

# RADIOPHARMACEUTICALS

## Abstract

Radiopharmaceuticals are biologically active compounds that emit radiation in the form of gamma rays, positrons, or beta particles. They are used in diagnostic applications, such as nuclear medicine imaging, and therapeutic applications, such as targeting diseased cells or tissues. The Curie (Ci) unit of radioactivity is used in some contexts, while the Gray (Gy) unit is used to quantify the amount of radiation energy absorbed per kilogram of substance. Gamma rays are high-energy electromagnetic waves produced by radioactive decay and can invade our bodies and damage delicate organs. Measurement of radioactivity is essential for monitoring radiation exposure, assessing radioactive contamination, and understanding the behavior of radioactive substances. Common methods include Geiger-Muller Counters, Scintillation Counters, Ionization Chambers, and Solid-State Detectors.

**Keywords:** Radiopharmaceuticals, Beta Particals , Alfa Particals, Measurement of radioactivity

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## I. INTRODUCTION

Radiopharmaceuticals are a class of pharmaceutical drugs that contain radioactive isotopes, and they are used in nuclear medicine for diagnostic and therapeutic purposes. These drugs are designed to target specific organs, tissues, or physiological processes in the body to provide valuable information or to treat certain medical conditions.

Here's a breakdown of the key aspects of radiopharmaceuticals:

- 1. Radioactive Isotopes:** Radiopharmaceuticals consist of a biologically active compound (e.g., a drug or ligand) coupled with a radioactive isotope. The radioactive isotope emits radiation in the form of gamma rays, positrons, or beta particles. Common isotopes used include technetium-99m, iodine-131, fluorine-18, and gallium-67.
- 2. Diagnostic Applications:** Radiopharmaceuticals are extensively used in nuclear medicine imaging to visualize and assess the functioning of organs and physiological processes. For instance, in Single Photon Emission Computed Tomography (SPECT) or Positron Emission Tomography (PET) scans, radiopharmaceuticals are injected into the patient's bloodstream. As they accumulate in specific areas of interest, the emitted radiation is detected by specialized cameras to create detailed images, allowing physicians to diagnose various diseases and conditions.
- 3. Therapeutic Applications:** Some radiopharmaceuticals are designed for therapeutic purposes. In this case, the radioactive emissions are used to target and destroy specific diseased cells or tissues. For example, radioactive iodine-131 is used to treat certain types of thyroid cancer, and strontium-89 and samarium-153 are used for bone pain palliation in metastatic cancers.
- 4. Half-life:** The radioactive isotopes used in radiopharmaceuticals have different half-lives, which determine how long the radioactivity remains active. Shorter half-lives are ideal for diagnostic purposes, as they reduce patient radiation exposure, while longer half-lives are more suitable for therapeutic applications.
- 5. Safety:** Radiopharmaceuticals are carefully formulated to minimize the exposure of patients and medical staff to radiation. They are subject to stringent regulatory controls to ensure safety, proper handling, and appropriate disposal of radioactive materials.
- 6. Administration:** Radiopharmaceuticals can be administered in various ways, including intravenously (most common), orally, or by inhalation, depending on the specific application and the targeted organ or system.

It is essential to note that the use of radiopharmaceuticals requires trained medical professionals, and the selection of appropriate radiopharmaceuticals depends on the patient's condition and the specific medical purpose. These substances have significantly contributed to the field of nuclear medicine, enabling non-invasive imaging and personalized treatments for various diseases.

## II. HISTORICAL TIMELINE

**Table 1: Historical Background**

<b>1896</b>	Henri Becquerel discovers enigmatic "rays" of uranium.
<b>1897</b>	Marie Curie named the mysterious light generated "radioactivity."
<b>1913</b>	Frederick Proescher find the first study on the first parenteral formulation of radium for therapy of various diseases.
<b>1932</b>	The first publication on "the generation of high speed light ions without the use of high voltages" is published by Ernest O. Lawrence and M. Stanley Livingston.
<b>1937</b>	Iron-59 was found by John Livingood, Fred Fairbrother, and Glenn Seaborg.
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<b>1941</b>	Saul Hertz administered the first therapeutic dose of iodine-130 to a patient.
<b>1948</b>	Abbott Laboratories began selling radioisotopes.
<b>1951</b>	The Food and Drug Administration (FDA) of the United States has approved sodium iodide 1-131 for treatment in thyroid patients. It was the first radiopharmaceutical to be approved by the FDA.
<b>1955</b>	Rex Huff used iodine-131 human serum albumin to calculate cardiac output in humans.
<b>1957</b>	H. Knipping measured lung ventilation with xenon-133.
<b>1959</b>	The first 3-inch rectilinear scanner was delivered by Picker X-Ray Company.
<b>1960</b>	John McAfee and Henry Wagner used radiomercury labeled chlormerodrin to scan the kidneys.
<b>1961</b>	At Washington University Medical School, Allis-Chalmers erected the first "medical center" cyclotron in the United States. M.M. Ter-Pogossian designed the cyclotron.
<b>1969</b>	C.L. Edwards discovered gallium-67 an accumulation in cancer.
<b>1993</b>	The FDA has approved Medi-Physics/Amersham to commercialize strontium-89 chloride for the treatment of bone pain.
<b>2002</b>	The National Institutes of Health establishes the National Institute of Biomedical Imaging and Bioengineering.
<b>2003</b>	IDEC Pharmaceuticals receives FDA approval for clinical use of Zevalin™, a radio immunotherapy drug.
<b>2008</b>	The fusion of pictures with PET/CT scans in molecular imaging is becoming more common, allowing a functional knowledge of the underlying causes of disease in the body by merging functional and anatomical information in the same image.

## 1. Definitions And Terminology

- Any medicinal or pharmaceutical product that, when ready for use, contains one or more radionuclides (radioactive isotopes) intended for human use in diagnosis or therapy is referred to as radiopharmaceutical..
- Nuclide is an elemental species distinguished by its mass number 'A' (the sum of the number of protons and neutrons in its nucleus), atomic number 'Z' (number of protons equal to the number of electrons in a neutral atom), and nuclear energy state.
- An element's isotopes are nuclides with the same atomic number 'Z' but distinct mass numbers 'A'. They have the same periodic table position and have similar chemical characteristics.
- Radionuclide Nuclides with an unstable arrangement of protons and neutrons that spontaneously convert to either a stable or another unstable combination of protons and neutrons with a constant statistical probability through radiation emission. These are known as radionuclide's and are considered to be radioactive.
- Radioactivity refers to the phenomena of radiation emission caused by the spontaneous transformation or disintegration of a radionuclide. The term radioactivity, on the other hand, is used to express the physical quantity (activity or strength) of this phenomenon. A preparation's radioactivity is defined as the number of nuclear disintegrations or transformations per unit time.

**2. Units of Radioactivity:** Radioactivity, the measure of the amount of radiation emitted by a radioactive substance, is expressed in several units. The three most common units of radioactivity are:

- **Becquerel (Bq):** The Becquerel is the International System of Units (SI) unit of radioactivity. It is defined as one radioactive decay per second. In other words, one Becquerel corresponds to one dis-integration of a radioactive nucleus per second. This unit is commonly used to measure the activity of a radioactive source.
- **Curie (Ci):** The Curie is a non-SI unit of radioactivity, but it is still used in certain contexts, especially in the United States. One Curie is equal to the activity of 1 gram of radium-226, which corresponds to approximately  $3.7 \times 10^{10}$  disintegrations per second or 37 gigabecquerels (GBq). While the Curie is not part of the SI system, it is still used in some legacy applications.
- **Gray (Gy):** The Gray is the SI unit of absorbed ionizing radiation dosage. It is defined as one joule of radiation energy absorbed per kilogram of substance. This unit is used to quantify the amount of radiation energy deposited in a material.

It's important to distinguish between the units of radioactivity (Becquerel and Curie) and the units of absorbed dose (Gray). Radioactivity measures how many radioactive decays occur per unit of time, while absorbed dose measures the amount of radiation energy deposited in a material. For practical purposes and adherence to the SI system, the Becquerel is the primary unit used to express radioactivity. The Curie is less commonly used but may still be encountered in specific situations, particularly in older literature or when dealing with legacy equipment or regulations.

### III. PROPERTIES OF $\alpha$ , $\beta$ , $\gamma$ RADIO ACTIVE RADIATIONS

All substances are made of atoms. These have electrons (e) all around them and a nucleus in the center. The nucleus is made up of protons (p) and neutrons (n) and is very tiny. (Atoms are almost entirely formed of empty space.). The nucleus of some atoms is unstable and will decay into a more stable atom. This radioactive decay is entirely natural. When an unstable nucleus decays, it can do so in one of three ways. It may give out:-

- an alpha particle ( $\alpha$ )
- an beta particle ( $\beta$ )
- an gamma ray ( $\gamma$ )

#### 1. Alpha Particles

- Because alpha particle radiation is made up of two neutrons and two protons, it is impacted by both electric and magnetic forces.
- The speed of the  $\alpha$ -particle varies greatly depending on the source, but is typically around 10% of the speed of light.
- The  $\alpha$ -particle's ability to penetrate materials is limited; it typically penetrates little more than a few centimeters in air and is absorbed by a comparatively thin layer of paper or human skin. However, due to their speed and small size, they can ionize a high number of atoms across a very limited range of penetration.

**2. Beta Particles:** Beta particles are a type of ionizing radiation that can be emitted by certain unstable atomic during radioactive decay, nuclei. Beta particles are classified into two types based on their properties: beta-minus ( $\beta^-$ ) particles and beta-plus ( $\beta^+$ ) particles.

- **Beta-minus ( $\beta^-$ ) Particles**

- These are high-energy electrons ( $e^-$ ) emitted from an atom's nucleus during beta decay.
- Beta-minus decay happens when a neutron in the nucleus is transformed into a proton, producing an electron and an antineutrino in the process.
- The electron is subsequently ejected from the nucleus, bringing the extra energy with it.
- As a neutron is converted into a proton, the nucleus's atomic number grows by one throughout this decay.

- **Beta-plus ( $\beta^+$ ) Particles**

- In some radioactive nuclei, beta-plus decay, commonly known as positron emission. A proton in the nucleus is transformed into a neutron during this process, which also produces a positron and a neutrino.
- The positron is an antiparticle of the electron, and when it encounters a regular both particles destroy each other, emitting gamma radiation as a result.

Both types of beta decay serve to make an unstable nucleus more stable by adjusting the ratio of protons to neutrons. Beta decay plays a important role in the natural radioactive decay of certain isotopes and is also utilized in various

applications, such as medical imaging and in the field of nuclear physics and engineering. It is essential to handle beta-emitting radioactive materials safely due to their ionizing nature, which can cause damage to living tissues if exposed to high levels of beta radiation.

- **Gamma Radiation**

- Gamma rays are high-energy electromagnetic waves produced by radioactive decay. They do not contain charge and are highly penetrating, capable of passing through tissues.
- Gamma radiation is commonly emitted by radionuclides such as technetium-99m (Tc-99m), iodine-131 (I-131), gallium-67 (Ga-67), and indium-111 (In-111).
- They have the ability to invade our bodies and damage delicate organs. They are especially harmful if consumed or breathed.

#### IV. MEASUREMENT OF RADIOACTIVITY

The measurement of radioactivity is essential for various purposes, including monitoring radiation exposure, assessing radioactive contamination, and understanding the behavior of radioactive substances. The unit used to measure radioactivity is the becquerel (Bq), which represents one decay event per second. Another commonly used unit is the curie (Ci), where 1 Ci equals  $3.7 \times 10^{10}$  becquerels. There are numerous methods for measuring radioactivity, and the method chosen is determined on the specific application and the type of radiation released. Here are some common techniques:

- 1. Geiger-Muller Counters:** Geiger-Muller (GM) counters are portable and widely used devices for detecting and measuring radioactivity. They work by ionizing gas in a tube when a radioactive particle or photon passes through it. The ionization triggers a discharge that can be detected, and the device provides a count rate of radiation events. GM counters are often used for quick assessments of radiation levels in various environments.
- 2. Scintillation Counters:** Scintillation counters are instruments that use certain materials (scintillators) that emit light when they interact with ionizing radiation. Photomultiplier tubes then amplify the emitted light, and the number of photons produced is proportional to the incident radiation's energy. Scintillation counters are used in research, medical imaging, and environmental monitoring.
- 3. Ionization Chambers:** Panels of ionization are devices that measure the amount of charge produced when ionizing radiation interacts with a gas (usually air). By measuring the ionization current, the radiation dose can be determined. Ionization chambers are widely used in radiation dosimetry for medical and industrial applications.
- 4. Solid-State Detectors:** Solid-state detectors, such as semiconductor-based detectors, are increasingly used for radiation measurement. They are more compact and efficient than older technologies and are commonly used in handheld dosimeters and personal radiation monitors.

- 5. Liquid Scintillation Counting:** The technique of liquid scintillation counting is used to measure low-energy beta and alpha particles. Radioactive samples are mixed with a liquid scintillator, which emits light when interacting with radiation. The emitted light is then detected and measured to determine the radioactivity.
- 6. Gamma Spectrometry:** Gamma spectrometry involves using high-resolution detectors to identify and quantify the energy of gamma-ray photons released by radioactive sources. This technique allows researchers to identify specific radioactive isotopes in a sample.

Regardless of the method used, it's crucial to calibrate the instruments regularly and follow proper safety protocols when working with radioactive materials. Radioactivity measurements are subject to stringent regulations and guidelines to ensure the safety of both workers and the public.

## V. MEASUREMENT OF RADIOACTIVITY OF SPECIFIC IONIZING RADIATION

The measurement of radioactivity is based on the detection and quantification of ionizing radiation emitted by radioactive materials. Alpha particles, beta particles, and gamma rays are the most prevalent kinds of ionizing radiation. Each type of radiation requires different methods of measurement. Here's a more detailed overview of the techniques used to measure radioactivity:

### 1. Alpha Particle Detection

- Alpha particles are large, positively charged particles, which mean they have limited penetration through materials. Therefore, alpha particle detection is typically conducted using specialized instruments such as alpha particle spectrometers or alpha scintillation detectors.
- Alpha spectrometry involves the use of semiconductor detectors or gas-filled proportional counters to measure the energies of alpha particles emitted by radioactive sources. This allows researchers to identify specific alpha-emitting isotopes in a sample.
- Scintillation detectors with special screens or mica windows can also be used to detect alpha particles. When an alpha particle interacts with the scintillator material, it produces light flashes that can be detected and measured.

### 2. Beta Particle Detection

- The high-energy electrons (-) or positrons (+) released during beta decay are known as beta particles. Because they have more penetration than alpha particles, beta particle detection can use a broader range of instruments.
- Geiger-Muller (GM) counters and scintillation detectors can detect beta particles, providing a count rate of radiation events.
- Solid-state detectors, such as silicon diodes or silicon carbide detectors, are also used to measure beta radiation.

Liquid scintillation counting is commonly used to measure low-energy beta particles emitted by certain isotopes. The radioactive sample is mixed with a liquid scintillator, and the emitted light is measured to determine the radioactivity.

### 3. Gamma Ray Detection

- Gamma rays are high-energy photons that can penetrate through materials, making gamma ray detection more challenging.
- Scintillation detectors, such as Crystals of sodium iodide (NaI) or bismuth germinate (BGO) are linked with photomultiplier tubes. are widely used for gamma ray spectroscopy. They can identify and quantify the energies of gamma rays, allowing researchers to determine the specific radioactive isotopes present in a sample.
- High-purity germanium (HPGe) detectors are also used for precise gamma ray spectroscopy due to their superior energy resolution.

The choice of the appropriate method depends on factors such as the type and energy of the radiation, the specific isotopes being measured, the required sensitivity, and the nature of the sample. Proper calibration, quality assurance, and adherence to safety regulations are essential when conducting radioactivity measurements to ensure accurate results and protect personnel and the environment from potential radiation hazards.

## VI. RADIOPHARMACEUTICALS USES

Radiopharmaceuticals are a class of drugs that contain a radioactive component and are used in nuclear medicine for diagnostic or therapeutic purposes. These drugs are designed to target specific organs, tissues, or biological processes, allowing healthcare professionals to visualize or treat various medical conditions. Radiopharmaceuticals can be categorized into two main groups based on their primary use:

**1. Diagnostic Radiopharmaceuticals:** Diagnostic radiopharmaceuticals are used for medical imaging to visualize and assess the physiological or biochemical functions of organs and tissues. They emit gamma rays or other forms of radiation that can be detected externally using imaging devices like gamma cameras or PET scanners. Some common types of diagnostic radiopharmaceuticals include:

- **Technetium-99m (Tc-99m) Radiopharmaceuticals:** Tc-99m is the most widely used radioisotope for diagnostic imaging. It has a short half-life and can be easily attached to various compounds to target specific organs or functions. Examples include Tc-99m MDP for bone scans and Tc-99m sestamibi for cardiac imaging.
- **Fluorine-18 (F-18) Radiopharmaceuticals:** F-18 is used in positron emission tomography (PET) imaging. Common F-18 radiopharmaceuticals include FDG (fluorodeoxyglucose) used to assess glucose metabolism and various other tracers targeting specific molecules or receptors in the body.
- **Iodine-131 (I-131) Radiopharmaceuticals:** I-131 is used in thyroid scans and therapy for certain thyroid disorders, as it is taken up by the thyroid gland.
- **Gallium-67 (Ga-67) and Indium-111 (In-111) Radiopharmaceuticals:** These are used for infection or inflammation imaging.



- **Technetium-99 (Tc-99) Radiopharmaceuticals:** Tc-99 imaging agents, although less common than Tc-99m, are also used in certain diagnostic procedures.
2. **Therapeutic Radiopharmaceuticals:** Therapeutic radiopharmaceuticals are used for targeted radiation therapy to treat specific diseases, particularly cancer. These drugs deliver radiation directly to the diseased cells, minimizing damage to surrounding healthy tissues. Some examples of therapeutic radiopharmaceuticals include:
- **Iodine-131 (I-131) Radiopharmaceuticals:** I-131 is used in targeted radiation therapy for thyroid cancer.
  - **Yttrium-90 (Y-90) Radiopharmaceuticals:** Y-90 is used for radioembolization, a treatment for liver cancer.
  - **Lutetium-177 (Lu-177) Radiopharmaceuticals:** Lu-177 is used in PRRT treating neuroendocrine tumors using peptide receptor radionuclide treatment.
  - **Radium-223 (Ra-223) Radiopharmaceutical:** Ra-223 is used to treat bone metastases in prostate cancer.

These categories represent some of the most commonly used radiopharmaceuticals. The discipline of nuclear medicine is still evolving. And researchers are continuously exploring new radiopharmaceuticals and applications for both diagnostic and therapeutic purposes.

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