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Influence of input functions in TLD-100 ion–gamma relative efficiencies calculated with MTST

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Abstract

Heavy charged particle-to-gamma relative efficiencies calculated with modified track structure theory (MTST) for individual peaks in TLD-100 are calculated and compared with recent measurements at intermediate energies by Massillon-JL et al. [2006a. Observation of enhanced efficiency in the excitation of ion-induced LiF:Mg,Ti thermoluminescent peaks, J. Appl. Phys. 100, 103521–103525; Erratum: Observation of enhanced efficiency in the excitation of ion-induced LiF:Mg,Ti thermoluminescent peaks [J. Appl. Phys 100, 103521 (2006)], J. Appl. Phys. 102, 079901, 2007]. The influence of input functions that enter the model is investigated. Two types of radial dose distributions, analytical and Monte Carlo, are used as well as two types of supralinearity functions, $f_\delta(D)$, measured for test radiations taken as ^{60}Co and 8.1 keV X-rays. Theoretical efficiencies are more sensible to the choice of test radiation than to the choice of dose profile. MTST efficiency values obtained with 8.1 keV X-rays $f_\delta(D)$ give a good description of TLD-100 data for peaks 5, 6a, and 7 at intermediate energies.

Keywords: Thermoluminescence; TLD-100; Heavy charged particles; Modified track structure theory

1. Introduction

Heavy charged particle (HCP)-induced thermoluminescence (TL) continues to be a subject of great interest due to its relevance in medical and space dosimetry. Assessment of available theoretical models allows a deeper understanding of TL phenomena which in turn might lead towards its optimum use in dosimetry applications. TLD-100 ion-to-gamma relative efficiency ($\eta_{\mathrm{HCP},\gamma}$) for individual peaks at intermediate energies have been recently measured (Massillon-JL et al., 2006a; Massillon-JL et al., 2007) and described with track structure theory (TST) (Butts and Katz, 1967) and modified TST (MTST) (Kalef-Ezra and Horowitz, 1982).

This work evaluates the influence of input functions in MTST calculated efficiencies for low and high temperature peaks. The effect of the radial dose distribution (RDD) profiles and the test radiation 'supralinearity' functions on relative efficiency calculations for linear energy transfer (LET) (in water) between 1 and 10^3 keV/μm are studied.

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2. Method

MTST states that the relative HCP-to-gamma efficiency is given by (Kalef-Ezra and Horowitz, 1982)

$$\eta_{\mathrm{HCP},\gamma} = \eta_{\delta,\gamma} \frac{\bar{W}_\gamma \int_0^{R_{\max}} \int_0^{r_{\max}} f_\delta(D) D(r, l, E) 2\pi r \, \mathrm{d}r \, \mathrm{d}l}{\bar{W}_{\mathrm{HCP}} \int_0^{R_{\max}} \int_0^{r_{\max}} D(r, l, E) 2\pi r \, \mathrm{d}r \, \mathrm{d}l}, \quad (1)$$

where $\eta_{\delta,\gamma}$ is the relative TL response to the secondary electrons of the HCP with respect to the one obtained with ^{60}Co gamma rays, $\bar{W}_\gamma$ and $\bar{W}_{\mathrm{HCP}}$ are the mean energies required to produce an electron–hole pair by the gamma and HCP radiation, respectively, $D(r, l, E)$ is the microscopic radial dose distribution around the ion path, $R_{\max}$ and $r_{\max}$ are the maximum axial and radial penetration distances reached at the radiation absorption stage by the charge carriers emitted from the HCP, and $f_\delta(D)$ is the measured TL supralinearity function of a reference test radiation which simulates, as much as possible, the ion's secondary electron spectrum, both in energy and irradiated volume. The supralinearity or 'dose response' function is

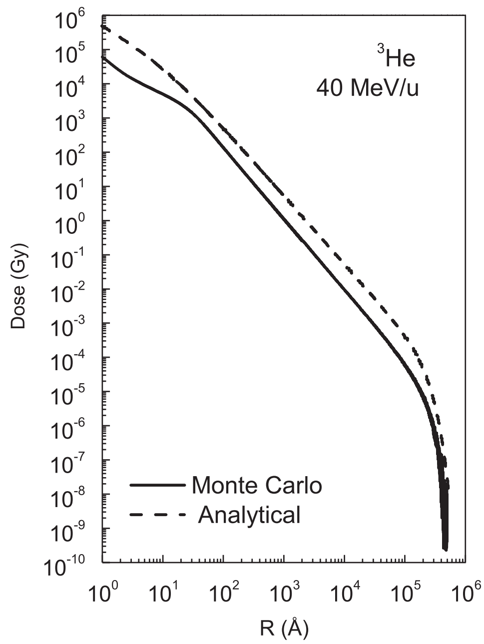

Fig. 1. Analytical and Monte Carlo track segment radial dose distributions for 40 MeV/u ^{3}He ions in lithium fluoride.

defined by

$$f_\delta(D) = \frac{F(D)/D}{F(D_0)/D_0}. \tag{2}$$

Here, $F(D)$ is the TL signal obtained at a dose D, and $F(D_0)$ is the TL signal obtained at a low dose D_0 where the TL response is linear.

This work evaluates theoretical efficiencies using two RDD profiles and two supralinearity functions ($f_\delta(D)$) for the reference test radiations.

Dose profiles used in this work were analytical calculations performed by Massillon-JL et al. (2006a) according to the method described by Katz et al. (1996) and RDD obtained through Monte Carlo (MC) simulations in solid state LiF calculated with the aid of a coupled ion–electron transport code (Avila et al., 1999). Both RDD types were obtained for 1–40 MeV/u ^{1}H, ^{3}He, ^{12}C, ^{16}O, and ^{20}Ne ions. Fig. 1 shows analytical and MC RDD for 40 MeV/u ^{3}He ions; in this case, MC RDD were calculated assuming the ion loses 5% of its initial energy (we define this as a track-segment calculation). The MC simulation (Avila et al., 1999) is implemented so as to allow ions to generate secondary electrons for ion energy transfers greater than a cut-off value of 250 eV. This results in 85% of the ion's lost energy going to secondary electrons. This value is similar to the expected energy (of the order of 75%) going to kinetic energies of secondary electrons according to Paretzke et al. (1995). The lower doses observed in the MC dose profile compared to analytical calculations (Fig. 1) may be attributed to the assumed transfer of only a fraction of the ion's lost energy to secondary electrons. Results after 10^6 histories for 40 MeV/u ^{3}He ions produce secondary electrons with energies up to $\sim$ 90 keV, though 90% of them have initial energies lower than 2.2 keV while their average energy at creation is 1.3 keV.

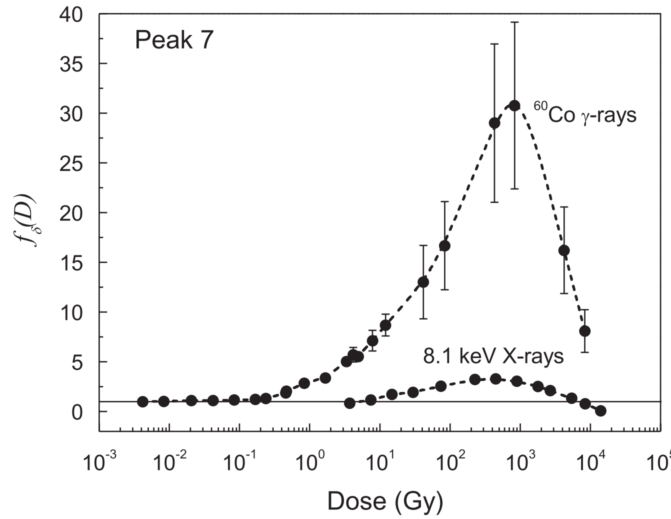

Fig. 2. Supralinearity functions $f_\delta(D)$ measured for reference test radiations taken as ^{60}Co and 8.1 keV X-rays for peak 7 in TLD-100.

Table 1
(a) Average and maximum energies for the secondary electrons generated by the $f_\delta(D)$ functions studied. (b) Average and maximum energy of secondary electrons for three chosen initial ion energies

(a) Test radiation	Average energy (keV)	Maximum energy (keV)
^{60}Co	560	1100
8.1 keV X-rays	8	8.1
(b) Ion energy (MeV/amu)		
40	1.341	95
25	1.233	57
4	0.860	9

Supralinearity functions $f_\delta(D)$ for TLD-100 used in this study were those previously measured for ^{60}Co gamma rays (Massillon-JL et al., 2006b) and 8.1 keV X-rays (Gamboa-deBuen et al., 1998) shown in Fig. 2 for peak 7. Table 1 indicates average and maximum energies of the initial secondary electron spectra produced by both test radiations studied and by three chosen ions. The average secondary electron energy for the initial spectrum of 8.1 keV X-rays is little higher than the average initial energy of secondary electrons generated by 40 MeV/u ions.

MTST MC calculations were performed using RDD track-segment calculations (defined above) for low LET (high energies), where ions traversing a TLD-100 detector would lose a negligible amount of their energy, and complete track calculations for those lower energies where the ions deposit all their energy in a 0.89 mm thick TLD-100 dosemeter. This corresponds to the situation encountered experimentally. An exception to this procedure are the results shown in Fig. 3, where