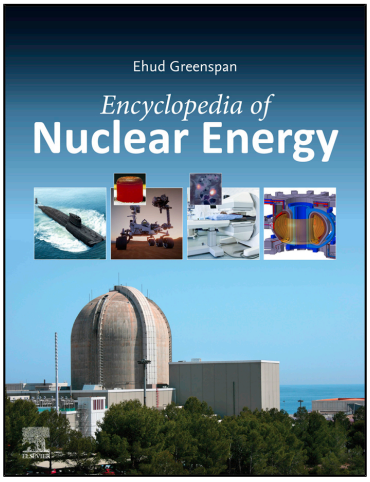

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Global Market for Radiation Applications

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Glossary

CAGR Compound Annual Growth Rate
CT Computerized Tomography
FAO Food and Agriculture Organization
FDA Food and Drug Administration (USA)
IAEA International Atomic Energy Agency
IR Ionizing Radiation
MRI Magnetic Resonance Imaging
PET Positron Emission Tomography
SIT Sterile Insect Technique
SPECT Single Photon Emission Computed Tomography
TAT Targeted Alpha Therapy
THz Terahertz Radiation
WHO World Health Organization

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Introduction

The use of nuclear technologies in modem society is widespread and pervasive, the economic benefits of radiation applications are enormous, and the global market for radiation applications is huge and is increasing rapidly (RadiationAnswers.org, 2020; World Nuclear Association, May, 2017; Lowenthal and Airey, 2001; "The Benefits of Nuclear Technology," November–December, 1992). However, the benefits of these non-energy nuclear technologies – which include medical and other radioisotopes and radioactive materials – are not widely known or sufficiently appreciated. The standard of living for most people in developed countries would not be possible without nuclear technologies. They are ubiquitous and extraordinarily important in many ways, both large and small, throughout all aspects of life (Waltar, 2004). In fact, Glenn Seaborg, one of the most prominent scientists of the 20th century, stated that even if not 1 W of electrical power had ever been generated from nuclear energy, all of the money invested in the nuclear energy field from the Manhattan Project forward would have been justified many times over by radioisotopes and radioactive materials (Bezdek and Wendling, 1997).

Aside from the generation of electricity, nuclear technologies play a critical role in:

- Maintaining the safety and structural integrity of buildings, airplanes, and roads and bridges.
- Maintaining the health and quality of the foods and liquids people consume.
- Testing and improving motor vehicles.
- Improving health and saving lives, while at the same time reducing the costs of health care.
- Increasing crop yields and improving the health and productivity of farm animals.
- Reducing the costs of energy exploration and production, and increasing energy efficiency.
- Reducing the threat of terrorism in air travel, in public places, and in other venues.
- Controlling insect pests in an environmentally benign manner.
- Controlling and abating air, water, chemical, and solid waste pollution.
- Facilitating R&D breakthroughs in all fields of science, industry, and technology.

It is generally recognized that nuclear power plants produce electricity and that radioisotopes are used in research. However, it is not widely known that:

- One-third of the patients hospitalized every year in many nations are treated with nuclear medicine techniques.
- Many new drugs must be tested with radioactive materials before they can be approved by regulatory authorities and sold to the public.
- Worldwide, industry depends on radioisotopes and radioactive materials for measurement and automation, process development, quality control and testing, and cost reduction. In many cases, there are no feasible substitutes for these materials.
- Many common, widely used consumer products, such as smoke detectors, non-stick pans, and radial tires, require radioisotope methods for their development, production, or operation. For example, smoke detectors rely on a tiny radioactive source to function, and non-stick pans are treated with radiation to ensure that the plastic coating adheres.
- Radioactive materials are used in thousands of applications ranging from bridge and building construction to police work and anti-terrorism, from dating of archeological artifacts to development of agricultural crops.
- The use of nuclear technologies in chemistry has had as profound an impact in that field of science as use of the electron microscope has had in physics.
- Businesses in all fields of industry and commerce rely heavily on nuclear technologies to maintain and enhance their competitiveness in an increasingly competitive world.
- Nuclear technologies have been used to resolve two of the most controversial archeological disputes in recent decades: The Dead Sea Scrolls and the Shroud of Turin.
- Nuclear technologies have been used to estimate the age of the earth and to support the theory that a cataclysmic impact of a huge asteroid was responsible for extinction of the dinosaurs and the evolution of current species, including homo-sapiens.
- Nuclear medicine techniques permit the detection, treatment, and cure of breast cancer and prostate cancer and many other diseases without surgery.
- One-third to one-half of the food produced in the world is lost due to spoilage and infestation between production and consumption, and nuclear technologies can prevent most of this loss.
- Nuclear technologies permit the exploration of space, which would be impossible without small, radioisotope-powered generators.
- Use of nuclear technologies has reduced the number of patients in the USA treated annually using surgery for hyperthyroidism from 3000 to 50.
- Radioactive iodine is the most reliable treatment available for hyperthyroidism.
- Radiography is used to check the welds on virtually all new oil and gas pipelines and to examine the structural integrity of bridges.
- Radionuclides were key in determining the structure of DNA and in unlocking the genetic code.
- Radioactive materials are used to measure pollution in reservoirs and coastal aquifers.
- Pipeline leaks can be detected using nuclear technologies in a matter of days or weeks at a cost of $40,000–$60,000; alternative methods can take six months to a year and cost $1 million, plus many millions of dollars in pipeline downtime costs.
- In recent decades the application of a single nuclear technique – tracers – in one industry – machine tools – has saved the USA economy nearly $100 billion.

- Nuclear electron beam processing can eliminate the air pollutants that can cause acid rain and global warming, without producing harmful by-products.
- Solid wastes and sewage can be treated with nuclear technologies without using toxic chemicals.

Perhaps most important, in many cases there are no adequate substitutes for nuclear technologies at virtually any price.

The myriad uses of nuclear technologies

Radioisotopes, nuclear power process, ionizing radiation heat and non-stationary power reactors, and other nuclear technologies have numerous essential uses across multiple sectors, including consumer products, food and agriculture, industry, medicine, scientific research, transportation, water resources, and the environment – Fig. 1. These uses are discussed below.

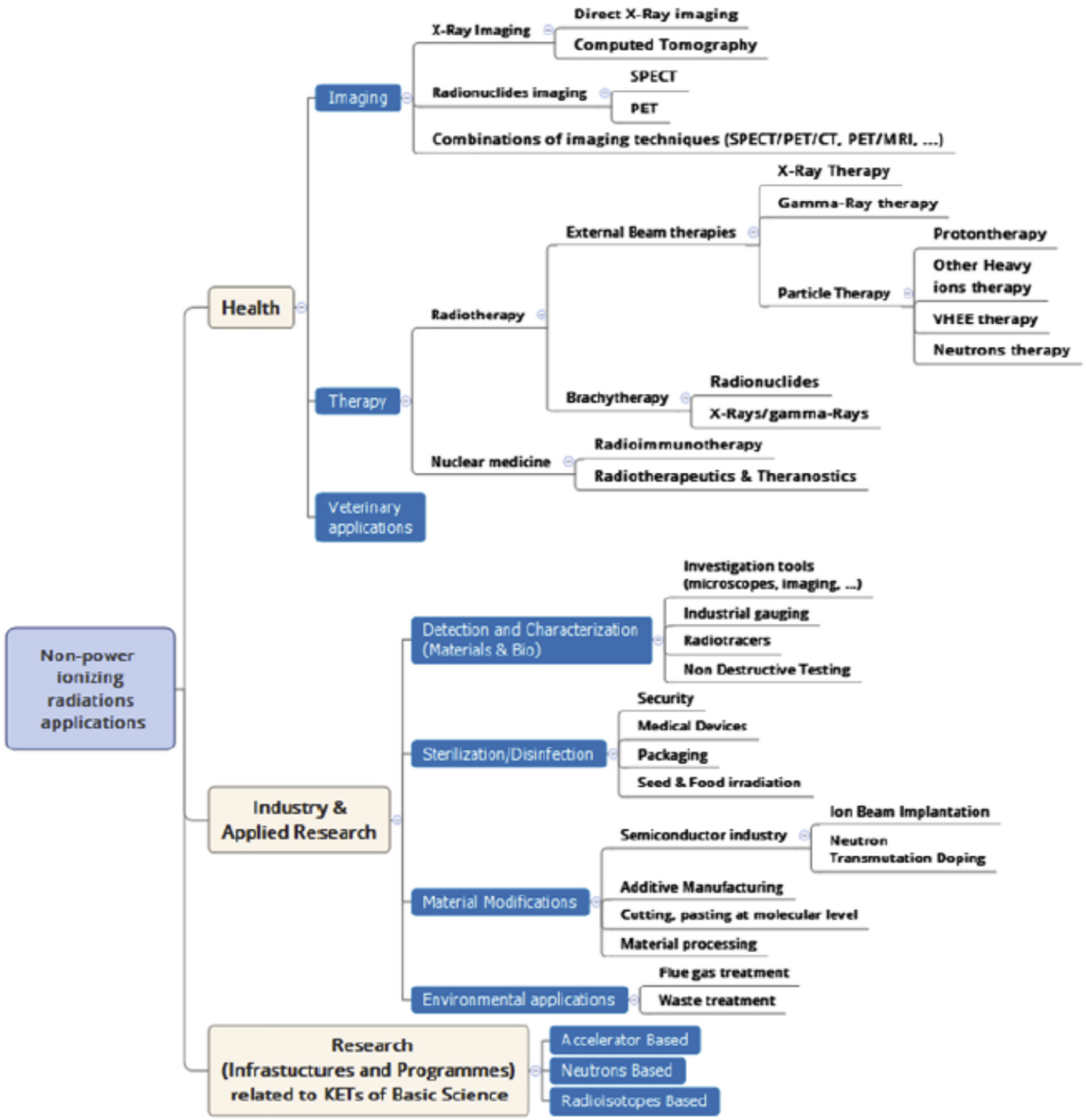

Fig. 1 Global summary of non-energy applications of ionizing radiation. From Kolmayer A, Mario M, Ligtvoet A, Van Barnevald J, Scholten C, and Davé A (2019) *European Study on Medical, Industrial and Research Applications of Nuclear and Radiation Technology*, Contract ENER/17/NUCL/SI2.755660, Luxembourg: Publications Office of the European Union.

Carbon dating

Analyzing the relative abundance of particular naturally-occurring radioisotopes is of vital importance in determining the age of rocks and other materials that are of interest to geologists, anthropologists, hydrologists, and archeologists, among others (American Chemical Society, 2019). Nuclear technologies play a critical role in these analyses.

Consumer products

The function of many common consumer products is dependent on the use of small amounts of radioactive material (World Nuclear Association, January, 2018). For example, smoke detectors, watches and clocks, radial tires, and non-stick materials, among others, all utilize the natural properties of radioisotopes in their design. One of the most common current uses of radioisotopes is in household smoke detectors. These contain a small amount of americium-241 which is a decay product of plutonium-241 originating in nuclear reactors. The Am-241 emits alpha particles which ionize the air and allow a current between two electrodes. If smoke enters the detector it absorbs the alpha particles and interrupts the current, setting off the alarm.

Environmental tracers

Radioisotopes play an important role in detecting and analyzing pollutants. Nuclear techniques have been applied to a wide range of pollution problems including smog formation, Sulfur dioxide contamination of the atmosphere, sewage dispersal from ocean outfalls, oil spills, and other pollution problems (Elliot, 2014).

Fertilizers

Fertilizers are expensive and if not properly used can damage the environment. It is important that as much used fertilizer as possible is "fixed" in the plant matter and that a minimum is lost to the environment. "Labeling" fertilizers with a particular isotope (e.g. nitrogen-15) provides a means of ascertaining how much has been taken up by the plants, allowing for optimal management of fertilizer use (Glibert et al., 2018).

Food irradiation

Approximately 25–30% of food harvested is lost as a result of spoilage before it can be consumed. This problem is particularly prevalent in hot, humid countries. Food irradiation is the process of exposing foodstuffs to gamma rays to kill bacteria that can cause food-borne disease, and to increase shelf life (Singh et al., 2013). In all parts of the world there is growing use of irradiation technology to preserve food. More than 60 countries worldwide have introduced regulations allowing the use of irradiation for food products.

In addition to inhibiting spoilage, irradiation can delay ripening of fruits and vegetables to give them longer shelf life, and it also helps to control pests. Its ability to control pests and reduce required quarantine periods has been the principal factors behind many countries adopting food irradiation practices.

Industrial tracers, inspection, and instrumentation

Radioisotopes are used by manufacturers as tracers to monitor fluid flow and filtration, detect leaks, and gauge engine wear and corrosion of process equipment. Small concentrations of short-lived isotopes can be detected, and no residues remain in the environment (Pandey, 2015). By adding small amounts of radioactive substances to materials used in various processes it is possible to study the mixing and flow rates of a wide range of materials, including liquids, powders and gases, and to locate leaks.

Radioactive materials are used to inspect metal parts and the integrity of welds across a range of industries. For example, new oil and gas pipeline systems are checked and tested by placing the radioactive source inside the pipe and the film outside the welds. Gauges containing radioactive (usually gamma) sources are in wide use in all industries where levels of gases, liquids, and solids must be assessed. They measure the amount of radiation from a source that has been absorbed in materials. These gauges are most useful where heat, pressure, or corrosive substances, such as molten glass or molten metal, make it impossible or difficult to use direct contact gauges.

The ability to use radioisotopes to accurately measure thickness is widely utilized in the production of sheet materials, including metal, textiles, paper, plastics, and others. Density gauges are used where automatic control of a liquid, powder, or solid is important, for example, in detergent manufacture.

Insect control

Crop losses to insects are significant. Despite the widespread use of insecticides, these losses total in excess of 10% globally, and are often notably higher in developing countries. One approach to reducing insect depredation in agriculture is to use genetically-modified crops, so that much less insecticide is needed. Another approach is to disable the insects.

Radiation is used to control insect populations via the Sterile Insect Technique (SIT) (Rossler, 2015). SIT involves rearing large populations of insects that are sterilized through irradiation (gamma or X-rays), and introducing them into natural populations. The sterile insects remain sexually competitive, but cannot produce offspring. The SIT technique is environmentally-friendly, and has proved an effective means of pest management and control even where mass application of pesticides had failed. The International Plant Protection Convention recognizes the benefits of SIT, and categorizes the insects as beneficial organisms (United Nations Food and Agriculture Organization, 2019).

SIT was first developed in the USA and has been used successfully for more than 60 years. At present, SIT is applied across six continents. Since its introduction, SIT has successfully controlled the populations of a number of high profile insects, including mosquitoes, moths, screwworms, tsetse flies, and various fruit flies (Mediterranean fruit fly, Mexican fruit fly, oriental fruit fly, and melon fly).

The most recent high-profile application of SIT has been in the fight against the deadly Zika virus in Brazil and the broader Latin America and Caribbean region (United Nations, April 19, 2018). Following its outbreak, impacted countries requested urgent support from the International Atomic Energy Agency (IAEA) to help develop the established technique to suppress populations of disease-carrying mosquitoes. The IAEA responded by providing expert guidance, extensive training, and by facilitating the transfer of gamma cell irradiators to Brazil. Three UN organizations – the IAEA, the Food and Agriculture Organization (FAO), and the World Health Organization (WHO) – with the governments concerned, are promoting new SIT programs in many countries.

Medicine

There is widespread use of radiation and radioisotopes in medicine, particularly for diagnosis (identification) and therapy (treatment) of various medical conditions (American Nuclear Society, 2014; Patton, 1993). In developed countries about one person in 50 uses diagnostic nuclear medicine each year, and the frequency of therapy with radioisotopes is about one-tenth of this.

Diagnosis

Diagnostic techniques in nuclear medicine use radiopharmaceuticals (or radiotracers) which emit gamma rays from within the body. These tracers are generally short-lived isotopes linked to chemical compounds which permit specific physiological processes to be scrutinized (Center for Disease Control and Prevention, 2014).

Depending on the type of examination, radiotracers are either injected into the body, swallowed, or inhaled in gaseous form. Emissions from the radiotracers are detected by the imaging device, which provides pictures and molecular information. The superimposition of nuclear medicine images with computed tomography (CT) or magnetic resonance imaging (MRI) scans can provide comprehensive views to physicians to aid diagnosis. An advantage of nuclear over X-ray techniques is that both bone and soft tissue can be imaged very successfully.

The most widely used diagnostic radioisotope is technetium-99 m, with a half-life of 6 h, and which gives the patient a very low radiation dose. Such isotopes are ideal for tracing many bodily processes with the minimum of discomfort for the patient. They are widely used to indicate tumors and to study the heart, lungs, liver, kidneys, blood circulation and volume, and bone structure.

Sterilization

Hospitals use gamma radiation to sterilize medical products and supplies such as syringes, gloves, clothing, and instruments that would otherwise be damaged by heat sterilization. Many medical products today are sterilized by gamma rays from a cobalt-60 source, a technique which generally is much cheaper and more effective than steam heat sterilization. The disposable syringe is an example of a product sterilized by gamma rays. Because it is a "cold" process, radiation can be used to sterilize a range of heat-sensitive items such as powders, ointments, and solutions, as well as biological preparations such as bone, nerve, skin, etc., used in tissue grafts (Finkiel, 2016).

There are significant benefits to sterilization by radiation. It is safer and cheaper because it can be done after the item is packaged. The sterile shelf life of the item is then practically indefinite provided the package is not broken open. Apart from syringes, medical products sterilized by radiation include cotton wool, burn dressings, surgical gloves, heart valves, bandages, plastic and rubber sheets, and surgical instruments.

Therapy

Nuclear medicine is also used for therapeutic purposes. Most commonly, radioactive iodine (I-131) is used in small amounts to treat cancer and other conditions affecting the thyroid gland. Cancerous growths are sensitive to damage by radiation, which may be external (using a gamma beam from a cobalt-60 source), or internal (using a small gamma or beta radiation source). Short-range radiotherapy is known as brachytherapy, and this is becoming the main means of treatment. Many therapeutic procedures are palliative, usually to relieve pain (Florida Medical Clinic, June 28, 2016).

A new field is targeted alpha therapy (TAT), especially for the control of dispersed cancers (Kozempel et al., 2018). The short range of very energetic alpha emissions in tissue means that a large fraction of that radiative energy goes into the targeted cancer cells once a carrier, such as a monoclonal antibody, has taken the alpha-emitting radionuclide to exactly the right places.

Plant mutation breeding

Plant mutation breeding is the process of exposing the seeds or cuttings of a given plant to radiation, such as gamma rays, to cause mutations (Beyaz, 2017). The irradiated material is then cultivated to generate a plantlet. Plantlets are selected and multiplied if they show desired traits. A process of marker-assisted selection (or molecular-marker assisted breeding) is used to identify desirable traits based on genes. The use of radiation essentially enhances the natural process of spontaneous genetic mutation, significantly shortening the time it takes.

Countries that have utilized plant mutation breeding have realized large socio-economic benefits. For example, in Bangladesh, new varieties of rice produced through mutation breeding have increased crops three-fold in the last several decades. During a period of rapid population growth, the use of nuclear techniques has enabled Bangladesh, and large parts of Asia in general, to achieve food security and improved nutrition.

Water resources

Adequate potable water is essential for life. However, in many parts of the world fresh water has always been scarce and in others it is becoming so. Isotope hydrology techniques enable accurate tracing and measurement of the extent of underground water resources (Barbieri, 2019). Such techniques provide important analytical tools in the management and conservation of existing supplies of water and in the identification of new sources. They provide answers to questions about origin, age, and distribution of groundwater, as well as the interconnections between ground and surface water, and aquifer recharge systems. The results permit planning and sustainable management of these water resources. For surface waters they can provide information about leakages through dams and irrigation channels, the dynamics of lakes and reservoirs, flow rates, river discharges, and sedimentation rates. Neutron probes can measure soil moisture very accurately, enabling better management of land affected by salinity, particularly in respect to irrigation.

Estimates of the sizes of the global markets for radiation applications

As discussed above, non-energy uses of nuclear technologies are widely used in health, industry, research, and many other areas. The markets for these technologies extends from the nuclear technologies and equipment themselves, to equipment servicing (maintenance, upgrades, training, etc.) and to health, industrial and research products, and services in which they are embedded, and where their specific added value is most often difficult to isolate. This makes evaluating and estimating the market particularly challenging.

Ionizing radiation (IR) technologies rely on charged particles beams (accelerators), X-Rays, or α, β, or γ-rays, and neutrons. It has been estimated that the Ionizing radiation (IR) technologies alone underpin nearly half a trillion dollars' worth of global commerce a year (Hamm and Kephart, 2017). More generally, the non-energy economic impact of nuclear technologies and applications is enormous. For example, the 2019 economic impact of these technologies is estimated to be $532 billion in the USA and $233 billion in Japan (Bezdek and Wendling, 1997; Bezdek et al., 2008; Waltar, 2004) (Economic impact estimates converted to USA 2019 dollars by the author).

The evaluation of the IR equipment market is somewhat more straightforward. The global market value of IR equipment is estimated at more than USA $40 billion per year, with health applications being the most important non-energy sector – see **Fig. 1**. This global equipment market is attractive, with a high 3–6% annual growth rate and favorable export prospects (Kolmayer et al., 2019). The equipment market is also competitive, driven by constant innovation, which requires substantial investments.

Assessing the global economic impact of such diverse applications is difficult because they are generally embedded within products and services and manufacturing processes and research where their specific added value is difficult to estimate. Nevertheless, as noted, it has been estimated that ionizing-radiation applications of accelerators alone underpin nearly half a trillion dollars-worth of commerce a year, without taking into account their invaluable health benefits (Hamm and Kephart, 2017).

Estimates of the current size of the global markets for radiation applications are presented below.

Food irradiation market

The global food irradiation market currently totals USA $250 million and is growing at a compound annual growth rate (CAGR) of 5% (McHugh, 2019; Hallman et al., 2016; Lacroix and Follett, 2015). This growth rate is due to increased consumer acceptance since the U.S. Food and Drug Administration (FDA) approved phytosanitary treatment of fresh fruits and vegetables by irradiation. Phytosanitary treatments disinfect traded commodities of potential quarantine pests, and phytosanitary irradiation treatments use ionizing radiation to accomplish this. The food irradiation market in Asia is also growing very rapidly owing to approval of government agencies in India and other countries. At present, over 40 countries have approved applications to irradiate over 40 different foods. More than half a million tons of food is irradiated worldwide annually. For, example about a third of the spices and seasonings used in the USA are irradiated.

Ionizing-radiation equipment market

Global market data are available for the ionizing-radiation equipment market (Kolmayer et al., 2019). The global annual market currently totals about USA $40 billion and is growing at a CAGR of about 5%. The market consist of the following major segments – data presented in USA $:

- Health – USA $32 billion
- Industry (excluding health) – USA $6 billion, excluding the consumer-products segment, which is likely to be significant
- Research – USA $2 billion

Healthcare applications are probably the most important non-energy field to use ionizing-radiation tools. The market is driven by Asian markets in particular. Competition in these markets is fierce, with an increasing presence of USA and Asian companies relying on strong domestic markets. Ionizing radiation technologies are used daily in Europe in a number of fields, including health, industry, and research, with significant impact on the health of European citizens, the European economy, and Europe's international influence.

Magnetic resonance imaging (MRI) market

The Magnetic Resonance Imaging (MRI)-guided radiation therapy systems market currently totals nearly USA $300 million and is increasing at a CAGR in excess of 20% (Eminent Research and Advisory Services, May, 2019). The MRI-guided radiation therapy systems industry has been underpinned by the emergence of advanced technologies in the healthcare and medical devices industries. Increasing adoption of radiotherapy in cancer treatment is fueling demand for MRI-guided radiation therapy systems.

Medical X-ray radiation protection glass market

The worldwide market for medical X-ray radiation protection glass currently totals about USA $350 million and is forecast to increase at a CAGR of nearly 2% (360 Research Reports, 2019).

Medicine and radiopharmaceuticals market

The medicine and radiopharmaceuticals market currently totals about USA $6 billion and, driven by the increasing number of successful clinical trials, is increasing at a CAGR of 9% (Fortune Business Insights, December 24, 2019). The market includes PET radiopharmaceuticals and SPECT radiopharmaceuticals, applications in neurology, cardiology, oncology, and other fields, and end users including hospitals, clinics, and diagnostic centers. The major growth factors driving this market include:

- Radiopharmaceuticals are substances that are used to diagnose specific medical problems or diseases, and increasing imaging capabilities and efficiencies have led to a wide product adoption across the world. Increasing numbers of successful clinical trials associated with radiopharmaceuticals are increasing demand for the product.
- Recent drug application area discoveries have showcased promise for the companies operating in the market, and technological advancements in nuclear imaging and their applications in diagnosis of cancer and other serious diseases have opened up a huge potential for growth.
- Growing awareness regarding the adverse effects of chronic diseases, and the need for early diagnosis, are facilitating market growth. The advancements in imaging systems have played a major role in the growth of the market.

The need for early and accurate diagnostic methods, coupled with increasing need for better therapies, is driving the market (Grand View Research, Inc. August, 2018). Increasing incidence of cancer and cardiovascular disorders is also contributing toward market growth, since nuclear medicine has proven to be critical in the diagnosis and treatment of such conditions (International Atomic Energy Agency, 2015). Medical exposures have grown considerably in the past several decades, mostly due to the marked increase in the use of CT scanning and other advanced imaging (United Nations Scientific Committee on the Effects of Atomic Radiation, 2008).

According to the World Health Organization (WHO), the number of new cases of cancer is expected to increase by around 70% over the next two decades (World Health Organization, September, 2018). Globally, about 10 million people die annually from cancer, and cancer accounts for one out of every six deaths worldwide.

Increasing prevalence of cardiovascular diseases is fueling market growth. These diseases account for nearly 20 million deaths annually worldwide. The number is anticipated to exceed 23 million by 2030. An estimated 31% of global deaths can be attributed to cardiovascular diseases (World Health Organization, September, 2017).

At present, radiopharmaceuticals are widely used in the field of oncology and cardiovascular diseases. Ongoing research and studies demonstrating positive results is widening the scope of radioisotope applications for diagnosis and treatment of bone diseases, respiratory diseases, thyroid-related diseases, and conditions of the digestive tract. In addition to these applications, radioisotopes are widely used in radiopharmacology to study drug movement in lab subjects.

Radiation cured products market

The radiation cured products market currently totals about USA $8.5 billion and is increasing at a CAGR of nearly 7% (Global Industry Analysts, Inc. April, 2018.) The global market for radiation cured products, including adhesives, coatings, inks, and electronics, currently exceeds 600,000 thousand metric tons and is driven by growing awareness of the numerous environmental and performance benefits offered by radiation curing. Also driving growth in the market are innovations in radiation curable chemistries and stringent environment safety norms that encourage environmentally-responsible curing of resins, inks, coatings, and adhesives. The adoption of radcure technology in a broad range of applications is attributed to several advantages, such as more rapid curing and processing time, lower volatile organic compounds emissions, improved physical characteristics, and cost-effectiveness. Construction, furniture, medical, and automotive industries represent attractive end-use markets for radcure technology. Europe represents the largest market worldwide. However, Asia-Pacific ranks as the fastest growing market led by strong Chinese demand for ultraviolet and electron beam curing technologies, which are rapidly replacing traditional methods in several applications such as wood coatings, industrial coatings, and electronics coatings.

Radiation detection, monitoring, and safety market

The global radiation detection, monitoring, and safety market currently totals about USA $30 billion and is increasing at a CAGR greater than 4% (Global Radiation Detectors Market by Manufactures, Types, Applications, and Forecast 2019-2024, 2019; Radiation Detection, Monitoring, and Safety Market by Product, Composition, and Application, 2019). The market includes products, such as detection & monitoring and safety equipment, gas-filled detectors, scintillators, solid-state detectors, and various applications in healthcare, homeland security, defense, and industry. The key factors driving the growth of this market include increasing security threats, growing prevalence of cancer worldwide, increasing safety awareness among people working in radiation-prone environments, growing safety concerns following the Fukushima disaster, growing security budgets of global sporting and entertainment events, growth in the number of PET/CT scans, increasing usage of nuclear medicine and radiation therapy for diagnosis and treatment, and use of drones for radiation monitoring.

Radiation dose management solution market

Radiation dose monitoring, dose management, dose recording, and radiation safety technologies include systems to reduce or block dose via barriers or computed tomography (CT) dose reduction technologies such as iterative reconstruction. The global radiation dose management solution market currently totals USA $250 million and is increasing at a CAGR of over 14%. The market is driven by the increasing adoption of medical imaging equipment. In addition, the demand for cloud-based systems is anticipated to further increase the growth of the radiation dose management solution market.

Factors such as increasing applications of diagnostic imaging modalities and rising prevalence of various diseases are driving the need to conduct medical imaging examinations. In addition, the increasing focus on prevention and early diagnosis of diseases along with the availability of reimbursement in countries such as the UK and the USA will further drive the demand for medical imaging equipment such as picture archiving, communication systems, and radiology information systems. This in turn, will drive the adoption of radiation dose management solution, which captures, tracks, and reports the radiation dose directly from these imaging devices. Thus, the increasing adoption of medical imaging equipment is expected to drive market growth during the forecast period.

Market growth has been primarily attributed to the major drivers such as increasing prevalence of chronic and lifestyle associated diseases, increasing installed bases of radiology equipment, growing geriatric population, increasing regulatory requirements for diagnostic devices, increasing concerns related to radiation overexposure, and growing awareness and initiatives for radiation dose management. The market is expected to grow at a significant growth rate due to the opportunities that lie within its domain, which include technological advancement in medical imaging, impact of cloud-based solutions, increasing adoption of radiation dose management technologies in emerging technologies, and radiation dose management for pediatric procedure. However, there are significant challenges which are restraining the market growth. These challenges include lack of trained and skilled professionals, and lack of benchmarking for dose optimization (Technavio, 2019a; BIS Research, 2019).

Radiation-hardened electronics market

Radiation-hardened electronics are electronic components, packages and products that have been designed and tested to provide protection against penetration radiation that may, if unimpeded, cause malfunction, damage circuitry, or cause the electronic device to shut down. The global radiation-hardened electronics market currently exceeds USA $700 million and is increasing at a CAGR greater than 4% (Global Industry Analysts, 2019).

Radiation safety and protection and shielding applications market

The global market for radiation safety and protection and shielding applications currently totals about USA $60 million and is increasing at a CAGR greater than 4% (Technavio, 2019b; BCC Research, June, 2019). The market is driven by a number of factors,

including the increasing number of installations of radiology equipment. In addition, advances in radiation shielding equipment are anticipated to further increase the growth of the medical radiation shielding market.

The adoption of diagnostic radiology equipment is increasing with the growing number of imaging examinations resulting from the high prevalence of chronic diseases. Other factors such as the increasing number of radiologists and high demand for technologically advanced diagnostic radiology equipment are further driving the installation of the radiation equipment. This is increasing the need for medical radiation shielding to minimize the exposure to excess radiation and protect patients from acute health effects. Thus, the increasing number of installations of radiology equipment is a major factor driving market growth.

Radiopharmaceutical and therapeutics market

The global radiopharmaceutical and therapeutics market current totals about USA.

$17 billion and is increasing at a CAGR in excess of 9% (Laxmi, 2019).

Radiation therapy market

The current global market for radiation therapy, also known as radiotherapy, exceeds USA $7 billion and is growing at a CAGR of nearly 7% (MarketsandMarkets Inc. July, 2019; Radiotherapy Market by Type, Product, Application and End User, 2019). Radiation therapy uses ionizing radiation, generally as part of cancer treatment to control or kill malignant cells, is normally delivered by a linear accelerator and includes *Stereotactic*, *Brachytherapy*, *CyberKnife*, *Gamma Knife*, *Tomotherapy*, *Particle Therapy*, *and related applications*. Radiation therapy may be curative in a number of types of cancer, such as breast cancer and prostate cancer, if they are localized to one area of the body. Market growth is driven largely by factors such as technological advancements, the need for cancer treatments, the increasing number of conferences and symposia focusing on spreading awareness about the benefits of radiotherapy, and the growing use of particle therapy for cancer treatment. In addition, the increasing adoption of radiotherapy procedures for cancer treatment, increasing use of particle therapy for cancer treatment, and the rising number of conferences and symposia focusing on the advancements in radiotherapy are some of the other major factors driving the growth of this market. The emerging markets, growing government and private investments to meet the increasing demand for cancer treatment, and the improving reimbursement scenario are expected to present a wide range of growth opportunities for market players.

Terahertz radiation devices and systems market

Terahertz (THz) radiation can penetrate fabrics and plastics and is used in surveillance, such as security screening, to remotely uncover concealed weapons and explosives. The global market for terahertz radiation devices and systems currently totals USA $170 million and is increasing at a CAGR in excess of 31% (BCC Research, August, 2019).

Summary

It is clear that modern society cannot function without nuclear technologies and that the benefits of these technologies are enormous and widespread. International markets for these technologies exceed USA $500 billion annually and are growing rapidly. For example the global market for:

- Food irradiation is growing at a CAGR of 5%.
- Ionizing-radiation equipment is growing at a CAGR of 5%.
- Magnetic resonance imaging (MRI)-guided radiation therapy systems are growing at a CAGR in excess of 20%.
- Medicine and radiopharmaceuticals is increasing at a CAGR of 9%.
- Radiation cured products is growing at a CAGR rate of nearly 7%.
- Radiation detection, monitoring, and safety is increasing at a CAGR greater than 4%.
- Radiation Dose Management is growing at a CAGR rate of over 14%.
- Radiation-hardened electronics is increasing at a CAGR greater than 4%.
- Radiation safety and protection and shielding applications is increasing at a CAGR greater than 4%.
- Radiopharmaceutical and therapeutics is increasing at a CAGR in excess of 9%.
- Radiation therapy is growing at a CAGR of nearly 7%.
- Terahertz radiation devices and systems is increasing at a CAGR in excess of 31%.

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