Radiation Detection and Measurement

Lecture 12

Chapter 5: Ionization chambers

Gamma-ray exposures

- 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.

Gamma-ray exposures

- 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.

Gamma-ray exposures

- Fig 5.9 illustrates how a uniform gamma field will compensate for lost secondary electrons in a finite detector volume.

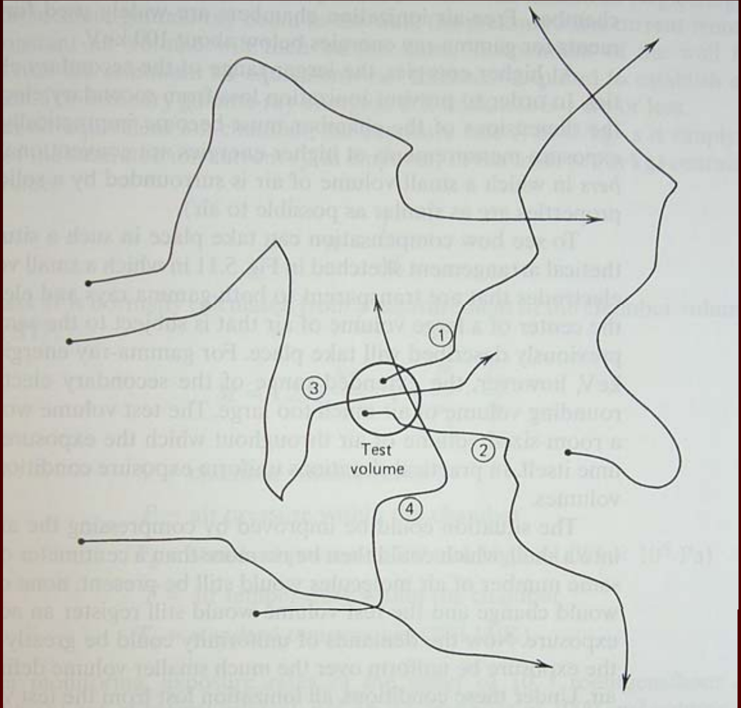

Figure 5.9 The principle of compensation in the measurement of gamma-ray exposure. If the density of gamma-ray interactions is uniform, the test volume will record an amount of ionization that is just equal to that produced along the extended tracks of all the secondary electrons formed within the test volume (such as tracks ① and ② above). The ionization produced by these electrons outside the volume is compensated by ionization within the volume which is produced by tracks originating elsewhere (such as tracks ③ and ④).

Gamma-ray exposures

- 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.

Gamma-ray exposures

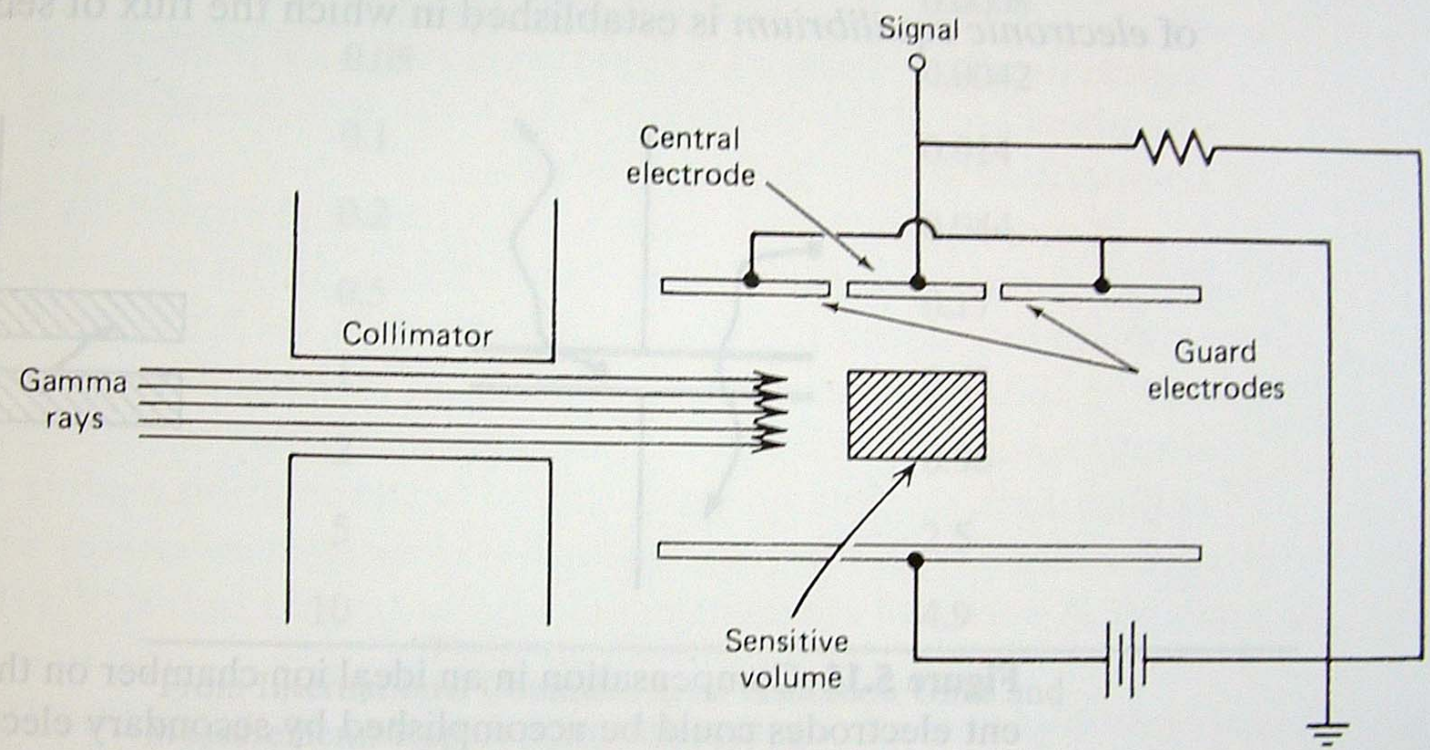

Figure 5.10 The free-air ionization chamber. Because secondary electrons created in the sensitive volume cannot reach the electrodes before stopping, compensation is required only in the dimension parallel to the incident radiation.

Gamma-ray exposures

- 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)

Compensation: primary uniform exposure vs. secondary electrons

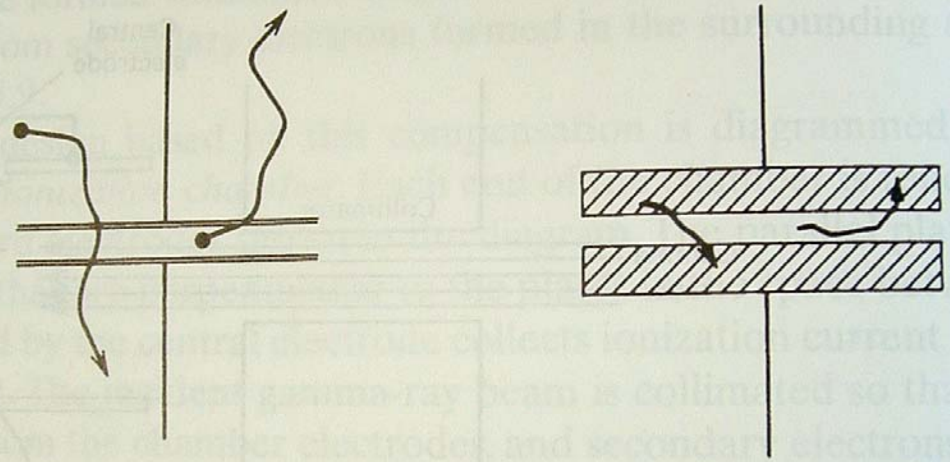

Figure 5.11 Compensation in an ideal ion chamber on the left with fully transparent electrodes could be accomplished by secondary electrons created outside the chamber. However, uniform irradiation conditions seldom exist over the required large surrounding volume of air. On the right, the chamber is provided with air-equivalent solid walls that are thicker than the maximum secondary electron range. Now compensation can take place from secondary electrons formed within the much smaller volume of the walls.

Gamma-ray exposures

Table 5.2 Thicknesses of Ionization Chamber Walls Required for Establishment of Electronic Equilibrium[a]

Photon Energy (MeV)	Thickness[b] (g/cm^2)
0.02	0.0008
0.05	0.0042
0.1	0.014
0.2	0.044
0.5	0.17
1	0.43
2	0.96
5	2.5
10	4.9

[a]From International Commission on Radiation Units and Measurements Report ICRU #20 (1971).

[b]The thickness quoted is based on the range of electrons in water. The values will be substantially correct for tissue-equivalent ionization chamber walls and also for air. Half of the above thickness will give an ionization current within a few percent of its equilibrium value.

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Gamma-ray exposures

- 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.

Gamma-ray exposures

- 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

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

Gamma-ray exposures

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

- Where *V* is the volume of the chamber [m^3] , *P* is the air pressure within the chamber, *P0* is standard pressure (760 mm Hg or 1.013 x 105 Pa), *T* is the temperature in the chamber and *T0* = 273.15 K

Gamma-ray exposures

- For routine monitoring R ~ 10^{-3} R/hr are of interest (7.167×10^{-11} C/kg s)
- For a 1000 cm3 ion chamber this lead to an I_s = 9.27×10^{-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 :

$$D_m = W S_m P$$

- 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.

Application of DC ion chambers: 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.

Application of DC ion chambers: 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

Application of DC ion chambers: Radiation source calibrations

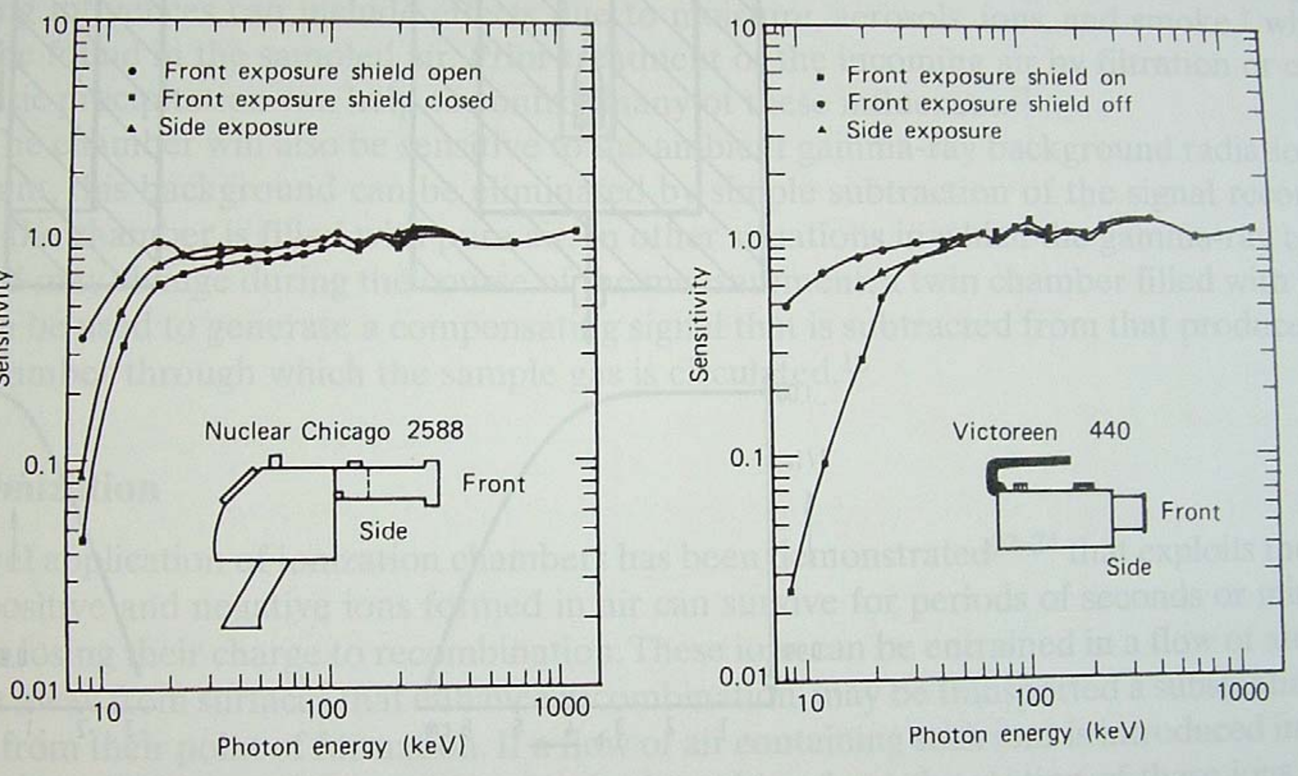

Figure 5.12 Energy calibration of two different gamma-ray survey meters. (From Storm et al.[15])

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Application of DC ion chambers: Radiation source calibrations

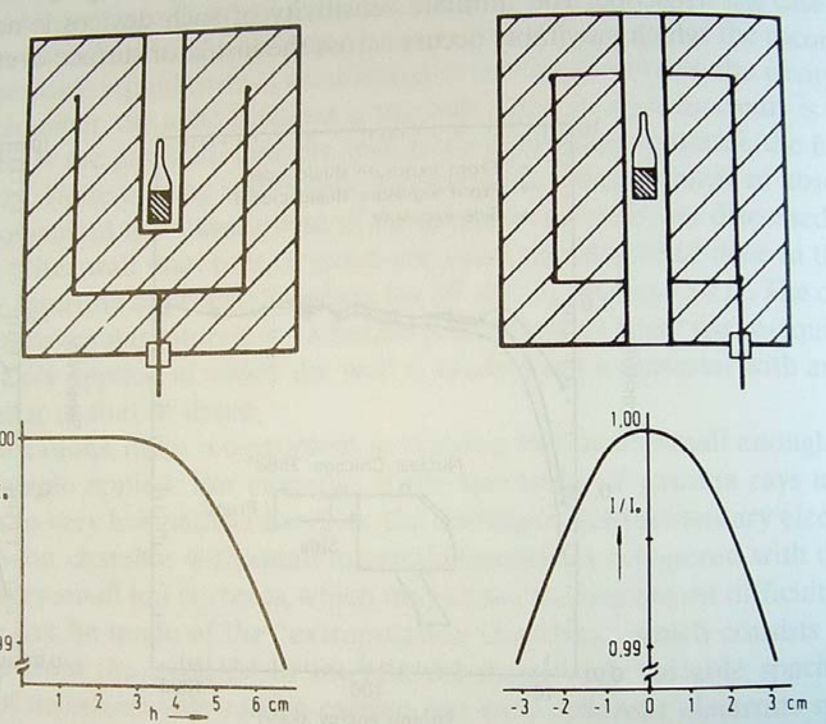

Figure 5.13 Ionization chambers used for calibration of gamma-ray sources. The curve below each configuration shows the behavior of the ionization current for small displacements of the source position. (From Weiss.[17])

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Application of DC ion chambers: 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

Application of DC ion chambers: Measurement of radioactive gases

- The ionization current in the chamber is given by:

$$I = \frac{\bar{E}\alpha e}{W}$$

  - 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].

Application of DC ion chambers: Remote sensing of ionization

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

Pulse mode operation: 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.

Pulse mode operation

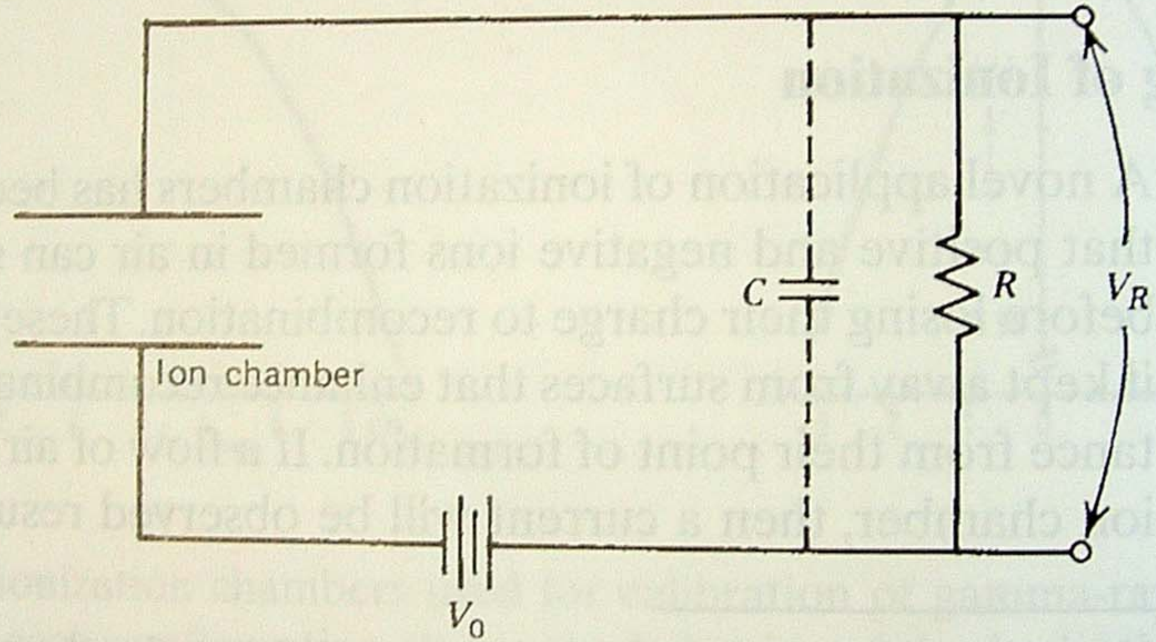

Figure 5.14 Equivalent circuit of an ion chamber operated in pulse mode. Here C represents the capacitance of the chamber plus any parallel capacitance. V_R is the output pulse waveform.

Pulse mode operation

- 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.

Pulse mode operation

- 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.