

The Quotient of Absorbed Dose and the Collision Part of Kerma for Photon Beams

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Abstract

With the conceptual definition of the quotient (β) of absorbed dose and the collision part of kerma for photon beams, the procedure of computing β is briefly described. A series of calculations of β was carried out for photons of 0.4, 0.5, 1 and 2 MeV in polystyrene, carbon, air and aluminum. Resultant values are tabulated and evaluated.

When a formal relationship between absorbed dose to the medium of interest in the user's beam, and the calibration factor assigned to an ionization chamber by calibration in a photon beam is being established, a number of dosimetry quantities enter into the formalism. Among them the quotient of absorbed dose and the collision part of kerma is an important parameter, in particular when the ionization chamber is calibrated in terms of exposure.

This short paper describes the concept of the quotient and a practical way of computing the numerical values of it. As an example, a series of actual calculation was carried out for several dosimetrically important materials at commonly encountered photon energies, and the resultant data are tabulated and evaluated.

The relationship of absorbed dose to photon energy fluence is more complex than that of exposure. Absorbed dose is the energy imparted per unit mass in the neighborhood of a point by electrons arising in the entire volume from which electrons can reach the point. Since absorbed dose can depend on the photon fluence throughout that volume, it is in general not uniquely determined by the photon fluence at the point. Let β be the quotient of absorbed dose, D , at a given point and collision part of kerma, K^{col} , at the same point.

$$\text{Then } \beta = \frac{D}{K^{\text{col}}} \quad (1)$$

$$\text{and } D = \beta \frac{\mu_{\text{en}}}{\rho} \Psi(\infty) \quad (2)$$

where K^{col} is defined as¹⁾

$$K^{\text{col}} = \int_0^{\infty} \frac{\mu_{\text{en}}}{\rho} \frac{d}{dE}$$

$$= \frac{\int_0^\infty \frac{\mu_{en}}{\rho} \frac{d\Psi}{dE} dE}{\int_0^\infty \frac{d\Psi}{dE} dE} = \frac{\mu_{en}}{\rho} \Psi(\infty) \quad (3)$$

$\frac{d\Psi}{dE}$ is the spectral distribution of the photon energy fluence corresponding to the integral distribution

$$\Psi(E) = \int_0^E \frac{d\Psi}{dE} dE \quad (4)$$

and μ_{en}/ρ is the mass energy-absorption coefficient.

The absorbed dose is related here to the collision part of kerma, and not to the kerma itself which is given by

$$K = K^{col} + K^{rad}$$

$$= \int_0^\infty [(1-g) + g] \frac{\mu_{tr}}{\rho} \frac{d\Psi}{dE} dE \quad (5)$$

where g is the fraction of the initial electron kinetic energy expended in radiative interactions, for photon of energy E , and μ_{tr}/ρ is the mass energy-transfer coefficient which is related to $\mu_{en} = (1-g)\mu_{tr}$.

The relationship between kerma and absorbed dose was first discussed by Roesch²¹. He defined a quantity that he named KERM, which corresponds to the quantity kerma except for the energy dissipated in the form of radiation by charged secondary particles. Thus KERM is to be identified with the collision part of kerma, K^{col} , as defined by equation (3). Roesch showed that, for a plane beam of 1.2 MeV photons in aluminum, under conditions of transient electron equilibrium, the quotient of absorbed dose and K^{col} can be expressed in the form of a series, the first two terms ordinarily being sufficient. Then

$$\beta \left(= \frac{D}{K^{col}} \right) = 1 + \mu X \quad (6)$$

Here, μ is the linear attenuation coefficient of the photon beam, and X is the mean distance, in the direction of the photon beam, that energy is transported by second-

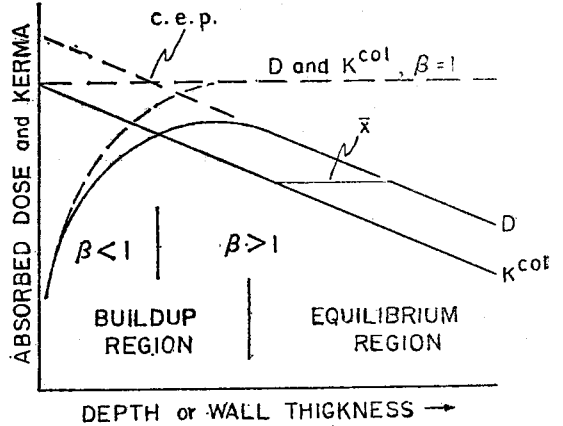


Fig. 1. Relationship between absorbed dose D and the collision part of kerma K^{col} . It is assumed that the photon beam enters a condensed medium from a vacuum. In the buildup region, $\beta = D/K^{col} < 1$ near the surface and $\beta > 1$ at depths near the equilibrium region. In the equilibrium region, $\beta > 1$ for transient electron equilibrium, and $\beta = 1$ for complete electron equilibrium.

\bar{X} is the mean distance of transport of energy by electrons, and c.e.p. is the "center of electron production" for an ionization chamber.

dary electrons. Because the beam attenuation of interest here is very small, X equals the separation in the beam direction of equal values of the collision part of kerma K^{col} and the absorbed dose D , as illustrated in Figure 1²¹.

In practical calculation of β , however, it is more convenient to use Allisy's method¹⁹ which can be expressed in the form

$$\beta = 1 + \mu \bar{R} X_p \quad (7)$$

where \bar{R} is the mean range of Compton recoil electrons produced by the incident photons in a medium, and X_p is the mean distance of energy transport under the assumption of plane perpendicular source of electrons.

X_p is primarily given by

$$X_p = \frac{\int_0^1 XJ(X) dX}{\int_0^1 (X) dX} \quad (8)$$

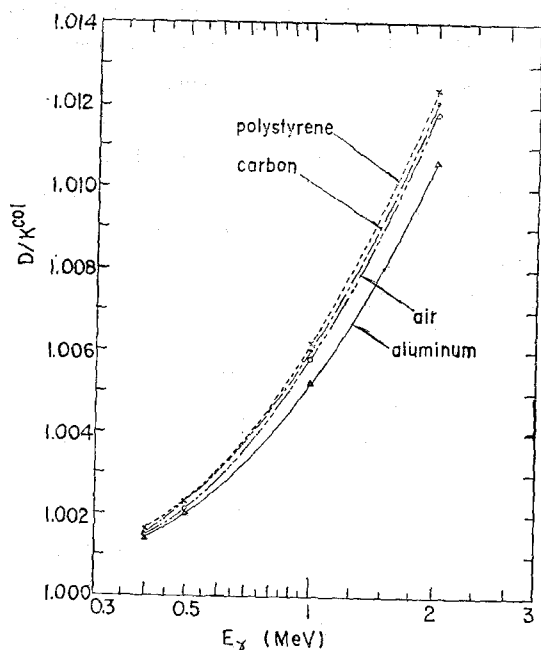


Fig. 2. The quotient of absorbed dose (D) and the collision part of kerma (K^{col}) in polystyrene, carbon, air and aluminum as a function of incident photon energy.

where $J(X)$ is the de-dimensionalized energy dissipation distribution and X is the distance from the electron source in units of residual range of electrons, $r_0 = r(E_0)$. Actually it refers to Z/r_0 , which is a dimensionless parameter, for plane perpendicular sources. Numerical values of $J(X)$ and X are tabulated by Spencer⁴⁾ for various electron energies in various materials.

Since $J(X)$ is effective for positions on both sides of the source plane, X_p is in fact calculated by

$$X_p = \frac{\int_0^1 XJ(X) dX - \int_0^1 XJ(-X) dX}{\int_0^1 J(X) dX - \int_0^1 J(-X) dX} \quad (9)$$

\bar{R} , on the other hand, can be obtained by³⁾

$$\bar{R} = \frac{\int_0^{T_{max}} R(T) T \frac{d\sigma}{dT} dT}{\int_0^{T_{max}} T \frac{d\sigma}{dT} dT} \quad (10)$$

where $R(T)$ and T are the range and kin-

etic energy of Compton recoil electrons, respectively. Numerical values of these quantities are given by Berger and Seltzer⁵⁾. $\frac{d\sigma}{dT}$ is the differential cross section for giving a free electron a recoil energy in the interval from T to $T+dT$, and the values of it as both functions of recoil electron energy and initial photon energy are graphically given by Nelms⁶⁾.

In this work the values of β in several dosimetrically important materials, namely, polystyrene, carbon, air and aluminum were calculated for several photon energies most commonly encountered — 0.4, 0.5, 1, and 2 MeV. The results are tabulated in Table 1 together with the relevant parameters. The attenuation coefficients are from Hubbell⁷⁾. For a quick estimation of the β values for the photon energies in between 0.4 and 2 MeV, the values are also plotted in a graph shown in Figure 2. An estimated

Table 1. The values of $\beta (=D/K^{col})$ for photon beams of 0.4~2 MeV in some materials.

Materials	E_r (MeV)	\bar{X}_p	$\rho\bar{R}$ (g/cm ²)	μ/ρ (cm ² /g)	β
Polystyrene	0.4	0.410	0.037	1.03×10^{-1}	1.001 ₆
	0.5	0.409*	0.059	9.38×10^{-2}	1.002 ₃
	1.0	0.407	0.221	6.85 "	1.006 ₂
	2.0	0.411	0.633	4.78 "	1.012 ₄
Carbon	0.4	0.394	0.041	9.55×10^{-2}	1.001 ₅
	0.5	0.393*	0.066	8.72 "	1.002 ₃
	1.0	0.392	0.240	6.37 "	1.006 ₀
	2.0	0.398	0.682	4.45 "	1.012 ₁
Air	0.4	0.371	0.042	9.53×10^{-2}	1.001 ₅
	0.5	0.368*	0.067	8.70 "	1.002 ₁
	1.0	0.367	0.247	6.36 "	1.005 ₁
	2.0	0.383	0.695	4.45 "	1.011 ₈
Aluminum	0.4	0.311	0.047	9.22×10^{-2}	1.001 ₄
	0.5	0.310*	0.075	8.41 "	1.002 ₀
	1.0	0.310	0.274	6.14 "	1.005 ₂
	2.0	0.323	0.760	4.32 "	1.010 ₆

*Estimated by graphical interpolation.

value of β , for instance, for 1.25-MeV photons in air from this graph is 1.007₅ which agrees very well with Allisy's theoretical value of 1.007₃ for ⁶⁰Co gamma-rays in air³⁾.

It is easily seen that, for the photons of same energy, the values of β do not vary more than $\pm 0.1\%$ for the materials listed in the table which consist of low-atomic-number elements. However, it is also noticeable that the dispersion of the values is getting gradually larger with photon energies, in the range of energy dealt with in this work.

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