Ionization Chambers

Ionization chambers or ion chambers are widely used as radiation monitors. They can be designed to respond to alpha particles, beta particles, gamma rays, x rays, and neutrons. The ion chamber is the most basic type of gas-filled radiation detector since it operates without gas multiplication. They are often operated by directly measuring the output current. When operated at the saturation current level (region II of Figure 2) as mentioned in previous lecture, the output current level is proportional to the intensity of the incident radiation and permits a direct measurement of the exposure rate. In an ion chamber with parallel-plate electrodes and a uniform electric field, current pulses from individual events can be registered, thereby allowing energy spectroscopy of the incident radiation. In their most common cylindrical geometry, however, ionization chambers cannot be used for this purpose since the pulse amplitude is dependent upon where the ion-electron pairs are formed in the detector.

Proportional Counters

Proportional counters are gas-filled chambers operated in region III of Figure (2) as mentioned in previous lecture. In this region, there is an internal multiplication in the chamber gas of the original ion-electron pairs created by the incident radiation. The physical mechanism for this multiplication process is discussed in the next section. This internal multiplication M is typically from 10 to 10,000. Because of the location of the gas multiplication avalanche, near the central wire, the output voltage pulse is not only amplified by a factor of M but the pulse amplitude is proportional to the total ionization energy deposited inside the active volume of the detector. This feature allows the proportional counter to be used as a spectrometer by using the output pulse amplitude to infer the energy of the incident radiation. Also, since the number of ion pairs is proportional to the initial ionization caused by the incident radiation, proportional counters can be used to distinguish between different types of charged particles. For example, one common application is to use a gas-flow counter to distinguish between beta particles and alpha particles.

Geiger-Mueller Counters

Geiger and Mueller developed the Geiger-Mueller (GM) detector in 1928. These radiation detectors are simple and robust devices that continue to be an important tool for sensing the presence of ionizing radiation. These gas filled detectors operate in region IV of Fig (2) as mentioned in previous lecture, and have the remarkable property that the size of the pulse, or total charge produced in the active volume is independent of the ionization energy deposited by the initial ion pairs. Consequently, these detectors do not have the inherent capability of distinguishing between different types of radiation or measuring radiation energy. They can, however, be configured so that they are sensitive to both charged particles (alpha particles and beta particles) and electromagnetic radiation (x rays and gamma rays).

A GM detector's sensitivity to charged particles is limited only by the thickness of the entrance window. The entrance window must be just thick enough to ensure that the chamber's filling gas does not escape. Once charged particles enter the active volume of the detector, they are detected with almost 100% efficiency since it takes only one ion-electron pair to initiate the pulse formation process.

Operating Voltage

One of the first steps in characterizing the operation of any gas-filled radiation detector is establishing the correct operating voltage. GM counters have a fairly wide range over which they can be operated. However, each counter should be operated near the center of its plateau within the GM region shown as region IV in Figure (2) as mentioned in previous lecture; this assures the best long-term performance because, at this voltage, small changes in the applied voltage have an insignificant effect on the amplitude of the output pulse. If the applied voltage is too low, then the gas multiplication is less than desired and the counting rate is very sensitive to small changes in voltage.

Applications

GM counters are often the detectors of choice for applications requiring information about only the magnitude or intensity of the radiation field. As such they find wide application in hand-held survey meters used to detector radiation fields. Other types of radiation detectors are more suitable if information is needed on the type or energy of the radiation. GM counters can be made in essentially any size and shape. Their low cost and high efficiency make them suitable as sensors of beta particles, x-rays and gamma rays. This is especially true if the radiation level is low enough that dead time losses are not a concern. These detectors are seldom used to detect neutrons although, with a cadmium cover surrounding the tube, the GM detector is sensitive to thermal neutrons and may be calibrated for thermal neutron flux density. Because of their poor energy response, inability to distinguish among different types of radiation, care must be taken to assure that some knowledge of the radiation field is available before making measurements with these counters.

Scintillation Detectors

There are two types of scintillation detectors, (1) solid crystals of inorganic material, and (2) plastics and liquids consisting of organic molecules. Their modes of excitation differ but the final result is the same. As charged particles pass through the material the energy that they lose is transferred into excitation energy of the inorganic crystals or molecular excitation of the organic molecules. The excitation energy is released in fluorescence, i.e., scintillation. The number of light photons emitted in any one event is proportional to the energy lost by the initial charged particle in that event. The time dependence of the fluorescence emission, and hence the output pulse shape, is dependent upon the specific type of material. Although scintillator material has been used for almost 100 years to detect ionizing radiation, their widespread application dates from the development of the photomultiplier tube (PMT) some 50 years ago. This vacuum tube device allows the measurement of extremely low levels of light. In a PMT the incident photons strike a photocathode thereby liberating photoelectrons. These photoelectrons are then accelerated towards another electrode at a higher potential where the energetic impinging electrons cause more electrons to be emitted. This electron multiplication process continues along a series of electrodes, each at higher potential than the previous and, at each, the electron population is increased. The number of electrons finally collected at the last electrode may be millions of times greater than the number of electrons that began the cascade. In essence, the PMT is a photon to electron amplifier. A typical scintillator detector assembly consists of a hermetically sealed scintillation material optically mounted to the PMT's photocathode, a voltage divider string in the PMT, and a preamplifier to produce a voltage pulse from the electrons collected at the last PMT electrode. These components are usually bound together in a single assembly By using this common configuration, the detector assembly is a stand-alone device that only requires an external voltage for the PMT and an external power supply for the preamplifier. Such an assembly is often called a scintillation detector.

The amplitudes of the output voltage pulses are proportional to the energy deposited by charged particles produced in the scintillation material. A gamma ray penetrating the scintillator material may give up its energy to the scintillator material through photoelectric interactions, Compton scattering and pair production reactions. If all of the incident gamma-ray energy is deposited in the scintillator material, the number of scintillation photons produced is proportional to the incident gamma-ray energy. Thus, by measuring the distribution of pulse sizes or the pulse height distribution (PHD) produced by the scintillation detector, the energy distribution of the incident gamma rays can be determined. Thus, one of the most important applications of scintillation detectors is gamma-ray spectroscopy.

NaI (Tl) Scintillation Detectors

The most popular inorganic scintillation material is NaI (Tl). These detectors are available in a variety of sizes and shapes. Because the maximum wavelength of light emitted by this material is 415 nm, it is easy to find commercially available PMTs whose maximum sensitivity matches the fluorescence emission spectrum. The relatively large decay time constant is normally not a problem since a very high efficiency for x-rays and gamma-rays dominates their radiation response. Of all the different NaI (Tl) detectors available to characterize gamma-ray radiation fields, the 3x3 inch right circular cylindrical detector, has historically been the favorite. This is the most extensively characterized NaI (Tl) detector and extensive efficiency data are available in the literature. A typical NaI (Tl) pulse height distribution is shown in Fig. (3). Because of its very high efficiency for electromagnetic radiation, NaI (Tl) is widely used to measure X-rays and gamma rays. X-ray detectors with a thin entrance window containing a very thin NaI (Tl) detector are often used to measure the intensity and/or spectrum of low energy electromagnetic radiation. Because NaI (Tl) detectors do not require cooling, they can be used in a great variety of applications. Field applications are possible since they can operate over a long time period in warm and humid environments, resist a reasonable level of mechanical shock, and are resistant to radiation damage. Basically, for any application requiring a detector with high gamma-ray efficiency and a modest resolution, the NaI (Tl) detector is clearly agood choice.

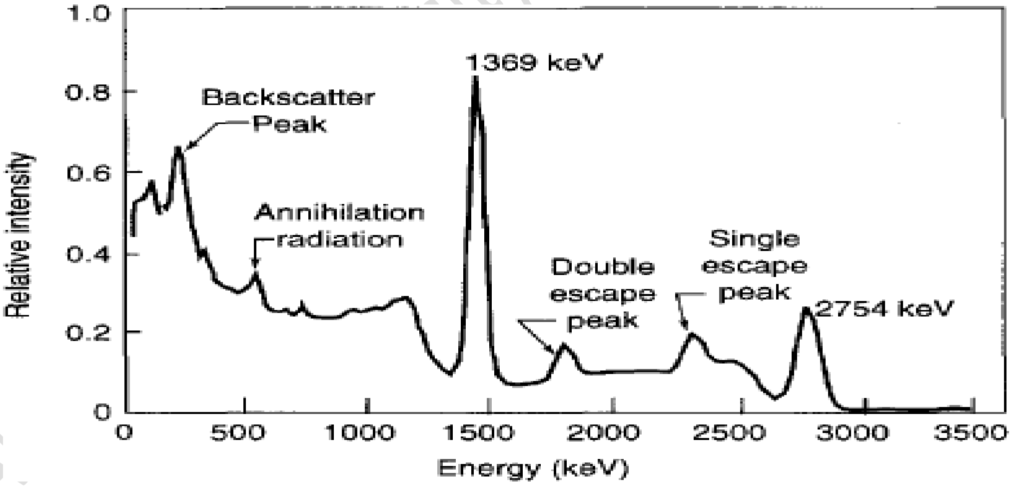

Figure (3): Pulse height distribution of the gamma rays emitted by the radioactive decay of ^{24}Na as measured by a NaI (Tl) scintillation detector. In addition to the two photo peaks, corresponding to the complete absorption of the ^{24}Na 2.754 and 1.369-MeV gamma rays, several other peaks are also apparent. The single and double escape peaks arise from the escape of one and both 0.511MeV annihilation photons generated in the NaI crystal by the annihilation of positrons created in pair- production interactions. The annihilation peak is caused by 0.511MeV annihilation photons produced outside the NaI crystal and subsequently depositing their energy in the crystal. The backscatter peak arises from photons scattered from the source material into the NaI detector.