AL-MUSTAQBAL UNIVERSITY

COLLEGE OF SCIENCE

MEDICAL PHYSICS DEPARTMENT

FOURTH STAGE

Al-Mustaqbal University – Medical Physics Depart.

Detection of Ionizing Radiation

Lecture five: Nuclear Detectors

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Nuclear Detectors:

Ionizing radiation is rarely detected directly. Instead, detectors usually measure the secondary products arising from the interactions of the radiation with the detector material. For example, as an alpha or beta particle traverses a detector's sensitive volume, electron-ion pairs or electron-hole pairs are created and the subsequent movement and collection of charges gives rise to an electrical pulse or current. Indirectly ionizing radiation such as gamma photons and neutrons must first undergo interactions in the detector material that produce secondary charged particles, recoil atoms or electrons that, in turn, produce charge pairs as they slow down.

The collection of the ionization created by radiation in a detector volume can be used simply to detect the passage of a radiation particle. The rate of generation of radiation-induced pulses can then be used to measure the rate at which radiation particles traverse the detector. Such detectors are termed radiation counters. In some detectors, the magnitude of the radiation induced pulse is related to the type of radiation particle and its energy. By measuring both the number of pulses and the distribution of pulse sizes produced by a given type of radiation, both the number and energy distribution of the incident radiation can be determined. These detectors can then be used as energy spectrometers. In some detectors the average current can be used as a measure of the amount of ionization or energy deposition, per unit mass of detector material, caused by incident radiation. These detectors can then be calibrated to measure radiation absorbed doses and are thus called dosimeters. In these lectures, the properties of some of the most common radiation detectors are reviewed.

An important aspect of radiation detection is an assessment of the uncertainties associated with ionization measurements. Both the release of radiation by radioactive decay and the interactions of radiation with matter are stochastic in

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nature. Thus, repeated measurements of radiation emitted by a source of constant activity, in a given detector volume in a given time interval, exhibit random statistical fluctuations. The quantification of such statistical fluctuations is a necessity in radiation measurements.

1- **Gas-Filled Radiation Detectors**

The idea of measuring the radiation induced ionization in a gas volume dates to the nineteenth-century. These early gas-filled detectors became known as ionization chambers. As ionizing radiation passes through a chamber, the motion within an electric field of the ion pairs formed inside the chamber produces an electrical current. The magnitude of the current is measured and correlated (calibrated) to the intensity of the radiation field. A very common geometry is a coaxial detector that consists of a thin, positively charged, center wire anode (held in place by insulators) surrounded by an outer, negatively-charged, cathode tube. The outer tube contains the gas and defines the active volume of the chamber. Air filled chambers may or may not be sealed from the ambient environment. A gas-filled chamber is illustrated in Fig. (1).

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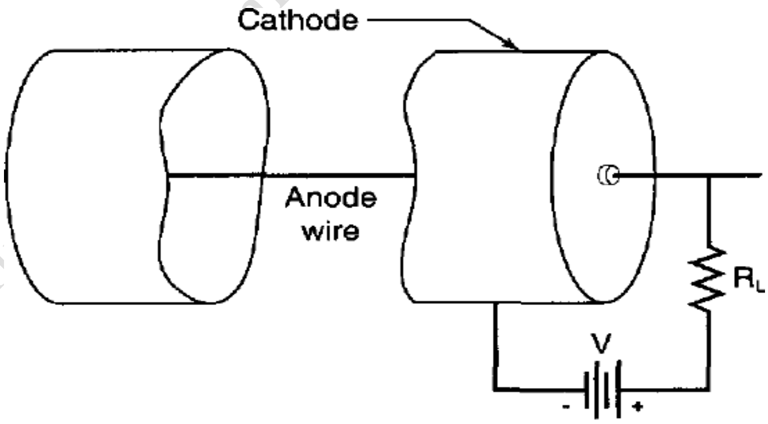

Figure (1) Basic elements of a gas-filled radiation-detector tube. The cathode is often used to seal the gas cavity from the ambient environment. The output voltage pulse is produced across the load resistor.

Radiation either interacts in the wall of the chamber or directly in the filling-gas. For incident electromagnetic radiation the dominant interactions, photoelectric effect, Compton scatter, and pair production, occur primarily in the chamber wall material. If the electrons released from the atoms in the wall material escape from the wall and enter the active gas volume of the chamber, then these charged particles (secondary radiation) produce ionization as they pass through the gas. The potential difference between the anode wire and the cathode establishes an electric field that causes positive and negative charges to move in opposite directions. Electrons rapidly drift toward the anode and positive ions migrate more slowly toward the cathode. The motion of these ion pairs causes a flow of current in the external circuit and establishes a voltage across the load resistance. If the incident radiation field contains beta particles, for example, then the chamber must be constructed so that these particles can enter the volume. This is achieved by placing a very thin "window" on one end of the tube.

There are three basic types of gas-filled radiation detectors: ionization chambers, proportional counters and Geiger-Mueller counters. All three are known asionization chambers, but they each have a unique process for forming the total number of ion pairs that are collected at the electrodes. All three operate by forming initial ion pairs from the incident radiation. Once these ion pairs are formed, it is important that they do not recombine and thereby fail to contribute to the electrical signal.

Figure (2) shows the various operational regions of gas-filled chambers. Region I represents the recombination region where the potential difference between the anode and cathode is not sufficient to collect all the initial ion pairs. Ion chambersoperating in this region are not useful radiation detectors.

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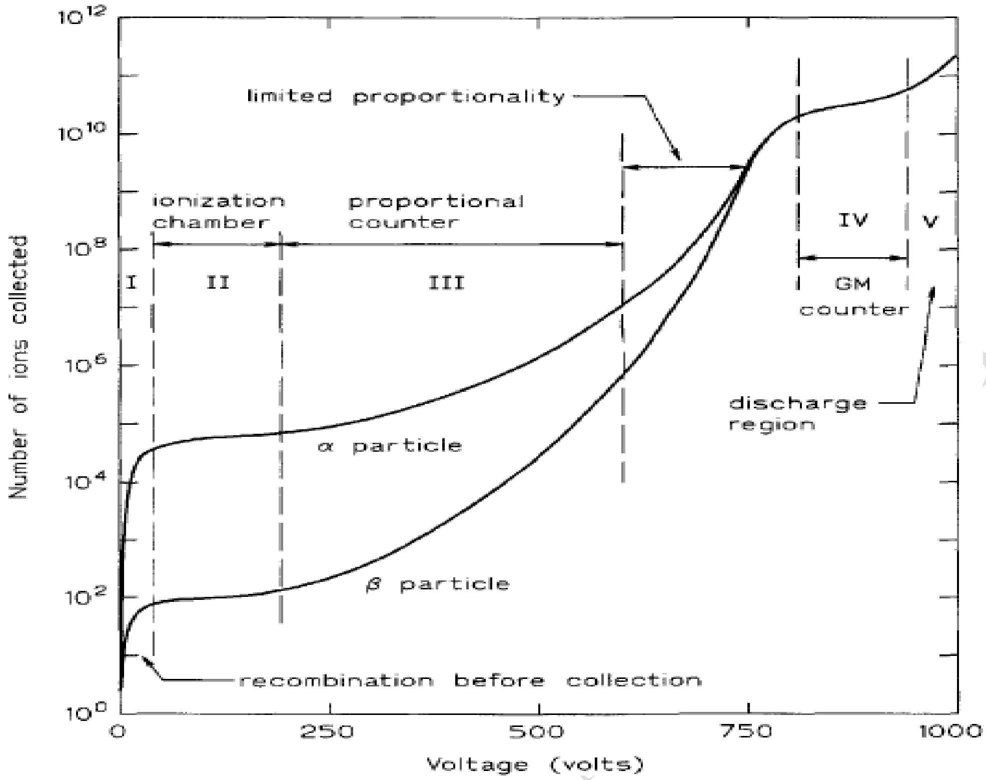

Figure (2) Operational regions for gas-filled radiation detectors.

As the potential difference between the anode and cathode is increased, the ionization chamber Region II is entered. In this region the resulting output current is referred to as the ionization chamber saturation current. Region III represents the proportional counter region. In this region, electrons acquire sufficient energy to induce secondary ionization, and hence multiplication. This internal ion-pair multiplication increases the total number of ion pairs in the active volume and, hence,the output current increases by a multiplicative factor M > 1. This region is called the proportional counter region since the output current, or total collected charge per interaction, is proportional to the initial number of ion pairs created by the incident radiation. Next is entered a limited proportionality region where the number of ion- electron pairs collected is relatively independent of the initial number of ion-electron pairs created by the incident radiation. This region generally is not useful operationally.

The region of Geiger-Mueller (GM) counter operation, Region IV, exhibits a "plateau" over which M reaches a nearly constant value. In this region one avalanche produces secondary photons whose interactions produce other local avalanches until the entire anode is surrounded by ion-electron pairs. In this region, the charge collected per interaction is no longer proportional to the initial number of ion pairs created. Therefore, it is very difficult to distinguish between different types of incident radiation or to gain knowledge about the energy of the incident radiation.

If the tube voltage is too large, the tube undergoes continuous avalanches around the central anode, one leading to another. This region V, is known as the continuous discharge region. Its entry normally leads to failure of the ion chamber.

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