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Water and tissue equivalency of some gel dosimeters for photon energy absorption

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HIGHLIGHTS

- Tissue and water equivalency of gel dosimeters is investigated.
- Effective atomic and electron numbers for gel dosimeters are calculated, with respect to the photon energy absorption.
- Calculations are compared to previous work for verification.

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ABSTRACT

The mass energy absorption coefficients, μ_{en}/ρ, effective atomic numbers for photon energy absorption, Z_{PEAeff}, and effective electron numbers for photon-energy absorption, N_{PEAeff}, is calculated for 14 polymer gel dosimeter, five gel dosimeter, soft tissue and water, in the energy range from 1 keV to 20 MeV. The $Z_{PEAeff}(Gel)/Z_{PEAeff}(Tissue)$ and $N_{PEAeff}(Gel)/N_{PEAeff}(Tissue)$ are used to evaluate the tissue equivalency.

1. Introduction

Gel dosimeters are mostly composed of water, gelatin and small amount of substance that changes under irradiation such as the transformation of the ferrous Fe^{+2} ions into ferric Fe^{+3} ions (Taylor et al., 2008). Polymer gel dosimeters are produced from radiation sensitive acrylic monomers in a water based-matrix, such as gelatin. When a polymer gel dosimeter is subjected to radiation, polymerization which is difference between polymer gel and gel dosimeters takes place. The associated chemical changes are used for measuring the radiation dose distribution in intensity-modulated radiation therapy (IMRT), stereotactic radiosurgery (SRS) and stereotactic radiotherapy (SRT) (Sellakumar et al., 2007; Baldock et al., 2010).

An ideal radiation dosimeter should have the same (effective atomic number, number of electrons per gram, mass energy absorption coefficient, mass attenuation coefficient and mass density) as water or tissue (Sellakumar et al., 2007; Baldock et al., 2010; Khan, 2010; Gorjiara et al., 2011). Water equivalency and radiological properties of some dosimeters were investigated in previous studies (Keall and Baldock, 1999; Venning et al., 2005; Sellakumar et al., 2007; Brown et al., 2008; Gorjiara et al., 2011, 2012). The mass energy absorption coefficient, μ_{en}/ρ, is a measure of the mean fractional amount of incident photon energy transferred to the kinetic energy of charged particles and its value is readily available (Hubbell, 1982; Hubbell and Seltzer, 1995).

The effective atomic number for photon energy absorption, Z_{PEAeff}, corresponding to mass energy absorption coefficients, μ_{en}/ρ, can also be used to determine water and tissue equivalency. The Z_{PEAeff} values are available for composite materials, such as soft tissue and some TL dosimeters (Un, 2013), and for some low-Z substances of dosimetric intereset (Shivaramu et al., 2001).

A third useful parameter is the effective electron density for energy absorption, N_{PEAeff} is introduced. The N_{PEAeff} values were calculated for soft tissue and some TL dosimeters by Un (2013). The three parameters are utilized in this work to assay the tissue and water equivalency for a number of polymer gel and gel dosimeters, listed in Table 1 in the energy range 1 keV–20 MeV.

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Table 1
Elemental compositions (% weight fractions) of soft tissue, water and different gel dosimeters.

Material	w_H	w_C	w_N	w_O	w_{Na}	w_P	w_S	w_{Cl}	w_K	w_{Fe}	w_{Cu}	w_{Br}
Soft tissue[a]	10.200	14.300	3.4000	70.8000	0.2000	0.3000	0.3000	0.2000	0.3000	–	–	–
Water	0.1119	–	–	0.8881	–	–	–	–	–	–	–	–
BANG-1[b]	10.7685	5.6936	2.0063	81.5316	–	–	–	–	–	–	–	–
BANG-2[c]	10.6369	5.6728	1.4152	81.7004	0.5748	–	–	–	–	–	–	–
PABIG[d]	10.6454	6.8373	1.5649	80.9524	–	–	–	–	–	–	–	–
PAG[e]	10.7367	6.2009	2.1804	80.882	–	–	–	–	–	–	–	–
MAGIC[f]	10.5473	9.2231	1.3916	78.8373	–	–	0.0003	–	–	–	0.0005	–
VIPAR[g]	10.7321	7.1825	2.0638	80.0217	–	–	–	–	–	–	–	–
ABAGIC[h]	10.5263	0.8963	0.3105	77.4054	–	–	0.0003	–	–	–	0.0005	–
PAGAT[i]	10.7257	6.2174	1.9688	80.2166	–	0.4064	–	0.4651	–	–	–	–
HEAG[j]	10.7641	5.7243	1.4152	82.0964	–	–	–	–	–	–	–	–
MAGAS[k]	10.5087	9.3591	1.3799	78.7523	–	–	–	–	–	–	–	–
MAGAT[l]	10.5220	9.5417	1.3660	77.6988	–	0.4064	–	0.4651	–	–	–	–
nMAG[m]	10.6775	7.5066	1.3868	80.2527	–	0.0822	–	0.0941	–	–	–	–
nPAG[n]	10.7107	6.5251	2.1814	80.1385	–	0.5748	–	0.2371	–	–	–	–
NIPAM[o]	10.8055	6.5998	1.7531	79.9702	–	0.4064	–	0.4651	–	–	–	–
PRESAGE[p]	8.9200	60.740	4.460	21.720	–	–	–	3.3400	–	–	–	0.8400
SDA[q]	11.0490	0.6910	0.0014	88.0290	–	–	0.2270	–	–	0.0027	–	–
Gelatin[r]	10.7630	1.9590	0.6650	85.7570	0.0021	–	0.8470	0.0033	–	0.0026	–	–
Fricke[s]	10.7360	2.0000	0.6700	85.7360	0.0021	–	0.8500	0.0033	–	0.0026	–	–
Genipin[t]	11.0500	1.5220	0.5216	86.9600	–	–	0.3108	–	–	–	–	–

[a] ICRU (1989).
[b] Maryanski et al. (1994); Michael et al. (2000).
[c] Maryanski et al. (1996a, 1996b).
[d] Sandilos et al. (2004).
[e] Maryanski et al. (1993); Maryanski et al. (1994); Baldock et al. (1998); Michael et al. (2000).
[f] Fong et al. (2001).
[g] Kipouros et al. (2001); Pappas et al. (1999).
[h] Taylor et al. (2008).
[i] Venning A. et al. (2005).
[j] Gustavsson et al. (2004).
[k] De Deene et al. (2002a, 2002b); Venning A.J. et al. (2005); Venning A. et al. (2005).
[l] De Deene et al. (2002a, 2002b); Venning A.J. et al. (2005); Venning A. et al. (2005).
[m] De Deene et al. (2002a, 2002b); Venning A.J. et al. (2005); Venning A. et al. (2005).
[n] De Deene et al. (2002a, 2002b); Venning A.J. et al. (2005); Venning A. et al. (2005).
[o] Senden et al. (2006).
[p] Brown et al. (2008); Mostaar et al. (2011).
[q] Kron et al. (1993).
[r] Kron et al. (1993).
[s] Keall and Baldock (1999).
[t] Gorjiara et al. (2011).

This is the range of photons commonly used in the radiation dosimetry and radiation applications. Using these three parameters together, an "ideal" dosimeter can be identified.

2. Calculating of the effective atomic number

The effective atomic number for photon energy absorption, Z_{PEAeff}, can be calculated using the mass energy absorption coefficient, μ_{en}/ρ, determined for composite materials by the additivity law (Shivaramu et al., 2001). The $(\mu_{en}/\rho)_i$ values of the ith constituent element is tabulated in Hubbel and Seltzer (1995).

The effective electronic energy absorption cross section, $\sigma_{e,en}$, is as follows:

$$\sigma_{e,en} = \frac{1}{N_A}\sum_i \frac{f_i A_i}{Z_i}\left(\frac{\mu_{en}}{\rho}\right)_i = \frac{\sigma_{a,en}}{Z_{PEAeff}}, \qquad (1)$$

where Z_i is the atomic number of the ith constituent element, $f_i = n_i/\sum_j n_j$ is the fractional abundance of the ith element and the effective atomic energy absorption cross section, $\sigma_{a,en}$, can be determined as

$$\sigma_{a,en} = \frac{\sigma_{m,en}}{\sum_i n_i}. \qquad (2)$$

The effective atomic number for photon energy absorption, Z_{PEAeff}, can be calculated using Eq. (1)

$$Z_{PEAeff} = \frac{\sigma_{a,en}}{\sigma_{e,en}}. \qquad (3)$$

The effective electron density for photon energy absorption, N_{PEAeff} (number of electrons per unit mass) can be derived as

$$N_{PEAeff} = \frac{N_A}{M} Z_{PEAeff} \sum n_i = \frac{\mu_{en}/\rho}{\sigma_e}. \qquad (4)$$

More detailed information about the calculation of Z_{PEAeff} and N_{PEAeff} is given in Manohara and Hanagodimath (2007), Un and Sahin (2012); Un (2013).

3. Results and discussion

The elemental compositions (% weight fractions) of soft tissue, water and different gel dosimeters are tabulated in Table 1. The energy dependence of the mass energy absorption coefficients, μ_{en}/ρ, are shown in Fig. 1 for the soft tissue, water and different gel dosimeters, while Figs. 2 and 3 show this dependence for Z_{PEAeff} for the polymer gel and the gel dosimeters, respectively.

In the low energy region $E < 0.01$ MeV, the maximum values of Z_{PEAeff} are found in the low-energy range because of the