INVESTIGATION OF THE IONISATION DENSITY DEPENDENCE OF THE GLOW CURVE CHARACTERISTICS OF LiF:Mg,Ti (TLD-100)

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The dependence of the shape of the glow curve of LiF:Mg,Ti (TLD-100) on ionisation density was investigated using irradiation with ⁹⁰Sr/⁹⁰Y beta rays, 60 and 250 kVp X rays, various heavy-charged particles and 0.2 and 14 MeV neutrons. Special attention is focused on the properties of high-temperature thermoluminescence; specifically, the behaviour of the high-temperature ratio (HTR) of Peaks 7 and 8 as a function of batch and annealing protocol. The correlation of Peaks 7 and 8 with average linear-energy-transfer (LET) is also investigated. The HTR of Peak 7 is found to be independent of LET for values of LET approximately $>30 \text{ keV } \mu\text{m}^{-1}$. The behaviour of the HTR of Peak 8 with LET is observed to be erratic, which suggests that applications using the HTR should separate the contributions of Peaks 7 and 8 using computerised glow curve deconvolution. The behaviour of the HTR following neutron irradiation is complex and not fully understood. The shape of composite Peak 5 is observed to be broader following high ionisation alpha particle irradiation, suggesting that the combined use of the HTR and the shape of Peak 5 could lead to improved ionisation density discrimination for particles of high LET.

INTRODUCTION

There is a continuing interest in the further development of the capabilities of LiF:Mg,Ti (TLD-100) thermoluminescent detectors in mixed-field neutron–gamma ray dosimetry, and as ionisation density discriminators [average linear-energy-transfer (LET) estimators] in various heavy-charged particle and neutron–gamma radiation fields in space and air-craft dosimetry, heavy-ion medical radiation dosimetry and other applications. Many of the dosimetric characteristics of TLD-100 are known to depend on ionisation density; for example, (i) the dose onset of supralinearity and the maximum value of the supralinearity are dependent on electron energy⁽¹⁾, (ii) the relative TL efficiency is a function of X-ray energy⁽²⁾ and (iii) the relative TL efficiency for heavy-charged particles decreases with increasing ionisation density⁽³⁾. Although these particular characteristics are a nuisance in practical dosimetry, they demonstrate that the TL mechanisms in LiF:Mg,Ti are strongly dependent on ionisation density. It is also well known that the shape of the glow curve (i.e. the relative intensity of the various glow peaks) also strongly depends on the ionisation density, and some of the aspects of this behaviour are the subject of this paper.

LiF:Mg,Ti probably possesses the most complex glow curve of all known dosimetric thermoluminescent materials. At least 10 glow peaks have been identified in the glow curve of this material ranging from room temperature to 400°C. The main glow peak used for dosimetry appears at $\sim 205^\circ\text{C}$ when a heating rate of 1°C s^{-1} is applied and is referred to as Peak 5. Even this peak, which is exceptionally narrow in width, is believed to be composed of two, possibly three, sub-entities. At higher temperatures than that of Peak 5, additional glow peaks appear (commonly labelled 6–10) extending to temperatures beyond 400°C. This complexity, especially in the low-temperature region below Peak 5, is also correctly considered a nuisance since the traps responsible for the low-temperature peaks can agglomerate and form Peak 5 traps during the storage and irradiation periods between readouts, and the charge carriers (during and following irradiation) can migrate and transfer resulting in both fading and build-up of the TL signal—both these mechanisms result in the well-known dependence of the LiF:Mg,Ti Peak 5 signal on thermal and irradiation history. A dependence that can be minimised by various pre- and post-irradiation anneals and careful control of protocols—but never entirely eliminated. Many studies have been carried out in an attempt to use the complex behaviour of the shape of the glow curve (i.e. the relative intensity of the various glow

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peaks) for various dosimetric purposes, e.g. as an indicator of the time interval since irradiation⁽⁴⁾ or in neutron–gamma discrimination⁽⁵⁾, but these have been limited in use when applied to field conditions encountered in environmental and personnel ‘work-place’ dosimetry, or, perhaps, are too complex to be easily applied⁽⁶⁾ in situations where high throughput is required.

In the present study, the dependence of the shape of composite glow Peak 5⁽⁷⁾ and the high-temperature thermoluminescence (HTTL)⁽⁸⁾ in the glow curve of TLD-100 on ionisation density are studied⁽⁹⁾. The shape of composite glow Peak 5 (specifically the ratio of Peak 5a/5) has been suggested as an ionisation-density-dependent nanodosimeter⁽¹⁰⁾ due to the localised nature of the electron–hole recombination giving rise to Peak 5a. This localised recombination is believed to give rise to a weak low-temperature component of Peak 5 (Peak 5a) situated at a temperature $\sim 10^\circ\text{C}$ lower than Peak 5. In LiF:Mg,Ti materials using a ‘standard’ rapid cooling procedure following the 400°C pre-irradiation anneal (i.e. removal of the TLDs from the annealing oven), the ratio of Peak 5a to 5 is strongly dependent on ionisation density: following low-ionisation density (LID) irradiation, however, the ratio of 5a/5 is very low (~ 0.05 – 0.1) leading to difficulties in its measurement in a reproducible manner, and this has severely inhibited its development as a practical dosimeter. Recently, however, an annealing procedure that increases the ratio of Peak 5a to 5 has been reported by researchers at Ben Gurion University⁽¹¹⁾, which greatly increases its precision of measurement, and research is still on-going to further develop this method.

Various authors^(12,13) have promoted the use of the HTTL as an estimator of average LET in space radiation fields due to the enhanced relative intensity of the HTTL at high-ionisation density (HID). This phenomenon was probably documented originally in the early 1980s⁽¹⁴⁾ in the hope that it would be possible to measure both ‘low-LET’ and ‘high-LET’ radiation dose simultaneously with one detector. Attempts were made to apply the ‘two-peak-method’ to fast neutron radiation fields in clinical dosimetry⁽¹⁵⁾, even though it was acknowledged that both Peak 5 and the high-temperature structure are supralinear to both neutrons and gamma rays in the dose region applicable to clinical irradiations. In later applications in space radiation fields^(12,13), essentially the same analysis method was dubbed the ‘high-temperature ratio’ (HTR) method, in which the ratio of the intensity of the TL light emission in the high-temperature region (~ 225 – 300°C) to the light intensity of glow Peak 5 following HID radiation is compared with the same ratio following gamma or electron LID irradiation. Although the technique has been claimed to be highly successful,

it has also been criticised^(16,17) on various grounds, both technical and theoretical, which are beyond the scope of this paper. Other researchers⁽¹⁸⁾ have not been as successful in applying the HTR technique, and considerable differences were found between HTR estimations and true values in a condition where broad-LET-range particles were present.

EXPERIMENTAL METHODS AND MATERIALS

The thermoluminescent detectors (TLDs) employed were $3\text{ mm} \times 3\text{ mm} \times 0.89\text{ mm}$ LiF:Mg,Ti (TLD-100) Harshaw chips. Two batches (CNS-4715 and CNS-4945 purchased in June 2002 and November 2006, respectively) were studied in order to investigate the possibility of batch effects. Two pre-irradiation annealing procedures were used: (i) 400°C for 1 h followed by a rapid non-linear cool down in ~ 15 min to room temperature achieved by removing the TLDs from the annealing oven (referred to as standard cooling: ST-C) and (ii) a programmer-controlled and linear slow-cooling rate (SL-C) of 100°C h^{-1} in the oven. A post-irradiation anneal on the reader planchet of 155°C for 6 s (Harshaw model 3500) was also applied in most cases in order to remove the low-temperature peaks 2 and 3 from the glow curve. A slow and linear glow curve heating rate of 1°C s^{-1} to a maximum temperature 400°C was employed to enhance glow peak resolution and allow the investigation of the behaviour of individual glow peaks. It is worth mentioning that 400°C annealing may not be a sufficiently high temperature to completely ‘re-set’ LiF:Mg,Ti following HID irradiation, but this subject has yet to be thoroughly investigated. The readout procedure was carried out in a flow of high-purity N_2 gas following passage through a dehydrator; the annealing procedure, however, was carried out in air with no special precautions.

The following heavy ion irradiations at fluence levels of $\sim 10^9\text{ cm}^{-2}$ were carried out at the Radiological Research Accelerator Facility (RARAF) of Columbia University on two batches of ‘standard-cooled (ST-C)’ TLD-100: (i) 2 and 7.5 MeV alpha particles, (ii) 1.3 and 4.5 MeV protons and (iii) 1.7 and 4.5 MeV deuterons. The following neutron irradiations were carried out on Batch CNS-4945: 0.2 and 14 MeV neutrons at dose levels of $\sim 1\text{ Gy}$ on both bare and covered (3 mm tissue-equivalent plastic) detectors. An additional series of heavy ion and neutron irradiations were carried out on the CNS-4945 SL-C materials⁽¹¹⁾—a procedure which enhances the relative intensity of Peak 5a but seems to reduce the values of the HTR (see following section). Neutrons of 14 MeV energy were produced using the $\text{T(d,n)}^4\text{He}$ reaction and are nearly monoenergetic since the neutron production targets are

hydrogen isotopes absorbed onto thin titanium coatings. Gamma ray dose rate was estimated at $\sim 6\%$. Neutrons of 0.2 MeV energy are produced using the $T(p,n)^3\text{He}$ reaction with an estimated gamma dose rate of $\sim 1\%$. Dosimetry for neutrons is performed using tissue-equivalent ionisation chambers for total dose measurements and gamma ray dosimetry using neutron insensitive Geiger–Mueller or an aluminium walled-argon filled ionisation chamber. Charged particle energies were measured using a silicon solid-state detector that can be moved radially to measure the beam uniformity, particle fluence and beam purity using energy spectra. The LET spectrum is measured with a self-calibrating LET counter simulating the appropriate tissue thickness using TE gas. Average LET values in water quoted in the manuscript, however, were calculated using the Brookhaven LET calculator. Further information is available on the RARAF web site (www.raraf.org).

Irradiations at Ben Gurion University using a $^{90}\text{Sr}/^{90}\text{Y}$ source at a dose level of 100 mGy were also carried out to serve as a reference-radiation glow curve at LID. We have developed a ‘background-subtraction-protocol’ for the ST-C material which results in a linear dose–response for Peak 7 within an error of $\pm 20\%$ up to a dose level of 200 mGy (Datz, H., unpublished). The value of 100 mGy was thus chosen to be well within this range of linear dose–response. The scatter of data points for the dose–response of Peak 8 was too great to allow any statement concerning the linearity or non-linearity below 200 mGy. When the dose–response data are fitted with a function of the form $S = aD^n$ (where S is the TL signal intensity and D is the dose), we obtain $n = 1.43 \pm 0.06$ (Peak 7) and 1.54 ± 0.2 (Peak 8) with R^2 correlation coefficients of 0.99736 and 0.97319, respectively. The microdosimetric dose deposition characteristics of the secondary electron spectra generated by $^{90}\text{Sr}/^{90}\text{Y}$ is expected to be similar to that of ^{60}Co gamma rays⁽¹⁹⁾, so that HTR values using either of these sources should be directly comparable.

RESULTS

In the following, typical glow curves following LID and HID radiation are shown, illustrating certain aspects of the behaviour of the glow curve with ionisation density (Figures 1–4). A typical glow curve following irradiation by $^{90}\text{Sr}/^{90}\text{Y}$ beta rays at a dose level of 100 mGy is shown in Figure 1. The dominant glow peak (referred to as Peak 5) occurs at a T_{max} of $\sim 205^\circ\text{C}$. Note the relatively low intensity of the HTTL between 250°C and 350°C . Two HTTL glow peaks can be seen at $\sim 270^\circ\text{C}$ (Peak 7) and $\sim 320^\circ\text{C}$ (Peak 8). The shoulder on the low-temperature side of Peak 5 is referred to as Peak 4. Peak 5a

Figure 1. TL glow curve of LiF:Mg,Ti Batch CNS-4945 (ST-C annealing) following irradiation by beta rays at a dose level of 0.1 Gy.

Table 1. Ratio of Peak 5 to HTTL Peaks 7 and 8.

Batch identification	Number of chips irradiated	Peak 5/ Peak 7	Peak 5/ Peak 8
CNS-4945 (ST-C) ^a	3	35.3 ± 0.3	110 ± 30
CNS-4715 (ST-C) ^a	5	39.9 ± 1.8	121 ± 14
CNS-4945 (SL-C) ^b	4	18.4 ± 1.2	51.3 ± 21.5
CNS-4175 (SL-C) ^b	4	18.7 ± 0.8	61.3 ± 7.1

^aST-C standard cooling procedure following the 400°C pre-irradiation anneal.

^bSL-C slow cooling: $100^\circ\text{C hr}^{-1}$ following the 400°C pre-irradiation anneal.

is sandwiched between Peaks 4 and 5 and cannot be visually observed in the glow curve. The ratios of Peak 5 to Peaks 7 and 8 in the two batches following both ‘standard’ and ‘slow’ cooling are shown in Table 1.

As can be observed, following LID irradiation, the difference in the value of the HTR for Peak 7 between the two batches in both the SL-C and ST-C material is quite reasonable, no more than $\sim 10\%$ (1 SD). For Peak 8, however, the batch difference in the HTR for the SL-C material is $\sim 20\%$. The SL-C has the same effect on both batches, i.e. it increases the intensity of both Peaks 7 and 8 relative to Peak 5 approximately by a factor of 2. Following HID irradiation, however, the differences between the two batches are significantly increased for some irradiations and the HTR for Peak 7 is actually decreased in the SL-C material (Figure 5). Figures 2–4 illustrate the typical glow curves following proton, alpha particle and neutron irradiation.

Figure 2 shows the greatly increased intensity of the HTTL compared with the LID irradiation. Peak 7 at $\sim 270^\circ\text{C}$ is again the dominant HTTL glow peak but appears to be composed of two glow peaks

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Figure 2. TL glow curve of Batch CNS-4945 following 4.5 MeV proton irradiation with ST-C annealing at a fluence level of 10^9 cm^{-2} .

Figure 3. TL glow curve of LiF:Mg,Ti Batch CNS-4945 (ST-C annealing) following irradiation by 7.5 MeV alpha particles at a fluence level of 10^9 cm^{-2} . The HTTL is now very intense and is composed of at least four glow peaks. Peak 8 appears to have two components at $\sim 300^\circ\text{C}$ and 330°C . Peak 5 is considerably broader presumably due to an enhanced intensity of Peak 5a.

Figure 4. TL glow curve of LiF:Mg,Ti following irradiation by 0.2 MeV neutrons at a dose level of 1 Gy. The dominant HTTL glow is now Peak 8.

with a lower temperature glow peak at $\sim 250^\circ\text{C}$ (referred to as Peak 7a). Peak 8 at $\sim 320^\circ\text{C}$ is of considerably lower intensity. For batch CNS-4945, the

ratio of Peak 5 to Peaks 7 and 8 is 2.7 ± 0.2 and 4.7 ± 0.3 , respectively. For Batch CNS-4945, these ratios increase to 3.6 ± 0.08 for Peak 7 and 6.0 ± 0.5 for Peak 8, an increase of $\sim 35\%$ and 28% , respectively, illustrating significant batch differences in the relative intensity of the HTTL following HID irradiation.

Initial glow curve analysis based on peak height and glow peak width has revealed a rich degree of intriguing and previously unobserved/unreported characteristics. These will be analysed in the future using computerised glow curve deconvolution⁽²⁰⁾ in order to study the ionisation density behaviour of the components of composite Peak 5 (Peaks 5a and 5) and the HTTL (Peaks 6,7a,7,8a,8). In the present discussion, only the behaviour of Peaks 5, 7 and 8 measured by peak height are considered. Values of the HTR for Peaks 7 and 8 as a function of LET for the various irradiation modalities are shown in Tables 2 and 3 and in Figures 5 and 6.

Some immediate/obvious highlights of the results are outlined below:

- (1) Batch differences. Significant differences in the relative intensity and shape (relative intensities of Peaks 6–8) of the HTTL are observed for the two batches as discussed in Figure 2 for 4.5 MeV proton irradiation. However, except for the results for 4.5 MeV deuterons, the HTR for Peak 7 seems reasonably similar for the two batches. The HTR values for Peak 8, however, are very erratic (Figure 6). The precision of measurement is poor due to the difficulty in measuring Peak 8 (peak height) precisely at 100 mGy LID irradiation. The HTR values recorded for 7.5 MeV alpha particles ($67 \text{ keV } \mu\text{m}^{-1}$) are anomalously low for both annealing procedures and in both batches.
- (2) Behaviour of HTR with LET. In both the ST-C and SL-C materials and in agreement with previous studies^(12,13), the behaviour of the HTR for Peak 7 is strongly correlated with ionisation density (LET) increasing in a well-behaved manner to a factor of 20 and 10, respectively, at $\sim 20 \text{ keV } \mu\text{m}^{-1}$ for the ST-C and SL-C materials, respectively. The latter value of ~ 10 is also in good agreement with Refs^(12,13) which also employ slow but exponential cooling (in the furnace) following the high-temperature anneal. However, at higher values of LET, the results of this study level off and enter into saturation much more rapidly and suggest that hidden variables are very much at play in the relative intensities of the HTTL. The levelling off of the HTR at HID is an unexpected result that has not been previously reported in the literature and, at least for these results, indicates that the HTR is a very poor indicator of LET if the radiation field

Figure 5. HTR for Peak 7 as a function of LET for the various irradiation modalities. Dashed and full lines are intended only to guide the eye.

Figure 6. HTR for Peak 8 as a function of LET for the various irradiation modalities. Dashed and full lines are intended only to guide the eye.

consists of a large component approximately $>25 \text{ keV } \mu\text{m}^{-1}$. It should be mentioned that for particles stopping in the material as in the present experiment, the TL signal is averaged over the entire spectrum of LET. This makes an accurate comparison with high-energy beams in

which the irradiation is more uniform (and the LET spectrum narrower) somewhat problematic. However, it has been reported⁽¹³⁾ that for particles stopping in the samples, the behaviour of the HTTR as a function of LET behaves in the same manner as for high-energy particles

Table 2. Values of the HTR Following HCP (high LET) irradiation.

Particle	Average LET in water ($\text{keV } \mu\text{m}^{-1}$)	HTR—Peak 7			HTR—Peak 8		
		CNS-4945		CNS-4715	CNS-4945		CNS-4715
		ST-C ^a	SL-C ^b	ST-C ^a	ST-C ^a	SL-C ^b	ST-C ^a
4.5 MeV p	9	12.9 ± 0.6	9.2 ± 0.9	11.3 ± 0.6	8.7 ± 2.6	6.9 ± 2.8	5.8 ± 0.6
4.5 MeV d	15	14.7 ± 0.7	11.6 ± 1.2	18.9 ± 1.0	11 ± 3	10 ± 4	16.6 ± 1.7
1.3 MeV p	22	—	10.3 ± 1.0	—	—	65 ± 25	—
1.7 MeV d	30	20.8 ± 1.0	10.8 ± 1.1	21.0 ± 1.0	89 ± 27	70 ± 28	58 ± 6.1
7.5 MeV α	67	24.4 ± 1.2	16.0 ± 1.6	23.9 ± 1.2	34 ± 10	22 ± 9	32 ± 3.6
2.0 MeV α	150	23.4 ± 1.2	13.8 ± 1.4	24.8 ± 1.2	88 ± 26	87 ± 35	62 ± 6.2

^aST-C: standard cooling procedure following the 400°C pre-irradiation anneal.^bSL-C slow cooling: 100°C h⁻¹ following the 400°C pre-irradiation anneal.

Table 3. Values of the HTR following neutron irradiation—Batch CNS-4945.

Particle	HTR Peak 7	HTR Peak 8
14 MeV neutrons		
Bare	10.1 ± 0.5	13.3 ± 4
Covered ^a	7.8 ± 0.4	7.1 ± 2
0.2 MeV neutrons		
Bare	13.0 ± 0.6 (8.2 ± 0.8) ^b	61 ± 18 (38 ± 15) ^b
Covered ^a	16.1 ± 0.8	145 ± 40

^aCovered with 3 mm tissue equivalent plastic.^bQuantities in parenthesis are for SL-C material.

uniformly irradiating the sample. It has been claimed⁽²¹⁾ that the LET dependence of the HTR looks very similar to the LET dependence of the quality factor proposed in ICRP-26 and that, therefore, the average quality factors derived by the HTR method are independent of the LET spectrum of the absorbed radiation. The quality factor proposed by ICRP-26 increases from ~ 5 at $30 \text{ keV } \mu\text{m}^{-1}$ (in tissue) to ~ 10 at $170 \text{ keV } \mu\text{m}^{-1}$ (in tissue), so that this statement certainly does not apply to the results reported herein which show a nearly constant behaviour with LET above $30 \text{ keV } \mu\text{m}^{-1}$.

- (3) The HTR for neutrons deserves a separate discussion because of their very broad LET spectrum (Table 3). When the TLD is covered with 3 mm tissue-equivalent plastic, the energy deposited in the phosphor is mainly via knock-on protons generated by neutron-H collisions. In the 'bare' case, the energy is mainly deposited by Li and F recoils at considerably higher values of LET. Bewley⁽²²⁾ has calculated the LET distribution for 14 MeV neutrons in tissue.

Approximately 60% of the dose is deposited at values of LET $< 25 \text{ keV } \mu\text{m}^{-1}$. Table 3 shows an HTR value of 7.8 for 14 MeV neutrons irradiating the top-covered TLDs. The low value of the HTR indicates that most of the TL signal arises from high-energy proton recoils. As expected, the value of the HTR is higher for the 14 MeV neutrons irradiating bare chips due to the relatively higher contribution of F and Li recoils to the TL signal. The HTR values for 0.2 MeV neutrons are considerably lower than expected when one considers that even 0.2 MeV protons (the highest energy possible for a recoil proton) have an LET of $75 \text{ keV } \mu\text{m}^{-1}$ and that a certain contribution to the TL signal will arise from low-energy Li and F recoils of much higher LET. In addition, it is surprising that the HTR for the 'covered' case is higher than for the 'bare' case since the contribution of low-energy protons (relative to low-energy/high-LET Li and F recoils) should be higher in the bare case. The HTR of Peak 8 following 0.2 MeV neutron irradiation is very high indeed and again the HTR in the 'covered' case is higher than in the 'bare' case. These anomalies of the behaviour of the HTR irradiated by low-energy neutrons are unexplained.

- (4) The potential advantage of computerised glow curve deconvolution. As previously mentioned, the HTR for Peak 8 behaves in an erratic manner. The implication is, therefore, that the use of the HTR in LET estimation should be based on Peak 7 alone. Since Peaks 7 and 8 overlap considerably, the application of computerised glow curve analysis to resolve the peaks may contribute to greater precision in the measurement of the HTR of Peak 7. The use of peak height analysis does not eliminate the contribution of Peak 8 (and its satellites) to the intensity of Peak 7.

- (5) From the point of view of microdosimetry and track structure theory⁽²³⁾, the results shown in Figure 2 are quite remarkable and suggest that Peak 8 may be a very strange 'beast' indeed. It is well known that the supralinearity of the glow peaks in LiF:Mg,Ti (TLD-100) is a strong function of recombination temperature, and indeed many papers have reported that the gamma/electron-induced dose-response of Peak 8 is far more strongly supralinear than that of Peak 7. This would suggest that the relative intensities of Peaks 7 and 8 shown in Figure 2 be reversed and that Peak 8 should be stronger in intensity than Peak 7, rather than the opposite behaviour of the relative intensities illustrated in Figure 2. One would expect that the relative intensities of Peaks 7 and 8 be at least approximately equal as shown in Figure 4 for low-energy neutrons.
- (6) The enhanced presence of Peak 5a (the low-temperature component of composite Peak 5) is clearly observed in the alpha particle irradiations and is evidenced by the increased width of composite glow Peak 5 and a shift of $T_{\max}$ of composite Peak 5 to lower temperatures. This behaviour, however, is not as obvious following proton or neutron irradiation. This suggests that the combined use of the shape of Peak 5 and the HTR (Peak 7 only) may have significantly increased potential in mixed-field radiation dosimetry when very high-LET particles are involved.

CONCLUSIONS

The experimental results, i.e. the values of the HTR at high values of LET approximately $>25\text{--}30\text{ keV }\mu\text{m}^{-1}$, do not agree with previous measurements^(12,13,21). These results are by themselves not surprising since the batch and protocol dependence of even the major dosimetric Peak 5 in LiF:Mg,Ti (TLD-100) is well known. It has been suggested that the HTTL arises from uncontrolled impurities in LiF rather than from the Mg, Ti additives^(8,16), which would naturally lead to considerable batch-to-batch variations in the characteristics of the HTTL. Of even greater significance, however, is the fact that in these results the HTR for Peak 7 is essentially constant for values of the LET $>30\text{ keV }\mu\text{m}^{-1}$. Clearly, much work remains to be done in order to understand the vagaries of the dependence of the HTR on measurement protocol and particle type.

Initial glow curve analysis based on peak height and glow peak width has revealed a surprisingly rich degree of intriguing and previously unobserved or at least unreported characteristics. These will be future analysed using computerised glow curve deconvolution⁽²⁰⁾ to study the ionisation density behaviour of

the components of composite Peak 5 and the HTTL (Peaks 6, 7a, 7, 8a and 8). The change in the shape of Peak 5 at very high-ionisation densities and the smooth increase of the HTR at LID (LET $<25\text{--}30\text{ keV }\mu\text{m}^{-1}$) suggests that materials/analysis protocols for improved ionisation density discrimination may be developed by further investigations using computerised glow curve deconvolution (to eliminate the erratic behaviour of Peak 8) and optimal usage of highly controlled annealing protocols. These studies may lead to an improved understanding of the phenomenon underlying the appearance of the HTTL and improved ionisation density discrimination using LiF:Mg,Ti TLDs⁽²³⁾.

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