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Photon and neutron kerma coefficients for polymer gel dosimeters

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ABSTRACT

Neutron and gamma ray kerma coefficients were calculated for 17 3D dosimeters, for the neutron and gamma ray energy ranges extend from 2.53×10^{-8} to 29 MeV and from 1.0×10^{-3} to 20 MeV, respectively. The calculated kermas given here for discrete energies and the kerma coefficients are referred to as “point-wise data”. Curves of gamma ray kermas showed slight dips at about 60 keV for most 3D dosimeters. Also, a noticeable departure between thermal and epithermal neutrons kerma sets for water and polymers has been observed. Finally, the obtained results could be useful for dose estimation in the studied 3D dosimeters.

1. Introduction

The kerma, *K*, is the acronym for “kinetic energy released in material”. Kerma and absorbed dose at a point in an irradiated target are equal when charged-particle equilibrium exists there and bremsstrahlung losses are negligible. As well as, the kerma replaces the traditional exposure as the shielding design parameter [1].

An essential step in the dosimetry evaluation is to relate the number of particles per unit area of a material of interest that cross a plane perpendicular to the beam (fluence, Φ, having the unit m^{-2}), to the energy release (kerma, Gy) in the material, which determines the absorbed dose. The fluence-to-kerma conversion coefficient or kerma per fluence, K/Φ, is termed the kerma coefficient, having units $J\,m^2\,kg^{-1}$ or $Gy\,m^2$, for uncharged particles of energy E in a specified material. The term kerma coefficient is used in preference to the older term kerma factor, as the word coefficient implies a physical dimension whereas the word factor does not [2].

Many researchers reported calculated and measured values for kerma coefficients. Caswell et al. reported calculated neutron kerma coefficients for 19 elements, and 44 compounds, for the neutron energy range from 8 eV to 30 MeV [3]. The neutron kerma coefficients for human body organs have been reported in ICRU [4].

Vega-Carrillo et al. reported a computer program for calculating the neutron kerma coefficients [5] based on Caswell et al. tabulation [3]. Also, Singh et al. calculated the neutron kerma coefficients of 24 tissue-substitutes [6]. Moreover, Paredes et al. showed that the neutron kerma coefficients for malignant tumors are smaller than soft tissue from 6% to 9% in the neutron energy range 11 eV–29 MeV [7].

On the other hand, gel dosimeters offer the advantage of 3D dose detection and of tissue equivalence [8]. They fulfill the requirements of conformal radiotherapy [9] accurately and are therefore suitable dosimeters for the verification of complex 3D dose distributions [10]. In addition, Gel dosimeters can be prepared in any shape (e.g. an anthropomorphic phantom) and they have shown to be a valuable device for displaying 3D dose distributions.

While the effective atomic numbers, radiological properties and water equivalent studies have been widely carried out for different polymer dosimeters [11–13], there are almost no studies in literature for kerma coefficients determination. In fact, these coefficients are of interest for biomedical applications. As well as, they are used for determining the heat deposited by radiation in materials for energy applications such as fission power reactors and fusion [14–16]. This prompted us to carry out the present work. In this study, we aimed to calculate the neutron and gamma kerma coefficients of 17 polymer 3D dosimeters.

2. Material and methods

Photon and neutron kerma coefficients are energy dependent coefficients used to convert photon or neutron fluence spectra to

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Table 1
Elemental composition (% weight fraction) of water and different 3D polymer dosimeters taken from the Ref. [11].

Material	**H**	**C**	**N**	**O**	**Na**	**Mg**	**P**	**S**	**Cl**	**K**	**Ca**	**Fe**	**Cu**	**Zn**	**Br**
a)Water	11.1898			88.8102											
b)FRICKE	10.736	2	0.67	85.736	0.0021			0.85	0.0033			0.0026			
c)Hypoxic															
BANG-1	10.7685	5.6936	2.0063	81.5316											
BANG-2	10.6369	5.6728	1.4152	81.7004	0.5748										
PAG	10.7367	6.2009	2.1804	80.882											
d)Reduced toxic															
VIPAR	10.7321	7.1825	2.0638	80.0217											
PABIG	10.6454	6.8373	1.5649	80.9524											
e)Normoxic															
MAGIC	10.5473	9.2231	1.3916	78.8373				0.0003					0.0005		
MAGAS	10.5087	9.3591	1.3799	78.7523											
MAGAT	10.522	9.5417	1.366	77.6988			0.4064		0.4651						
PAGAT	10.7257	6.2174	1.9688	80.2166			0.4064		0.4651						
*n*PAG	10.7107	6.5251	2.1814	80.1385			0.5748		0.2371						
*n*MAG	10.6775	7.5066	1.3868	80.2527			0.0822		0.0941						
ABAGIC	10.5263	8.963	3.105	77.4054				0.0003					0.0005		
NIPAM	10.8055	6.5998	1.7531	79.9702			0.4064		0.4651						
HEAG	10.7641	5.7243	1.4152	82.0964											
f)PRESAGE[a]															
Formulation 1	8.8500	61.7800	4.9600	20.6900				0.3800	3.1100						0.2300
Formulation 2	8.9200	60.7400	4.4600	21.7200					3.3400						0.8400

[a] Calculated from the chemical formulae given in Ref. [17].

kerma (absorbed dose). Consequently, determination of kerma coefficients is an essential for any dosimeter.

The chemical compositions of the studied polymer dosimeter are taken from the references [11,17] and listed in the Table 1. Beside the Fricke gel dosimeter, polymer gel dosimeters may be generally classified as either hypoxic, reduced toxic or normoxic gels. Different types of these polymers are listed in Table 1. In order to provide a set of kerma coefficients for polymer dosimeter, the mass energy absorption coefficients for photons by Hubbell and Seltzer [18], and the elemental kerma coefficients for neutrons from Caswell et al. [3] have been employed. Some calculation details are given in the following section.

2.1. Kerma calculation from nuclear constants

Photon kerma coefficients for polymer dosimeter are obtained by summing the products of the mass fraction w_i of the ith constituent element in polymer, the photon energy E_γ, and the mass energy-absorption coefficient $(\mu_{en}(E_\gamma)/\rho)_i$ of the element for photons of that energy.

$$k_P(E_\gamma) = k_D \cdot E_\gamma \sum_i w_i \cdot [\mu_{en}(E_\gamma)/\rho]_i \ \text{Gy cm}^2/\text{photon}. \tag{1}$$

or

$$k_P(E_\gamma) = \sum_i w_i \cdot k_i(E_\gamma) \ \text{Gy cm}^2/\text{photon}. \tag{2}$$

where

$$k_i(E_\gamma) = k_D \cdot E_\gamma \times [\mu_{en}(E_\gamma)/\rho]_i \ \text{Gy cm}^2/\text{photon}. \tag{3}$$

$k(E_\gamma)$ is the energy dependence of specific photon kerma (kerma coefficient), $k_D (k_D = 1.602 \times 10^{-13}$ Gy g/MeV) is the energy conversion coefficient from MeV to Gy g, (obtained from the well known relation:1 MeV $= 1.602 \times 10^{-13}$ J), E_γ is the photon energy in MeV, and $\mu_{en}(E_\gamma)/\rho$ is the mass energy-absorption coefficient in cm^2/g. These coefficients are tabulated by Hubbell and Seltzer [18] and online available on the site: http://physics.nist.gov/PhysRefData/XrayMassCoef/.

To calculate neutron kerma coefficients a similar relation can be used

$$k_n(E_n) = k_D \sum_i w_i \cdot k_i(E_n)_i \ \text{Gy cm}^2/\text{neutron}. \tag{4}$$

Where $k(E_n)$ are the elemental kerma coefficients for neutrons from Caswell et al. [3]. Their tabulation gave the kerma coefficients for a “thermal neutron point” at 0.0253 eV and for 116 contiguous energy “groups” or “bins” extending from 0.026 eV to 30 MeV. Each bin was characterized by a mean energy and an energy interval of a given width [3]. The kerma coefficients were calculated from cross-sections averaged over the full energy width of each bin. Neutron kerma calculations have been carried out using the kerma program [5]. It is important to emphasize that the sums of the Eqs. (2) and (4) are, respectively, calculated for discrete photon and neutron energies, and the kerma coefficients are referred to as “point-wise data”.

3. Results and discussion

The kerma coefficients given here are the kerma in polymer dosimeter per unit particle fluence of either neutrons or photons at a specified energy. Figs. 1 and 2 present these kerma factors for 17 polymer dosimeters as a function of neutron and gamma energies from 2.53×10^{-8} to 29 MeV and 1.0×10^{-3} to 20 MeV, respectively.

The neutron kerma coefficients of the selected polymer dosimeters can be divided into three regions according to the neutron energy, as shown in Fig. 1. These regions are the thermal (< 0.4 eV), the epithermal and the intermediate (energy range of 0.4 eV to 10 keV), and the fast neutrons (> 10 keV).

It is seen that thermal neutron kerma coefficients for water, Fricke, Formulation 2, and Formulation1 go down with neutron energy, reaching minima at neutron energies of 2, 11, 36 and 63 eV, respectively. The most majority of the other polymer dosimeters are reaching to their minima at 20 eV.

At energies beyond about 100 eV (upper end epithermal, intermediate and fast neutron regions), the sets of neutron kermas of polymer dosimeters and water are in close agreement (Fig. 1).