Journal club

Dr A. Haghparast
Medical physics department

Ionization Chambers

Chapter 12

F.A. Attix, Introduction to Radiological Physics and Radiation Dosimetry

Introduction

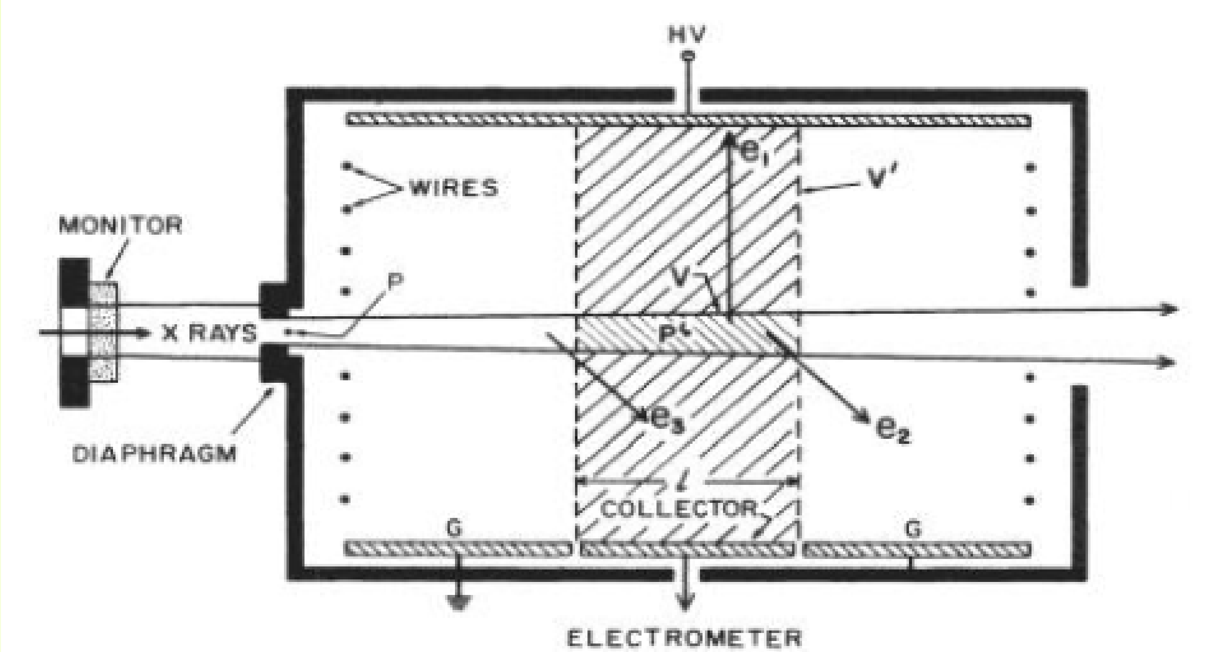
- The ionization chamber is the most widely used type of dosimeter for precise measurements
- They are commercially available in a variety of designs for different applications
- If the ion-collecting gas volume is precisely known the chamber is an absolute dosimeter
- This is not usually practicable outside of national standards laboratories, as there are advantages to working with dosimeters having calibrations traceable to such a laboratory

Free-air ion chamber

- The objective is to measure all the ionization produced by collision interactions in air by the electrons resulting from x-ray interactions in a known air mass, which is related to exposure
- There are different designs of free-air chambers used in standardization laboratories in different countries, some cylindrical and some plane-parallel in geometry
- First consider the plane-parallel type, used at the NBS in calibrating cavity ion chambers for constant x-ray-tube potentials from 50 to 300 kV

Free-air ion chamber

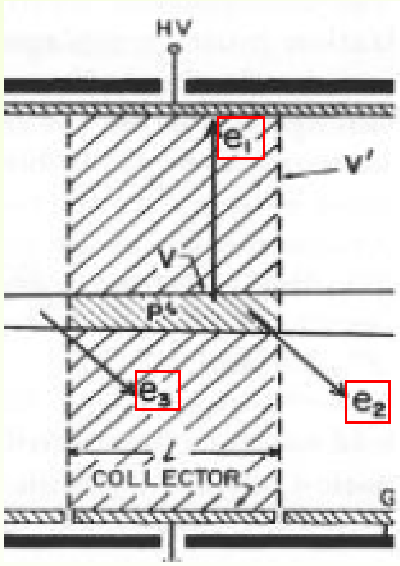
Typical standard free-air ionization chamber (Wyckoff-Atix)



- Main components: Pb shielding box, diaphragm, plates parallel to the beam
- Guard electrodes, and a set of wires provide a uniform electric field
- The ionization for an exposure measurement is produced by electrons originating from volume V; the measured ionization is collected from V`

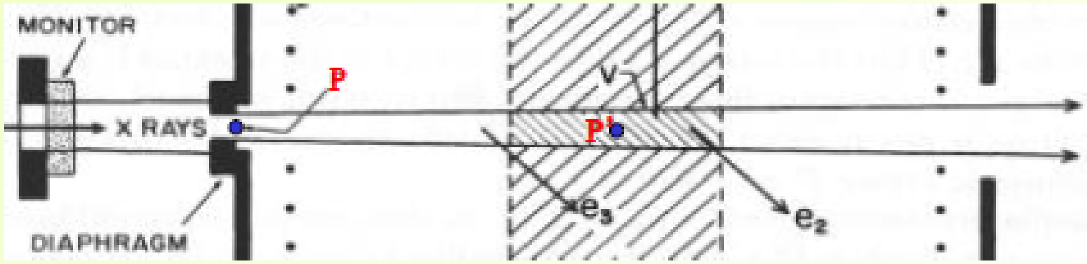
Free-air ion chamber

- The lateral dimensions of the chamber are great enough to accommodate electrons like e_1, which remain within V' and thus produce all their ionization where it will be collected and measured
- The electrons like e_2, which originate within V, may have paths that carry some of their kinetic energy out of V', but the remaining ionization they produce will go to the grounded guard plate instead of collector plate



- This ionization is replaced by other electrons such as e_3 that originate in the beam outside of volume V
- Volume V` as a whole is in CPE

Free-air ion chamber



- The exposure at the aperture (point P) determined by the measurement must be corrected upward by the air attenuation between P and the midpoint P' in V
- The volume of origin V can be replaced by a cylindrical volume $V_c = A_0 l$, where A_0 is the aperture of area, l is the path length of photon traversing V
- If Q (C) is the charge produced in V', the exposure at point P is

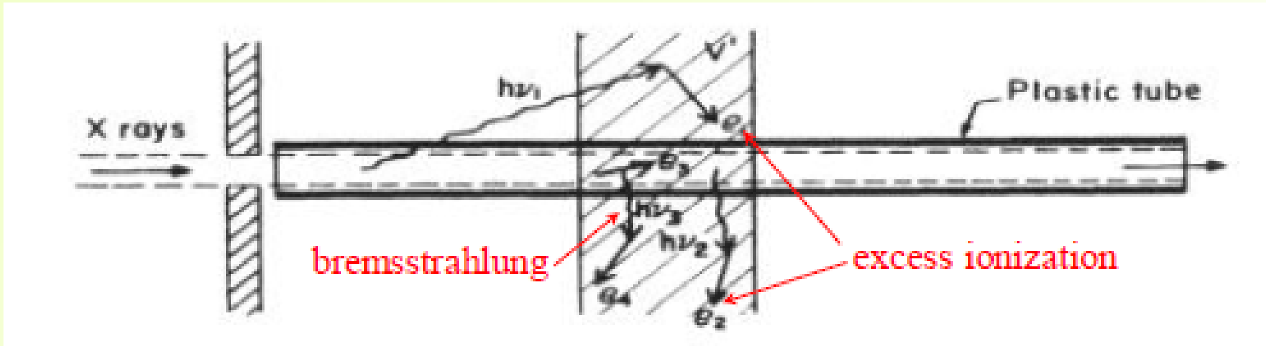
$$X = \frac{Q}{m} e^{\mu x'} = \frac{Q}{l A_0 \rho} e^{\mu x'}$$

where x' is the distance from P to P', and μ is the air attenuation coefficient

Free-air ion chamber

- In the preceding treatment μ was taken to be the narrow-beam attenuation coefficient for the x-rays passing through air
- This supposes that scattered photons do not result in measurable ionization in the chamber, which is not strictly the case
- A plastic-tube method was developed to experimentally determine the ionization contribution due to scatter and bremsstrahlung x-rays producing ionization

Free-air ion chamber

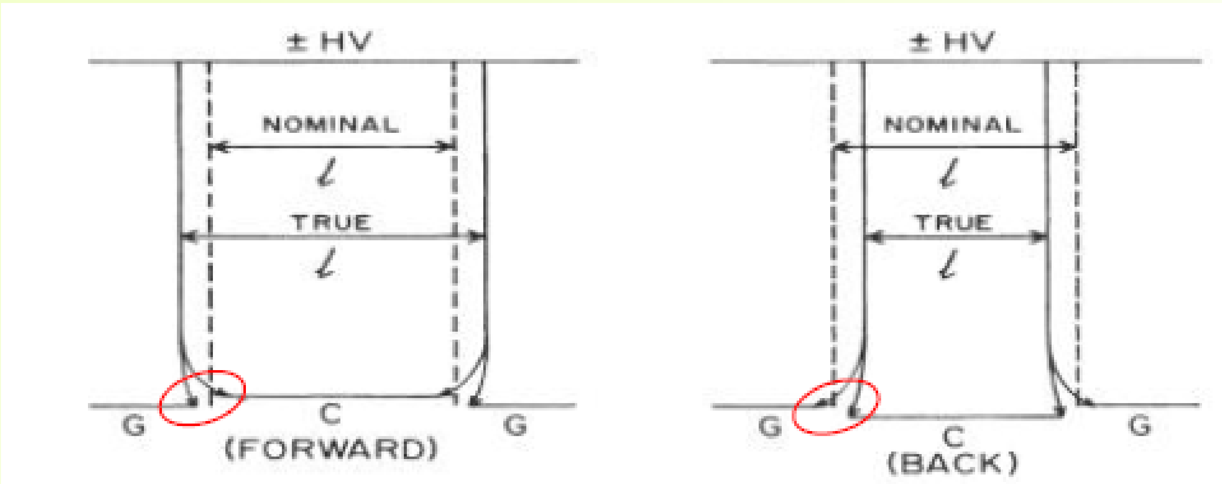


- A tube of nearly air-equivalent material such as Lucite, extending the full length of the ion-chamber enclosure, is positioned inside the chamber so that the x-ray beam passes through it from end to end without striking it
- The plastic is completely coated with conducting graphite, and biased at half of the potential of the HV plate to minimize field distortion
- The ratio of the ionization measured with and without the tube gives the fraction f_s (~0.003 for a chamber of 50x20x20 cm^3) of the total ionization that is contributed by scattered and bremsstrahlung x rays

Electric field distortion in parallel-plate chamber

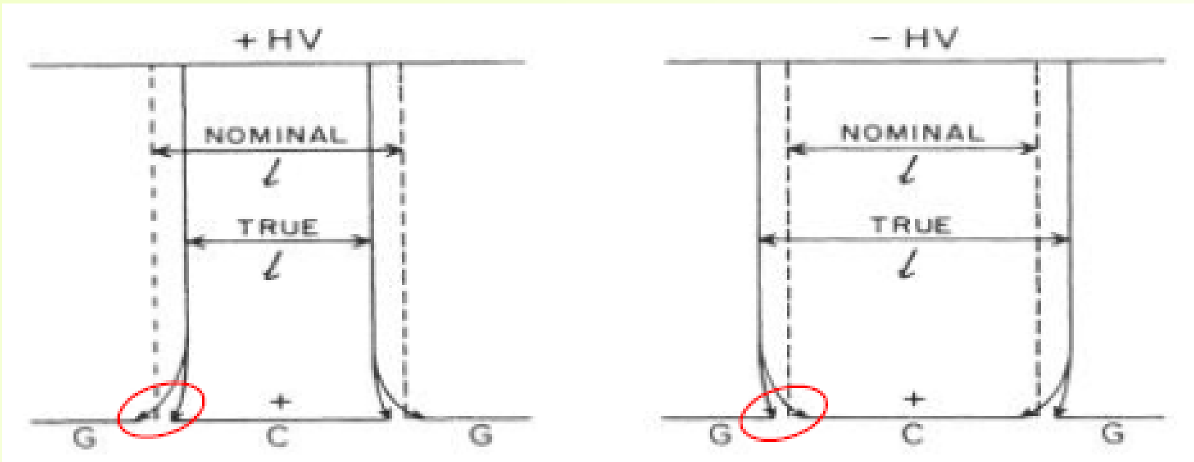
- Parallel-plate free-air chambers must have a uniform electric field between the plates, to assure that the dimensions of the ion-collection volume V' and the length of the volume V are accurately known
- In addition to the graded-potential guard wires:
  a. all the plates must be parallel to each other and to the beam axis, which must be perpendicular to the front and back boundaries of the volume V',
  b. the collector and guard plates must be coplanar, and
  c. the collector has to be kept at the same electrical potential as the guards (usually at ground)

Electric field distortion in parallel-plate chamber



Effect of collector (*C*) misalignment with guards (*G*); condition *b* is not satisfied

Electric field distortion in parallel-plate chamber



Effect of collector plate surface potential being higher (~ +1 V) than guard plates; condition *c* is not satisfied

Conception and realization of a parallel-plate free-air ionization chamber for the absolute dosimetry of an ultrasoft X-ray beam

J.-E. Groetz,[1, a)] N. Ounoughi,[1,2] C. Mavon,[1] A.Belafrites,[2] and M. Fromm[1]

[1)] *Laboratoire Chrono-Environnement UMR CNRS 6249,*
Université de Franche-Comté, 16 route de Gray, 25030 Besançon Cedex,
France

[2)] *Laboratoire de Physique des Rayonnements et Applications, Université de Jijel,*
B.P. 98 Ouled Aissa, Jijel 18000, Algérie

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We report the design of a millimeter-sized parallel plate free-air ionization chamber (IC) aimed at determining the absolute air kerma rate of an ultra-soft X-ray beam ($E = 1.5$ keV). The size of the IC was determined so that the measurement volume satisfies the condition of charged-particle equilibrium. The correction factors necessary to properly measure the absolute kerma using the IC have been established. Particular attention was given to the determination of the effective mean energy for the 1.5 keV photons using the PENELOPE code. Other correction factors were determined by means of computer simulation (COMSOL and FLUKA). Measurements of air kerma rates under specific operating parameters of the lab-bench X-ray source have been performed at various distances from that source and compared to Monte-Carlo calculations. We show that the developed ionization chamber makes it possible to determine accurate photon fluence rates in routine work and will constitute substantial time-savings for future radiobiological experiments based on the use of ultra-soft X-rays.

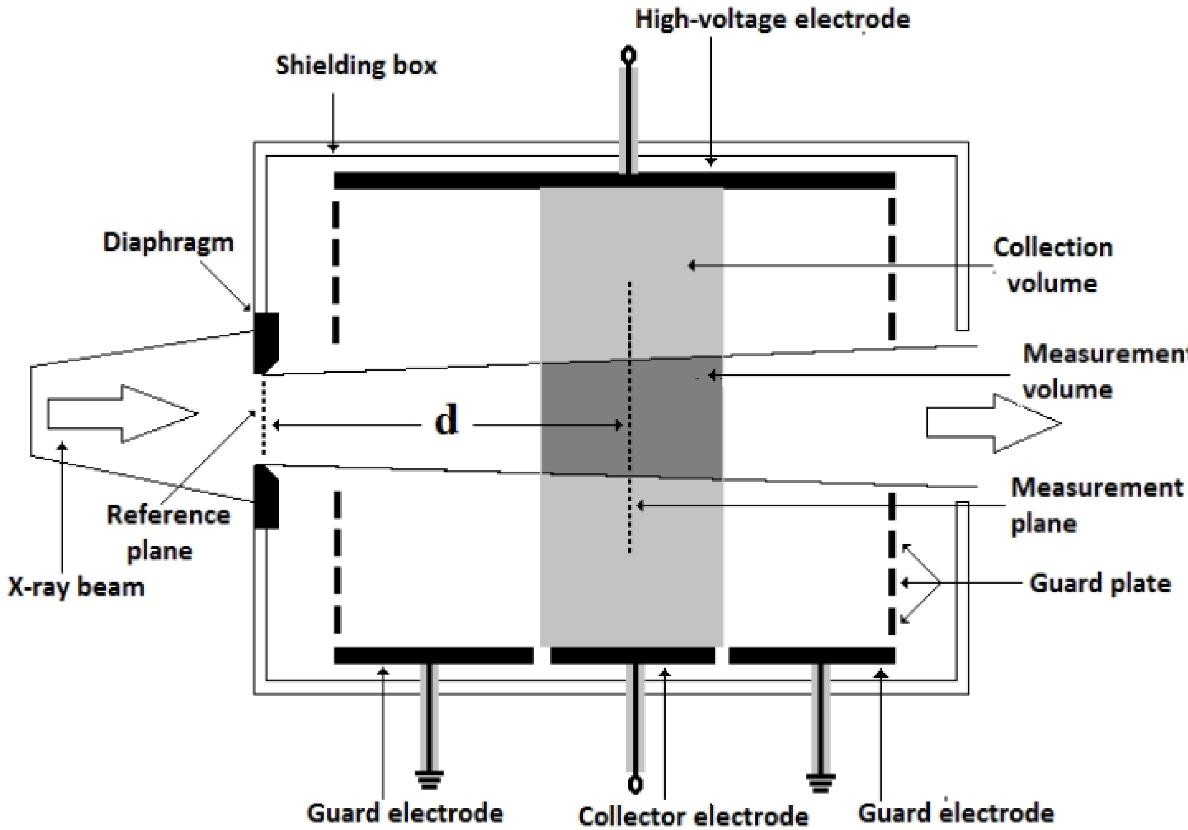

FIG. 1. Schematic diagram of a parallel-plate free-air ionization chamber, d represents the distance between the reference plane and the measurement plane.

$$\dot{K} = \frac{I}{\rho_{\text{air}} V_m} \times \frac{W_{\text{eff}}}{e} \times \frac{1}{1-g} \prod_i k_i \quad (1)$$

where I (A) is the measured ionization chamber current, ρ_{air} is the density of dry air under measured temperature and pressure conditions (at standard conditions 293.15 K and 101.33 hPa, $\rho_{\text{air}} = 1.2048$ kg.m^{-3} with relative uncertainty 0.01%, as defined by NIST), W_{eff} is the effective mean energy necessary to create an electron-ion pair in dry air (W_{eff} must be calculated for the Al Kα X-rays, i.e. for 1.5 keV photons,[27,28] detailed in section III B) ; e is the elementary charge; g is the mean fraction of the secondary electron energy lost to bremsstrahlung radiation which is negligible when ultrasoft X-rays are absorbed in air[21,29] and $\prod_i k_i$ is the dimensionless product of all necessary chamber correction factors.[21,22,27,28,30–33]

- $k_{\rm at}$, the attenuation factor in air along the distance d between reference and measurement plane[22] (see Fig. 1.); since this factor depends on the density of air in the ambient conditions of temperature and pressure, it was calculated with these corrections;[34]

- $k_{\rm TP}$, the mass correction factor for taking account of the pressure and temperature variations.[35] This factor has a low sensitivity to ambient pressure variations, but it is more sensitive to ambient temperature variations. In our case, an artificial weathering chamber is used to circulate dry or humid air in the irradiation chamber, to control both temperature and hygrometry;

- $k_{\rm H}$, the factor applied to correct the variation in the air hygrometry

- $k_{\rm R}$ is the factor for correcting the initial recombination in the collection volume, determined according to the two-voltage method;[36,37] for small volume chambers, the general recombination is negligible;[38] $k_{\rm R}$ is determined based on a set of two electrical current measurements I_1 and I_2 at two different voltages V_1 and V_2 :
  $k_R = 1 + (I_1/I_2 - 1)/(V_1/V_2 - I_1/I_2)$

- k_p is the polarization factor calculated using direct (I_+) and inverse (I_-) chamber currents[21] : $k_p = (|I_+| + |I_-|)/(2|I_-|)$

- k_{Exc} the factor to correct the excess charge due to the ion pairs produced by the initial photon interaction in air,[22,27] calculated with the following relation $k_{\mathrm{Exc}} = 1 - 1/N_{\mathrm{ion}} = 1 - W(T)/(E \times \mu_{\mathrm{en}}/\mu)$; at $E = 1500$ eV, μ_{en} and μ are very close (0.25% difference) and W(T) is equal to 34.36 eV (see section III B);

- k_{Field} the factor to correct the distortion of the electric field in the collection volume;[39],

- k_e and k_s are respectively the correction factors for electron-loss and coherently scattered and fluorescence photons;[30] those factors are generally determined with Monte-Carlo simulations.