Unit – 5 Radioisotopic techniques

Introduction

Isotopes are atoms of an element with the same number of protons but different numbers of neutrons. Some of these isotopes are stable and exist fine with the extra neutrons. Others, however, are unstable, making these atoms radioactive. These are called radioisotopes and are useful in a variety of sciences, including biology, mining, industry and agriculture.

Isotopes are atomic species of the same atomic number (belonging to the same element) that have different mass numbers. The number of elements in the periodic table is about 110, and each one has more than one isotope; the total number of known isotopes is more than 1500. Each isotope of a given element has the same number of protons in its atomic nucleus, but differs in the number of neutrons in its nucleus. Isotopes of an element cannot be distinguished chemically because they have the same electronic structure and undergo the same chemical reactions.

Although some isotopes are stable, the nuclear configurations of radioisotopes (or radionuclides) are unstable, and they spontaneously undergo a radioactive transformation (or decay) to a more stable energy state. The half-life of each radioisotope is the time required for exactly one-half of the atoms to undergo radioactive transformation. Radioisotopes may decay to either stable or other radioactive species. Decay from one radioisotope to another is called a decay series.

Radioisotopes occur in small amounts in nature as the result of the decay of long-lived primordial materials (such as uranium-238). Atmospheric reactions with solar particles also produce radioactive species. Approximately 50 radionuclides occur naturally in the atmosphere, ocean, or the earth's crust; these include carbon-14, potassium-40, radon-222, radium-226, and uranium-238.

Radioisotopes can be produced artificially by nuclear high energy reactions that combine atomic nuclei. The first human-made or artificial radioisotopes were made by Frederic and Irene Joliot-Curie in 1933, who irradiated a thin aluminum foil with alpha particles and observed tracks in a cloud chamber that diminished in intensity with a half-life of about 3 min, due to phosphorus-30 beta-plus decay. When they replaced aluminum with a boron foil, they found new activity, with a half-life of 14 min, due to nitrogen-13 beta-plus decay.

Lawrence produced small amounts of new radioisotopes. **Fermi** produced heavier radioisotopes of the same element by neutron bombardment. **Hevesey** conducted the first biological studies with radioisotope tracers. These developments made it possible to discover, produce, and test a large number of scientifically significant radioisotopes during the decade that followed.

Radioisotopes can be detected easily and identified using radiation detection instruments or photographic film (see Autoradiography and Fluorography). Therefore, they have numerous practical applications in the physical, chemical, and biomedical sciences.

- **Use of radioisotopes in life sciences**

1. In Biomedical research / In studies of life processes

Tagging of a radioisotope is performed to a biomolecule to permit tracking of the molecule in reaction processes and metabolism. The most important radioisotopes are those of hydrogen, carbon, sulfur, and phosphorous, because these elements are present in practically all cellular components essential to maintaining life. These are used more commonly in biomedical research.

Animal tissues containing radioisotopes are analyzed by nuclear radiation-detection techniques such as liquid scintillation counting, gamma spectroscopy, alpha spectrometry, and neutron activation analysis— depending on the relevant radiation emission.

2. In molecular biology

The most important application of radioisotopes is the radioactive labeling of nucleic acids and proteins. Radioactively labeled cells, such as organelles and chromosomes, can be imaged on high speed X-ray film in a process called autoradiography.

Genetic manipulation have dependent heavily upon use of radioisotope in DNA and RNA sequencing, DNA replication, transcription, synthesis of complementary DNA, recombinant DNA technology and many similar studies.

3. In Metabolic Pathways

Radioisotopes are frequently used for tracing metabolic pathways. This usually involves adding a radioactive substrate, taking samples of the experimental material at various times, extracting and chromatographically or otherwise separating the products.

Radioactivity detectors can be attached to gas liquid chromatography or high performance liquid chromatography columns to monitor radioactivity coming off the column during separation.

4. In Metabolic Turnover Times

Radioisotopes provide a convenient method of ascertaining turnover times for particular compounds.

5. In Studies of Absorption, Accumulation and Translocation

Radioisotopes have been very widely used in this study of the mechanisms and rates of absorption, accumulation and translocation of inorganic and organic compounds by both plants and animal.

6. In Pharmacological Studies

Radioisotopes are widely used is in the development of new drugs such as whether a drug has a desirable effect, the site of drug accumulation, the rate of accumulation, the rate of metabolism and the metabolic products must all be determined.

7. In Enzyme and Ligand Binding Studies

Virtually any enzyme reaction can be assayed using radiotracer methods provided that a radioactive form of the substrate is available. Radioisotopes are used in the study of the mechanism of enzyme action and in the studies of ligand binding to membrane receptors.

8. In Radioimmunoassay

One of the most significant advances in biochemical technique in recent years has been the development of the radioimmunoassay.

9. In Radio Dating

A quite different analytical use for radioisotopes is in the dating (i.e., determining the age) of rocks, fossils and sediments.

10. In Clinical Diagnosis

Radioisotopes are very widely used in medicine, in particular for diagnostic tests. Lung function tests routinely made using xenon-133 (^{133}Xe) are particularly useful in diagnosis of malfunctions of lung ventilation. Kidney function tests using [133] iodohippuric acid are used in diagnoses of kidney

infection, kidney blockages or imbalance of function between the two kidneys. Various aspects of hematology are also studied by using radioisotopes. These include such aspects as blood cell lifetimes, blood volumes and blood circulation times

11. In Ecological Studies

Migratory patterns and behaviour patterns of many animals can be monitored using radiotracers. Another ecological application is in the examination of food chains where the primary producers can be made radioactive and the path of radioactivity followed throughout the resulting food chain.

12. In Sterilization of Food and Equipment

Very strong y-emitters are now widely used in the food industry for sterilization of pre-packed foods such as milk and meats. Normally either ^{60}Co or ^{137}Ce is used,

13. In Mutagens

Radioisotopes may cause mutations, particularly in micro-organisms. In various microbiological studies mutants are desirable, especially in industrial microbiology. For instance, developments of new strains of a micro-organism that produce higher yields of a desired microbial product frequently involve mutagenesis by radioisotopes.

==========

Some important radioisotopes used in biology

1. Carbon-14

It is a major research tool. It helps to the testing the potentiality of new drugs whether it is metabolized without formation of harmful byproducts. It is also used in biological research, pollution control, agriculture and archeology. used in determination of hormone concentration in the plasma and in radioimmunoassay techniques.

2. Calcium-47

Important aid to biomedical researchers studying the cellular functions and bone formation in mammals

3. Cesuim-137: Used to treat cancerous tumors...to measure correct patient dosages of radioactive pharmaceuticals.

4. Chromium-51: Used in research in red blood cell survival studies.

5. Cobalt-57 / 60: Used as a tracer to diagnose pernicious anemia, sterilize surgical instruments, cancer treatment, food irradiation, gauges, and radiography.

6. Copper-67: Helps the antibodies bind to and destroy the tumor.

7. Iodine-123, 125, 129, 131: used to diagnose thyroid disorders and other metabolic disorders including brain function

8. Phosphorus-32: Used in molecular biology and genetics research.

9. Selenium-75: Used in protein studies in life science research.

10. Strontium-85: Used to study bone formation and metabolism.

11. Sulphur-35: Used in genetics and molecular biology research.

12. Technetium-99: The most widely used radioactive pharmaceutical for diagnostic studies in nuclear medicine. Different chemical forms are used for brain, bone, liver, spleen and kidney imaging and also for blood flow studies

13. Tritium: Major tool for biomedical research. Used for life science and drug metabolism studies to ensure the safety of potential new drugs...

14. Uranium-234: Used in dental fixtures like crowns and dentures to provide a natural color and brightness.

15. Uranium-235: Fuel for nuclear power plants and naval nuclear propulsion systems...and used to produce fluorescent glassware, a variety of colored glazes and wall tiles.

16. Xenon-133: Used in nuclear medicine for lung ventilation and blood flow studies

==========

❖ Radioactive labeling / principle and application of tracer techniques,

A **radioactive tracer**, or **radioactive label**, is a chemical compound in which one or more atoms have been replaced by a radioisotope so by virtue of its radioactive decay it can be used to explore the mechanism of chemical reactions by tracing the path that the radioisotope follows from reactants to products. **Radiolabeling** is thus the radioactive form of isotopic labeling.

Radioisotopes of hydrogen, carbon, phosphorus, sulphur, and iodine have been used extensively to trace the path of biochemical reactions. A radioactive tracer can also be used to track the distribution of a substance within a natural system such as a cell or tissue,[1] or as a flow tracer to track fluid flow. Radioactive tracers are also used to determine the location of fractures created by hydraulic fracturing in natural gas production

Isotopes of a chemical element differ only in the mass number. For example, the isotopes of hydrogen can be written as ^{1}H, ^{2}H and ^{3}H, with the mass number at top left. When the atomic nucleus of an isotope is unstable, compounds containing this isotope are radioactive. Tritium is an example of a radioactive isotope.

The principle behind the use of radioactive tracers is that an atom in a chemical compound is replaced by another atom, of the same chemical element. The substituting atom, however, is a radioactive isotope. This process is often called radioactive labeling. The power of the technique is due to the fact that radioactive decay is much more energetic than chemical reactions. Therefore, the radioactive isotope can be present in low concentration and its presence detected by sensitive radiation detectors such as Geiger counters and scintillation counters. George de Hevesy won the 1943 Nobel Prize for Chemistry "for his work on the use of isotopes as tracers in the study of chemical processes".

There are two main ways in which radioactive tracers are used

1. When a labeled chemical compound undergoes chemical reactions one or more of the products will contain the radioactive label. Analysis of what happens to the radioactive isotope provides detailed information on the mechanism of the chemical reaction.
2. A radioactive compound is introduced into a living organism and the radio-isotope provides a means to construct an image showing the way in which that compound and its reaction products are distributed around the organism.

Production

The commonly used radioisotopes have short half lives and so do not occur in nature. They are produced by nuclear reactions. One of the most important processes is absorption of a neutron by an atomic nucleus, in which the mass number of the element concerned increases by 1 for each neutron absorbed. For example,

$^{13}C + n \rightarrow {}^{14}C$

In this case the atomic mass increases, but the element is unchanged. In other cases the product nucleus is unstable and decays, typically emitting protons, electrons (beta particle) or alpha particles. When a nucleus loses a proton the atomic number decreases by 1. For example,

$^{32}S + n \rightarrow {}^{32}P + p$

Neutron irradiation is performed in a nuclear reactor. The other main method used to synthesize radioisotopes is proton bombardment. The proton are accelerated to high energy either in a cyclotron or a linear accelerator

Hydrogen

Tritium is produced by neutron irradiation of ^{6}Li

$^{6}Li + n \rightarrow {}^{4}He + {}^{3}H$

Tritium has a half-life 4,500±8 days (approximately 12.32 years),[4] and it decays by beta decay. The electrons produced have an average energy of 5.7 keV. Because the emitted electrons have relatively low energy, the detection efficiency by scintillation counting is rather low. However, hydrogen atoms are present in all organic compounds, so tritium is frequently used as a tracer in biochemical studies.

Carbon

^{11}C decays by positron emission with a half-life of ca. 20 min. ^{11}C is one of the isotopes often used in positron emission tomography.[3]

^{14}C decays by beta-decay, with a half-life of 5730 y. It is continuously produced in the upper atmosphere of the earth so it occurs at a trace level in the environment. However, it is not practical to use naturally-occurring ^{14}C for tracer studies. Instead it is made by neutron irradiation of the isotope ^{13}C which occurs naturally in carbon at about the 1.1% level. ^{14}C has been used

extensively to trace the progress of organic molecules through metabolic pathways.

Nitrogen

^{13}N decays by positron emission with a half-life of 9.97 min. It is produced by the nuclear reaction

$$^{1}H + {}^{16}O \rightarrow {}^{13}N + {}^{4}He$$

^{13}N is used in positron emission tomography (PET scan).

Oxygen

^{15}O decays by positron emission with a half-life of 122 sec. It is used in positron emission tomography

Fluorine

^{18}F decays by positron emission with a half-life of 109 min. It is made by proton bombardment of ^{18}O in a cyclotron or linear particle accelerator. It is an important isotope in the radiopharmaceutical industry. It is used to make labeled fluorodeoxyglucose (FDG) for application in PET scans.[3]

Phosphorus

^{32}P is made by neutron bombardment of ^{32}S

$$^{32}S + n \rightarrow {}^{32}P + p$$

It decays by beta decay with a half-life of 14.29 days. It is commonly used to study protein phosphorylation by kinases in biochemistry.

^{33}P is made in relatively low yield by neutron bombardment of ^{31}P. It is also a beta-emitter, with a half-life of 25.4 days. Though more expensive than ^{32}P, the emitted electrons are less energetic, permitting better resolution in, for example, DNA sequencing.

Both isotopes are useful for labeling nucleotides and other species that contain a phosphate group.

Sulfur

^{35}S is made by neutron bombardment of ^{35}Cl

$^{35}Cl + n \rightarrow {}^{35}S + p$

It decays by beta-decay with a half-life of 87.51 days. It is used to label the sulfur-containing amino-acids methionine and cysteine. When a sulfur atom replaces an oxygen atom in a phosphate group on a nucleotide a thiophosphate is produced, so ^{35}S can also be used to trace a phosphate group.

Technetium

^{99m}Tc is a very versatile radioisotope, and is the most commonly used radioisotope tracer in medicine. It is easy to produce in a technetium-99m generator, by decay of ^{99}Mo.

$^{99}Mo \rightarrow {}^{99m}Tc + e^{-} + \nu e$

Iodine

Main article: Isotopes of iodine

^{123}I is produced by proton irradiation of ^{124}Xe. The caesium isotope produced is unstable and decays to ^{123}I. The isotope is usually supplied as the iodide and hypoiodate in dilute sodium hydroxide solution, at high isotopic purity

==========

- **Principle and application of tracer techniques**

An isotope is a form of an element which has the same atomic number of electrons as the common form of the element but it differs in atomic weight. The difference of atomic weight is due to difference of number of neutrons in its nucleus. An isotope may be stable or radioactive depending on the relative number of protons and neutrons in its nucleus.

An *isotopic tracer*, (also "isotopic marker" or "isotopic label"), is used in chemistry and biochemistry to help understand chemical reactions and interactions. In this technique, one or more of the atoms of the molecule of interest is substituted for an atom of the same chemical element, but of a different isotope (like a radioactive isotope used in radioactive tracing). Because the labeled atom has the same number of protons, it will behave in almost exactly the same way as its unlabeled counterpart and, with few exceptions, will not interfere with the reaction under investigation. The difference in the number of neutrons, however, means that it can be detected separately from the other atoms of the same element.

Nuclear magnetic resonance (NMR) and mass spectrometry (MS) are used to investigate the mechanisms of chemical reactions. NMR and MS detects isotopic differences, which allows information about the position of the labeled atoms in the products' structure to be determined. With information on the positioning of the isotopic atoms in the products, the reaction pathway the initial metabolites utilize to convert into the products can be determined. Radioactive isotopes can be tested using the autoradiographs of gels in gel electrophoresis. The radiation emitted by compounds containing the radioactive isotopes darkens a piece of photographic film, recording the position of the labeled compounds relative to one another in the gel.

Both stable and radioactive isotopes of an element are identical in chemical properties, and thus they undergo all the physical and chemical changes like the ordinary form of the element. Moreover, the can be detected at any time by atomic weight or radioactivity. By **Ginger-Muller counter** or other sensitive detectors the radioactive isotopes can be detected by their radioactivity even when it present in very small quantity. Detection of stable isotopes can be done by their atomic weight through a **mass spectrograph.** Stable or radioactive isotopes used for studying the fate of a molecule in physical, chemical or biological processes are called **tracer element** and the methods for such studies are called **tracer techniques** . Commonly used radioactive tracers in the study of biology are C^{14}, P^{12}, H^{3} etc. An important stable isotope used as tracer in biology is $O^{18.}$

At specific positions in their molecules inorganic and organic compounds can be prepared with isotopes. Such compound containing an isotope in its molecule is used as a tracer. In the tracer technique the isotope element in the molecule is said ‘tagged ‘or ‘labelled’. When an isotopically labelled compound is administrated to an animal or a plant or incubated with tissue preparations, it undergoes same fate as the unlabelled form of the compound and the isotopically labelled products can be detected. In this way, this source, metabolic pathway and end products of bio-molecules can be studied with the use of isotopically tagged tracers.

The process of Tracer techniques tracers are also used for determining the following:

1. Metabolic turnover of a substance.
2. Relative proportion of a substance being catabolised through different pathways.
3. Intestinal absorption of the nutrient.
4. Volume of body fluids.
5. Blood level of a hormone.
6. Mechanism and site of action of a hormone.
7. Cardiac output.
8. Flow of blood through an organ.
9. Intracellular distribution, i.e. autoradiography.
10. C^{14}. P^{32}, radioactive tracer is mainly used to study the phosphorylation reactions.
11. H^3 or tritium is also a radioactive isotope which is used as a tracer in the form of tritium oxide (THO) for determination of total body fluid volume.
12. O^{18} is a stable isotope and it is used to trace the source of O_2 liberated in photosynthesis. When O^{18} labelled water (H_2O^{18}) is used in photosynthesis, $O^{18}{}_2$ is liberated. It is thus proved that the water is the source of oxygen liberated in photosynthesis.
13. In metabolism research, Tritium and ^{14}C-labeled glucose are commonly used in glucose clamps to measure rates of glucose uptake, fatty acid synthesis, and other metabolic processes.
14. ^{13}C are more commonly used in current human clamp studies.
15. Used to study lipoprotein metabolism in humans and experimental animals.
16. In medicine, tracers are applied in a number of tests, such as ^{99m}Tc in autoradiography and nuclear medicine, including single photon emission computed tomography (SPECT), positron emission tomography (PET) and scintigraphy.
17. The urea breath test for *Helicobacter pylori* commonly used a dose of ^{14}C labeled urea to detect *H. pylori* infection. If the labeled urea was metabolized by *H. pylori* in the stomach, the patient's breath would contain labeled carbon dioxide. In recent years, the use of substances enriched in the non-radioactive isotope ^{13}C has become the preferred method, avoiding patient exposure to radioactivity.
18. In hydraulic fracturing, radioactive tracer isotopes are injected with hydraulic fracturing fluid to determine the injection profile and location

of created fractures. Tracers with different half-lives are used for each stage of hydraulic fracturing.

19. For the study of biological pathway and mechanism **Tracer techniques** has its importance. Tracer techniques involve use of isotopically labelled molecules and detection of the isotopes for the study.

==========

❖ **Detection and measurement of radioactivity**

All substance are made of atoms. These have electrons (e) around the outside, and a nucleus in the middle. The nucleus consists of protons (p) and neutrons (n), and is extremely small. (Atoms are almost entirely made of empty space!). In some types of atom, the nucleus is unstable, and will decay into a more stable atom. This radioactive decay is completely spontaneous.

When an unstable nucleus decays, there are three ways that it can do so. It may give out:-

- an **alpha particle** (we use the symbol α)
- a **beta particle** (symbol β)
- a **gamma ray** (symbol γ)

Many radioactive substances emit α particles and β particles as well as γ rays.

Alpha Particles (α):

Alpha particles are made of **2 protons and 2 neutrons**. This means that they have a **charge** of **+2**, and a **mass** of **4** *(the mass is measured in "atomic mass units", where each proton & neutron=1).* Alpha particles are relatively **slow** and **heavy**. They have a **low penetrating power** - you can stop them with just a sheet of **paper**. Because they have a large charge, alpha particles ionize other atoms strongly and have a range of only a few centimetres in air.

Alpha particles are made of 2 protons with 2 neutrons. This means that when a nucleus emits an alpha particle, it loses 2 protons and so its **atomic number decreases by 2**. Also, when a nucleus emits an alpha particle, its **atomic mass decreases by 4** (that's 2 protons plus 2 neutrons). So Americium-241 (an α -source used in smoke detectors), which has an atomic number of 95 and an atomic mass of 241 will decay to Neptunium-237 (which has an atomic number of 93 and an atomic mass of 237). The equation would look like this:-

Alpha-decay occurs in very heavy elements, for example, Uranium and Radium. These heavy elements have too many protons to be stable. They can become more stable by emitting an alpha particle.

Beta Particles (β):

Beta particles have a charge of **minus 1**, and a mass of about **1/2000th of a proton**. This means that beta particles are **the same as an electron**. They are **fast**, and **light**. Beta particles have a **medium penetrating power** - they are stopped by a sheet of **aluminium** or plastics such as **perspex**. Beta particles ionise atoms that they pass, but not as strongly as Alpha particles do.

It appears strange that when the nucleus contains protons and neutrons, how can an electron come out of a nucleus?

To answer this, we need to know more about protons and neutrons:

Protons & neutrons are made of combinations of even smaller particles, called "quarks". Under certain conditions, a neutron can decay, to produce a proton plus an electron. The proton stays in the nucleus, whilst the electron flies off at high speed.

This means that when a nucleus emits a β -particle,

- the **atomic mass is unchanged**,

- the **atomic number increases by 1**

This is because a neutron has changed into a proton (almost the same mass - we can ignore the tiny mass of the electron) and thus the number of protons has gone up.

Example: Strontium-90 undergoes β decay and forms Yttrium-90.

$$^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + \beta$$

Beta decay occurs in very "neutron-rich" elements, for example, Strontium-90 and Iodine-130. These elements are typically created in nuclear reactors.

These elements have too few protons and too many neutrons to be stable. They can thus become more stable by emitting a beta particle.

Beta particles have a charge of -1, and weigh only a tiny fraction of a neutron or proton. As a result, β particles interact less readily with other atoms than alpha particles.

Thus beta particles cause less ionization than alphas, and have a longer range, typically a few metres in air. In Beta decay, the atomic number increases by one while the atomic mass remains unchanged.

Gamma Rays (γ):

Gamma rays are **waves, not particles**. This means that they have **no mass** and **no charge**. Gamma rays have a **high penetrating power** - it takes a thick sheet of metal such as **lead**, or **concrete** to reduce them significantly. Gamma rays do not directly ionise other atoms, although they may cause atoms to emit other particles which will then cause ionisation.

Gamma rays (γ) are electromagnetic waves, rather like X rays and radio waves. Thus gamma rays have **no mass** and **no charge**.

After a nucleus has emitted an α-particle or a β-particle, it may still have too much energy: we say it is in an "excited state". It can get rid of this energy by emitting a pulse of very high frequency electromagnetic radiation, called a gamma ray. Gamma rays do not pull electrons off atoms they pass, as α-particles and β-particles do. This means that they do not lose much energy as they travel, as they do not interact as much with the matter they pass. Therefore, gamma rays have a **high penetrating power**, and a **very long range**.

It's worth noting that there is no such thing as a pure γ-ray source. Gamma rays are given off by most α-emitters and β-emitters. If we want a source of pure gamma rays, we can get it by using a substance that emits both β and γ, and simply keep it in an aluminium container that stops the β-particles.

Useful gamma sources include Technetium-99m, which is used as a "tracer" in medicine. This is a combined β and γ source, and is chosen because betas are less harmful to the patient than alphas (less ionisation) and because Technetium has a short half-life (just over 6 hours), so it decays away quickly and reduces the dose to the patient. In Gamma decay, both atomic number and atomic mass remain unchanged

For Detection and measurement of radioactivity, following techniques are used

1. Ionization chamber
2. Proportional chamber
3. Geiger- Muller counters
4. Scintillation counters

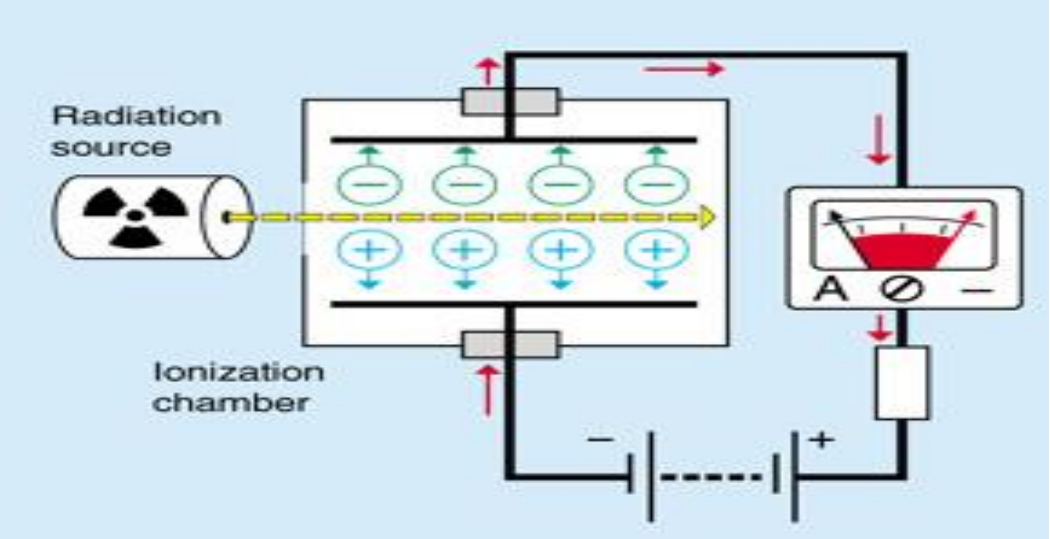
1. **Ionization chamber**

The **ionization chamber** is the simplest of all gas-filled radiation detectors, and is widely used for the detection and measurement of certain types of ionizing radiation; X-rays, gamma rays and beta particles. Conventionally, the term "ionization chamber" is used exclusively to describe those detectors

which collect all the charges created by *direct ionization* within the gas through the application of an electric field. It only uses the discrete charges created by each interaction between the incident radiation and the gas, and does not involve the gas multiplication mechanisms used by other radiation instruments, such as the Geiger-Müller counter or the proportional counter.

Ion chambers have a good uniform response to radiation over a wide range of energies and are the preferred means of measuring high levels of gamma radiation. They are widely used in the nuclear power industry, research labs, radiography, radiobiology, and environmental monitoring

An ionization chamber measures the charge from the number of ion pairs created within a gas caused by incident radiation. It consists of a gas-filled chamber with two electrodes; known as anode and cathode. The electrodes may be in the form of parallel plates (Parallel Plate Ionization Chambers: PPIC), or a cylinder arrangement with a coaxially located internal anode wire.



A voltage potential is applied between the electrodes to create an electric field in the fill gas. When gas between the electrodes is ionized by incident ionizing radiation, ion-pairs are created and the resultant positive ions and dissociated electrons move to the electrodes of the opposite polarity under the influence of the electric field. This generates an ionization current which is measured by an electrometer circuit. The electrometer must be capable of measuring the very small output current which is in the region of femtoamperes to picoamperes, depending on the chamber design, radiation dose and applied voltage.

Each ion pair created deposits or removes a small electric charge to or from an electrode, such that the accumulated charge is proportional to the number of ion pairs created, and hence the radiation dose. This continual

generation of charge produces an ionization current, which is a measure of the *total* ionizing dose entering the chamber. However, the chamber cannot discriminate between radiation types (beta or gamma) and cannot produce an energy spectrum of radiation.

The electric field also enables the device to work continuously by mopping up electrons, which prevents the fill gas from becoming saturated, where no more ions could be collected, and by preventing the recombination of ion pairs, which would diminish the ion current. This mode of operation is referred to as "current" mode, meaning that the output signal is a continuous current, and not a pulse output as in the cases of the Geiger-Müller tube or the proportional counter.

Referring to the accompanying ion pair collection graph, it can be seen that in the "ion chamber" operating region the collection of ion pairs is effectively constant over a range of applied voltage, as due to its relatively low electric field strength the ion chamber does not have any "multiplication effect". This is in distinction to the Geiger-Müller tube or the proportional counter whereby secondary electrons, and ultimately multiple avalanches, greatly amplify the original ion-current charge

Chamber types and construction

Free-air chamber, Vented chamber, Sealed low pressure chamber, High pressure chamber, Thimble chamber, Parallel-plate chambers,

Applications of Ionization chamber

Nuclear industry

Ionization chambers are widely used in the nuclear industry as they provide an output that is proportional to radiation dose They find wide use in situations where a constant high dose rate is being measured as they have a greater operating lifetime than standard Geiger-Müller tubes, which suffer from gas break down

Smoke detectors

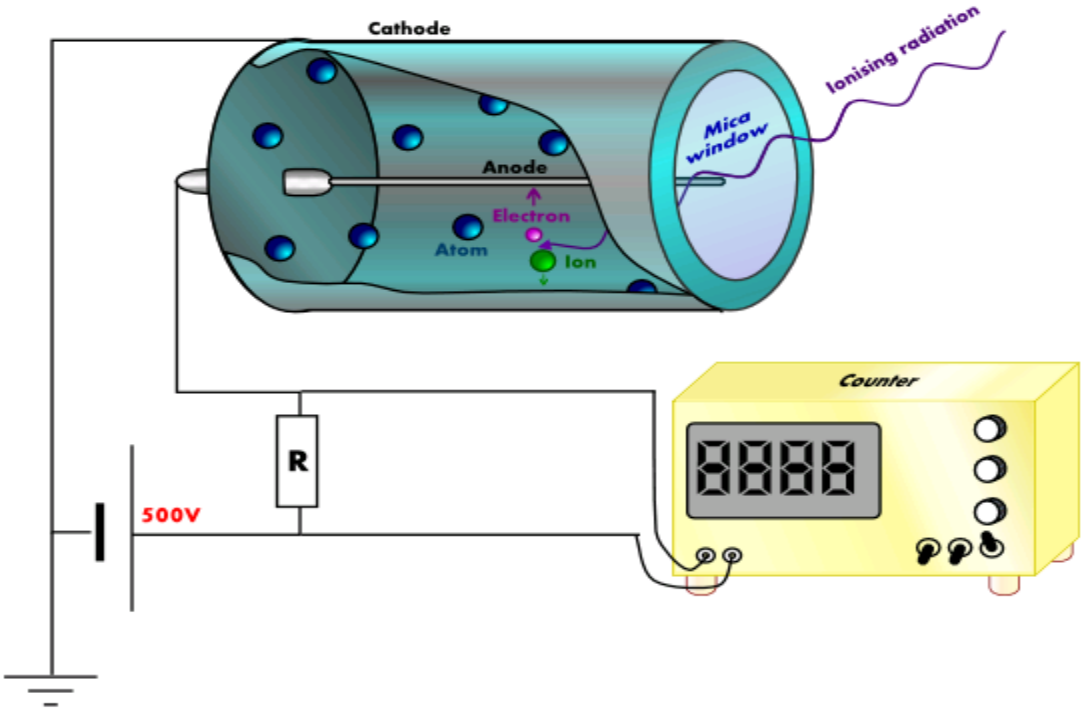
The ionization chamber has found wide and beneficial use in smoke detectors. In a smoke detector, ambient air is allowed to freely enter the ionization chamber. The chamber contains a small amount of americium-241, which is an emitter of alpha particles which produce a constant ion current. If smoke enters the detector, it disrupts this current because ions strike smoke particles and are neutralized. This drop in current triggers the alarm.

Medical radiation measurement

In medical physics and radiotherapy, ionization chambers are used to ensure that the dose delivered from a therapy unit[8] or radiopharmaceutical is what is intended.

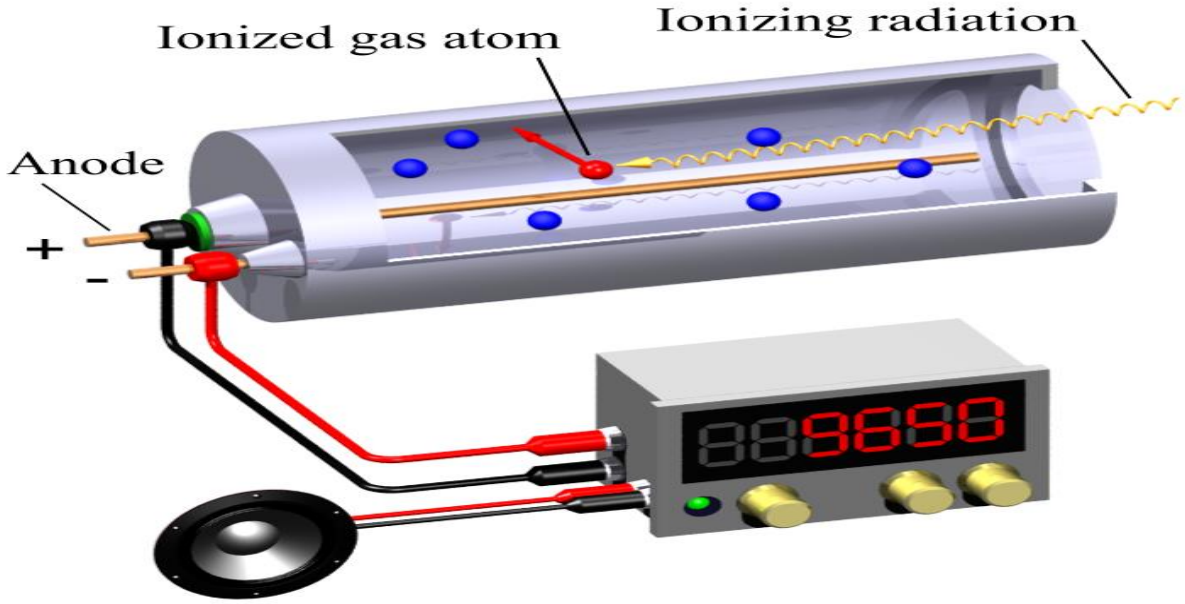
2. Proportional chamber

The voltage applied in gas-flow proportional detectors is the next range higher than ionization chamber detectors, and is sufficient to create ions with enough kinetic energy to create new ion pairs, called secondary ions. The quantity of secondary ions increases proportionally with the applied voltage, in what is known as the gas amplification factor. The signal pulse heights produced can be discerned by the external circuit to differentiate among different types of radiation. Gas-flow proportional detectors generally are used to detect alpha and beta radiation. Systems also detect photon radiation, but the detection efficiency for photon emissions is considerably lower than the relative efficiencies for alpha and beta activity. Physical probe areas for these types of detectors vary in size from approximately 100 cm^2 up to 600 cm^2. The detector cavity in these instruments is filled with P-10 gas which is an argon-methane mixture (90% argon and 10% methane). Ionizing radiation enters this gas-filled cavity through an aluminized Mylar window. Additional Mylar shielding may be used to block alpha radiation; a lower voltage setting may be used to detect pure alpha activity.



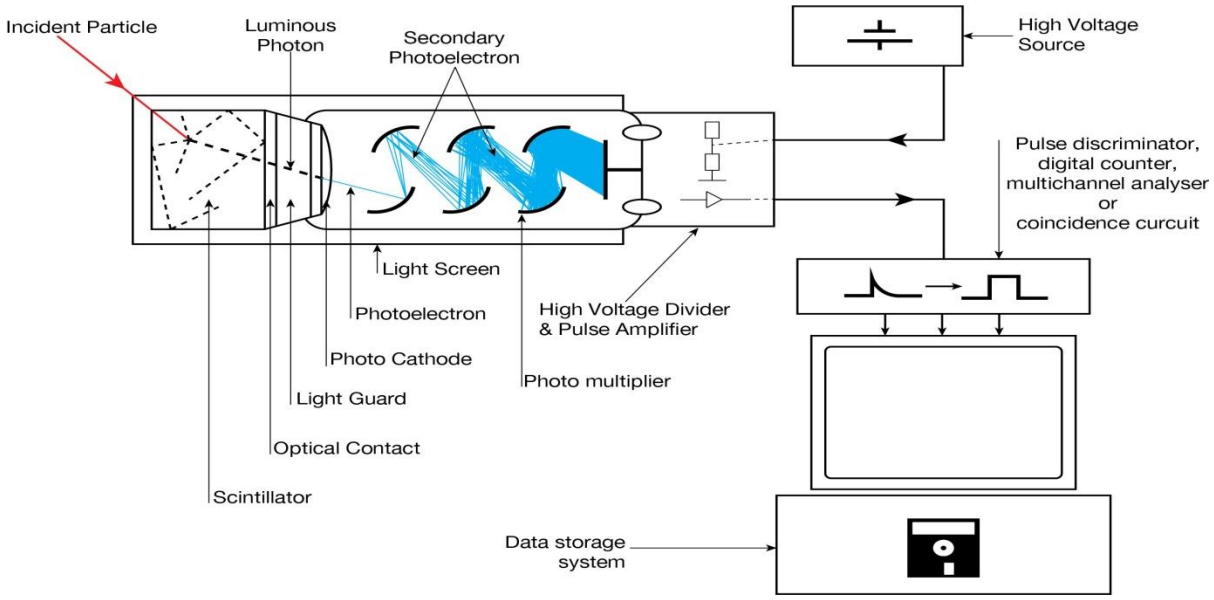
3. Geiger- Muller counters

GM detectors operate in the voltage range above the proportional range and the limited proportional range. This range is characterized by extensive gas amplification that results in what is referred to as an “avalanche” of ion and electron production. This mass production of electrons spreads throughout the entire chamber, which precludes the ability to distinguish among different kinds of radiation because all of the signals produced are the same size. GM detectors are most commonly used for the detection of beta activity, though they may also detect both alpha and photon radiation. GM detectors have relatively short response and dead times and are sensitive enough to broad detectable energy ranges for alpha, beta, photon, and neutron emissions (though they cannot distinguish which type of radiation produces input signals) to allow them to be used for surveying M&E with minimal process knowledge. GM detectors are commonly divided into three classes: “pancake”, “end-window”, and “side-wall” detectors. GM pancake detectors (commonly referred to as “friskers”) have wide diameter, thin mica windows (approximately 15 cm window area) that are large enough to allow them to be used to survey many types of M&E. Although GM pancake detectors are referenced beta and gamma detectors, the user should consider that their beta detection efficiency far exceeds their gamma detection efficiency. The end-window detector uses a smaller, thin mica window and is designed to allow beta and most alpha particles to enter the detector unimpeded for concurrent alpha and beta detection. The side-wall detector is designed to discriminate between beta and gamma radiation, and features a door that can be slidor rotated closed to shield the detector from beta emissions for the sole detection of photons. These detectors require calibration to detect for beta and gamma radiation separately. Energy-compensated GM detectors may also be cross-calibrated for assessment of exposure rates.



4. Scintillation Counters

Scintillation detectors (sometimes referred to as “scintillators”) consist of scintillation media that emits a light “output” called a scintillation pulse when it interacts with ionizing radiation. Scintillators emit low-energy photons (usually in the visible light range) when struck by high-energy charged particles; interactions with external photons cause scintillators to emit charged particles internally, which in turninteract with the crystal to emit low-energy photons. In either case, the visible light emitted (i.e., the low-energy photons) are converted into electrical signals by photomultiplier tubes and recorded by a digital readout device. The amount of light emitted is generally proportional to the amount of energy deposited, allowing for energy discrimination and quantification of source radionuclides in some applications.



a) Zinc Sulfide Scintillation Detectors

Zinc sulfide detector crystals are only available as a polycrystalline powder that are arranged in a thin layer of silver-activated zinc sulfide (ZnS(Ag)) as a coating or suspended within a layer of plastic scintillation material. The use of these thin layers makes them inherently dispositioned for the detection of high linear energy transfer (LET) radiation (radiation associated with alpha particles or other heavy ions). These detectors use an aluminized Mylar window to prevent ambient light from activating the photomultiplier tube. The light pulses produced by the scintillation crystals are amplified by a photomultiplier tube, converted to electrical signals, and counted on a digital scaler/ratemeter. Low LET radiations (particularly beta emissions) are detected at much lower detection efficiencies than alpha emissions and pulse characteristics may be used to discriminate beta detections from alpha detections.

b) Sodium Iodide Scintillation Detectors

Sodium iodide detectors are well-suited for detection of photon radiation. Energy-compensated sodium iodide detectors may also be cross-calibrated for assessment of exposure rates. Unlike ZnS(Ag), sodium iodide crystals can be grown relatively large and machined into varying shapes and sizes. Sodium iodide crystals are activated with trace amounts of thallium (hence the abbreviation NaI(Tl)), the key ingredient to the crystal's excellent light yield. These instruments most often have upper- and lower-energy discriminator circuits and when used correctly as a single-channel analyzer, can provide information on the photon energy and identify the source radionuclides. Sodium iodide detectors can be used with handheld instruments or large stationary radiation monitors.

c) Cesium Iodide Scintillation Detectors

Cesium iodide detectors generally are similar to sodium iodide detectors. Like NaI(Tl), cesiumiodide may be activated with thallium (CsI(Tl)) or sodium (CsI(Na)). Cesium iodide is more resistant to shock and vibration damage than NaI, and when cut into thin sheets it features malleable properties allowing it to be bent into various shapes. CsI(Tl) has variable decay times for various exciting particles, allowing it to help differentiate among different types of ionizing radiation. A disadvantage of CsI scintillation detectors is due to the fact that the scintillation emission wavelengths for CsI are longer than those produced by sodium iodide crystals; because almost all photomultiplier tubes are designed for NaI, there are optical incompatibilities that result in decreased intrinsic efficiencies for CsI detectors. Additionally, CsI scintillation detectors feature relatively long response and decay times for luminescent states in response to ionizing radiation.

d) Plastic Scintillation Detectors

Plastic scintillators are composed of organic scintillation material that is dissolved in a solvent and subsequently hardened into a solid plastic. Modifications to the material and specific packaging allow plastic scintillators to be used for detecting alpha, beta, photon, or neutron radiation. While plastic scintillators lack the energy resolution of sodium iodide and some other gamma scintillation detector types, their relatively low cost and ease of manufacturing into almost any desired shape and size enables them to offer versatile solutions to atypical radiation detection needs.

==========

❖ Autoradiography

The use of radioactive radiations to obtain the photographic film of the test material, incorporated with the radioactive tracers, is called autoradiography and the film obtained is called autoradiograph. After development the irradiated areas appear on the film as dark areas corresponding to the distribution of the tracer.

Autoradiography can be detected either directly with a scintillation counter or indirectly via their effect on photographic film. At the light microscopic level the autoradiography is based on the principle that if a photographic emulsion is brought in to contact with radioactive material, the ionic radiations will convert the emulsion as dark spots of silver at certain points.

Radioactive substances are introduced into the test material either in a given chemical form or tagged with certain metabolic precursors. Nucleic acid can be made radioactive by incorporation of radioactive phosphate during nucleic acid synthesis.

Autoradiography is the technique of recording an image of a preparation containing beta-particle emitting radioactivity, using photographic film, X-ray-sensitive film, an emulsion, or other radiation-sensitive medium. The samples are placed directly against the film for a period of time to allow radioactive emissions from the sample to interact with the film emulsion and create an image. A photographic emulsion is a suspension of crystals of silver bromide embedded in gelatin. When crystals of silver bromide are struck by charged-particle or photon radiation, the silver atoms are ionized and form an invisible latent image. After exposure to the sample, the photographic grains in the emulsion are fixed using standard photographic developing, which removes silver bromide that has not been ionized. After the emulsion is developed, each small aggregate of reduced silver atoms becomes a visible dark spot on the emulsion; collectively, they make up the photographic image.

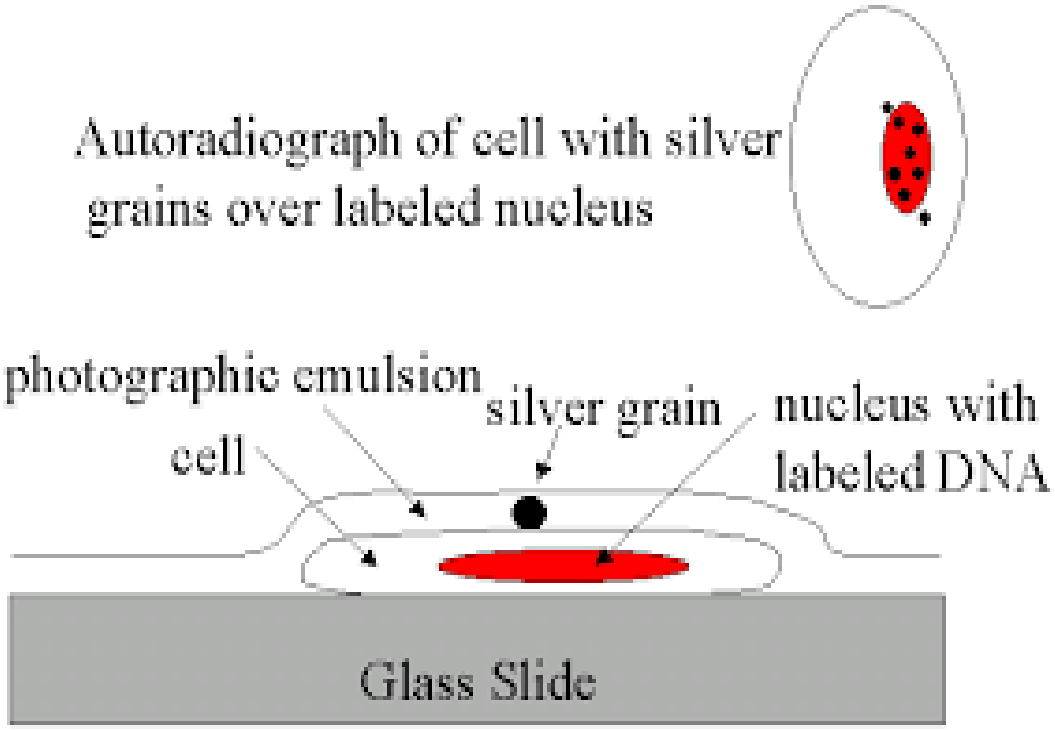
Production of a visible silver grain requires a number of ionization events, so the photographic response is not exactly linear to the amount of radiation present. Preflashing the film with a uniform low intensity of light "primes" each grain of silver to become reduced and visible after absorbing just one or a very few additional beta particles from the sample. This increases substantially the sensitivity of the film and also makes the photographic response more directly proportional to the amount of radiation in the sample. The signal-to-noise ratio is often increased by exposing the film to low

temperatures. The sensitivity can also be enhanced by using scintillation screens that emit visible light on encountering a beta particle; the light is recorded by the film.

Film-Less Autoradiography

Modern trends in autoradiography involve replacing high speed X-ray film with radiation detector systems, laser scanners, and computer-based imaging systems. A variety of radiation-detecting crystals and phosphors have been developed for this purpose. Storage phosphor screens are more sensitive, by a factor of about 20-100 for beta-emitting radionuclides, and they are reusable. The exposure time is also much less, by a factor of about 10, over conventional X-ray film, and samples may be processed at room temperature and without a darkroom or chemicals for film developing. Applications of filmless autoradiography include two-dimensional gels, Southern blots, Northern blots, immunoblots, and quantitative polymerase chain reaction (PCR).

Microchannel array detectors have been introduced to replace both X-ray films and phosphor screens. The new instruments are faster (by a factor of ~10) and have greater image resolution than do phosphor screens for detecting latent images from hybridization studies using macromolecules labeled with carbon-14, sulfur-35, phosphorus-32, and iodine-125 from flat gels, blots, membranes, tissue slices, and other flat specimens



Applications of Autoradiography

i. in the biological, chemical, and physical sciences, because it provides both qualitative and quantitative information (eg., images and amounts present).
ii. It may be used to image large, small, and microscopic specimens, including sectioned whole organisms, organs, tissues, cellular structures, and nucleic acids that contain some radiolabeled compound.
iii. Cells may be autoradiographed either in culture as a monolayer, on a glass slide, or on thinly sectioned living tissues from an animal organ or tumor.
iv. Microautoradioagraphy involves coating the sample directly with a radiation-sensitive emulsion; cellular constituents that have incorporated the radiolabel can be clearly identified.
v. Autoradiography is used with electrophoresis or chromatography to image radiolabeled macromolecules and other separated chemicals for quantitative analysis. For example, autoradiography is useful for indicating the position of hybridized nucleic acids on Southern blots and Northern blots, and of proteins on Western blots.

==========

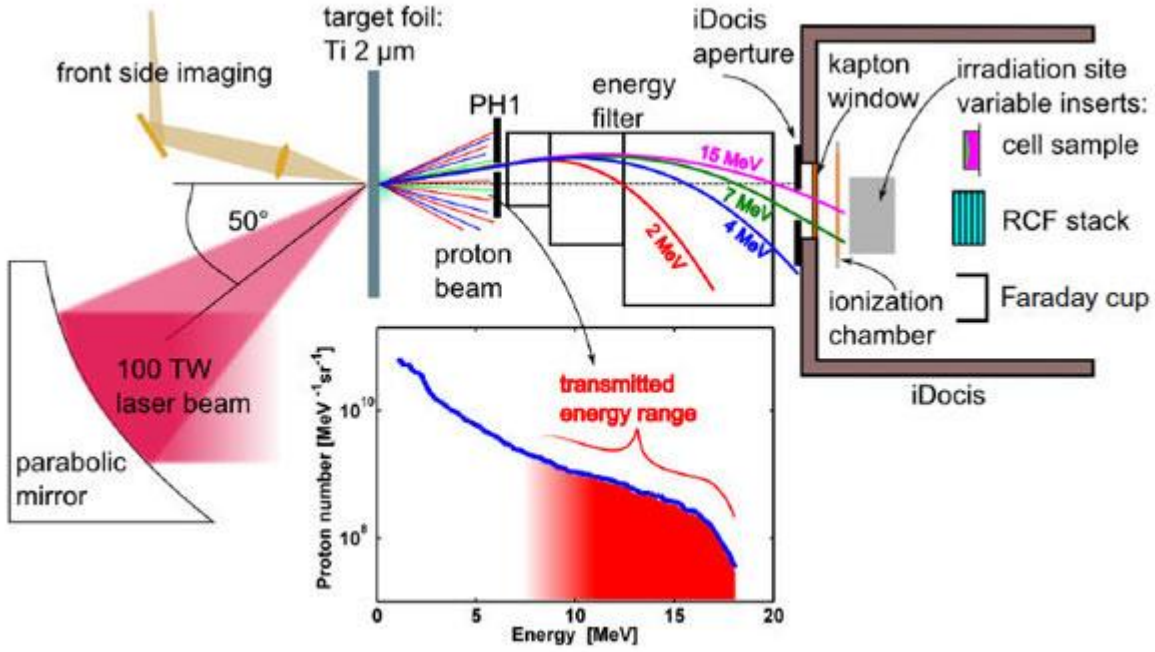
❖ Dosimetry

Radiation dosimetry in the fields of health physics and radiation protection is the measurement, calculation and assessment of the ionizing radiation dose absorbed by the human body. This applies both internally, due to ingested or inhaled radioactive substances, or externally due to irradiation by sources of radiation.

Internal dosimetry assessment relies on a variety of monitoring, bio-assay or radiation imaging techniques, whilst external dosimetry is based on measurements with a dosimeter, or inferred from measurements made by other radiological protection instruments.

Dosimetry is used extensively for radiation protection and is routinely applied to monitor occupational radiation workers, where irradiation is expected, or where radiation is unexpected, such as in the aftermath of the Three Mile Island, Chernobyl or Fukushima radiological release incidents. The public dose take-up is measured and calculated from a variety of indicators such as ambient measurements of gamma radiation, radioactive articulate monitoring, and the measurement of levels of radioactive contamination.

Other significant areas are medical dosimetry, where the required treatment absorbed dose and any collateral absorbed dose is monitored, and in environmental dosimetry, such as radon monitoring in buildings.



Measuring radiation dose

External dose

There are several ways of measuring absorbed doses from ionizing radiation. People in occupational contact with radioactive substances, or who may be exposed to radiation, routinely carry personal dosimeters. These are specifically designed to record and indicate the dose received. Traditionally, these were lockets fastened to the external clothing of the monitored person, which contained photographic film known as film badge dosimeters. These have been largely replaced with other devices such as the TLD badge which uses Thermoluminescent dosimetry or optically stimulated luminescence (OSL) badges.

A number of electronic devices known as Electronic Personal Dosimeters (EPDs) have come into general use using semiconductor detection and programmable processor technology. These are worn as badges but can give an indication of instantaneous dose rate and an audible and visual alarm if a dose rate or a total integrated dose is exceeded. A good deal of information can be made immediately available to the wearer of the recorded dose and current dose rate via a local display. They can be used as the main stand-alone dosimeter, or as a supplement to such as a TLD badge. These devices are particularly useful

for real-time monitoring of dose where a high dose rate is expected which will time-limit the wearer's exposure.

The ICRP guidance states that if a personal dosimeter is worn on a position on the body representative of its exposure, assuming whole-body exposure, the value of personal dose equivalent Hp(10) is sufficient to estimate an effective dose value suitable for radiological protection.[1] Such devices are known as "legal dosimeters" if they have been approved for use in recording personnel dose for regulatory purposes. In cases of non-uniform irradiation such personal dosimeters may not be representative of certain specific areas of the body, where additional dosimeters are used in the area of concern.

In certain circumstances, a dose can be inferred from readings taken by fixed instrumentation in an area in which the person concerned has been working. This would generally only be used if personal dosimetry had not been issued, or a personal dosimeter has been damaged or lost. Such calculations would take a pessimistic view of the likely received dose.

Internal dose

Internal dosimetry is used to evaluate the committed dose due to the intake of radionuclides into the human body.

Medical dosimetry

Medical dosimetry is the calculation of absorbed dose and optimization of dose delivery in radiation therapy. It is often performed by a professional health physicist with specialized training in that field. In order to plan the delivery of radiation therapy, the radiation produced by the sources is usually characterized with percentage depth dose curves and dose profiles measured by medical physicists.

In radiation therapy, three-dimensional dose distributions are often evaluated using the dosimetry technique known as gel dosimetry.

Environmental dosimetry

Environmental Dosimetry is used where it is likely that the environment will generate a significant radiation dose. An example of this is radon monitoring. Radon is a radioactive gas generated by the decay of uranium, which is present in varying amounts in the earth's crust. Certain geographic areas, due to the underlying geology, continually generate radon which permeates its way to the earth's surface. In some cases the dose can be significant in buildings where the gas can accumulate. A number of specialised

dosimetry techniques are used to evaluate the dose that a building's occupants may receive.

Measures of dose

To enable consideration of stochastic health risk, calculations are performed to convert the physical quantity absorbed dose into equivalent and effective doses, the details of which depend on the radiation type and biological context. For applications in radiation protection and dosimetry assessment the International Committee on Radiation Protection (ICRP) and International Commission on Radiation Units and Measurements (ICRU) have published recommendations and data which are used to calculate these.

Units of measure

There are a number of different measures of radiation dose, including absorbed dose (*D*) measured in:

- grays (Gy) energy absorbed per unit of mass ($J \cdot kg^{-1}$)
- Equivalent dose (*H*) measured in sieverts (Sv)
- Effective dose (*E*) measured in sieverts
- Kerma (K) measured in grays
- dose area product (DAP) measured in gray centimeters^2
- dose length product (DLP) measured in gray centimeters
- rads a deprecated unit of absorbed radiation dose, defined as 1 rad = 0.01 Gy = 0.01 J/kg
- Roentgen a legacy unit of measurement for the exposure of X-rays

Equivalent dose

Equivalent dose

The absorbed dose required to produce a certain biological effect varies between different types of radiation, such as photons, neutrons or alpha particles. This is taken into account by the equivalent dose (H), which is defined as the mean dose to organ T by radiation type R ($D_{T,R}$), multiplied by a weighting factor W_R .

Effective dose

Effective dose is the central dose quantity for radiological protection used to specify exposure limits to ensure that the occurrence of stochastic health effects is kept below unacceptable levels and that tissue reactions are avoided.

==========