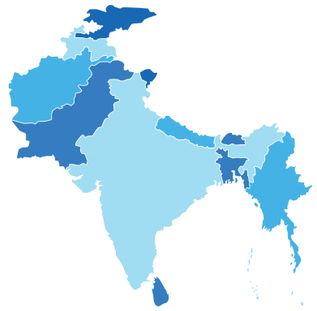
There are approximately 45 additional small-scale irradiators in Latin America that are used in research of irradiation technologies and applications. This research has resulted in the development of important new applications including its use in the production of biomaterials for skin replacement of burn victims and the improvement of plant species to make them more resistant to climate changes.

Argentina contributes to the supply of Cobalt-60 used in radiation processing. This material is used locally and exported to support the irradiation industry and its important applications.

Safety and sustainability of food are a major priority for Latin America. Irradiation technology plays a critical role in addressing these issues, supporting the economy of the region and the wellbeing of its population.

The 'Radura' is the international symbol indicating that a food product has been irradiated

South Asia



India was an early adopter of irradiation technology, particularly gamma irradiation, by establishing demonstration and research facilities for studying medical device sterilisation, microbial decontamination of spices and seasonings, preservation of agricultural products and fresh produce and the decontamination of sludge.

Since the 1970s, radiation processing has become increasingly popular in India with investment in facilities and government initiatives.

The sterilisation of medical devices using gamma irradiation is well established in India with some manufacturers operating their own in-house irradiators. Other gamma irradiators are operated as multi-purpose service centres that typically treat single-use medical items and spices. This is also the case in Bangladesh, Pakistan and Sri Lanka where in-house and service irradiators treat similar products.

Indian Government policy is encouraging private entrepreneurs to establish large gamma and e-beam radiation processing facilities. 22 large scale gamma irradiators have been commissioned in India since 2000. Additionally, 15 e-beam irradiators have been installed since 2015, all but one are used to improve the insulation of wire and cable and one is used to modify the colour of diamonds. Two further e-beam facilities are under construction and expect to be operational by the end of 2020 for irradiation treatment of medical products and food packaging.

Food irradiation is developing in the region and there are moves to establish public-private partnerships to invest in further irradiation facilities for food preservation. The objective is to use irradiation to reduce spoilage of some fruit, vegetable and other horticultural produce. Food safety issues can also be addressed with irradiation and there is interest in many applications, for example the treatment of ingredients for convenience foods for which the demand is growing in the region.

Phytosanitary irradiation is now being used effectively to enable the export of mangoes from India to the USA. The irradiation process ensures that no invasive insect pests will reproduce when they reach their destination.

Dog chews, a treat for pet dogs made from rawhide, are commonly manufactured and irradiated in India. Irradiation achieves microbial decontamination so that owners and their pets can safety handle the treat.

In 2019 a dry sewage sludge gamma irradiator was commissioned in Ahmedabad, India. This fully automated irradiator processes 100 tons of sludge every day to eliminate its high pathogenic microbial load. The hygienised sludge is then inoculated with useful bacteria to provide a value-added bio-fertilizer.

While indigenous e-beam accelerator technology is still to be made available, India is a major producer of Cobalt-60 that is used in radiation processing. Most of this is used to meet local demand from gamma irradiators but some surplus volume is occasionally exported to meet international demand. India is also home of gamma irradiator suppliers that serve both the local and export markets.

South East Asia and Australasia has a long and varied history in radiation processing that is now well developed and routinely used for many beneficial applications. The technologies have brought international business into the region and enabled countries to make the best of their resources. The health and wealth of the populations, the safety and quality of products and the level of international trade have all benefited from the application of irradiation.

SOUTH EAST ASIA

In Thailand, the government established an irradiation centre to explore the potential of radiation processing, particularly for treatment of food. Irradiation was developed to improve the microbiological safety of naem, a popular and typically Thai fermented sausage, that can otherwise be responsible for severe food poisoning. Similarly, in Vietnam, the government constructed demonstration facilities during the 1990s for the irradiation of food. This industry has now been expanded by several privately owned companies using gamma and e-beam irradiation for the treatment of frozen and dry fish products for safety and preservation purposes as well as spices, medicinal herbs and medical devices.

Vietnam is developing irradiation technology further to enable it to become a major exporter of fresh fruit and vegetables. Fruits that were previously barred from export for biosecurity reason can now be treated with irradiation as a phytosanitary measure. In 2019 more than 8,000 tons of dragon fruit, longan, mangoes and other fruit were exported to USA, Australia and New Zealand. Similarly, small volumes of Thai tropical fruit such as mangosteens are exported to the USA after being irradiated to meet quarantine requirements.

In the early 2000s, many foreign medical device manufacturers from Europe, Japan and the USA started establishing production sites in Thailand. These manufacturers required sterilisation facilities and this local demand was met by the construction of several large radiation processing centres. These in turn attracted more medical device manufacturer to the region and the radiation processing facilities now treat a wide range of products including food, pharmaceutical and cosmetic ingredients and packaging.

The medical device manufacturing sector and the radiation processing industry are often symbiotic. Malaysia, a country producing natural latex, has seen growth in both the latex and the radiation processing industries over the last twenty years since a major glove manufacturer established a gamma irradiator. The country is now the world's largest producer of medical gloves and there are several companies using gamma, e-beam and X-ray irradiation for the treatment of latex products, to improve polymers used in wires, cables and tyres as well as several other applications.

In Singapore, a large U.S. medical device manufacturer has been operating a gamma irradiator to sterilise its products for more than thirty years.

Thailand is a major international hub for the trade and manufacturing of gemstones. Two dedicated e-beam irradiators, one private and one public, irradiate various kinds of gemstones to modify their colour, thereby increasing their commercial value.

South East Asia & Australasia

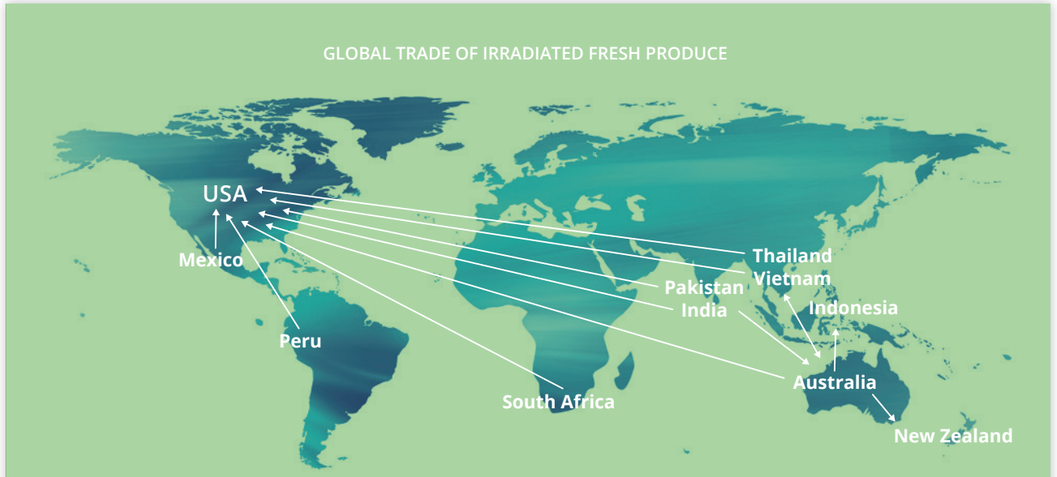
AUSTRALASIA

Gamma irradiation was established in Australia in the 1950s to stop the spread of anthrax, a potentially deadly bacteria, in wool for export. Today there are multiple gamma irradiators and an X-ray facility in Australia, primarily used for the sterilisation of medical items. There is one irradiator in New Zealand for the treatment of vaccines.

Irradiation is a valuable tool for enforcing the strict biosecurity requirements of both Australia and New Zealand that are two of the few countries that remain free from the world's most severe pests and diseases. From grain imported to feed the horses during the Sydney Olympics to wooden souvenirs brought in by tourists, or seeds imported to feed domestic birds, irradiation helps to protect the unique flora, fauna and agriculture of these countries.

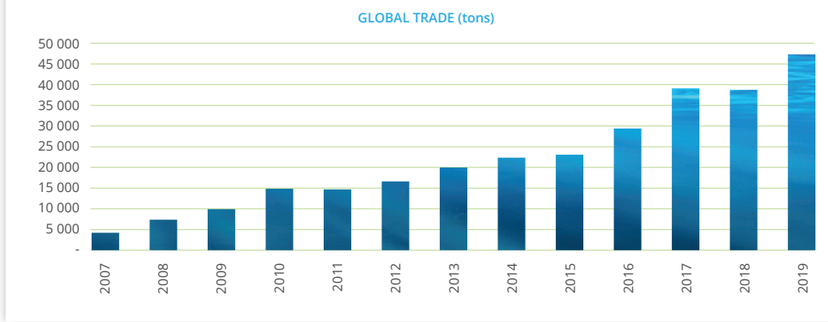
After the ban on several pesticides used for phytosanitary purpose, Australia adopted irradiation of fresh fruit and vegetables for export to New Zealand, Vietnam and other countries as well as for interstate commerce between Queensland and areas that are free from the fruit fly pest.

Australia pioneered the treatment of beehive equipment. American foulbrood is a honeybee disease caused by bacteria that results in serious beehive and economic losses to beekeepers. When an outbreak occurred in 1982, rather than burn the hives, it was found that gamma irradiation was effective in eliminating the pathogens and insects from the contaminated equipment. The method has since been used outside Australia.



Most of the trade in fresh produce irradiated for phytosanitary purposes is between the Americas, Asia, Australia and New Zealand with the United States of America being the greater importer.

In 2019 the global volume of fresh produce irradiated for phytosanitary purposes is estimated at 47,000 tons. Traded volumes have increased almost ten-fold since 2007.



Source: Phytosanitary Irradiation Platform psipglobal.org

MEDICAL DEVICE MARKET

Sterilisation of single use medical devices represents approximately **80%** of **radiation processing volume** in the USA

Value of U.S. medical device market **USD 156 billion**

Expected **growth** by 2023 **USD 208 billion**

JOBS: **2 million** | EXPORTS: **USD 43 billion**

BENEFITS & CONTRIBUTION

SOCIAL	Healthcare	• Sterilisation critical in healthcare, wound-care, surgery etc. • Medical isotopes used in diagnosis and treatment of patients
	Safety	• Safer material used in consumer products and industry • Improved food safety and reduced food bourne illness
	Security	• Protecting borders by cargo screening using irradiation • Protecting government agencies by irradiation of post
ECONOMIC	USA & Canada is world's largest user and supplier of irradiation technology	
	Supports	Irradiation supports multi-billion dollar industries and sectors
	Protects	Competitive position and international trade of U.S. and Canadian companies
	Employs	Jobs created by users, suppliers, manufacturers and indirect industries

USA & Canada

Radiation processing makes an important and significant positive socio-economic contribution in both the USA and Canada.

The sterilisation of single use medical devices represents approximately 80% of radiation processing volume in the USA[1]. The United States remains the largest medical device market in the world, valued at USD156 billion, representing 40% of the global medical device market in 2017. U.S. exports of medical devices in key product categories identified by the U.S. Department of Commerce exceeded USD43 billion in 2018. The industry includes almost 2 million jobs in the U.S., including both direct and indirect employment[2].

The need for sterile and safe medical devices will continue to grow in USA and Canada as the population increases, there is earlier detection of disease and life expectancy is extended. By 2023, the U.S. medical device market is expected to grow to a value of USD208 billion [2].

Most medical devices sterilised by radiation processing are treated by gamma irradiation. There are currently 51 gamma irradiators located at 44 sites within the USA and together they sterilise approximately 200 million cubic feet of product annually[1]. Most of these facilities are operated by companies offering a contract irradiation service and a few are used in-house by large North American medical device companies that sterilise their own product prior to sale globally.

Gamma irradiation uses Cobalt-60 that is produced in nuclear reactors that already supply electricity and contribute to clean air and long term climate change goals. This Cobalt-60 is also used in medical therapy, particularly the treatment of cancer and complex brain conditions. More than 50% of the world's Cobalt-60 is produced in reactors in Canada and up to 80% of the world's Cobalt-60 sealed sources are manufactured in Canada. Significant investment continues to be made in these infrastructures to ensure long term reliable supply as demand for Cobalt-60 increases.

Other products that benefit from radiation processing in the USA and Canada include laboratory and cleanroom equipment, pharmaceutical products, packaging used by the healthcare and food industries, and some approved food and food ingredients. Many of these products are treated using high energy e-beam (5-10 MeV) and there are approximately 40 of these machines in operation in U.S. and Canada. About half of these are operated by contract irradiation service providers and approximately 35% are operated for in-house product sterilisation. The remaining 15% are used for the production of medical radioisotopes, cargo screening and research.

The production of medical radioisotopes secures the reliable domestic supply of diagnostic testing and treatment material for U.S. and Canadian patients. Cargo screening helps ensure border security with the use of X-rays to inspect large shipping containers.

In October 2001, the infectious disease anthrax was found in mail sent to several news agencies and the offices of two United States Senators [3]. Since then, one high energy e-beam facility has been dedicated to use by the U.S. government for irradiation of post addressed to certain government agencies to ensure that packages and letters do not contain harmful bacteria.

There are many medium energy e-beams (1-5 MeV) in operation in North America. Almost all are in-house facilities with approximately half used for heat shrink and material science, a third used in the wire and cable industry and the balance used for sterilisation and research.

There is currently a high level of interest from the healthcare industry and regulators in further developing X-ray technology for use in medical product sterilisation. Greater investment in this technology is now being made in USA and Canada and X-ray irradiation is expected to evolve over the coming years. This will ensure that irradiation maintains its position as a critical technology for healthcare.

Other new applications are being studied and universities and research organisations are highly engaged in developing irradiation technologies. This includes government associated facilities researching fundamental science, the development of advanced materials and consumer product, and other new irradiation solutions that benefit our populations and environment.

The USA and Canada are not only the world's largest users of radiation processing but are also the homes of some of the largest suppliers of this technology to the global irradiation industries. This results in significant economic contribution, job creation and the knowledge that it supports critical industries. Radiation processing is robust, the technologies and applications are developing, and U.S. and Canadian suppliers are committed to this industry for the long term.

Radiation processing is critical to our healthcare industries and to the wellbeing of millions of North Americans. The contribution to multibillion-dollar economic sectors will continue; the competitive position of North Americas highly regarded medical device companies will be maintained; and innovation, international trade and employment numbers will all grow.

(1) Non-Radioisotopic Alternative Technologies White Paper, September 2019, U.S. Department of Homeland Security
(2) Medical Technology Spotlight, Medical Technology in the United States, selectusa.gov
(3) Radtown, Mail Irradiation, U.S. Environmental Protection Agency

American Nuclear Society
ANS, USA | ans.org

Asociación Latinoamericana de Tecnologías de la Irradiación
ALATI, Latin America | alati.la

Canadian Nuclear Isotope Council
CNIC, Canada | canadianisotopes.ca

China Isotope & Radiation Association
CIRA, China | cira.net.cn

National Association for Application of Radioisotopes and Radiation in Industry
NAARRI, India | naarri.com

Panel on Gamma & Electron Irradiation
UK | irradiationpanel.org

INTERNATIONAL IRRADIATION ASSOCIATION

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