Determination of absorbed dose in a water phantom from the measurement of absorbed dose in a graphite phantom

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Abstract

We have determined by calculation the ratio of the absorbed dose produced in a water phantom to the one occurring in graphite, both for a depth of 5 g/cm^2, with the reference point placed at 1 m from the BIPM ^{60}Co source. This result has then been applied to the experimental measurement of absorbed dose in a graphite phantom in order to obtain the corresponding quantity for water, at the same depth and at the same distance from the source.

At BIPM the measurement of absorbed dose in a graphite phantom is performed with a graphite wall cavity ionization chamber. From this ionometric measurement and the calorimetric measurements made by four national laboratories taking part in a comparison of absorbed dose standards, a weighted mean is obtained which gives the absorbed dose in the BIPM beam with an uncertainty** of 0.1%.

The principle of the present calculation is to compare, for the same incident radiation, the energy fluences in water and graphite and to deduce therefrom the ratio of absorbed doses. For the sake of simplicity, we distinguish between the part of energy fluence, Ψ_p, which is due to the primary beam, and that of energy fluence, Ψ_s, which is due to the photons scattered inside the phantom. We have

$$\begin{aligned} \Psi_c &= \Psi_{c,p} + \Psi_{c,s} , \\ \Psi_w &= \Psi_{w,p} + \Psi_{w,s} , \end{aligned} \qquad (1)$$

where subscripts c and w represent graphite and water.

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* Revised version of December 1986. All the changes concern numerical values in Table 1 which are now based on more extensive calculations.

** In this paper all uncertainties are expressed as 1 σ.

The primary beam consists of all photons incident on the phantom. It includes the direct photons coming from the ^{60}Co source and all the photons that are scattered inside the source itself and its environment. For the BIPM primary beam, the energy fluence of these scattered photons amounts to 19% of the unscattered ones.

If Ψ_o is the energy fluence of the primary beam at the distance z from the source in the absence of a phantom, we have for the two parts of the energy fluence in the phantom, at the same distance z,

$$\begin{aligned} \Psi_{w,p} &= \Psi_o \exp[-(\mu/\rho)_w\, d] , \\ \Psi_{c,p} &= \Psi_o \exp[-(\mu/\rho)_c\, d] , \end{aligned} \tag{2}$$

where d is the depth in the phantom, and $(\mu/\rho)_w$ and $(\mu/\rho)_c$ are the mass attenuation coefficients for water and carbon. These values are calculated for the primary beam spectrum from Hubbell's tables [1]. The kermas due to the primary beam are given from (2) by

$$\begin{aligned} K_{w,p} &= (\mu_{tr}/\rho)_w\, \Psi_o \exp[-(\mu/\rho)_w\, d] , \\ K_{c,p} &= (\mu_{tr}/\rho)_c\, \Psi_o \exp[-(\mu/\rho)_c\, d] , \end{aligned} \tag{3}$$

where (μ_{tr}/ρ) are the mass energy transfer coefficients.

The fraction of absorbed dose due to the primary beam can be deduced from the kerma by the relations

$$\begin{aligned} D_{w,p} &= K_{w,p} \left[1 + (\mu + \frac{2}{z})\, \overline{r\, x_p}\right]_w (1 - g_p)_w , \\ D_{c,p} &= K_{c,p} \left[1 + (\mu + \frac{2}{z})\, \overline{r\, x_p}\right]_c (1 - g_p)_c , \end{aligned} \tag{4}$$

where g is the fraction of the electron energy lost in bremsstrahlung and the term in brackets stems from the energy dissipation of the electrons. x_p is the first moment of the dissipation function for the electrons set in motion by the primary beam photons and r is their mean range. The quantity $\overline{r\, x_p}$ is the mean for the electron spectrum. For more details, see eq. (33) of reference [2].

For the photons scattered inside the phantom, we have calculated by the Monte Carlo method the ratio R of the kerma due to the scattered photons to that due to the primary ones, i.e.

$$R_w = \frac{K_{w,s}}{K_{w,p}} , \qquad R_c = \frac{K_{c,s}}{K_{c,p}} . \tag{5}$$

These calculations were made taking into account the scattered radiation present in the incident beam. Fig. 1 shows the values of R_w and R_c as a function of the depth in the phantom.

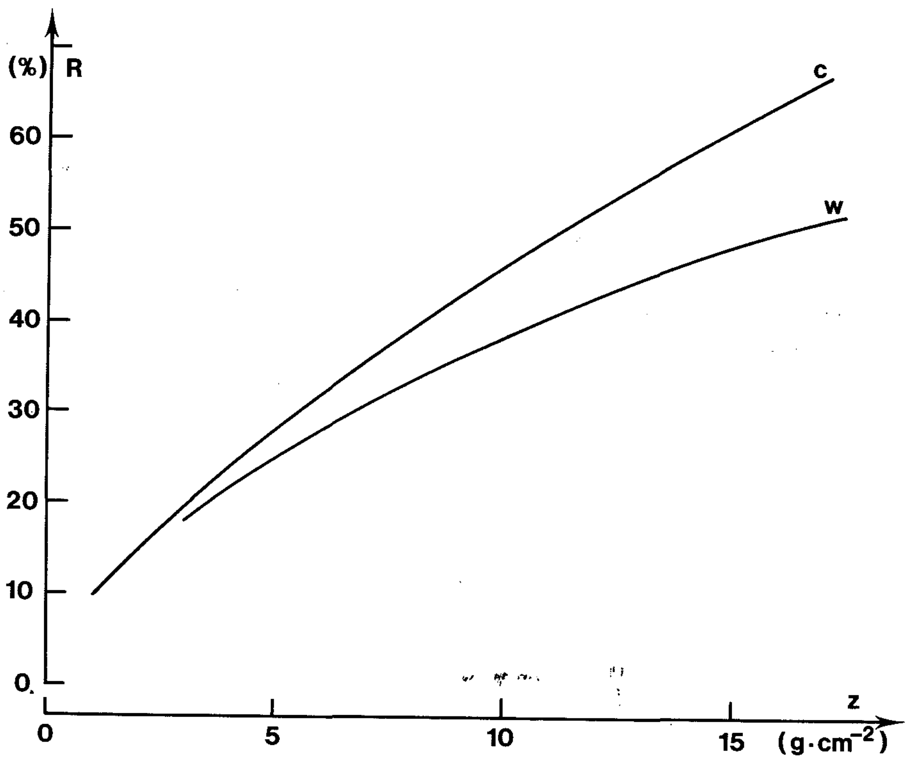

Figure 1 - R as a function of depth, for a graphite phantom (c) and a water phantom (w), for the BIPM ^{60}Co beam

The fraction of absorbed dose due to the radiation scattered inside the phantom is deduced from the kerma by

$$\begin{aligned} D_{w,s} &= K_{w,s} \left[1 + (\mu + \frac{2}{z} - \beta)\, \overline{r\, x_s}\right]_w (1 - g_s)_w \,, \\ D_{c,s} &= K_{c,s} \left[1 + (\mu + \frac{2}{z} - \beta)\, \overline{r\, x_s}\right]_c (1 - g_s)_c \,, \end{aligned} \tag{6}$$

where the term in brackets concerns the energy dissipation of the electrons set in motion by the photons scattered inside the phantom. The term $\beta = (d\,R)/(R\,dz)$ represents the relative slope of the quantity R at the point of reference. For more details, see eq. (7) of reference [3].

By combining equations (3), (4), (5) and (6) we obtain for the ratio of the absorbed dose in water to that in graphite

$$\frac{D_w}{D_c} = \frac{\exp[-(\mu/\rho)_w\, d]}{\exp[-(\mu/\rho)_c\, d]} \; \frac{(\mu_{en}/\rho)_w}{(\mu_{en}/\rho)_c} \cdot$$

$$\cdot \frac{[1 + (\mu + 2/z)\, \overline{r\, x_p}]_w + R_w\, [1 + (\mu + 2/z - \beta)\, \overline{r\, x_s}]_w}{[1 + (\mu + 2/z)\, \overline{r\, x_p}]_c + R_c\, [1 + (\mu + 2/z - \beta)\, \overline{r\, x_s}]_c} \,. \tag{7}$$

The value of this ratio at 5 g/cm^2 is equal to 1.050.

We give in Table 1 the different numerical values of the quantities occurring in eq. (7) as well as their uncertainties.

Table 1

Numerical values of the quantities occurring in the determination of D_w/D_c, together with their uncertainties

Quantities	Numerical values at $d = 5\ g/cm^2$	Uncertainty (%) (relative values)	Resulting (1)	uncertainties on the ratio D_w/D_c (%)
$\dfrac{\exp[-(\mu/\rho)_w\ d]}{\exp[-(\mu/\rho)_c\ d]}$	0.969 3	0.12	(2)	0.12
$\left(\dfrac{\mu_{en}}{\rho}\right)_w / \left(\dfrac{\mu_{en}}{\rho}\right)_c$	1.110 9	0.12	(3)	0.12
$[1 + (\mu + \frac{2}{z})\ \overline{r\ x_p}]_w$	1.009 1	0.04		0.03
$[1 + (\mu + \frac{2}{z})\ \overline{r\ x_p}]_c$	1.008 0	0.04		0.03
R_w	0.243 2	3.5		0.4
R_c	0.269 6	3.5		0.4
$[1 + (\mu + \frac{2}{z} - \beta)\ \overline{r\ x_s}]_w$	0.998 3	0.08		0.02
$[1 + (\mu + \frac{2}{z} - \beta)\ \overline{r\ x_s}]_c$	0.996 9	0.08		0.02
D_w/D_c	1.055 8			0.6

(1) These uncertainties represent 1σ.

(2) For the uncertainty of this ratio we use the same value as in (3).

(3) We assume that the uncertainty of this ratio is the same as that quoted in Hubbell's tables, namely an overall uncertainty of 0.3% between 0.6 and 1 MeV for the ratio $(\mu_{en}/\rho)_{air}/(\mu_{en}/\rho)_{wall}$. This uncertainty is supposed to correspond to $2.5\ \sigma$.

References

[1] J.H. Hubbell, Photon mass attenuation and mass energy-absorption coefficients for H, C, N, O, Ar and seven mixtures from 0.1 keV to 20 MeV, Rad. Res. 70, 58-81 (1977)

[2] A. Allisy, Contribution à la mesure de l'exposition produite par les photons émis par le ^{60}Co, Metrologia 3, 41-51 (1967)

[3] M. Boutillon, Perturbation correction in the ionometric determination of absorbed dose in a graphite phantom, Rapport BIPM 79/6, 12 p. (1979)

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