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APPLICATIONS OF RADIOACTIVE ISOTOPES

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Abstract: *The discovery of radioactivity, a fundamental property of certain atoms, is credited to several scientists, including Henri Becquerel and Marie and Pierre Curie, who together made ground-breaking discoveries that paved the way for the use of radioactive isotopes in various applications in fields such as medicine, agriculture, industry, or archaeology. In medicine especially, radioactivity plays a crucial role, with application in both diagnosis and treatment of various diseases, including cancer. However, radioisotopes also pose potential risks to human health and the environment if not handled properly, causing damage to cells and increase the risk of cancer and other health problems. Nevertheless, their uses are regulated and monitored to ensure safety and, therefore, their utilization has firmly increased in the last decades. Overall, radioactive isotopes are a valuable tool in a wide range of fields and their continued development and application will remain important for years to come.*

Keywords: radioisotopes, radiations, radioactive decay, tracer technique, nuclear medicine

1. Introduction

Isotopes are atoms of the same element, having the same number of protons but a different number of neutrons in their nuclei. Some isotopes are unstable if the nucleus contains either too many protons or neutrons and are known as radioisotopes. A radioisotope attains its stability by spontaneously emitting nuclear radiations such as alpha, beta (electron/positron) particles or gamma rays (Fig. 1). This process is called radioactive decay, and occurs at a constant rate, which is measured by its half-life. The half-life of a radioisotope is the time it takes for half of the unstable atoms to decay.

Radioisotopes can be either natural or artificial. The natural ones are those that occur naturally in the environment and are created through various natural processes, such as the decay of primordial isotopes, cosmic ray interactions and radioactive decay chains. Artificial radioisotopes, on the other hand, are those created in laboratories or nuclear reactors through nuclear reactions. They do not occur naturally in the environment [1].

The radioactivity was discovered by Henri Becquerel in 1896, when he accidentally discovered that uranium slats emit a penetrating radiation that can be recorded on a photographic plate.

However, Marie Curie introduced the word "radioactivitè" to describe the rays emitted by uranium, thorium, polonium, or radium. Several notable scientists who worked with radioactive materials, including Marie Curie and her daughter Irène, suffered from radiation-related illnesses [2]. This is due to radioisotopes emitting radiation with enough energy to remove electrons from atoms, causing the atoms to become ionized

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or charged. Thus, the nuclear radiation is considered ionizing and can alter the molecules within the cells of living organisms, including DNA, which can increase the risk of developing certain health conditions, such as cancer [1].

Despite all these risks to human health and environment, radioisotopes have played a significant role in improving the quality of human beings. Here in, we will focus on the most important applications of radioisotopes in various fields.

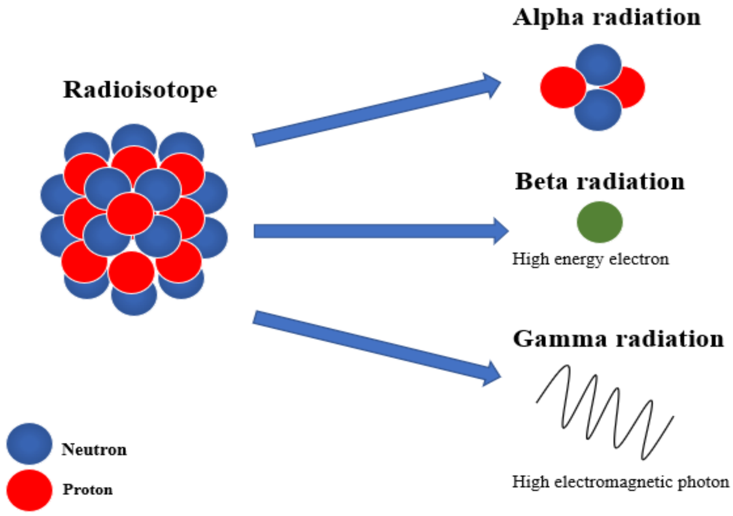

Figure 1: Types of radioactive decays

2. Applications of radioisotopes

After more than 100 years since the discovery of radioactivity, radioisotopes are successfully used in many aspects of human life, such as energy, medicine, agriculture, archaeology, or various industries (Fig. 2).

2.1. Radioisotopes in medicine

The use of radioisotopes in medicine has revolutionized the diagnosis and treatment of many diseases and conditions, saving the lives of millions of patients. Over 90% of the procedures involving nuclear medicine are for diagnosis, where special radionuclides with short half-life are used to complement the traditional imaging methods based on X-rays. The patients are administered a small amount of these radionuclides which emit gamma radiation that is detected and used to create images of the body's organs and tissues.

Radioactivity can be used for treatment through a technique called radiation therapy, or radiotherapy. This technique involves the use of radionuclides that emit high-energy radiation, such as gamma rays, X-rays, or charged particles to cancer cells, in order to kill them and shrink tumours. The radiation damages the DNA of the cancer cells, which leads to their death. This can be done either:

- externally, when the radiation source is placed outside the body, and only a limited area of the body is irradiated, or
- internally, where a radioactive nuclide is administered to the patient and deliver a toxic level of radiation to the targeted sites [3].

Even though radiotherapy can have some side effects, such as fatigue, nausea, or skin irritation, it is considered very well tolerated compared to more traditional treatments, due to their minimum damage to healthy tissue and is considered a powerful tool in the fight against cancer.

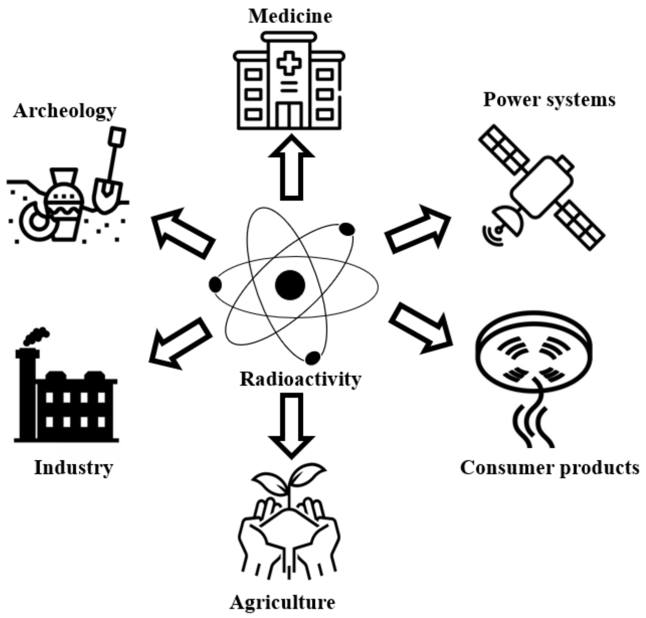

Figure 2: Radioisotopes applications

2.2. Radioisotopes in agriculture

Radioactivity has several important applications in agriculture, improving the quality and productivity of agricultural products. Radioisotopes are very useful in the effective use of the fertilizers, which may result in lower costs and minimal damage to the environment. The working principle is quite simple, the nutrients taken by the plant are labelled with a radioactive tracer such as Nitrogen – 15 or phosphorus – 32 and the movement of these species through the plant and the soil can be monitored [4]. Radioisotopes were also used to induce mutations, by exposing seeds to radiation, thus leading to new and desirable treats, such as disease resistance, earlier ripening, and ultimately, higher yield.

Radioactive nuclei are also used in insect pest management. Agricultural productivity is at risk due to insect pests, which not only cause a reduction in crop yields, but also spread diseases to cultivated crops. To monitor the persistence of pesticide residues in food items, soil, groundwater, and the environment, radiolabel pesticides have been employed. These studies have been beneficial in identifying and reducing the adverse effects of insecticides and pesticides.

Another great use of radioactivity was recorded in food processing and preservation. Between 25 and 30 percent of the world's food production is lost due to spoilage caused by microbes and pests, and these losses are even higher in developing countries. However, this loss of food can be prevented by implementing effective food preservation methods. Radiation is one method that can be used to eliminate microbes in food and control insect and parasite infestation in harvested food, which prevents different types of wastage and spoilage. The agents responsible for spoilage, such as microbes and insects, are eliminated by irradiation from packaged food, and the packaging materials are impermeable to bacteria and insects, preventing recontamination. Also, it can replace or significantly reduce the use of hazardous food additives and fumigants, which are dangerous for both consumers and food processing workers. General dose requirements for various applications are listed in Table 1, where the unit of absorbed dose, kGy (kilo Gray) represents 1kJ/kg absorbed energy [5], [6].

Table 1. Main applications and general dose requirements of food irradiation [5], [6]

Application	Dose requirement (kGy)
Inhibition of sprouting	0.03 – 0.12
Insect disinfestation	0.2-0.8
Parasite disinfestation	0.1 – 3.0
Shelf-life extension	0.5 – 3.0
Elimination of non-spore forming pathogenic bacteria	1.5 – 7.0
Reduction of microbial population in dry food ingredients	3.0 – 20
Production of meat, poultry, and fishery products shelf-stable at ambient temperature	25 - 60

2.3. Radioisotopes in archaeology

Radioactivity has various applications in archaeology, primarily in the field of radiocarbon dating. Radiocarbon dating is a technique used to determine the age of organic materials based on the decay of the radioactive isotope carbon-14. When plants and animals are alive, they absorb carbon-14 from the atmosphere. Once they die, the carbon-14 decays at a known rate, and by measuring the remaining amount of carbon-14 in a sample, scientists can calculate the time elapsed since the organism died [7].

2.4 Radioisotopes in industry

The main use of radioisotopes in industry is in smoke detecting. Smoke detectors use a small quantity of radioactive material, such as Americium-241, which emits alpha particles. These particles ionize the air, creating a small electrical current. When smoke is the air, it disrupts the flow of ions and reduces the current [8].

Radioactive isotopes can be used as radiotracers, tracking and monitoring industrial processes. They can be added to a material or a process stream, and their movement and behaviour can be detected and measured. The main industries that radiotracers are used in include:

- Oil and gas industry: flow rates of oil and gas in pipelines, leaks and blockages or the performance of oil wells can be monitored with radiotracers.
- Mining industry: Radiotracers are used to monitor the movement of ores and minerals through processing plants, and to determine the effectiveness of mineral extraction processes.
- Chemical industry: The mixing and dispersion of chemicals in industrial reactors and performance of catalysts can be monitored with radiotracers.
- Environmental industry: The path of contaminants in the environment and the effectiveness of environmental remediation processes can be monitor with radiotracers [9].

2.5 Radioisotopes in consumer products

A variety of consumer products contain radioactive isotopes, either as a working part of the product or as naturally occurring radioactive material. The most commonly used radioisotopes are:

- Tritium (H-3), used in exit signs, watches and other products that require long-lasting, low-level illuminations.
- Americium (Am-241), used in smoke detectors.
- Radium (Ra-226), used in older watches or clocks, to make dials and numbers visible in the dark.
- Thorium (Th-232), used in the production of lenses for cameras. However, due to its radioactivity, the use of Th has declined in recent years.
- Uranium, used as a colorant in glass or ceramics before the adverse effects of its radioactivity were

understood [10].

2.6 Radioisotopes in power systems

Radioisotope power systems generate energy from the natural decay of radionuclides. A radioisotope power system typically consists of two main parts, namely, a radioisotope heat source and an energy conversion system. During the decay process, heat is produced and is partially transformed into electricity. These power systems are known for being rugged, compact, and highly reliable. They can also be produced and used safely, with minimal risk both to the operating personnel and the public, as well as having minimal impact on the environment. The most commonly used isotopes for this purpose are plutonium-238 (Pu-238) and strontium-90 (Sr-90). Both isotopes emit alpha particles, which can be converted to heat when they collide with a solid material.

Radioisotope power systems are commonly used in space probes and satellites, where they can provide a reliable source of power for many years without the need for refuelling or maintenance. They are also used in remote or harsh environments on Earth, such as in buoys, lighthouses, and research stations in Antarctica [11].

3. Conclusions and future perspectives

Over the last century, the utilization of radioactivity has steadily increased across various fields. Today, radioisotopes play a critical role in various aspects of human life and their property to spontaneously emit radiation is successfully used in medicine, agriculture, consumer products, or various industries. The future of radioactivity usage is promising, as continued advancements in technology and scientific understanding are likely to lead to new and innovative applications. For instance, new and improved cancer therapies and diagnostic imaging may be developed based on radioisotopes. Radioisotopes may also become increasingly important in environmental monitoring and remediation efforts due to growing concerns about climate change and pollution. Furthermore, as the energy sector searches for new sources of energy, radioisotopes may present a valuable asset.

Overall, radioactivity is likely to continue playing a significant role in many different fields, with its impact continuously growing.

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