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The Efficiency of ^{7}LiF Thermoluminescent Dosimeters for Measuring 250 MeV/amu $^{6+}$C Ions*

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Abstract

A measurement of the efficiency of the ^{7}LiF thermoluminescent dosimeters to 250 MeV/amu $^{6+}$C ions is reported.

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1. Introduction

The response of thermoluminescent dosimeters is known to be a function of the linear energy transfer (LET) of the incident radiation (Cameron, Suntharalingam and Kenney, 1968a). This note reports a determination of the efficiency, relative to the ^{60}Co γ rays, of ^{7}LiF thermoluminescent dosimeters (TLD) measuring 250 MeV/amu $^{6+}$C ions.

2. Experimental techniques

LiF "chips" (1/8×1/8×0.035 inch; approx. 25 mgm mass) manufactured by the Harshaw Chemical Company were used in the measurements reported here. New chips were used which had been preannealed at a temperature of 450°C for 1 h, followed by 2 h at 100°C in accordance with the manufacturer's recommendations. After irradiation, the chips were annealed at 100°C for 10 min before reading, to eliminate any contribution to the measured thermoluminescence from low temperature peaks in the glow curve which are susceptible to fairly rapid fading (Cameron et al., 1968b). Dosimeters were read using a Mark IV series, 110 TLD reader produced by the Radiation Detection Company (1967). During measurements the reader was flushed with nitrogen at a rate of about 4 $ft^3 h^{-1}$.

2.1 Dosimeter response to γ rays

The response of the dosimeters to ^{60}Co γ-rays was determined using the irradiation facility of the Biomedical Division of the Lawrence Berkeley Laboratory (LBL-no date). The activity of this source was measured as 1226 ± 39 Ci on October 27, 1972, using a cavity ionization chamber (Victoreen Condenser R-meter Model 570, 1950). The corresponding exposure rate at 1 m from the source was 26.6 R min^{-1}. To

assure that electronic equilibrium had been achieved, the dosimeters were irradiated under 3.5 mm of lucite (Cameron et al., 1968c).

Figure 1 shows the dosimeter readings as a function of exposure. The response was found to be linearly proportional to exposures up to 1000R; at larger exposures the detector response increases at a faster rate (supralinearity). Over the linear region a least-squares analysis gave the thermoluminescent response in arbitrary units (TLU) per Roentgen, τ, as

$$\tau = 1.20 \pm 0.01 \text{ TLU/Roentgen.}$$

The value of detector sensitivity to ^{60}Co γ-rays, τ, was found to be constant over a period of several months, being determined on four separate occasions during the period. Using a value of 0.805 rads/R for ^{60}Co γ-rays in ^{7}LiF (Attix, 1969) we obtain a value of

$$\tau = 1.49 \pm 0.01 \text{ TLU/Rad.}$$

2.2 Dosimeter response to carbon ions

Dosimeters were exposed to 252 MeV/amu $^{6+}$C ions. (The LET in LiF was 11.6 KeV/micron. Correspondingly, the LET in tissue would be 14.2 KeV/micron.) Irradiations were monitored using a nitrogen-filled parallel-plate ionization chamber. The dose, D, in the LiF dosimeters is given by

$$D = 10^5 \left(\frac{W\,Q}{m} \right) S,$$

where

W is the energy required to create an ion pair (eV),

Q is the charge collected by the ionization chamber (coulomb),

m is the mass of gas in the chamber (g),

S is the ratio of the stopping power of LiF to that of air for $^{6+}$C ions.

At the time of irradiation the density of nitrogen in the chamber was determined to be 1.21×10^{-3}. The value of S was taken to be 0.934 from the data of Steward (1968, 1969) and a value of W of 36 eV was assumed (Curtis, 1973). Table 1 summarizes values of thermoluminescent dosimeter response for more than 60 dosimeters for four absorbed doses. The dosimeter response in ^{7}LiF is seen from table 1 to be 1.32 ± 0.1 TLU/rad for 252 MeV/amu $^{6+}$C ions. The dosimeters thus have an efficiency, ϵ, compared to ^{60}Co of 0.90 ± 0.01. The error quoted here is only statistical—the absolute error largely depending upon the value of W assumed for $^{6+}$C ions in nitrogen. Myers (1968) quotes values of W in nitrogen of 34.6 ± 0.03, 36.39 ± 0.04 and 36.6 ± 0.5 for γ rays, α particles and protons respecitvely. We therefore believe our value of efficiency, ϵ, to be accurate to about $\pm$ 5%: $\underline{\epsilon = 0.89 \pm 0.04}$.

Conclusions

Jähnert (1972) has reported measurements of ϵ in ^{7}LiF for protons and α particles of various energies. For protons of energy 13.3 MeV (21 KeV/micron in LiF) he measured an efficiency relative to ^{60}Co of 0.86 ± 0.04. Jähnert has proposed two alternative theoretical models, both of which fit his experimental data well in the LET range 0.02 to 300 KeV/micron. (See fig. 2.) Our value of 0.89 ± 0.04 at 11.6 KeV/micron is in good agreement with these theoretical predictions. Tochilin, Goldstein and Lyman (1969) have reported measurements using normal LiF thermoluminescent detectors which might be expected to respond in a similar manner to ^{7}LiF dosimeters. (The isotopic abundance of ^{7}Li in natural lithium is 92.6%). At an LET of 11 KeV/micron, Tochilin et al. (1969) measured an efficiency of 0.88 ± 0.05, in good agreement with the value reported here.

The value of ϵ reported here is most dependent upon the accuracy of the value of W assumed. It is intended to measure values of W for a number of heavy ions over a wide range of energy at the Lawrence Berkeley Laboratory (Smith, 1973). We also intend to make further measurements of ϵ for a variety of ions over a wide range of LET. Absolute measurements will be made using nuclear emulsions.

We would like to thank John Lyman for loaning us the ionization chamber used in our measurements. Philip de la Riviere (Radiation Detection Company, California) provided us with helpful advice on the techniques of thermoluminescent dosimetry. George Wigle was responsible for the absolute calibration of the ^{60}Co irradiation facility. B. Jähnert provided us with details of his measurements.

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Table 1. ^{7}LiF response to 250 MeV/amu ^{6+}C ions

Dose in LiF (rad)	Thermoluminescent dosimeter response (arbitrary units)		TLU/rad
50.8	66.8 ± 0.6		1.31 ± 0.01
77.0	102 ± 1		1.33 ± 0.01
102	135 ± 2		1.32 ± 0.02
154	203 ± 4	Mean	1.32 ± 0.01

Figure Captions

Fig. 1. ^{7}LiF Thermoluminescent dosimeter response to ^{60}Co γ-rays. One representative error bar is indicated.

Fig. 2. Response of ^{7}LiF as a function of linear energy transfer.

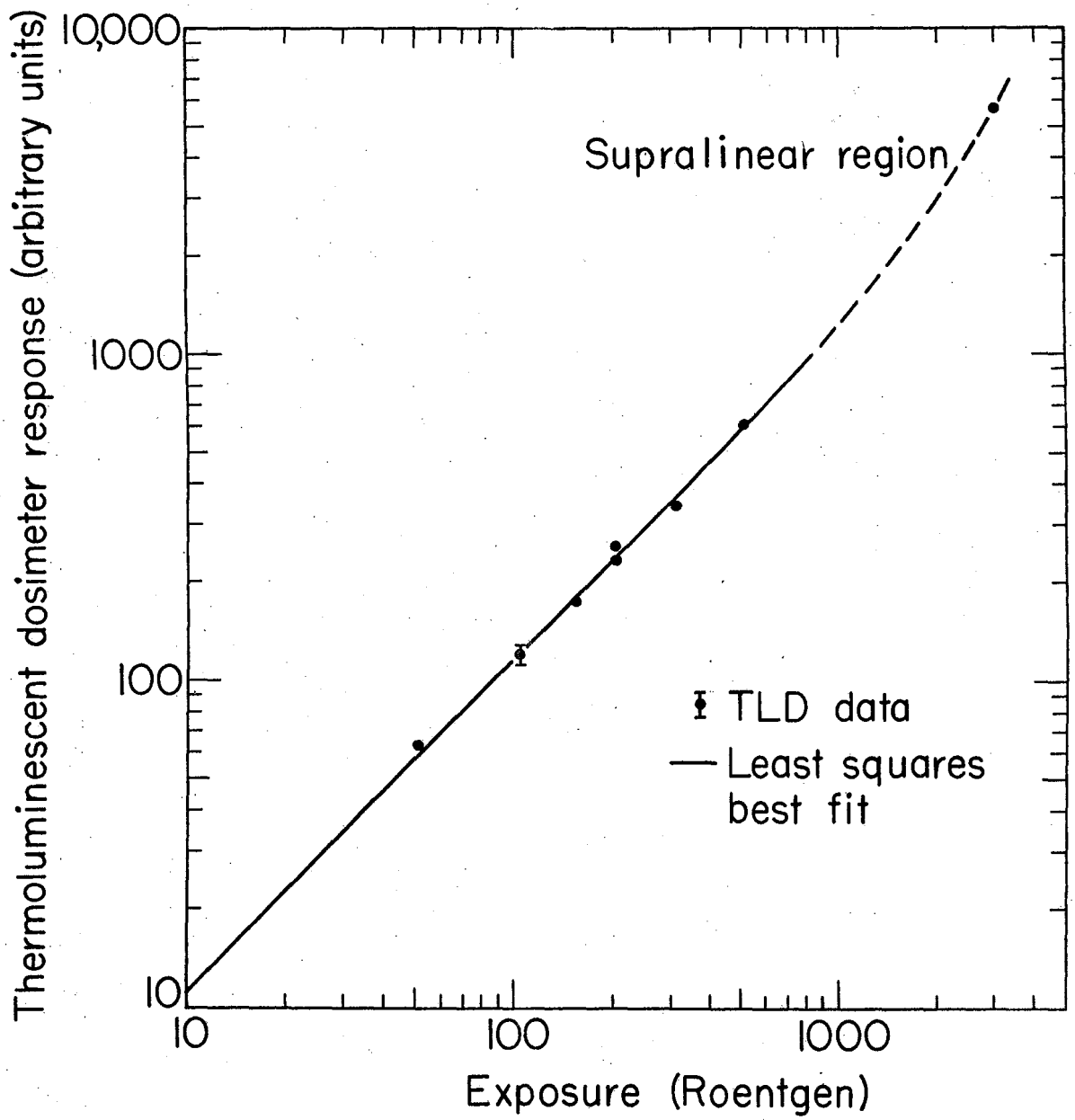

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Fig. 1

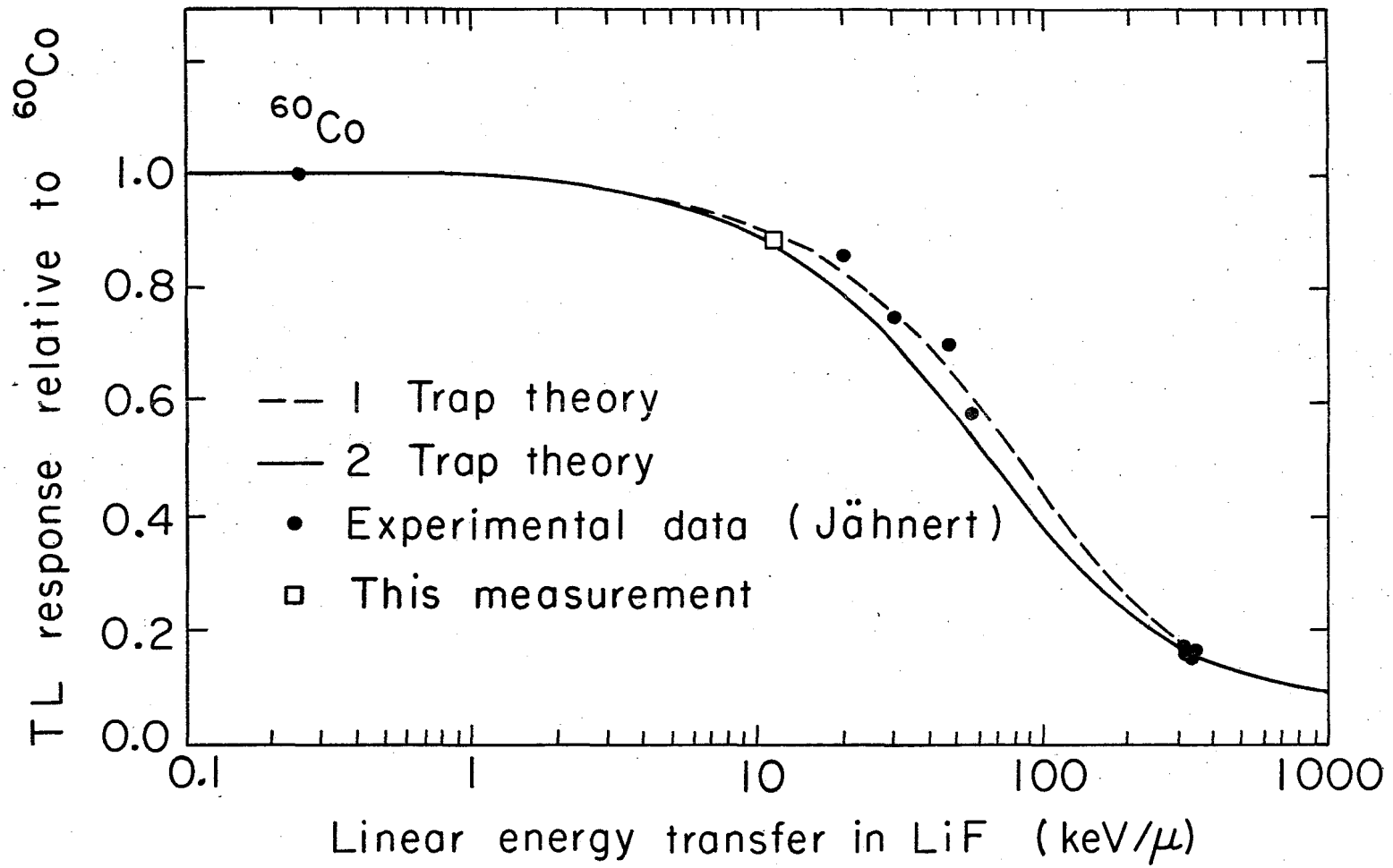

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Fig. 2