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Review: Radiation Applications by Hisaaki Kudo

Hayder. K. Obayes

Department of Physics Sciences, Faculty of Science Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
Directorate General of Education in Babylon Governorate, Ministry of Education, Baghdad, 51001, Iraq

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ABSTRACT

Radiation interacts in unique ways with matter, offering a wide variety of application information that is used by scientists, engineers, architects, and medical professionals to support their work. Over the years, these researchers have improved radiation technologies through their theoretical development, improvements in hardware, and software developments that allow for better corrections for system imperfections. Many of these advances have allowed the application of radiation science to support a wide variety of other applications. These improvements have allowed radiation applications that were once limited to use in large research laboratories to be applied in field and industrial applications.

INTRODUCTION

What makes radiation unique? No other probe can penetrate into and through thick layers of matter and still carry information about the interior structure of that matter. Many derived from nuclear physics, these techniques can provide bulk and surface information about a material's chemical and crystallographic composition, phase and crystallite size, strain, magnetic properties, and degree of order: for both crystalline and non-crystalline materials. A nuclear spin is the lowest possible magnetic moment, thus thermal neutrons precess in an external magnetic field at a controlled frequency; Modulated Magnetic Fields precess the nuclear spins to a higher energy state, then collapse them into the basic low-energy nuclear spin state; thus, modulated magnetic moments can be detected. Atoms with certain electron densities interact and can be used to identify crystalline and polycrystalline microstructures. Crystalline materials that scatter Bragg planes can be used to obtain the atomic positions within the lattice. Gamma-ray and X-ray resonant scattering also can be used to obtain the atomic positions. The presence of Pt scatters X-rays with 7.07 keV energy to account for the atomic displacements when this metal is used as a catalyst.

TYPES OF RADIATION

Radiation is a natural phenomenon characterized by the emission of energy and/or particles resulting from spontaneous transformations of unstable atomic nuclei occurring in radioactive isotopes. The radiation produced in the decay process is termed radioactive or nuclear radiation. Another category of radiation is the electromagnetic radiation produced by decelerated charged particles incident on the field of atomic nuclei and by accelerated charged particles. Thermal effects produced on matter by radiation is a measure of its intensity. There are various types of radiation, generally classified into two great families, particles and electromagnetic waves. However problems of nomenclature exist because specific types of particle radiation and electromagnetic radiation have the same name.

Before Nobel prizes were instituted, particular categories of particle radiation were differentiated by the names of their discoverers.

Radiation is commonly designated by the letters α, β, γ, and X. Synonyms for this nomenclature include alphons, betatrons, gamatrons and xitrons. Other designations for particle radiation are H, Hs, Li, Li+ (protons and protons of solar winds), (deuterons, antimatter), e, e+ (exotic electrons emitted in beta-decay), n, n (neutrons emitted in nuclear reactions) and other letters of the Latin or Greek alphabet. Notation for particle radiation generally utilizes letters denoting the electrical charge and/or mass of the particle, while symbols for electromagnetic radiation are purely conventional. The name of a particular radiation source usually precedes the letter or symbol. For example: U, U, 232Th, Californium are respectively sources of radiation emitting α particles, α+8346d, 8370g, 23290g (radiation emitted in decay processes by uranium series, thorium series and actinide series, exotic electrons emitted in beta-decay of uranium), n, 210Pb, D, 232Th (neutrons emitted from beryllium, and by plutonium by neutrons incident on actinide nuclei). Radiation produced in a nuclear interaction is designated with an asterisk (for example: D*, D*, 11C).

1. Alpha Radiation

In 1899, Ernest Rutherford and Frederick Soddy found that some of the radioactive disintegrations used up elements e-scattering particles made up that which penetrated matter the least, possessing characteristics like a high mass, a +2 charge, and great speed but lacking electromagnetic interactions. Their conclusion was that with δ electrons and argon, particles accounting for electrical neutrality were roaming about in nuclei. In 1932, Chadwick discovered, by bombarding beryllium with α particles, their mass-neutral particles: the neutrons.

Nowadays, the α man-made isotope gel comprises the 93 natural ones, produced when with β or γ emissions and chemical disintegrations. They become increasingly unstable with A in the presence of high Z. In 1/2 times, most α isotopes emit α particles + light isotopes, e.g., the α of uranium-238 emits alpha particles from radon-222, the only gas emanation technique to extract uranium oxidized ores and concentration pyrometallurgical methods. Emanation techniques are needed to locate radon salts due to α particle lethargy, their very tiny flux on the Earth's surface.

2. Beta Radiation

Beta particles are described as high-energy electrons, ejected from the nucleus as a consequence of the weak nuclear force interaction, which occurs when a neutron is converted into a proton. A proton then remains in the atom nucleus, making a daughter atom more proton-rich, while the beta particle, accompanied by a tiny antineutrino particle, is ejected. This process transforms the original atom into a chemically different atom, given that its atomic number has changed; this is called beta decay, and its exponentiation into chemical equations implements the change, both inducers and products of the process being called beta emitters.

Beta radiation is the final effect generated by a very complex process that involves the interaction of quarks – and participating in the nuclei of atoms, together with gluons, protons and neutrons. Beta emission has been studied thanks to the Zeeman effect, which is the splitting of light emitted by atoms subjected to an external magnetic field. Beta particles leading to gamma photons activate pair production in the field of other radioisotope, which is beta plus emitted and used in medicine. In the presence of beta radiation, medical physics and the patient's isotopic image are essentially based on the recoil implanted in semiconductor detectors and scintillators led to in a momentum exchange with beta particles emitted in body tissues. Furthermore, scintillation and charge coupled devices enhancers are base not only in the detection of beta radiation, but also of positron emission tumors, beginning with the emission of relatives in the human.

3. Gamma Radiation

Gamma radiation consists of high-energy electromagnetic photons emitted during the de-excitation of excited nuclear states. Gamma photons are about 10,000 times more energetic than optical photons and have a wide range of energy from about 1 keV to over 30 MeV. Gamma rays with energy less than about 500 keV usually arise from the decay of long-lived isomeric nuclear states. Higher energy gamma rays are produced during alpha or beta decay to excited states of the final nucleus. Nuclear transitions with energy in the MeV range are the main source of gamma radiation from astrophysical sources, especially when nuclear abundances are significantly larger than those of other elements.

Although gamma rays are electromagnetic waves like visible light, they differ drastically from normal optical radiation in three very important respects. First, they are produced in high-energy nuclear transitions, while optical photons are produced in low-energy atomic transitions. Second, they are highly penetrating, due to their high photon energies. Their interactions with matter are dominated by pair production and Compton scattering, rather than the much larger photoelectric cross section that dominates optical radiation. This high penetrating power makes gamma rays particularly dangerous, since even small amounts of a radioactive source can emit, via pair production or Compton scattering, a large flux of penetrating radiation. Moreover, they can produce secondary radiation by colliding with nearby material. In radiation detection, secondary radiation greatly complicates noble gas detection for photon signals since it is emitted by the detector material during the electron's passage through. Finally, gamma rays transport much more energy than does ordinary radiation.

2.4. X-rays

X-Rays were discovered in the late nineteenth century. X-Rays are electromagnetic radiations with short wavelengths, ranging from 10−9 to 10−12 m. Due to their tendency to go in a straight path, X-Rays are used in machines for examining the internal structures of objects and are also used for the detection of defects in components. However, the harmful effects of X-Rays are larger than other types of radiations; hence precautions should be taken against these radiations, and if possible, the use of these radiations in any field should be minimized. X-Rays are now used in medicine, printing, electronics, while they have also been effectively used for finding out the properties of matter.

Most of the time, X-Rays are produced when high-velocity electrons strike a metal plate in a vacuum. X-Rays are rarely emitted by other sources in nature. The most optimum source for producing X-Rays is barium platinocyanide, and the most economical and widely used sources are tungsten and molybdenum. In X-Rays, first of their kind, the characteristic rays were produced, which were found for nickel, platinum, etc. at especial conditions in a vacuum tube. Later, it was discovered that including some bivalent and trivalent metals, generally, any elements can produce characteristic X-Rays. The various processes that are involved in the production of X-Rays through a vacuum tube are (i) Bremsstrahlung (ii) Characteristic radiation process.

MEDICAL APPLICATIONS OF RADIATION

Radiation medicine is an explicitly intriguing area of medicine. It uses radiation whose effects are typically untoward in large doses to treat, carefully and locally, malignancies, chronic pain, or overactive organs. In smaller doses, it can help diagnosis and follow up all sorts of diseases. The efficacy of these medical procedures is likely due to the fact that they are based on some of the earliest recognized but not understood characteristics of disease. Namely that, in many cases, neoplastic or infected tissues are more permeable than healthy tissues, and that certain tissues are more permeable to certain substances than other types of tissues. The initial studies that supported those hypotheses were made by a German chemist and by a seminal American doctor. The first experimented by using concentrations of unknown chemical agents that damaged neoplastic tissues to determine their composition. The other also damaged such tissues, but with careful injections of bacterial toxins.

Herein, we review the scientific background that led to these extraordinary contributions and to the subsequent harmonization of X-ray, radioisotope and radiopharmaceutical techniques and radiochemical agents into radiation medicine. Today, radiotherapy is an integral part in the management of nearly 60% of all tumor patients, not only in the treatment of primary tumors, but also as part of the multimodality approach in handling certain tumor types. Diagnostic imaging and nuclear medicine are complementary disciplines, with highly specialized performing sectors. Diagnostic imaging applications mostly focus on the morphology and structural changes of the targeted tissues, while nuclear medicine is specifically used to study the biological activity of diseased tissues and organs.

1. Radiotherapy

The application of radiation in medicine is most commonly associated with the treatment of disease – radiotherapy. The radiation dose delivered to patients is several orders of magnitude greater than is received in a typical diagnostic X-ray investigation, and the potential damaging effects on normal tissues are, therefore, correspondingly greater. Because the actual curing effect of radiation is based on a deterministic tissue reaction, there is no equivalent to the principles governing the use of X rays for medical imaging, where the risk of a possibility of radiation-induced cancer and the risk of detecting a disease in a patient about whom there is no objective medical suspicion must be balanced. The most common use of radiotherapy is the treatment of malignant tumors. Such tissues have a greatly increased sensitivity to radiation because they are characterized by a high proliferation rate, and their capacity to repair the damage produced by irradiation is greatly diminished. The principle of radiotherapy is that a large radiation dose is delivered to the malignant tissue while the dose to surrounding normal tissues is kept to a minimum. This can be achieved, in principle, by three-dimensional planning of the treatment combined with use of high-energy X rays or γ rays penetrating the normal tissues and depositing their energy in inverse proportion to the density of these tissues. However, it is extremely difficult to spare fully the surrounding tissues, as a consequence of the phenomenology of ionizing radiation propagation through matter and the inherent limitations in its definition. In practice, therefore, a compromise must be achieved, usually by careful three-dimensional planning of the treatment, and the use of high-energy X rays or γ rays in order to spare as much as possible the healthy surrounding tissues. The determination of the optimal dose and fractionation schedule to be utilized to achieve the cure of the tumor while maintaining a low level of normal-tissue complication is critical to the success of the treatment.

2. Diagnostic Imaging

Diagnostic imaging refers to a wide variety of techniques applied to visualize and create images of the interior of a human body in order to diagnose diseases or evaluate bodily damage. As with the rest of the applications of nuclear physics to medicine, diagnostic imaging techniques are based on our understanding of the interaction between radiation and matter. Different tissues in the body absorb or scatter different types and energies of radiation differently, creating a contrast that can be sensed and imaged.

The first and most widely recognized form of diagnostic imaging is represented by X-ray techniques. Over a century ago, a high-energy radiation was discovered that could penetrate soft tissue but was absorbed by bone. This discovery opened a new field in diagnostic medicine. Nowadays, the most high-profile and widely performed X-ray utilization is for assessment of fractures. By far, the broadest application of X-ray penetration is represented by X-ray computed tomography (CT). This technique allows the production of cross-sectional slab images of the body. CT is widely and indiscriminately applied for most areas of the body and for most diseases, being particularly useful for the diagnosis of pulmonary and brain diseases.

Besides CT, the other high-impact developments of X-ray imaging technologies involve the utilization of different soft tissue scatter contrast mechanisms that have been employed in digital mammography and digital tomosynthesis of the breast. These new modalities are expected to further improve the devoted detection and characterization of breast cancer patients, eventually allowing the early treatment of those patients.

3. Nuclear Medicine

Nuclear medicine – fusion of imaging and therapy – is a subdivision of medicine dealing with the diagnostic and therapeutic application of radioactive isotopes or radiopharmaceuticals. Firstly, radiation is emitted as gamma rays. Diagnostic imaging in nuclear medicine is usually performed using a single photon emission computed tomography or positron emission tomography. Radioactivity in diagnostic nuclear medicine has an advantage over other imaging techniques, such as x-ray, computed tomography, ultrasound, and magnetic resonance imaging, because activity concentration can be directly connected with biological processes. Nuclear medicine therapy is based on the destruction of cancer cells by targeted delivery of a therapeutical activity concentrated directly in tumors.

Radiopharmaceuticals for diagnostic imaging usually carry long-lived isotopes, while medical treatments are more frequently linked with radioisotopes emitting particles with a shorter or intermediate half-life connected with a relatively strong radiation. Sodium iodide with radioactive iodine is a typical radiopharmaceutical used for imaging thyroid cancer even in small metastatic deposits. In addition, high concentrations of iodine in the thyroid gland are performed both for imaging and for therapy of thyroid cancer by using sodium iodide with a radioactive isotope. Occasionally, a small concentration of iodine in plasma indicating a thyroid tumor in the state of "thyroid stripping" is used for treatment of the accompanying hyperthyreosis.

A variety of radiopharmaceuticals and procedures for diagnostic imaging as well as the treatment of malignant lesions throughout the body are used in modern nuclear medicine. Investigation of the blood, pulmonary, cardiac, liver, renal, and skeletal systems is utilized in diagnostic nuclear medicine. The major applications of therapeutic nuclear medicine are the treatment of hyperthyreosis and radioimmunology as well as radioembolization of liver tumors using labelled microspheres.

INDUSTRIAL APPLICATIONS OF RADIATION

Radiation is used in industry to ensure product quality, reliability, and safety. Industrial activity places an emphasis on efficiency; therefore, methods are needed which are both effective and fast. These aspects of industry led to the development of unique industrial radiation methods. There is no equivalent available using x-rays or neutrons on the scale and speed with which gamma rays can penetrate a material. There are few alternatives to cobalt-60, cesium-137, or rubidium-88 for large-scale radiation sterilization processes. The applications of radiation in industry are so diverse that almost any contact with an industrial process discloses additional unique uses of radiation. We provide only several general outlines of industrial radiation applications to give an overview of potential applications. A few categories are provided in the table below. Within each category, a few specific items are listed.

Radiography is the non-destructive testing of structural components, packaging or shielding of radioisotopic sources, and industrial pipelines for defects which may cause component failure. Radiation-emitting isotopes are gamma-ray sources. Industrial radiography uses all types of radiation. Radiography is conducted using gamma or x-rays. Recently, accelerated neutrons have been used for special applications. Radiographic images are recorded on film, or using real-time x-ray video, the picture can be directly displayed on a screen. Radiographic film is so sensitive that densities obtained are equal to the response of an optical photomultiplier. Very small particles on the order of 0.1 μm can be detected using high sensitivity film. Radiography, especially gamma radiography, is the most efficient non-destructive method for detecting internal defects in thick steel and other metallic components. The prohibitive cost of x-ray machines has limited the industrial application of x-ray radiography. With very few exceptions, radiography requires safety procedures to avoid exposing personnel to high radiation doses.

1. Radiography

Radiography is widely applied to non-destructive examination of various materials, mainly metal. X-ray and gamma-ray systems are employed. For very small thicknesses, because of the better detection limit, X-rays are more advantageous, whereas for very large thicknesses a gamma-ray source may be more attractive. In the intermediate range there is a wide overlap. Industrial X-ray and gamma-ray systems, with applications in different fields, are provided by a number of manufacturers. X-rays of energy 0.04–0.3 MeV are generated by cool-tube X-ray tubes, the higher energy range being needed for radiography of steel plates thicker than 30 mm or with heavier alloys. Except for high-brilliance cool-tube X-ray tubes, the systems are not economically attractive for testing very high energy or very thick targets because of the low conversion efficiency.

QDT radiographs thick components (up to few hundreds of mm) of small primary energy (0.04 MeV). Conventional electro-mechanical and digital radio-photographic techniques are used. The wide-angle backscattering radiography is the more sensitive technique; however it needs positionable small sources and correspondingly very long acquisition time in comparison with the expeditiously access and time reducing other techniques, like the conventional digital X-ray and gamma-ray radiographic methods. To test cases of components that cannot be moved, X-ray and neutron TV-radiographic techniques are used; the neutron method assures greater penetration and sensitivity than the X-ray technique. The enclosures are made from various metals and alloys: copper in particular, because it absorbs as much as possible the thermal radiation; nickel and iron for economically attractive enclosures and cobalt for testing Fe-less components; and steel for bake-out. The sources of function in the range $1x10^{-8}$ to $1x10^{-5}$ agents Hz^{-1} of flux.

2. Radiation Sterilization

In addition to radiation's recognized roles as a diagnostic and quality control tool for medicine, its ability to sterilize is essential for medical and pharmaceutical devices and products. Many medical and pharmaceutical devices are inserted into sterile parts of the body where infection can lead to serious consequences. Sterilization is thus an essential aspect of medical and pharmaceutical technology. Medical and pharmaceutical devices can introduce infecting microorganisms into the body or can be affected by such microorganisms if these devices exceed their use date during storage. For example, catheters inside blood vessels are subject to blockage by microorganisms producing clots or biofilms. Stents, together with a catheter, are inserted into coronary arteries that are blocked by cholesterol and fat, but the stent must not be inoculated by microorganisms, which would cause thrombus formation and heart attacks. Surgical grafts are inserted into the body for a purpose but can also be occupied and colonized by microorganisms if the graft is not sterile. Surgical devices such as scalpels must be kept sterile by sterilization after each utilization. This is also an essential aspect for soft tissues such as skin where microorganisms can produce postoperative infections.

Radiation is one of the few methods that can achieve the sterilization of products in their final packaging. Ethylene oxide and other sterilization vapors can enter a sealed package to sterilize its content, but radiation cannot kill all microorganisms. Ionizing radiation is then a well-established sterilization technique, and approximately 48% of single-use surgical devices are gamma sterilized. This statistic emphasizes that sterile medical and pharmaceutical products are generally dependent on radiation sterilization for ensuring safety. However, the use of gamma sterilization is gradually diminishing because industrial radiation sterilization is being transferred to the electron beam.

3. Thickness Gauging

Radiation has found its application in thickness gauging of a variety of materials and their products, with the following notable features in thickness gauging that as an industry requirement for speed and precision, it provides high sensitivity on-line, faster than other methods, for continuous thickness measurement of paper and plastic films, it provides a range of thickness sensitivity for metals from micro to millimetres, it has a unique advantage in performing real time single-sided thickness gauging of production with different inner and outer compositions irrespective of the product geometry and density. Radiation thickness control gauges were originally introduced in the 1940s for use in the steel industry to establish control of the thickness of rolled steel plate and sheet. Following this early development, the uses extended into industries concerned with nonferrous materials, such as copper and aluminum, as well as to fabricators of steel and nonferrous metal products. Subsequently, use of radiation gauges has extended into many different areas of industrial processes, including those for the paper, plastic, rubber, glass, ceramics, textiles, and food processing and packaging. Now more than 50 companies involved in the design, manufacture, and calibration of radiation gauges. Such gauges are used to measure the thickness of foils and sheets, including aluminum, plastic, rubber, and paper; coatings, including paper and plastic coatings; product density, including of concrete, ceramics, and silt; and beta backscatter gauges for use with concrete, coal, and sand.

ENVIRONMENTAL APPLICATIONS OF RADIATION

Ambient radiation represents only a minute fraction of certain natural and artificial radiation sources on and near the earth surface, which is within the realm of detection of radiation instruments. No doubt that radiation technology plays an important role in our environment and its application to increase food production is the most important.

1. Radiation in Agriculture For several decades, the use of radioactive materials and radiation technology in agriculture is a well-established fact. For instance, diagnosis of several tropical disease is being done with the help of radiation markers in plants and micro-organism, whereas biological control of insects, bacteria and viruses is world famous. The most frequently used isotope in the diagnosis of various plant diseases is used with the help of radiation markers. Several typical examples of radioisotopes used to help diagnose plant diseases are cited here. Root rot disease is one of the major plant diseases and is commonly associated with fungi found in the soil and on the roots. Thus, the disease can be diagnosed by introducing elements, which are used by the roots and are transported systemically to the leaves. If the roots are infected, the concentration in the leaves will be small. Radioisotopes such as and are utilized for this purpose. Other radioisotopes used to diagnose root rot disease are, and. Additionally, can be checked in some cases where the effect of δ-aminolevulinic acid on plants is being studied.

2. Radiation for Environmental Monitoring Determining radioactivity in our surroundings by means of monitoring devices or radiation survey meters is not new and there are existing geographical data. However, to measure some radiation levels to calibrate dosimeters is more recent. Calibration fields have been established at several locations in the world. The increasing activity of lowlevel radioactive waste discharge into the environment by power and nuclear weapons has made it essential to monitor gamma radiation intensity over large areas, especially those near sensitive or man-made interest.

1. Radiation in Agriculture

Diploma and crops of various types and growing conditions respond somewhat differently to ionizing radiation effects during growth and development. On one hand, in the early stages of exposure, germination speed is inhibited, while spore germination, selected species, motile spore production by selected species, growth at high temperature, in the absence of nicotinamide and in high salt concentrations are stimulated; sporulation of some species is partly stimulated; other species require further study in increasing plant resistance to pathogenic fungi. Ionizing radiation is extensively used to develop all types of mutants of higher organisms: especially in agriculture; plants and crops are sources of food and feed. By selecting and describing the parameters of the appropriate radiation source and radiation dose, it is possible to create a large number of specific life mutants in a short time: the study of radiation biology in different types of organisms, including types that are different from each other in a phylogenetic sense.

On the basis of evaluation of sources and doses of radiation, it is possible to irradiate seeds, callus and embryonated cells, excess parental doses, pollen, anthers, oocytes, tubers, shoots, etc. Somaclon and gametoclon mutants of crops are primarily created for accelerated selection of mutants of plants that differ from wild types, specifically by increasing or decreasing the size of blooming flowers, stimulating organ formation or physiological activity of various crop organs; integrate the synthesis of biologically active secondary metabolites or expand the spectrum of produced metabolites.

2. Radiation for Environmental Monitoring

Besides its many applications in industry, medicine, and basic research including the use of ionizing radiation to sterilize medical instruments and to treat cancer, the development of isotopic tracers, or the radioactive carbon dating of archaeological materials, radiation is also increasingly used in various aspects of environmental conservation. These applications include the detection of atmospheric, terrestrial, and marine pollution and contamination, the control of the release of toxic contaminants of radioactive isotopes, the monitoring of ocean currents, the labeling of radioactive isotopes in aquatic ecosystems to study the resulting effects, and the visualization of ecosystem structures.

Nuclear or isotopic methods are increasingly being adopted in the monitoring of various contaminants in the environment, especially those affecting the air we breathe and the water we drink or use for various activities. This trend is largely based on the unique properties of many radioactive isotopes, with large relative intensities, sufficiently long-lived or even stable isotopes or radionuclides, specific activity, and high sensitivity detection systems. These properties yield perfect indicators for the detection and control of varied environmental pollutants. Emergency monitoring and detection of radiation is also essential to detect and identify threats of nuclear attack or other terrorist activities. Facilities can measure the effect of a nuclear attack. The 1950s and 1960s fear of nuclear war and the long atmospheric half-life of Radioactive

Cesium137 led to its use in studying soil erosion and deposition.

The enduring presence of 137Cs in our ecosystem makes it especially useful in routine hydrological studies, and its behavior as a tracer in soil and sediment provides accurate models of sediment transport dynamics. Because 137Cs is rapidly removed from volcanic ash layers deposited on the ground by vegetation and sedimentation, it can be used to date buried soil layers. It is also applied to elucidate chemical and physical processes, mainly isostatic crustal adjustments, in large floodplains and river systems.

RADIATION SAFETY AND PROTECTION

Radiation safety, also known as radiation protection, is defined as all the technical and administrative measures intended to protect individuals and populations from the danger of ionizing radiations. Both users and nonusers of radioactive materials must be considered. Radiation is a companion of all radiations applications in general, but mainly of those who concern, or are obviously related, to human, animal, plant, and environmental radiotoxicity. A consequence of the incapacity to verify experimentally the actual response of sensitive living systems or of accumulation on an eventual risk after chronic exposure is the very serious charge, scientifically and ethically, and responsibility of protecting people, animals, and plants. In order to prevent possible hazards with radiation utilization, authorities decide on the basis of preventive and conservative policies on possible nonacceptable risks, and possible authorized activities, dose limits, surveillance, and implementation of cost-effective shielding and waste-removing policies.

6.1. Radiation Dosimetry The relative response of sensitive biological systems to radiation exposure varies greatly as a function of radiation quality. The effective radiation dose is in everyone's culture: the damages from high-dose solar ultraviolet radiation are widely reported. The unit of exposure considers only the radiative ionization of dry air, not the possible risks from the secondary beta and hard X and gamma photons radiated in air, due to radiolytic breakdown, or other radiative products, such as ozone. Moreover, the roentgen only accounts ionization but not the efficiency in producing tissue damage of radiative transitions, which may also be +1. He showed that the ratio of dose equivalents due to gamma and clouds of beta radiations is about 2.5. Moreover, air kerma is not suitable as an unambiguous quantity when the quality of photonic ionizing radiation is variable, or when there are secondary radiative emissions, such as alpha and beta particles. Therefore, it is essential to combine the formalism of dose conversion coefficients with environmental models. The computation of the organ and tissue doses can be performed with Monte Carlo or adapted microdosimetric techniques. A fundamental aspect of any radiological operation, in radiotherapy, nuclear medicine, in particular, the utilization of radiolabeled drugs, the utilization of radioactive sources in diagnostics, or for palliation of palliative patients, has to take patient and collective safety and protection.

1. Radiation Dosimetry

Radiation dosimetry was established at the early time of health physics as the science of dose measurement, and has been widely applied since then toward radiation safety, control, and protection both for work environments and for the management of individuals. Individual external and internal exposure assessment for persons working with radiation, exposure surveillance for the nearby public, inpatient and outpatient exposure surveillance for medical radiation patients, and exposure surveillance for aviation crewmembers flying human-made cosmic radiation exposed high-altitude routes etc, are some dosimetric practices implemented for radiation safety control. The concept of radiation dose is uniquely linked to the interaction of ionizing radiation in biological tissues; it specifies radiation dose in terms of detriment from stochastic effects on exposed people and their offspring, as well as the risks of non-stochastic effects of radiation exposure.

Radiation dose responds to the relative biological effectiveness for radiation types, radiation quality for a given radiation type, and a radiation weighting factor or quality factor for given radiation quality and intended effect etc. As a result, absorbed dose and equivalent dose for deterministic effects, and effective dose for stochastic effects, are generally appropriate and widely implemented in radiation dosimetry of humans, which usefully summarizes the currently developed concepts, quantities, and units for projecting radiation health risks; absorbed dose:¯D , gray (Gy); equivalent dose:¯H , sievert (Sv); effective dose:¯E , sievert (Sv). Other physics dosimetric quantities and units introduced in radiation protection may be applied to facilitate the dose assessments in relation to the management of specific radiation-induced health detriment as follows: collision kerma:¯K, gray (Gy); collision kerma for neutrons with energy greater than 10 MeV:¯K, gray (Gy); air kerma:¯K, gray (Gy); air kerma rate:¯K, gray per second (Gy/s); exposure:¯X, coulomb per kilogram (C/kg); photon fluence:¯ϕ , per square meter (m −2); photon fluence, stochastic effect of radiation exposure:¯Φ , per square meter (m −2); personal dose equivalent:¯H, sievert (Sv); ambient dose equivalent:¯H, sievert (Sv); directional dose equivalent:¯H, sievert (Sv); neutron fluence:¯ϕ , per square meter (m −2); neutron fluence, stochastic effect of radiation exposure:¯Φ , per square meter (m −2); photon spect. fluence:¯ϕ , per square meter (m −2); photon spect. fluence, stochastic effect of radiation exposure:¯Φ , per square meter (m −2); neutron spect. fluence:¯ϕ , per square meter (m −2); neutron spect. fluence (neutrons > 20 MeV):¯Φ , per square meter (m −2); radon thoron emanation rate:¯E, becquerel (Bq); radioactive material activity concentration:¯A, becquerel per cubic meter (Bq/m 3); radioactive material relative activity concentration:¯A , percent (%) or ratio (no unit); aerosol-concentration in the alveolar region of the respiratory tract:¯C, becquerel per cubic meter (Bq/m 3); aerosol-concentration in the air-interstitial lung region:¯C, becquerel per cubic meter (Bq/m 3).

2. Protective Measures

Radiation protection (also known as radiological protection) is defined as "the protection of people from harmful effects of exposure to ionising radiation, and the safety of source to prevent accidental exposure." The objective is to provide information and recommendations so that an adequate protection of workers, the general public, and the environment is guaranteed during radiological procedures and practices. It is paramount that people who made diagnosis or treatment or those who receive diagnostic or therapeutic radiation exposure have the minimum possible dose.

The recommended system of radiation protection is based on the following four principles: the justification principle (in order to avoid cases that the benefits do not exceed the risk; the choice of alternative techniques which do not use ionising radiations; the minimisation of the number of irradiated individuals; the elimination of repeat procedures), the dose limit principle (the limits of the annual effective doses must not be exceeded), the optimisation principle (the doses must be "as low as reasonably achievable", i.e. the application of special technical means, that is proportional to the energy and risk reduction, must be used).

There are two basic types of protection from ionising radiations: those referring to radiation sources and those referring to individuals, since the first can be used for switching off or reducing the intensity of radiations and the second for reducing the biological effect of ionising radiations after irradiation. The application of radiation protection principles generally needs a combination of all or some of the basic measures that are available, since the amount of the prevention of the radiations depends on many factors (the place of exposure, the type of radiation, the surrounding environment, the levels of energy, etc.).

REGULATORY FRAMEWORK FOR RADIATION USE

Radiation is used in a variety of applications predominantly in the medical, industrial, research and security fields. Due to the human exposure to potentially hazardous sources of radiation, there needs to be a regulatory framework that is followed in order to minimize the health effects both to the worker and the general public. National and international governing bodies have established guidelines or recommendations that countries adopt in their own national regulations and how they implement these recommendations. These recommendations are based on the events that have occurred in history regarding radiation exposure and adverse health effects observed. The following section provides a brief overview of the international and national guidelines, background and history regarding radiological regulations. Part of the motivation of compiling this information is to allow others to understand some of the rationale for the establishment of various criteria and standards.

The responsibility for protecting the public from health hazards associated with the use of atomic energy and radioactive materials was delegated to the United States Atomic Energy Commission by the United States Congress as a section of the Federal Agency Act. An early temporary AEC radiation safety guideline recommended exposure limits of ionizing radiation. Over time upgrades were made to these limits. Earliest comments that these exposure limits were excessive were made in the late 1950s. In the early 1990s the AEC adopted recommendations of the National Academy of Sciences, in essence establishing new standards based on the BAC, in the place of the AEC original standards based on early NBS calculations as amended by Harington. Indeed, it is the same basic recommendations and rationale that are now embodied in the 1993 recommendations of the International Commission on Radiological Protection that propose yet lower exposure doses from all man-made radiation sources combined.

1. International Guidelines

This chapter reviews international and national regulations concerning radiation applications in human subjects. It describes guidelines that pertain to research and diagnostic procedures, assessments of patient risk, and recommendations to maintain radiation exposure as low as reasonably achievable, among others. In the field of radiotherapy, strictly focused on cancer patients, the regulatory burden is considerably increased due to patient protection being considered as very substantial. Furthermore, international and national guidelines specifically made for radiotherapy are precisely outlined. Though many national regulations on radiology and radiotherapy are derived mainly from international guidelines, the focus of these guidelines differs substantially. Commissioning these guidelines is a consequence of the continuing demands of radiation use in these fields. This chapter describes them briefly.

Limitations on radiation use are based on ethics. The ethics of radiation use has been reviewed in earlier chapters. Virtually all radiological and radiotherapy applications are focused on human beings. Radiological procedures represent part of the diagnostic process directed to perfecting clinical practice. Benefits for patients or for the promotion of public health should result from compliance with recommended actions. It would be unethical to use radiation to verify a diagnosis where a non-ionizing method might provide a viable solution.

2. National Regulations

Most countries regulate the use of ionizing radiation through specific laws; however, in some countries, these laws may be included in general laws regarding nuclear energy. With a few exceptions, such as Mexico, which has its regulation on the use of radiation and radioactive sources included in its atomic law, these national laws do not contain detailed regulations about the application in practice of the provisions of the laws. Broadly speaking, national laws generally regulate the responsibilities and authority of the radiation protection authorities, the establishment of safety and security conditions, the licensing and control of the use of radiation for its respective applications, as well as penalties for violations of regulations. Most national regulations delegate the authority to establish more detailed requirements to safety authorities, who are also responsible for their implementation. These requirements may be included in technical bulletins or additional detailed regulations, depending on the country. While the actual gravity and detail of the national laws and regulations vary greatly between countries, there are common elements that are present to varying degrees. Generally, national laws or regulations appoint a regulatory authority responsible for the evaluation and approval of plans and technical specifications related to the use of radiation.

Although regulations can differ significantly, in most cases regulations generally have requirements that on applicable practices prior to their use, a notice of no-objection will be issued only when the regulations are met; they will also be licensed through a permit, which will be based on the practice meeting the requirements. These permits will apply for certain radiation doses; the devices will have specific labels, and there will be periodic renewals of licenses and certificates for the personnel related to the practice. There are also generally requirements regarding monitoring and control, and a record must be kept regarding the use of the devices and the doses delivered; there will be sanctions for non-compliance.

FUTURE TRENDS IN RADIATION APPLICATIONS

Determining future trends in the areas of radiation technologies and applications is challenging. This is particularly true in the energy medicine and energetics areas. These areas have the least practical applications and scientific research to date. There are great hopes that in these areas, as well as in the rest of practical energy medicine, there will be a rapid increase in applications and relevant research over the coming decade. Here, we present several examples of potential future applications in more mature fields of radiation applications, such as food and materials decontamination, cross linking, or dark field microscopy.

Emerging Technologies The future of food and material decontamination technologies most likely lies in the development of very compact, low-power, very versatile devices. The development of portable, practical devices for environmental monitoring is important. It may have far-reaching implications in numerous aspects of everyday life, ranging from security considerations to possible new, innovative medical and biological applications. Another interesting emerging concept in the area of energy medicine relates to invisibility. This topic is rarely discussed and is perhaps more philosophy than science. It is, however, clear that an attempt to apply the laws of quantum information processing in such applications as communication, amplification, and enhanced imaging could also become an interesting direction of research in the future.

Innovative Practices In energetics, several companies successfully manufacture and sell energy stimulators. These devices are based on the saturating method of induced energy effects on matter. Energy medicine may develop and apply new energy methods elsewhere. One interesting new component could become information in the form of combined holograms as the principal carriers of information and biophysical signals promoting the stability and homogeneity of bacterium and phytoplankton populations and preventing the rapid proliferation of viruses and unsuitable bacteria.

1. Emerging Technologies

Emerging technologies, such as quantum computing and accelerated artificial intelligence, have the potential to dramatically enhance the current tools used to study fundamental radiation interactions. Whereas previous generations of computing have relied on binary logic, quantum mechanics enables quantum computing to perform certain tasks at incredibly faster speeds than are currently possible. For example, the chemical reaction rates critical to radiation chemistry, but still poorly understood, may be gauged in real-time. Artificial neural nets have recently gained favor for many applications, including reducing uncertainty in measured cross sections for indirect radiative capture reactions. These rapid developments in computational tools will be paralleled by accelerated machine learning based numerical methods, which have recently gained favor throughout numerical solutions to partial differential equations. As physics-informed neural networks are combined with physics-based numerical solvers, validating and reducing uncertainties in radiative process cross sections will become increasingly feasible. Novel high power continuous wave femtosecond lasers have recently been shown to dramatically enhance spontaneous emission control. As experimental capabilities in this area rapidly improve, the prospects for radiation experimentation in this area may be revolutionized.

Innovations in radiation experimental and measurement methods will accompany these revolutionary developments in computing and numerical methods. Presently, experimentalists are limited by issues with detector resolutions. As detectors and scintillator materials change on the nanoscale, future experiments will be able to take advantage of exciting new measurement concepts enabled by increasingly keyed particle detection. These experimental and detector advances will enable finer resolution measurements of de-excitation gamma photon emission via delayed gamma emission methods. With the future combination of these confinement methods and ongoing development of quantum detectors, which have been shown to measure optical wavelength light with single photon sensitivity, even more precise measurements of keV and MeV level gamma radiation will become possible.

2. Innovative Practices

Innovation in workplace practices engages employees and is essential to implement scientific and technological advances. Key components of using radiation technologies, like robotics, process automation, and artificial intelligence, are practice innovation. Empowering employees in new advanced radiation technology adoption, research partnerships, and workforce development enables further application of existing and development of new radiation processes. These include advanced manufacturing capabilities that have less environmental impact, such as new composite materials and additive manufacturing capabilities that enable functionally optimized efficient design. Where functionally optimized material solutions for specific applications do not already exist, users of additive manufacturing may unleash a flood of part designs that expose the limits of known manufacturing capabilities and accumulated long-term actual operating service experience. For those applications where operation has shown that lifetime service may be influenced by defects or in-service exposure, existing tests for manufactured parts used in other industries are normally ignored. Hence, they need to be updated to identify defects or localized changes that could affect the reliability of a specific part design. Many critical additive manufacturing applications for components in national security and defense missions, as well as other industries in commercial and civilian missions, are designing with long predictable lifetimes. Recent lifetime predictability successes of library data for radiation sensitivity in parts for space applications illustrate how patterns that reappear with lifetime can capture past failures. Such libraries of accelerated radiation hardening process decisions, design options, and technology development can be adapted to other, possibly radiation-influenced, controlled environments.

ETHICAL CONSIDERATIONS IN RADIATION USE

There are ethical considerations about radiation use in medicine, primarily the balance between the benefits gained and risks incurred. Radiation should not be used without justification and patients must give informed consent. There are no laws against exposing people or the environment to ionizing radiation, but most countries do so following recommendations and other guidelines set by local authorities. Using theoretical rather than real risk estimates gives more important guidelines. Following these recommendations reduces the theoretical lifetime excess cancer risk for the general population from medical exposure to less than 1 in 1,000.

The first ethical consideration about radiation use in medicine is that a patient must give consent for x-ray examinations and treatments, and for other types of ionizing radiation. Informed consent, at least for elective procedures, is a legal requirement in most countries. Procedures should be justified with respect to natural progression, and estimates provided of the chance of disease in an irradiated population versus those who are not irradiated. Justification should also compare the health benefits to the risks of exposing an ill patient to ionizing radiation. Risks taken from a patient's own population would be 2 to 20 times larger than the normal risk estimates. Although informed consent for radiation-based diagnosis and therapy has been called for by some, this has not been universally accepted as a legal requirement.

1. Patient Consent

Balancing the risks and benefits of radiation use can be difficult. Invasive procedures such as surgery are commonly agreed upon by patients and the medical team. Generally, patients will undertake a surgery, recognizing the severity of its repercussions should it not take place, such as the loss of limbs or other vital functions. However, non-invasive and non-painful procedures involved in diagnostic imaging with radiation such as X-ray, CT, and fluoroscopy, are often outrightly rejected by patients, who do not recognize the need for these procedures. Modern-day diagnoses may seem trivial at times, but diagnostic imaging may unveil a critical finding, such as an aortic dissection that can then be intervened upon surgically. Patients who are unwilling to undergo diagnostic imaging when strongly urged by their medical team may be disregarding consensus practice guidelines and could be held responsible for serious adverse events.

Assistance with obtaining informed consent is considered a crucial responsibility of the medical team. Informed consent is the process of not only relaying essential information to a patient and making sure that they are sufficiently aware to make an informed decision, but also to respect the preferences, values, culture, and beliefs of the patient in the process. It is helpful to imagine that any decision involving a patient's health and well-being must be overseen together with that particular patient. This includes the decisions of an appropriate imaging test at the present stage, the outcomes and subsequent decision-making process, and the advantages and drawbacks involved. Without a doubt, imaging tests carry risks associated with radiation exposure. To ensure that the patient is protected to the greatest extent possible, imaging guidelines and recommendations need to be coupled with patient discussion to inform them of the potential effects of the procedure.

2. Environmental Impact

Radiation has multiple environmental impacts during its production, application, and disposal, as well as its susceptibility to cause radiation pollution. Several natural and anthropogenically produced radiation sources could produce radiation pollution that could irreversibly harm innocuous, living, and non-living components of the environmental ecosystem. However, the neglect of radiation pollution is evident, featuring relatively little literature, research, and depth. Whether the environmental impact of radiation is disclaimed, the impact is beyond doubt and possibly beyond scope. For the present study, the environmental impacts of radiation in the nuclear production of the atomic bomb and its use during the nuclear war are described in the context of ethical issues.

Radiation impacts biodiversity and affects non-living and living biological entities, irrespective of dosage; although the extent of impact varies. Non-living biological entities impacted by radiation are clouds, soil, air, and water; causing acid rain, forest fires, erosion, damage to astro-chemicals, and aggregates, as well as aquatic and freshwater damage via thermal shock. On living biological entities, the radiation impact includes radioactive resuspension, wildfires, microbial cultures, algae, fungi, plants, animals, and humans. The harmful effects of radiation on the ecology of plants include inhibited growth, delayed seed germination, damage to the root system, morphology, and flowering time, death of apical meristems, oxidative stress, as well as altered chlorophyll content, photosynthesis, malondialdehyde content, and catalase activities. The effects of radiation on animals include loss of wrists and knees, premature birth, altered radiosensitivity, immune effects, malignancy for leukemia, sarcoma, breast cancer, and altered tissue repair in the living matter. The effects of radiation on people include elevated psychosomatic problems, stressful thoughts and actions, enhanced psychological and neurotic disturbances, and increased risk of cerebrovascular disease mortality; increasing the need for environmental pollution consultations for abnormal environmental changes.

CASE STUDIES

The appended bibliography highlights a sampling of published papers that describe interesting stories and results. The papers cover a wide range of topics. In this section, a few are highlighted. Several papers covering the medical applications of the technology were co-authored with a board-certified radiation oncologist, who also serves as a clinical professor of radiation oncology. He is the editor-in-chief of a journal and was editor-in-chief of another journal for many years.

1. Successful Medical Treatments

As an example of an application of the technology within one of the priority disease areas identified by a group, the use of ionizing radiation to treat major depressive disorder is covered. The story of the first patient to be treated is presented in detail, and somewhat derivative treatments of additional patients are summarized. The patient presented was actually treated outside formal clinical trial design. Of interest, but not presented, is that another patient at the same facility was treated within formal clinical trial design before the first patient received his second treatment. Chronic, treatment-resistant major depressive disorder is severely disabling and may result in excessively high mortality rates due to suicide or medical comorbidities.

2. Industrial Innovations

Of interest to engineers and scientists engaged in industrial radiation processing are accounts of products involving the use of radiation to achieve results that cannot be attained at reasonable cost or sufficiently without damage by any competing processes. Some inventions are now patented based on new applications and technical methods that have evolved from pilot plant work and research funded by governmental and industrial sponsors over a period of decades. Microbial radiation sterilization is now commonplace, but it was a relatively new early application that helped convince authorities to approve the use of radiation for this purpose.

1. Successful Medical Treatments

Radiation medicine refers to the application of radiation and nuclear technology to the diagnosis, treatment, prevention, or alleviation of human disease. This practice encompasses the development and production of radioactive pharmaceutical products for use in nuclear medicine and radiopharmaceutical therapy and diagnostic imaging and also the development and application of innovative technologies and techniques in radiation diagnostics, radionuclide therapy of heart, thyroid, liver, bone and other diseases, radiation oncology, radiation dermatology, and radiation hematology, as well as radiation protection of patients undergoing treatment. The "return on investment" of the nuclear and radiation medicine field can be measured by the invaluable and critical contribution these fields make in the alleviation of human suffering and the considerable economic returns to society.

Nuclear technology and radiation applications in medicine generated significant benefits for the diagnosis and treatment of disease throughout the 20th century and into the 21st century. Ongoing and future developments in both basic science and applied research provide even more exciting and expanding opportunities for these fields to provide life-saving breakthroughs during the coming decades. The responsibility of the nuclear medicine community is to capitalize on existing opportunities and develop new ones to ensure that the unique capabilities of nuclear technology fulfill their intended role.

2. Industrial Innovations

From the very beginning, the work of the atomic scientists differed in important ways from that of other researchers who had preceded and later accompanied them in exploring the nuclear world. The possibilities for scientific progress in their work were obvious but the potential for new or improved industrial processes or products was perhaps even greater—both calorically and economically. The enormous energy density of atomic nuclei and the potential for tapping that energy through nuclear fission or fusion provided the scientific and technological basis for the new industries of nuclear technology. But, the particulars of these nuclear processes were unique and their implementation required both scientific and engineering talent in order to permit systematic exploitation of their potential in such a way as to provide electric power or specialized radioisotopes for use in medicine or the commercial sector.

The atomic scientists and their successors made pioneering technical advancements, laying open vast new industrial domains where nuclear processes were developed for such diverse purposes as radiographing welds and pipelines, using particle accelerators for medical and industrial inspections, making isotopes for fertility control, using radiation to enhance food safety and eliminate disease vectors, and sterilizing hospital and commercial items with radiation. How carefully all of these products and processes were developed and how verifiably safe and productively efficient they were as compared to industry’s previous methods is illustrated by the fact that some of them have now been widely used for decades. The challenges facing engineers engaged in these developments have been as unique as the nuclear processes themselves. Ironically, some of these challenges have been facilitated by the very special behavior associated with radioactive processes which result in phenomena such as atomic clocks capable of measuring time accurately over long durations.

CHALLENGES IN RADIATION APPLICATIONS

Although accelerator technology has been steadily advancing, it is still not yet fully ready for beaming high daylight fluxes of ions and protons that could be employed for exploration of the Moon and Mars or to enable, exceptionally useful on our planet, emission of muon neutrinos at the energies yet unreachable by other means. Furthermore, our planet's sustainable development would considerably profit from better nuclear waste management, e.g. transmutation of long-lived isotopes. As an accelerator could be devoted to neutrinos production with benefits for particle astrophysics, a tabletop classical accelerator could be used for transmutation. It could provide protons and ions for intense light beams, of a kind already in reach of laser without yet following particle acceleration. During the last six decades, classical accelerators dedicated to or supporting radiation applications have demonstrated great improvements and achieved prestige. Colleges, military and industry, health and nuclear medicine, metrology, materials science, radiation technologies, radiobiology and sanitary hygiene share this capital, and ask for more. They expect from the scientists and engineers involved the radiation generation and the interaction with matter to be mastered, allowing the interaction processes and the range of the background radiation levels to be simulated and predicted, and the requested targets to receive the desired neutralizing, sterilizing, or disrupting treatments. In this regime, production is fast and efficient. On the one hand, extended use of radiation in our daily life, either for economy development or for solving environmental problems, still faces some developments, technologically or politically, counter-reasons or difficulties. On the other hand, progresses in terms of mastering radiation applications will certainly promote broader acceptance and enable wider choice of applications.

1. Public Perception

Radiation has a rich and diverse range of applications that range from daily activities such as purchasing watches and alarm clocks to more sophisticated uses in medicine, environmental studies, archaeology, security, as well as studying the primordial universe. Many entities are involved such as research centers, universities, laboratories, hospitals, and companies, and yet radiation applications are still today not economically self-sufficient nor widely disseminated. Several reasons could explain this status, but two in particular should be expected; the first is technological limitations, and the second is public perception, which has a great influence on political decisions regarding funding. Radiation applications are therefore not as popular as they should be. For example, most people know about medicine uses, as hospitals and clinics are easily accessible and very present in society. Nevertheless, the general public tend to identify radiation for diagnosis in X-rays or treatment in radiation therapy. Even among those exposed to radiation in medical diagnosis, very few are aware that other applications exist. Applications such as cancer treatment, which affect a great number of people through contact, radiation and are also relatively well-known, still see a lower tolerance for radiation in treatment than any other invasive treatment. Restricted to medical applications, the public perception of radiation use – as well as the associated risks – is very limited. But radiation applications don't stop at diagnosis or treatment of diseases. Design for the manufacture of a great variety of medical instruments requires expertise in radiation applications, as do industrial uses requiring quality control. Research in various fields also requires advanced knowledge in radiation use.

2. Technological Limitations

Although radiation has become an important and necessary area of technology application, from imaging to electricity generation to cancer treatment, there are several areas where new technology is still required to become a productive application. These include, but are not limited to, the following: (1) alpha radioisotope electricity generation; (2) measurements of mass and concentration of liquids; (3) gains in sensitivity and price for radiation detectors; (4) new isotope production; (5) remote detecting and identifying radioactivity; (6) remote survey and pump down for cm to m scale radioactive items; (7) multiplying the signal from a surface contamination detector to obtain a measurement of concern; (8) radioactive waste processing and reduction; (9) thin section and high resolution gamma imaging; (10) air pollution measurements; (11) nanometer flow rates at small scale; (12) neutrinoless double beta decay; (13) nuclear thermal propulsion; (14) and gamma radiography and geothermometry. This list is selective, and there are certainly many other uses of radioisotopes where enhanced technology could greatly improve the performance and/or cost. Moreover, and more exciting to the impatient inventor, several of these problems – such as improved portable and hand-held instruments for in-line help in additive machining – and portable sensors for monitoring particulate pollution from mega-fires and volcanoes - have immediate and near term urgent requests because the needs are already well established and have not been met.

CONCLUSION

Radiation Applications has, since 2004, provided a selection of topical collections that preserve the work of eminent scientists in the fields of radiation and radiobiology. The current forty-two title series has supervised six reprints and many substantial collections. Underlying our activities was the desire that the originals, most of which were published in journals with more specialized readerships, would be available to a broader audience. Accordingly, we aimed to provide theme-based collections in accessible disciplines, pertinent to both academic scientists and those engaged in the application of their work. These topics include reviews, original work, theoretical and experimental research, and applications; interdisciplinary connections are encouraged. The advances in paradigm application that we focus on include, in no particular order: advances in both the theoretical and experimental support of MR methodology developments; advances in the use of MRS and MEGA-PRESS spectroscopy; advances in the demonstration of the neurochemical correlates of behavior; which includes advances in demonstrating connections and alternative accounts that are sensitive to the microstructure and time course of behavior; advances combining DTI or fiber tracking techniques with spectroscopic correlates; advances validating animal models; and advances in animal behavioral studies that really involve the analytical power of in vivo spectroscopic analysis, putting spectroscopic wisdom to work in a real word context. These advances are drawn from a number of thematic areas: the development of more specialized hardware and software; the incorporation of other imaging modalities and analytical approaches; the creative application of NMR research, especially DTI and spectroscopy, to neuroethology; and experimental studies that validate the efficacy and sensibility of decisions that have been made concerning animal neuroimaging while also enhancing the behavioral perspectives that guide such decision-making processes.

REFERENCE

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