Course title: Atomic and Nuclear Physics

Week # 12

Main Topics: Radiation detector types and measurement statistics

Lecturer: Jojo Panakal John

Lecture Learning Outcomes:

At the end of the lecture, you will be able to:

(i) Classify different types of survey detector types

(ii) Explain three classes of detectors and working

(iii) Describe possible errors and counting statistics

When it is necessary to detect, measure and monitor radiation in environment and living things we need to use the radiation survey detectors. These instruments are designed to detect and measure the presence of ionizing radiation and radioisotopes in the biosphere. There are several types of radiation survey detectors, each with its own characteristics and applications. Here we discuss some common types of survey dosimeters:

Geiger-Muller (GM) based survey meters:

GM counters are widely used for detecting and measurement of ionizing radiation. GM counters, sometimes called GM tubes (because of their shape) are operated by a gas filled tube with two electrodes kept at high potential difference. When radiation enters the chamber and interacts with gas in it, produces ionisation at large scale and an electric pulse is produced. The number of such electric pulses which are independent of the energy and nature of ionising radiation are counted with the accompanying electronics. GM survey meters are very compact, versatile and can be used for general radiation monitoring, environmental monitoring, and detecting radioactive contamination. With proper electronic and software support, they can be used to directly measure the radiation dose and other radiological parameters used in radiation survey.

Ionization Chamber:

The principle and operation of Ionization chamber is somewhat similar to that of GM counter. It is the simplest type of gas filled ionisation detector. It can be sued for detection and measurement of many classes of ionizing radiation like X-rays, gamma rays, alpha particles and beta particles. Ionisation chamber has a uniform response to radiation for a wide range of energies. It operates by measuring the electrical charge produced by an ionizing radiation passing through the gas in the chamber. Unlike the GM tube, it can provide continuous measurements and are often used for dose rate measurements as well as detection. Ionization chambers are commonly used in medical radiation therapy, industrial settings, and environmental monitoring.

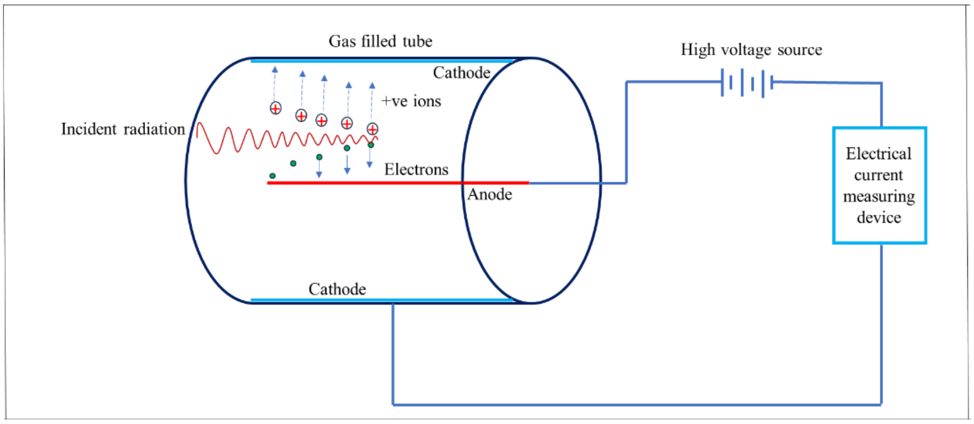

Figure 1 Schematic diagram of ionisation chamber

Scintillation Detectors:

The principle of all radiation detectors is the interaction of the incident radiation with a medium and resulting charges or light or tracks of radiation are used for the radiation detection. In the case of scintillation detector, scintillating material produces light flashes when the gamma rays from the radioactive material interacts with it. These light flashes are subsequently interacting with a photodiode which emits electrons. These electrons are amplified using photomultiplier tubes (PMT).

Scintillation detectors make use of special materials like NaI and ZnS those emit light flashes (scintillations) when exposed to ionizing radiations. Photodiodes detect light flashes from scintillators and photomultiplier tube amplify the emitted light in the form of electrons. Scintillation detectors are used in various fields, including medical imaging, environmental monitoring, and nuclear physics research.

Proportional Counters:

Proportional counters work similar to GM counters but at higher gas pressures and lower potential. Proportional counters can provide more detailed information about the energy of the incident radiation. Proportional counters are used in nuclear physics research and for identifying specific radionuclides in samples. The proportional counter is a type of gaseous ionization detector device used to measure particles of ionizing radiation. The most important feature of proportional counter is its capacity to measure the energy of incident radiation, by producing a detector output proportional to the radiation energy. It is widely used where energy levels of incident radiation must be known, such as in the discrimination between alpha and beta particles, or accurate measurement of X-ray radiation dose. The proportional counter uses a combination of the mechanisms of a Geiger–Müller tube and an ionization chamber. It operates with an intermediate working voltage between GM counter and ionisation chamber.

Solid-State Detectors:

Solid-state detectors use semiconductor materials to detect ionizing radiation. They offer advantages such as high sensitivity and the ability to discriminate between different types of radiation. Solid-state detectors are used in medical imaging, homeland security, and nuclear power plants.

Thermoluminescent Dosimeters (TLDs):

TLDs are materials that, when exposed to ionizing radiation, trap electrons. When heated, these trapped electrons release as visible light. The intensity of the light is proportional to the radiation dose. When a thermoluminescent material is exposed to ionizing radiation, it absorbs and traps some of the energy of the radiation in its crystal lattice. Later, when heated, the crystal releases the trapped energy in the crystal interstice in the form of visible light. A specialized detector measures the intensity of the emitted light, and this measurement is used to calculate the dose of ionizing radiation the crystal was exposed to. Since the crystal density is similar to human soft tissue density, the dose measurement can be used to calculate absorbed dose as well. TLDs are commonly used for personal dosimetry in occupational radiation monitoring and medical dosimetry.

Neutron Detectors:

Since neutrons are neutral, they do not ionise the medium through which it passes. But through wise use indirect ionisations by neutrons, they can be detected. Neutron detectors are specific detectors designed to specifically measure neutron radiation. They often use materials that interact with neutrons, producing detectable signals. By making slight modifications a normal GM counter can be converted into a neutron detector. When boron compounds (gaseous) are added in the gas filled tube, neutrons can fission boron leaving charged particles. These particles can ionise the medium thereby enabling the gas filled tube to detect them. Neutron detectors are used in nuclear power plants, research reactors, and for monitoring neutron fields in various applications.

Dosimeters:

Dosimeter is a generic name to a class of devices used primarily to measure the cumulative dose of ionizing radiation they receive over time by the persons exposed. Personal dosimetry is very important in radiation protection of general public as well as radiation workers. Dosimeters are commonly used by workers in radiation fields, such as nuclear power plant workers and healthcare professionals, to monitor their radiation exposure. The choice of detector depends on the specific requirements of the application, including the type of radiation to be detected, the energy range, and the level of sensitivity needed.

Resolving Time:

Resolving time of a radiation detector is the time interval between the detection of a radiation event and the production of a distinct output signal by the detector. In applications that involve rapidly changing radiation fields or require precise timing information, a fast-resolving time is critical. It influences the detector's ability to accurately capture the timing and sequence of events.

Different types of radiation detectors have varying intrinsic resolving times. For example, scintillation detectors and solid-state detectors often exhibit faster response times compared to gas-filled detectors. The physical design of the detector, including the size and geometry of the sensing element, can impact resolving time. Smaller detectors and those with optimized geometries tend to respond more quickly. The efficiency and speed of the electronics used to process and amplify the signals from the detector contribute to the overall resolving time. Advanced readout systems can enhance the speed of signal processing.

In nuclear physics experiments involving particle physics, the resolving time is crucial for accurately determining the properties of subatomic particles and understanding their interactions. Similarly in positron emission tomography (PET) and other medical imaging techniques, fast resolving times are essential for precise localization of radioactive tracers and improving image quality.

Resolving time of a radiation detector is a critical parameter that influences the detector's ability to capture the timing of radiation events accurately. Different applications have varying demands, and the choice of a radiation detector should consider the specific requirements of the intended use.

Statistics of radiation measurements:

Radioactive decay is a random process and one can expect variations in the measurement of radioactivity. The accuracy of a measurement of a quantity indicates how closely it agrees with the actual value. The precision of a series of measurements describes the reproducibility of the measurement. The closer the measurement is to the average value, the higher the precision. The closer the measurement is to the actual value, the more accurate the In many cases of radiation measurement, the measurements may be quite precise, but their average value may be far from the true value (less accuracy). Precision can be improved by eliminating the random errors, whereas better accuracy is obtained by removing both the random and systematic errors

When a series of measurements are made with a radioactive sample, the most probable value or the representative of these measurements is the average (arithmetic mean). The standard deviation of a series of measurements indicates the deviation from the mean value and is a measure of the precision of the measurements. Radioactive decay follows the Poisson distribution law, from which one can see that if a radioactive sample gives an average count of

$\bar{x}$, then its standard deviation σ is given by: $\sigma = \sqrt{\bar{x}}$

The mean of measurements is then expressed as $\bar{x} \pm \sigma$

Problem 1 A detector with a 30% efficiency was used to count a radioactive sample. The sample was counted for 300 mins and got a total count of 6,000. The background count was determined for 200 min a count rate of 10.0 cpm was obtained. What is the net sample count rate ?

Count rate of the sample, R = $\frac{6000}{300}$ – 10 cpm

= 20 cpm – 10cpm

= 10 cpm

Standard deviation of the count rate = σ

$$= \sqrt{\frac{10}{300} + \frac{10}{300}}$$

= 0.25

Activity of the sample, A $= \frac{10 \pm 0.25}{0.30}$

$$= \frac{10}{0.30} \pm \frac{0.25}{0.30}$$

= (33.3 ± 0.83) counts per minute

= (0.56 ± 0.014) Bq

Minimum Detectable activity:

The Minimum Detectable Activity (MDA) is defined as the smallest quantity of activity that we can detect with a system, in specific measurement conditions. MDA is evaluated with a predefined probability of 95%. That is 5% probability of making type I errors (assumption that a radionuclide is present, but actually it is not) and making type II errors (assumption that the radionuclide is not present, but actually it is).

The three formulae used in these methods are:

$$\text{MDA}_{\text{Currie}} = \frac{k^2+2k\sqrt{2B}}{\varepsilon \times i \times t}$$

$$\text{MDA}_{\text{KTA}} = \frac{0.5\times 2k^2+2k\sqrt{B'+B'\frac{N}{2m}}}{\varepsilon \times i \times t}$$

$$\text{MDA}_{11929} = w \times \frac{k^2+2k\sqrt{2B}}{1-k^2\times var(w)}$$

where B, B′ is the background, ε is the detection efficiency, *i* is the emission intensity, t is the measurement time and w is the weighting factor ($w = \frac{1}{\varepsilon \times i \times t}$), N is the number of channels of the ROI and m is the number of channels to the left and to the right of the ROI, used for background subtraction. The confidence level (k) used was 1.645.

In gamma ray spectrometry, the MDA value depends to a variety of parameters such are: detector intrinsic efficiency for E energy photons, emission intensity, spectrum acquisition time, detector resolution, geometric efficiency, the activity of other radionuclides found in spectrum, cosmic and telluric radiation background and electronic noise background which affects the resolution.

References:

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