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Some remarks concerning the measurement of kerma with a cavity ionization chamber

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The relation between exposure X and kerma K in air is by definition given by

$$X = K\,(1 - G)\,\frac{e}{\overline{W}} \;, \tag{1}$$

where

G is the part of the electron energy lost in bremsstrahlung,

e is the electron charge and

$\overline{W}$ is the mean energy to produce an ion pair in air.

I. Determination of exposure and kerma

When exposure is measured with a graphite cavity chamber, one generally assumes that the bremsstrahlung produced by electrons originating in the chamber walls is not reabsorbed. Then exposure is given by the relation

$$X = \frac{dQ}{dm}\,\frac{1}{\overline{f}}\,\frac{\mu_{en}/\rho}{\mu'_{en}/\rho'}\,k_{at}\,k_{CEP}\,k_{sc}\,k_{an} \;, \tag{2}$$

where

dQ is the electrical charge produced in the air of the cavity (mass dm),

$\overline{f}$ is the mean ratio of stopping powers for air and graphite,

μ_{en}/ρ and μ'_{en}/ρ' are the mass energy absorption coefficients for air and graphite.

All k's are correction factors due to the causes mentioned:

k_{at} : attenuation of the beam in the walls,

k_{CEP} : mean origin of electrons,

k_{sc} : photons scattered from the chamber walls,

k_{an} : axial non uniformity of the beam.

The other correction factors (saturation, humidity, etc.) are supposed included in the ratio dQ/dm.

From equations (1) and (2) we obtain for the kerma

$$K = \frac{dQ}{dm} \frac{\overline{W}}{e} \frac{1}{f} \frac{\mu_k/\rho}{\mu'_{en}/\rho'} \prod k . \tag{3}$$

μ_k/ρ and μ'_k/ρ' are the mass energy transfer coefficients for air and graphite, for which we have the relations $\mu_{en}/\rho = (\mu_k/\rho)(1 - G)$ and $\mu'_{en}/\rho' = (\mu'_k/\rho')(1 - G')$.

$\prod k$ is the product of all correction factors quoted above.

If bremsstrahlung would be entirely reabsorbed in the chamber walls, equations (2) and (3) should be replaced by

$$X = \frac{dQ}{dm} \frac{1}{f} \frac{\mu_{en}/\rho}{\mu'_k/\rho'} \prod k , \tag{4}$$

$$K = \frac{dQ}{dm} \frac{\overline{W}}{e} \frac{1}{f} \frac{\mu_k/\rho}{\mu'_k/\rho'} \prod k . \tag{5}$$

As a matter of fact, part of the bremsstrahlung is always reabsorbed in the walls and this part increases with wall thickness. Then, one might expect that in reality the numerical values of X and K should be intermediate between those resulting from the two sets of equations given above. However, one usually applies an extrapolation technique to zero wall thickness which not only corrects for scattered radiation, but also for the part of bremsstrahlung which is reabsorbed. Therefore equations (2) and (3) are still valid.

II. Some calculations concerning bremsstrahlung

Although the correction for the reabsorption of bremsstrahlung is performed in an experimental way, as said above, it is interesting to try to evaluate it, at least approximately. For this purpose, we have to determine the values of G and G', the bremsstrahlung spectrum, and the reabsorption of the bremsstrahlung. The calculation is made for a ^{60}Co source.

1. Bremsstrahlung production: values of G and G'

The tables of Hubbell (1969) giving μ_{en}/ρ and μ_k/ρ are not sufficiently accurate for a good determination of G and G' for the energy of ^{60}Co. It is preferable to calculate these values (for the Compton electron spectrum) from the tables of Berger and Seltzer (1964). We then find G = 0.43% and G' = 0.36%.

2. Bremsstrahlung spectrum

When an electron of initial energy T_o, in the course of its slowing down, passes from an energy T to an energy $T - \Delta T$, the loss ΔT may be expressed as

$$\Delta T = \Delta T_{coll} + \Delta T_B ,$$

where ΔT_{coll} is the part of energy lost in collisions and ΔT_B the part transferred to bremsstrahlung photons.

The spectral distribution $S(T,\tau)$ of the energy fluence of these photons is given by

$$S(T,\tau) = \tau \frac{d\sigma(T,\tau)}{d\tau} \Bigg/ \int_o^T \tau \frac{d\sigma(T,\tau)}{d\tau} \, d\tau , \qquad (6)$$

where τ is the bremsstrahlung photon energy and $d\sigma(T,\tau)/d\tau$ is the cross section for bremsstrahlung. The values of the cross section were calculated from Koch and Motz (1959). As the spectrum $S(T,\tau)$ varies with energy T, a weighted mean of the spectrum $\bar{S}(T_o,\tau)$ has to be evaluated on the slowing down electron spectrum. This was done in the continuous-slowing-down approximation. A second weighted mean for the initial energy electron Compton spectrum was performed leading to the spectrum $\bar{\bar{S}}(h\nu,\tau)$ which is given in Fig. 1 for the case of incident photons of 1.25MeV. The mean energy of the bremsstrahlung is about 0.04 MeV.

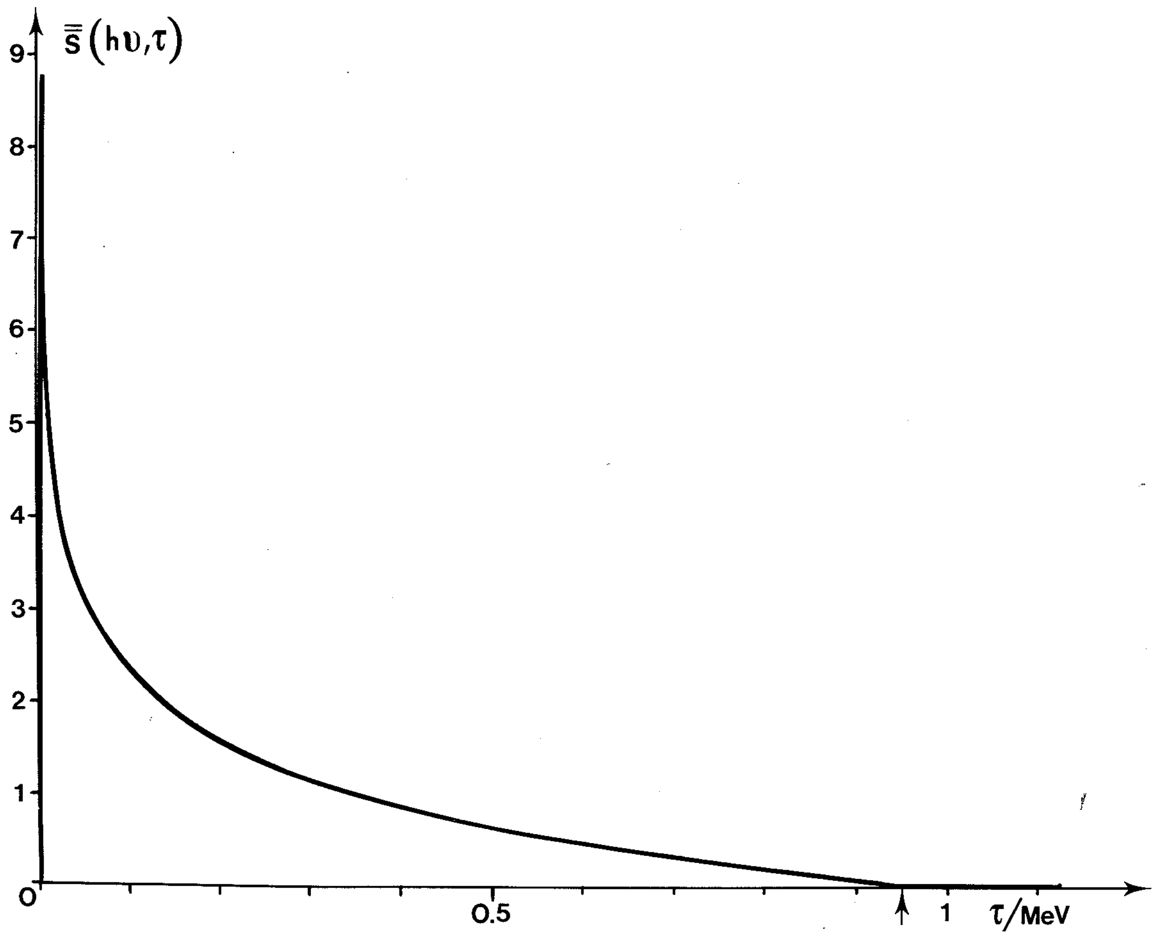

Figure 1 - Spectral distribution $\bar{\bar{S}}(h\nu, \tau)$ of the energy fluence of bremsstrahlung photons ($h\nu$ = 1.25 MeV)

3. Reabsorption of the bremsstrahlung

The calculation was made for a graphite cavity chamber, type BIPM, the section A of which is placed perpendicularly to the beam axis with the chamber positioned between the planes z_1 and z_2 from the source origin. The cavity placed in the middle plane z_m has a thickness dz_m supposed infinitely thin.

The energy E_B produced by bremsstrahlung in the graphite walls is given by

$$E_B = \int_{z_1}^{z_2} A \, \rho' \, dz \, G' \, K'_m \, \frac{z_m^2}{z^2} \, e^{-\mu'(z - z_1)} , \qquad (7)$$

where K'_m is the kerma in graphite at z_m* and μ' is the linear attenuation coefficient of the primary beam. Neglecting second order terms, we have

$$E_B = A \rho' (z_2 - z_1) G' K'_m e^{-\mu'(z_m - z_1)} . \tag{8}$$

A fraction α of this energy is reabsorbed in the graphite walls. For the sake of simplicity (and since the order of magnitude of G is small), it is assumed that the energy αE_B is uniformly reabsorbed in the graphite. In a volume element $a\,dz_m$ at z_m, the reabsorbed energy ΔE is

$$\Delta E = \alpha G' K'_m e^{-\mu'(z_m - z_1)} a \rho' dz_m . \tag{9}$$

If the graphite element $a\,dz_m$ is replaced by air, the contribution ΔQ to the ionization, due to bremsstrahlung, is

$$\Delta Q = e \frac{f}{W} \frac{\rho}{\rho'} \Delta E = e \frac{f}{W} \alpha G' K'_m e^{-\mu'(z_m - z_1)} a \rho dz_m ,$$

where f holds for electrons ejected by bremsstrahlung photons.

The ionization Q corresponding to the electron energy lost by collision is

$$Q = e \frac{\bar{f}}{W} K'_m (1 - G') e^{-\mu'(z_m - z_1)} a \rho dz_m \Big/ k_{CEP} k_{an} . \tag{10}$$

Hence, the bremsstrahlung correction to be applied for exposure is

$$k_B = 1 - \frac{\Delta Q}{Q} \approx 1 - \frac{f}{\bar{f}} \alpha G' .$$

α was determined by Monte Carlo calculation for a graphite ionization chamber with a diameter of 5 cm and a thickness of 0.6 cm, and for a mean energy of bremsstrahlung of 0.04 MeV. It is supposed that these photons originate uniformly and isotropically from the graphite. Simulation performed with 2 000 histories gives a value of about 4.5% for α .

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* Here, as in Allisy (1967), K'_m is the kerma in graphite at z_m when the quantity of graphite placed at z_m is so small that it does not perturb the photon fluence.

For a cavity of 2 mm thickness (BIPM chamber) and taking into account the experimental results of Attix and DeLaVergne (1958), f should be replaced by a factor of about 1.5. This factor corrects for the fact that the cavity cannot be considered as an ideal Bragg-Gray cavity for such a low photon energy. It accounts for the undesirable production of electrons in the air of the cavity. $\bar{f}$ is very close to 1. We finally obtain

$$k_B = 0.999\,8 .$$

The uncertainties are

- for G : 20% (Berger and Seltzer)
- for α : 25%
- for $f/\bar{f}$: 10%
- for the approximation made in the determination of ΔE : 10%.

For k_B this results in a final relative uncertainty of about 1×10^{-4} (quadratic addition).

References

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