RADIATION PROTECTION NOTE 3: RADIATION DETECTION AND MEASUREMENT

INTRODUCTION

The fact that the human body cannot detect a lethal dose of ionising radiation has done much to raise apprehension in the public about this type of hazard.

In order to detect radiation we rely on devices that are based on the physical or chemical effects of radiation and they can be found in the following categories.

(a) The ionisation in gases
(b) The ionisation and excitation in certain solids
(c) The changes in chemical systems
(d) The activation by neutrons

Instruments used for the measurement of radiation fall into two classes; survey instruments and personal monitoring devices. The majority of survey instruments rely on detectors that utilise the ionisation of gases. Others use crystalline materials that react to gamma ray photons by producing a Compton effect electron or a photo-electron. Personal dosimeters rely on thermo-luminescence, photographic or optical luminescence effects.

SURVEY INSTRUMENTS

<u>The Ion Chamber</u>

The interaction of radiation in a gas results in the production of ion pairs consisting of a negative ion (electron) and a positive ion. The ion chamber consists of a cylindrical chamber containing air at atmospheric pressure. A moderate voltage (100 volts) is applied between two electrodes, the anode and cathode. Ionising radiation entering the chamber by a thin end window produces ion pairs and the negative ions are attracted to the positive electrode (anode) and the positive ions to the negative electrode (cathode). This flow of ions produces a small electric current which is a measure of the radiation dose rate, ie ionisation produced per second.

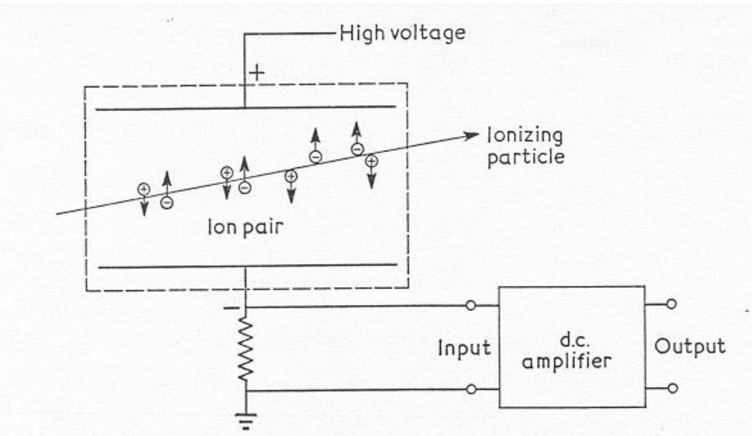

Figure 1: The Ion Chamber

The current produced in the ion chamber is very small (~ 10^{-12}amps) and therefore very sensitive amplification electronics is required making this type of monitor very expensive.

The ion chamber is the ideal instrument for measuring dose rate and cumulated dose in integrating models since the ionisation properties of air are similar to those of the elements in the human body. Ion chambers are not recommended for the measurement of surface contamination as they are relatively insensitive and have a moderately slow response time to the detection of ionising radiation.

The Geiger-Muller Counter

If the voltage in an ionisation system is increased beyond a certain point, an effect known as gas amplification occurs. The negative ions are now accelerated towards the anode and are of sufficient energy to cause further ionisation themselves before reaching the anode.

If the voltage is increased further the gas amplification or avalanche effect is so great that a single ionising particle produces a large pulse of current which can be converted by a simple rate meter to produce a click on a loudspeaker. The size of the pulse is the same regardless of the energy of the incident radiation.

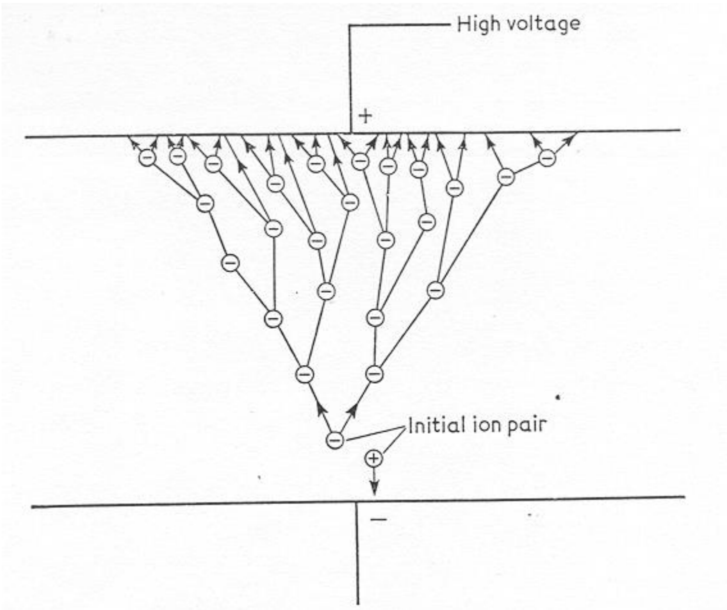

Figure 2: Gas amplification

The Geiger counter is normally constructed in a tubular form with the metal outer casing acting as the cathode and a thin wire running through the centre acting as the anode. There is a thin end window usually constructed of mica to allow soft beta particles to enter. Inside the tube the counter gas (normally 90% argon and 10% methane) is held at less than 1 atmosphere. The methane is there as a quenching agent to "mop" up the positive ions which would otherwise strike the cathode, releasing further electrons which would cause the counter to go into continuous discharge.

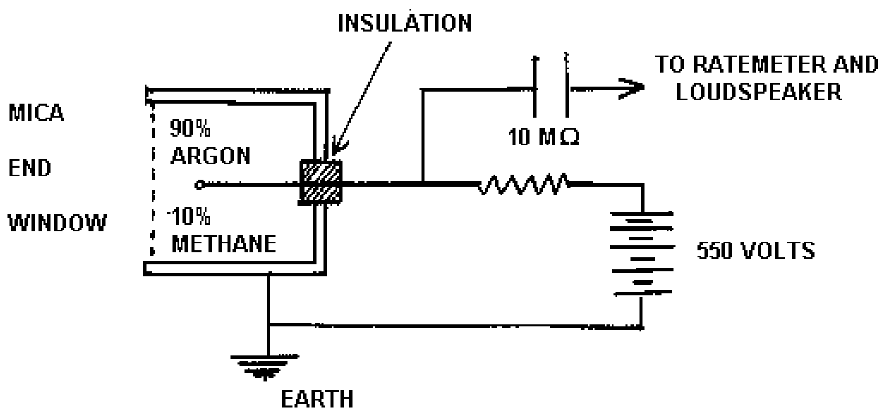

Figure 3: The Geiger-Muller counter

Modern counters now use halogen as a quenching agent as methane has a finite lifetime and halogen does not.

Solid State Detectors

The term solid state detectors refers to certain classes of crystalline substances which exhibit measurable effects when exposed to ionising radiation. In these substances electrons exist in discrete energy bands separated by forbidden bands. The two highest energy bands in which electrons normally exist are called the valence band and the conduction band. The transfer of energy from a photon or charged particle to a valence band electron may raise it to through the forbidden band into the exciton band or the conduction band. The vacancy left behind by the electron is known as a hole.and is analogous to a positive ion in a gas system.

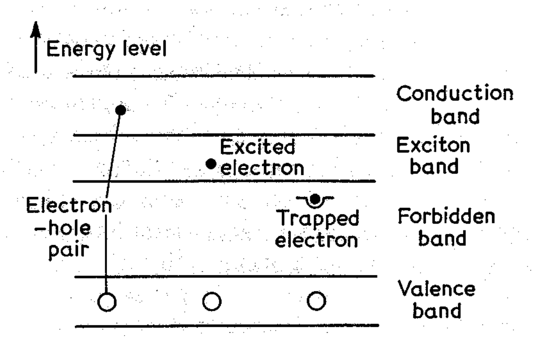

Figure 4: Ionisation, excitation and trapping

The three states shown above may be permanent or only exist for a short time depending on the material and temperature. In returning to the valence band the difference in energy is emitted as fluorescent radiation, normally a light photon.

The Scintillation Counter

Scintillation counters are based on detection of the fluorescent radiation emitted when an electron returns from an excited state to the valence band.

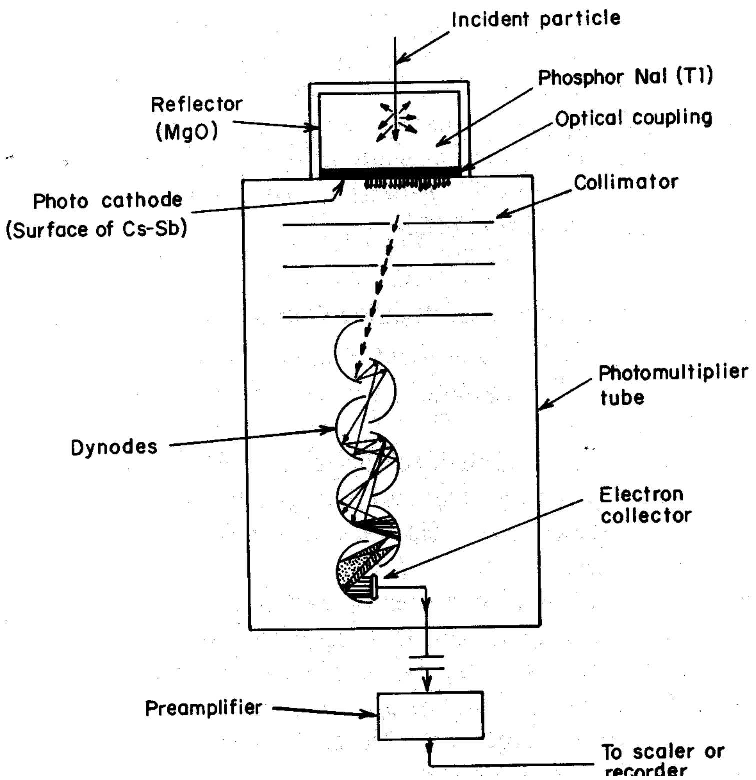

Figure 5: The scintillation counter

Most monitors use sodium iodide (NaI) as the scintillator as it only takes about 1 μs for the electron to return to the valence band. The absorption of 1 MeV gamma photon results in about 10,000 excitations and the same number of photons of light.

These scintillations are detected by the front face of a photomultiplier tube via optical coupling between the light tight can surrounding the NaI and the photo-cathode of the PM tube. The photo-cathode detects these very faint light signals and converts them into electrical pulses. The size of the pulse is proportional to the photon energy dissipated in the crystal.

PERSONAL MONITORING DEVICES

Thermoluminescent detectors

These detectors utilise the electron trapping process. One of the most common materials is lithium fluoride which is selected because after irradiation electrons in the crystal matrix are raised to a metastable excited state. Under normal temperatures these electrons remain in this state, but heating the material to over 200^{0}C releases them from the traps and they rapidly return to the valence band with the emission of a light photon. If the device is heated in the dark in the presence of a photomultiplier tube the light photons can be measured and this is proportional to the radiation dose that the TLD badge received. Once these devices have been "zeroed" they are rewrapped and reissued for further wear. Some of these devices can reach a considerable age and are expensive to replace if they are lost. Sometimes full zeroing does not take place and badges have been known to arrive at the customer already carrying a small apparent radiation dose. This can lead to problems when the wearer has been credited with a radiation dose which may be classed as penetrating and the only work carried out has been with beta emitters which would give a skin dose only.

Film badge dosimeters

Ionising radiation reacts with photographic film in the same way as visible light ie, exposure to radiation blackens the film. Photographic film contains molecules of silver bromide that forms metallic silver when irradiated. When the film is developed the optical density is used to assess the dose that the dosimeter has received over a set wearing period. Film badge holders contain several filters to ascertain whether the dose received is whole body or skin.

Film badges can only be used once and therefore are much cheaper than TLD badges. They also arrive at the customer with a guaranteed zero dose which avoids the problems associated with TLD badges.

Optically stimulated luminescence (OSL) dosimeters

Optically stimulated luminescence dosimeters measure radiation exposure due to X-ray, gamma and beta radiation through a thin layer of aluminium oxide. After use, the aluminium oxide is stimulated with laser light causing it to fluoresce in proportion to the amount of radiation exposure. These devices are extremely sensitive and more accurate than TLD or film dosimeters.

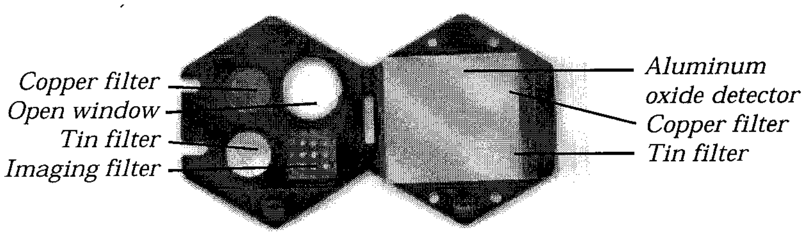

Figure 6: The Luxel optically stimulated luminescence dosimeter