Measuring Radiation: An Introductory Discussion (Part I)

Introduction

The purpose of this publication is to introduce the concepts and terminology needed to understand the operation and use of scintillation systems that are used in the detection of radiation. The text is intended to be at an introductory level so that those who are looking at a radiation detection system for the first time may find it comprehensible.

I. What is radiation and how is it detected?

We have all heard about x-rays. They are a form of radiation that is accepted as useful. With x-rays, it is possible to see inside objects without cutting them open. It is the basis of diagnostic tools that can show cavities in teeth, broken bones, tumors, tuberculosis and other diseases. X-rays also are familiar to us as the basis for the luggage inspection stations at airports.

X-rays are photons of electromagnetic radiation, e.g., light or radio waves, that have more energy and are more penetrating. Gamma radiation is less familiar because it does not enter into our daily lives as much as x-rays, and it has a bad reputation because it is associated with nuclear power plants and bombs. It should not be forgotten, however, that gamma rays are also used in cancer therapy (cobalt treatments), in medical imaging and in PET scanning. Gamma rays and x-rays are the radiation that is most often detected with scintillation detectors. Radiation such as electrons, positrons and other particles can be detected also.

To be able to detect the presence of gamma ray or x-ray radiation, it is necessary to convert the energy it carries to another form — an electric current, light pulse or chemical change. The energy range of interest for these photons is about 5 keV to 5 MeV. An eV is 1.6 x 10^{-19} watt-second; so 5 keV to 5 MeV is about 1 x 10^{-15} to 1 x 10^{-12} watt-second. This is a very small amount of energy and explains why a human being cannot feel the radiation! Compare it, for example, to a night light that uses about 5 watt-second of energy each second.

On the atomic scale, however, this represents an enormous amount of energy — sufficient energy to knock out or liberate hundreds and thousands of electrons. These electrons are measurable and observable. In the typical medical x-ray, these freed electrons cause chemical changes in photographic film which show up as an image when developed. Photographic film is one way to detect radiation, but it is difficult to be quantitative with a high degree of accuracy using this chemical means.

Measuring the liberated electrons directly (electric current) would be quantitative and is the most accurate but is limited for technical reasons to small volumes or low density detectors. Good examples are CdTe, silicon surface barrier (SB) and lithium drifted silicon Si(Li) detectors that can be up to a few cm in diameter and a few mm thick. An SB detector is used primarily for particle detection at room temperature and can do better than 0.5% energy resolution at 5.5 MeV. Germanium gamma-ray detectors can be fairly large, up to approximately 3 inches in diameter by 3 inches in length, but must be operated in a vacuum at liquid nitrogen temperatures. These detectors can achieve energy resolutions of better than 0.2% for 1.3 MeV gamma rays.

The most efficient detectors that can be made quite large and are quite dense are scintillation detectors. These convert the energy of the radiation to a light pulse. The

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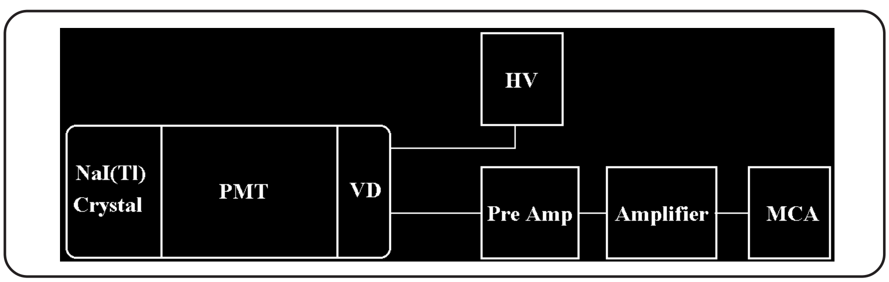
light is converted to electrons (an electric current) in a vacuum tube called a photomultiplier tube (PMT), which also amplifies the electron current by 5 or 6 orders of magnitude. A diagram of a basic scintillation detection system is shown below.

The PMT is biased by a high voltage (HV) power supply that connects to a voltage divider (VD). The VD divides the HV into discrete steps through a bank or series of resistors. Typically, 125 volts (V) is dropped per stage. The 125 V supplies the accelerating voltage to move the electrons from one PMT stage to the next PMT stage. At each stage, there is a multiplication factor of 4 to 5 giving a typical 8 or 10 stage PMT an overall gain of approximately 1×10^6.

The preamplifier is a charge integrating amplifier that collects the charge output of the PMT and generates a voltage pulse. The amplitude of the voltage pulse is proportional to the input charge. The output pulse has a slow exponential decay constant of 30 to 50 microseconds typically and is called a tail pulse.

The main amplifier is often referred to as a linear amplifier or a shaping amplifier. It increases the gain of the preamplifier signal from a few hundred millivolts to a few volts for input to the MCA. It also shapes the tail pulse, changing it to a near gaussian-shaped pulse that is appropriate for the MCA.

The MCA is a sophisticated voltmeter with a memory. It measures the voltage amplitude of the input pulse and stores a count in the appropriate memory location. When many pulses have been collected and binned, the result is called a histogram of counts vs. voltage or counts vs. channel. This histogram is referred to as a spectrum and the system or instrument is doing spectroscopy. All of the electronics are designed to be linear such that each bin is proportional to the energy of the photon that was detected and inversely proportional to the wavelength. Thus, an increasing channel number is indicative of increasing energy.



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