Lecture 12

Radiation Dose Measurements with Ion Chambers

Gamma ray Exposure:

- The definition of exposure is the measured amount of charges due to the ionization created by the secondary electrons 9 negative electrons or positive positrons) formed within a volume element of air and mass when there secondary electrons are completely stopped in air.
- Since it is unlikely that all the secondary electrons will be stopped within a finite volume, we use the idea of compensation.
- The principle of compensation is that there is a sea of air outside the detector volume which also produces secondary electrons. Statistically there should be a uniform interaction of gamma radiation in all localized space, so those secondary electrons which escapes form a finite detector volume are compensated by secondary electrons formed in the air sea which will trigger (deposit their energy) into the chamber. Thus the charge registered is balanced by both contributions.
- Fig 5.9 illustrates how a uniform gamma field will compensate for lost secondary electrons in a finite detector volume.
- Fig. 5.10 shows a free air ionization chamber where compensation is required in the horizontal direction only since secondary electrons are formed in a volume that does not allow the electrons to reach the electrodes, so all energy is deposited in the vertical direction, however, since the horizontal direction has 2 area rendered insensitive (due to guard rings) compensation is required for the secondary electrons which pass into the insensitive areas.
- Note that this design works as long as the incident beam intensity is not appreciably reduced as it goes through the detector. This design is also used for energies < 100 keV
- For higher energies a small chamber with an enclosure material whose properties are as similar to air as possible and a thickness larger than the range of the secondary electrons is used (Table 5.2 gives several E vs. thickness examples)
- In this case the shell is said to be air equivalent if it reacts in the same way as a compressed air shell (which could replace the enclosure material)
- When the walls are sufficiently thick (and the flux of secondary electrons leaving the surface is no longer dependent on the wall thickness) electronic equilibrium is attained and the current from a chamber of constant air volume will be independent of wall thickness.
- For standard gamma rays this is ≤ 1 cm of material with ≈ atomic number
- The exposure rate for such a chamber is

  $R[C/kg.s] = I_s[A]/M[kg]$ where I_s is the saturated ion current and M is the mass of the air volume at STP

$$M = 1.293\left[\frac{kg}{m^3}\right]V\left[m^3\right]\frac{P}{P_0}\frac{T_0}{T}$$

Where V is the volume of the chamber [m^3] , P is the air pressure within the chamber, P_0 is standard pressure (760 mm Hg or 1.013 x 10^5 Pa), T is the temperature in the chamber and T_0 = 273.15 K

- For routine monitoring R ~ 10^{-3} R/hr are of interest (7.167 x 10^{-11} C/kg s)
- For a 1000 cm^3 ion chamber this lead to an I_s = 9.27 x 10^{-14} A, which is quite small, so sensitive electrometers and careful chamber designs are required.
- Chamber meant to measure very low dose rates are filled with high pressure to increase their sensitivity, generally Ar to reduce recombination rates

Absorbed Dose:

Bragg-Gray Principle – the absorbed dose D_m in a given material can be deduced from the ionization produced in a small gas-filled cavity within that material by :

$$D_m = WS_mP,$$

where W is the average energy loss per ion pair, S_m is the relative mass stopping power (energy loss per unit density) of that material to that of the gas, and P is the number of ion pairs per unit mass found in the gas.

<u>Applications of DC ion chambers</u>

Radiation Survey instruments:

- Properties include air equivalent enclosures of closed air chambers and battery powered electrometer circuits. Walls are generally Al or plastic.
- The "condenser R-meter" uses charge integration, where a charged capacitor discharges when irradiated.
- A pocket chamber is a small condenser R-meter where a built in quartz fiber electroscope may be used for readout.

Radiation Source Calibrations:

- Typically the walls are made of brass or steel and may accommodate a highly pressurized gas (20 atm) for better sensitivity.
- The inner electrode are made of thin foil Al or Cu
- The calibrator have geometry dependence seen in Fig.5.13

Measurement of Radioactive gases:

- Can measure radioactive gases by introducing them as part of the fill gas of the chamber, sampling on a continuous flow basis (this is useful for β emitters)
- Entrances and exits are provided on the chamber to allow sampling of continuous flow
- The ionization current in the chamber is given by:

$$I = \frac{\overline{E}\alpha e}{W},$$

where I is the ionization current in [A], $\bar{E}$ is the average energy deposited in the gas per disintegration [eV], α is the total activity [Bq], e is the electronic charge [C], and W is the average energy deposited per ion pair in the gas [eV].

Remote sensing of ionization:

- An application where irradiated air is introduced into the chamber and detected (the chamber is not irradiated).

<u>Pulse Mode Operation:</u>

General Considerations:

- Analyzing the representative circuit (Fig 5.14) indicates the reaction of the detector to ion pair production. C is the capacitance in the chamber plus any other parallel capacitance. V_R is the output waveform.
- The voltage across the load R is the basic electrical signal and when there are no ionizing charges in the chamber, there is no electrical flow and the voltage across R and the signal are zero.
- With ionized particle drift, the particles induce charges on the electrodes reducing the initial voltage on the chamber electrodes V_0, producing a voltage across the resistor V_R, building to a max value of accumulated charge from all the pairs.
- Once the maximum has been reached (all ion pairs collected) the charge will decrease as dictated by the time constant, RC of the circuit.
- Even though free electron collection times are on the order of 10^{-6} s, the drift time of the ions is ~ 10^{-3} s, so time constants must be on the order of milliseconds, which may lead to pulse pile up.
- To alleviate these concerns, pulse type chambers are run in electron sensitive mode where a time constant between ion and electron collection times is chosen. The amplitude of the pulse will then reflect the electron drift and pulses will have much faster rise and fall times.