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Discussion of track structure models and efficiencies of luminescence dosimeters to HCP

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Abstract

In this work we present a discussion on preliminary predictions of efficiencies to HCP using four different analytical track structure models: Chatterjee [1,2], Katz [3,4], Katz-Waligorski [5] and Katz-Fageeha [6]. The method used in this work consists of using an analytical track structure model convoluted with the dose response of the luminescence material.

1. Track Structure

1.1 Chatterjee's model

In Chaterjee's model (equation 1.1) [1,2] $D(r)$ is the local dose at a radial distance r from the path of the primary particle, r_c is the radius of the so called core region and r_p is the radius of the penumbra region. Expressions for r_c and r_p are given together with equation 1.1.

1. Track Structure

1.1 Chatterjee's model

$$
D(r) = \begin{bmatrix} \dfrac{LET_\infty/2}{r_c^2} + \dfrac{LET_\infty/2}{r_c^2\left(1+2\ln\dfrac{r_p}{r_c}\right)}, & r < r_c = \sqrt{\dfrac{4\;\; n e^2}{m}}\, v \\[2ex] \dfrac{LET_\infty/2}{r_c^2\left(1+2\ln\dfrac{r_p}{r_c}\right)}, & r_c < r < r_p = 396\, v^{2.7} \end{bmatrix} \quad (1.1)
$$

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1. Track Structure

1.2 Katz's model

$$D(r)=\frac{Ne^4}{mc^2}\frac{Z^{*2}}{\alpha\beta^2}\frac{1}{r}\left[\frac{1-\left(1-\frac{r+\theta}{R+\theta}\right)^{1/\alpha}}{r+\theta}\right] \qquad (1.2)$$

where

$$R=kW^{\alpha};\qquad \theta=kI^{\alpha}$$

k and are constants, I is the ionization potential, W is the maximum delta ray energy [3,4]

$$W=2mc^2\frac{\beta}{1-\beta^2}$$

1. Track Structure

1.3 Katz-Waligorski's model

In order to correct Katz's model to fit to the experimental data in the region of small radial distances and also to predict the correct stopping power when the distribution of dose is radially integrated, Waligorski *et al.* [5] multiplied equation 1.2 by an arbitrary function.

$$D(r) = D_{Katz}(r)\left[1 + K_W(r)\right]$$

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1. Track Structure

1.3 Katz-Waligorski's model

$$K_W(r) = A\left(\frac{r-B}{C}\right)\exp\left(-\frac{r-B}{C}\right) \qquad (1.3)$$

where

$$(a)\quad r > B = 0.1\,nm, \quad C = 1.5\,nm + 5\,nm \times \beta$$

$$A = \begin{bmatrix} 8 \times \beta^{1/3}, & for\,\beta < 0.03 \\ 19 \times \beta^{1/3}, & for\,\beta > 0.03 \end{bmatrix}$$

$$(b)\quad r < B = 0.1\,nm$$

$$K_W(r) = 0$$

1. Track Structure

1.3 Katz-Fageeha's model

Fageeha *et al.* [6] improved Katz-Waligorski's model using a different arbitrary function

$$K_F(r) = A\beta^B (r - 0.1)\exp\left(-\frac{r}{C}\right)$$

where

$$B = 0.215; \quad C = 3.127 - 0.434\beta$$

$$A = \begin{bmatrix} 0, & for\, \beta < 0.0081 \\ 112\beta - 0.899, & for\, 0.008 < \beta < 0.09 \\ 0.674\beta + 9.21, & for\, \beta > 0.091 \end{bmatrix}$$

2. Dose response

2.2 Experimental data

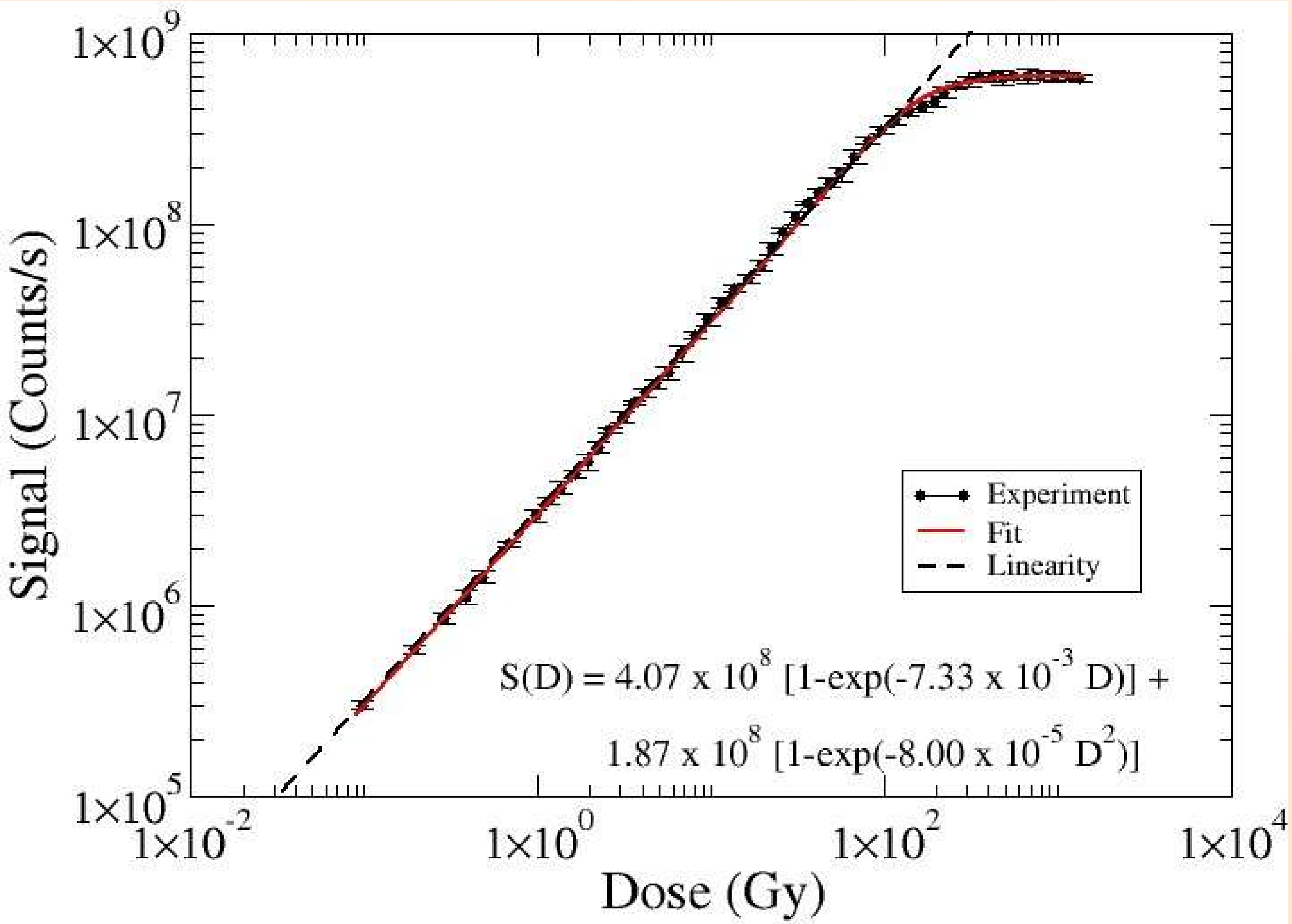

Figure 1: Dose response of luxel irradiated with a ^{90}Sr source.

3. Predictions

3.2 Results

$$\eta = \frac{\int_{r_{min}}^{r_{max}} r\, S[D(r)]\, dr}{\int_{r_{min}}^{r_{max}} r\, S_0[D(r)]\, dr}$$

Table 1: Comparison between experimental efficiencies of luxel and predictions using different track structure models.

Beam	LET (keV/ m	Experiment	Chatterjee	Katz	Katz-Waligorski	Katz-Fageeha
H: 230 MeV	0.41	0.951(6)	0.80	0.57	0.81	0.83
H: 70 MeV	0.96	0.928(2)	0.53	0.92	0.92	0.91
He: 150 MeV/n	2.18	0.923(7)	0.53	0.86	0.88	0.84
C: 400 MeV/n	10.96	0.684(7)	0.50	0.74	0.76	0.64
C: 290 MeV/n	12.97	0.626(8)	0.49	0.79	0.76	0.63
O: 400 MeV/n	19.48	0.609(7)	0.48	0.75	0.72	0.57
Ne: 400 MeV/n	30.44	0.467(16)	0.47	0.75	0.68	0.52
Fe: 500 MeV/n	186.3	0.341(20)	0.43	0.71	0.50	0.35

4. Conclusions

- All the models failed to predict efficiencies of high LET_∞ particles where the efficiency levels off (Table 1 and Figure 2).
- Chatterjee and Katz models are very poor to predict the efficiencies (Table 1).
- Katz-Waligorski and Katz-Fageeha models fail to predict efficiencies of high energy particles. The models give unphysical results for energies higher than a limit that depend on the type of particle (see proton data).

4. Conclusions

- Although Katz-Waligorski and Katz-Fageeha models have deficiencies, the models presented reasonable results for the type of particles and energies studied here (Figure 2).

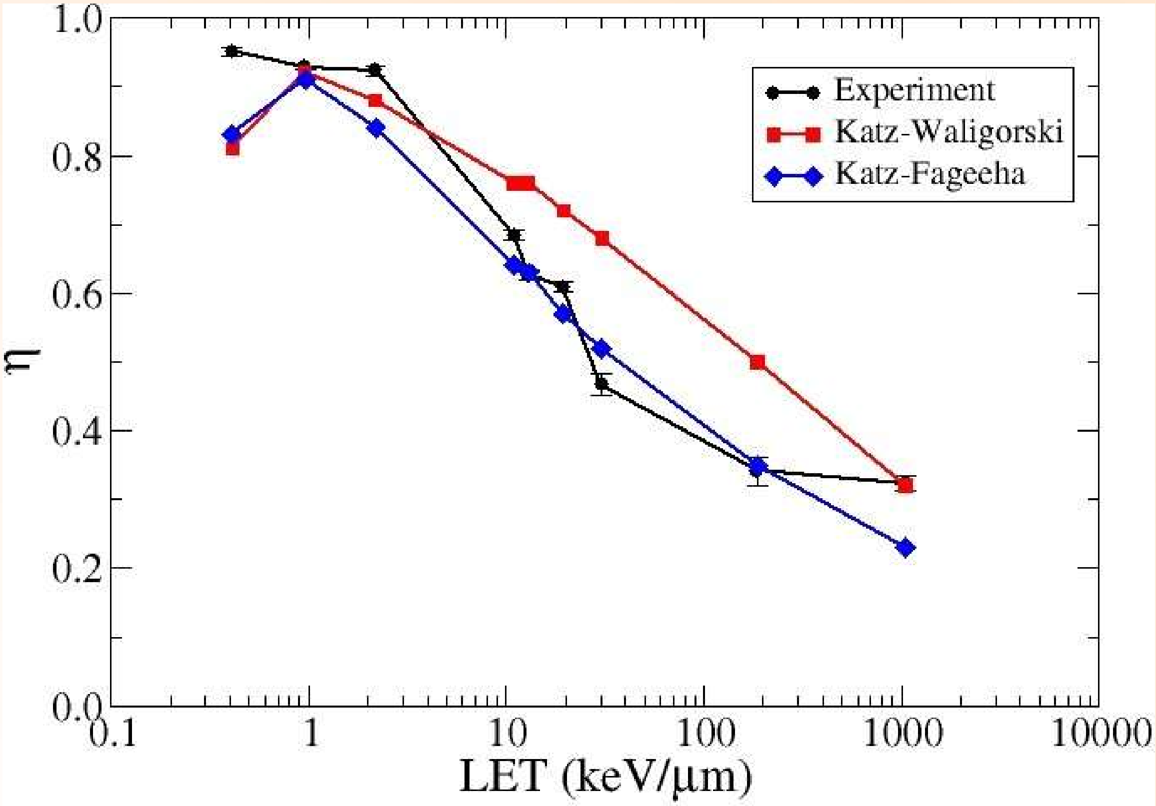

Figure 2: Comparison between experimental efficiencies and predictions using Katz-Waligorski and Katz-Fageeha models.

4. Other points to consider

- A "monoenergetic" dose response curve may not reproduce the delta ray energy spectrum created when a HCP transverses the material.
- The fitted range-energy relation used by Katz, Katz-Waligorski and Katz-Fageeha models deviates from experimental data for electrons of energies larger than 1 MeV [5].

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References

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