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Computation of exposure build-up factors in teeth

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ABSTRACT

The G-P fitting method has been used to compute the exposure build-up factor of teeth [enamel outer surface (EOS), enamel middle (EM), enamel dentin junction towards enamel (EDJE), enamel dentin junction towards dentin (EDJD), dentin middle (DM) and dentin inner surface (DIS)] for a wide energy range (0.015–15 MeV) up to the penetration depth of 40 mean free paths. The dependence of exposure build-up factor on incident photon energy, penetration depth, electron density and effective atomic number has also been studied. The computed exposure build-up factor is useful to estimate the relative dose distribution in different regions of teeth.

1. Introduction

When photons enter the medium/body, they degrade their energy and build up in the medium, giving rise to secondary radiation, which can be estimated by a factor called the 'build-up factor'. Calculations of the energy absorbed in a medium include not only the contribution of uncollided photons from the source, but must also include contributions from collided and secondary photons. In practice, this is done by multiplying the contribution of uncollided photons with the energy absorption build-up factor (Harima, 1993; Shultis and Faw, 2005). The energy absorption build-up factor is the ratio of the total energy absorbed due to uncollided, collided and secondary photons to the energy absorbed due to only uncollided photons. The energy absorption build-up factor is also defined as the build-up factor in which the quantity of interest is absorbed or deposited energy in the interacting material and the detector response function is that of absorption in the interacting medium, whereas the exposure build-up factor is defined as that build-up factor in which the quantity of interest is exposure and the detector response function is that of absorption in air. The build-up factor is an important parameter in the distribution of photon flux in every object. In brachytherapy, radioactive seeds are planted in the patient's body to destroy the cancer tumor (Chibani, 2005; Tsiakalos, 2006). Thus it is important to consider the photon build-up factor in the calculation of radiation dose received by the cancer cells.

The build-up factor data were computed by different codes such as PALLAS-PL (Takeuchi, 1973), RADHEAT-V4 (Yamano et al., 1989), ADJMOM-1 (Simmons, 1973) and ASFIT (Gopinath and Samthanam, 1971). Several authors have provided different build-up factor data for extensive utilization of design in radiation shields and for other purposes (Hubbell, 1963; Chilton et al., 1980; Harima, 1983; Sakamoto et al., 1988; Brar et al., 1994; Brar and Mudahar, 1995). American National Standard (ANS) (1991) ANSI/ANS 6.4.3 used the G-P fitting method and provided build-up factor data for 23 elements, water, air and concrete at 25 standard energies in the energy range 0.015–15 MeV with suitable interval up to the penetration depth of 40 mean free path. Earlier works (Harima et al., 1986) compared computed build-up factors using the G-P fitting method with the PALLAS code. Good agreement was observed for penetration depth up to 40 mean free path. Shimizu et al. (2004) compared the build-up factors obtained by three different methods (G-P fitting, invariant embedding and Monte Carlo method) and only small discrepancies were observed for low-Z elements up to 10 mean free path.

Singh et al. (2008) studied the variation of energy absorption build-up factors with incident photon energy and penetration depth for some solvents. Sidhu et al. (2000) computed the exposure build-up factors in biological samples and studied the variation of exposure build-up factors with incident photon energy and effective atomic number.

In the present work an attempt has been made to compute exposure build-up factors for different regions of teeth such as enamel outer surface (EOS), enamel middle (EM), enamel dentin junction towards enamel (EDJE), enamel dentin junction towards dentin (EDJD), dentin middle (DM) and dentin inner surface (DIS) for a wide energy range (0.015–15 MeV) up to the penetration depth of 40 mean free path using the G-P fitting method. Such data will be of prime importance in medical dosimetry.

2. Present work

Computations of the exposure build-up factor have been divided into three parts, which are as follows.

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2.1. Computation of effective atomic number

Theoretical values for the mass attenuation coefficient can be found in the tabulation by Hubbell and Seltzer (1995). Instead of interpolating tabulated values and using the mixture rule, some computer programs such as WinXCom or its predecessor XCOM can save a lot of manual work and time. The XCOM program was originally developed by Berger and Hubbell (1987) for calculating mass attenuation coefficients or photon interaction cross sections for any element, compound or mixture in the energy range 1 keV–100 GeV. Later, this well known and widely used program was enhanced and transformed to the Windows platform by Gerward et al. (2001, 2004) under the name WinXCom. All computations in the present work have been carried out using the program WinXCom. The chemical composition of teeth was analyzed with characteristic X-ray energy dispersive spectroscopy (Pilar et al., 2003), and is given in Table 1.

The molecular cross section has been estimated using the equation

$$\sigma_m = \frac{1}{N}\left(\frac{\mu}{\rho}\right)_{bio}\sum_i n_i A_i \tag{1}$$

where n_i is the number of atoms of the ith element in a given molecule, $(\mu/\rho)_{bio}$ the mass attenuation coefficient of the bio molecule, N the Avogadro number and A_i the atomic weight of the element i. $(\mu/\rho)_{bio}$ was estimated based on the chemical composition of teeth. The atomic cross section is estimated using the equation

$$\sigma_a = \frac{\sigma_m}{\sum_i n_i} \tag{2}$$

The electronic cross section is estimated using the equation

$$\sigma_e = \frac{1}{N}\sum_i\left(\frac{f_i A_i}{Z_i}\right)\left(\frac{\mu}{\rho}\right)_i \tag{3}$$

where f_i is the fractional abundance (a mass fraction of the ith element in the molecule) and Z_i the atomic number of the ith element in a molecule. Finally Z_{eff} is estimated as

$$Z_{eff} = \frac{\sigma_a}{\sigma_e} \tag{4}$$

The effective electron density (N_{el}) expressed as the number of electrons per unit mass is closely related to the effective atomic number, which is calculated by the following equation:

$$N_{el} = \frac{N}{\sum_i n_i A_i} Z_{eff} \sum_i n_i \tag{5}$$

Table 1
Composition of teeth enamel and dentin.

Element	EOS>	EM	EDJE	EDJD	DM	DIS
C	0.3859	0.3628	0.3705	0.59	0.5227	0.4984
O	0.3259	0.3421	0.3451	0.3067	0.3057	0.3354
Na	0.0024	0.0044	0.0066	0.0047	0.0042	0.0036
Mg	0.0016	0.0023	0.0022	0.0025	0.0034	0.0045
P	0.1067	0.1086	0.1046	0.0441	0.0623	0.0632
Cl	0.1063	0.0025	0.0009	–	–	–
Ca	0.1736	0.1774	0.1699	0.0519	0.0915	0.095

EOS—enamel outer surface, EM—enamel middle, EDJE—enamel dentin junction towards enamel, EDJD—enamel dentin junction towards dentin, DM—dentin middle and DIS—dentin inner surface.

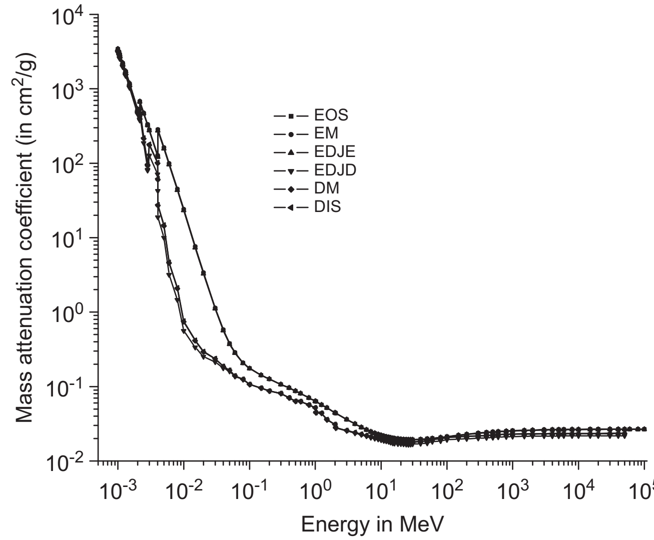

Fig. 1. Variation of mass attenuation coefficients with photon energy for teeth.

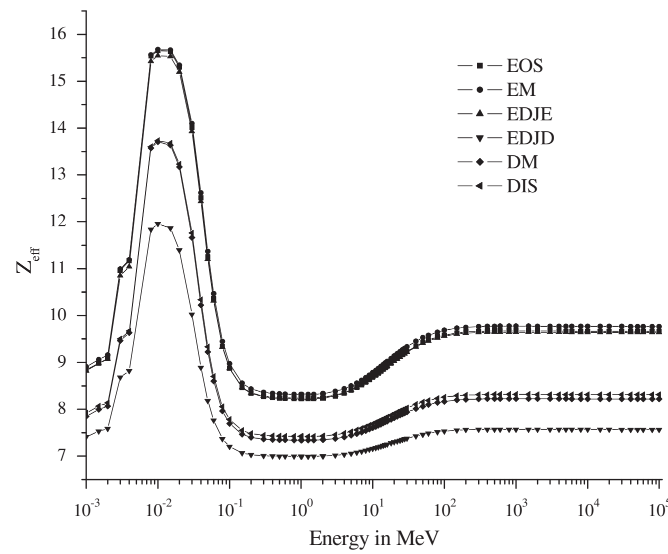

Fig. 2. Variation of effective atomic number with photon energy for teeth.

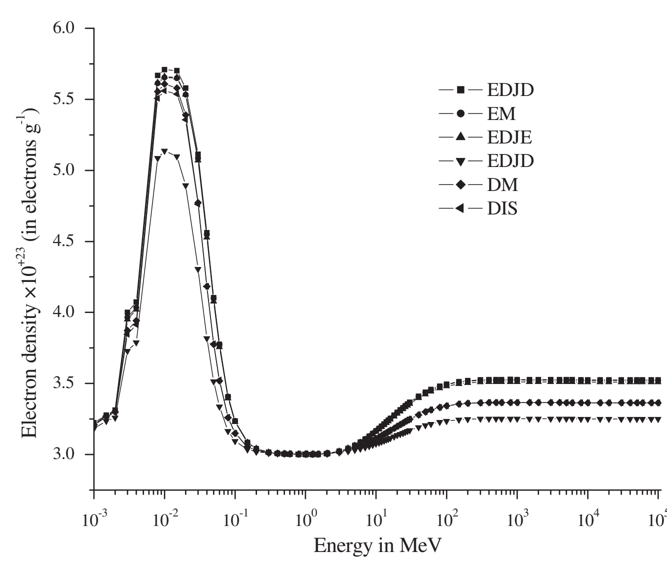

Fig. 3. Variation of effective electron density with photon energy for teeth.