RE-ESTIMATION OF LOW LEVEL GAMMA RAY DOES
DETECTED BY LITHIUM FLUORIDE
THERMOLUMINESCENCE DOSEMETERS

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Abstract — An experimental method has been described for the re-estimation of low level gamma ray doses detected by
standard Harshaw TLD cards, consisting of two extruded ribbon type LiF thermoluminescence dosemeters covered with
thin Teflon foils. After the first readout at a temperature plateau of 300°C for 10 s the dosemeters were exposed to 254 nm
UV light for 25 min at a temperature of 110°C and re-evaluated. A primary gamma ray dose as low as 2 mSv was re-assessed
with an accuracy of ±25% from the second evaluation of the glow peak, resulting from the UV induced phototransferred
thermoluminescence.

INTRODUCTION

Lithium fluoride thermoluminescence dosemeters are nowadays being increasingly used for personal
dose monitoring and recognised as a reliable
detecting device by various governmental radiation
protection authorities. The glow curve of LiF:Ti,Mg
TLD, exposed to ionising radiation, consists of
several peaks(1) of which the most intensive one
appears at 204°C ± 2.3°C(2) and is thus considered to
be suitable for dosimetry purposes. The temperature
and the width of a TL glow peak depend mainly on
heating rate, the nature of the ionising radiation, and
the thickness and other physical properties of the
dosimeter.

On exposing the TLD irradiated by ionising
radiation to 254 nm ultraviolet (UV) light after first
readout, the charge carriers stored in the high energy
traps beyond the readout temperature range, are
transferred to the low energy traps and produce
thermoluminescence when heated up again(3). This
UV-induced phototransferred thermoluminescence
(PTTL) phenomenon has been utilised to re-assess
gamma ray doses detected by LiF thermoluminescence
dosimeters. In particular Mason et al.(4,5) have reported the lowest re-
assessable doses of 7.5 mSv ± 13% and 20 mSv for
LiF PTFE disc and LiF extruded ribbon type
dosimeters respectively. In a more recent article
McKinlay et al.(6) have described an experimental
procedure for an automated routine re-estimation of

gamma ray doses with LiF PTFE dosemeters to a
threshold dose of 20 mSv.

In the Austrian Research Centre Seibersdorf
investigations have been carried out in order to
determine the lowest achievable limit of gamma ray
dose that could be re-assessed by a PTTL technique.
Throughout the experiment the automated TLD
readout system (Model 2271) and numerically coded
TLD card (Type G1) from the Harshaw Chemical
Company were used(7). With the optimum off-line
UV exposure and annealing conditions a threshold
dose of 2 mSv was achieved. The calibration curve
(re-estimated dose relative to primary absorbed dose)
and the review of experimental results of other
investigators (Table 1) are also provided.

MATERIALS AND METHOD

Determination of optimum time of UV exposure

Fifty dosemeter cards (Type G1) consisting of a
pair of extruded ribbon type TLD chips (TLD-100),
sandwiched between thin Teflon foils and mounted in
a aluminium frame, were selected randomly from a
batch of 100 cards. The TLDs were annealed at 300°C
for 30 s in the readout unit as recommended by the
manufacturer and then at 100°C for 24 h in a muffle
oven (manufactured by Laybold Heraeus, FRO).
After annealing, the cards were divided into five
equal batches and exposed to 137Cs gamma rays to a
dose level of 10 mSv at the gamma irradiation facility
of the Austrian Research Centre Seibersdorf(7). The
gamma exposed TLD cards were re-annealed for 20
min at 95°C, gradually cooled down to room
Table 1. Review of experimental results on dose re-assessment with the PTTL technique carried out by various investigators.

<table>
<thead>
<tr>
<th>Threshold dose</th>
<th>TL phosphor used</th>
<th>Experimental conditions</th>
<th>Aim of the experiment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mSv ± 13%</td>
<td>LiF:PTFE disc</td>
<td>UV exposure: at 115°C Readout: ramp heating</td>
<td>Re-estimation of high gamma ray doses</td>
<td>McKinlay et al. 1980(5)</td>
</tr>
<tr>
<td>7.5 mSv ± 13%</td>
<td>LiF:PTFE disc</td>
<td>UV exposure: at 80°C Readout: ramp heating</td>
<td>Re-estimation of high gamma ray doses</td>
<td>Mason et al. 1977(5)</td>
</tr>
<tr>
<td>11 mSv ± 13%</td>
<td>LiF:PTFE disc</td>
<td>UV exposure: at room temp. Readout: ramp heating</td>
<td>Re-estimation of high gamma ray doses</td>
<td>Mason et al. 1977(5)</td>
</tr>
<tr>
<td>20 mSv ± 13%</td>
<td>LiF:Extruded ribbon</td>
<td>UV exposure: at 110°C Readout: plateau (300°C heating)</td>
<td>Re-estimation of very low gamma ray doses</td>
<td>This work</td>
</tr>
<tr>
<td>2 mSv ± 25%</td>
<td>LiF:Card (TLD-100)</td>
<td>UV exposure: at 110°C Readout: plateau (300°C heating)</td>
<td>Re-estimation of very low gamma ray doses</td>
<td>This work</td>
</tr>
</tbody>
</table>

*The value of the uncertainty is not given.

The flow diagram of the experimental procedure and the principle of the UV irradiation facility are shown in Figures 1 and 2 respectively. The re-estimation efficiency $E_r$ ($E_r = TL$ output after UV exposure/1st TL output) is plotted against the corresponding UV exposure time, $t_e$, in Figure 3.

**Determination of optimum temperature at UV exposure**

All TLD cards of the five batches were annealed (Step 1 of Figure 1), exposed to $^{137}$Cs gamma rays up to a dose level of 10 mSv and read out (Step 4 of Figure 1). The cards were then exposed to UV light for the optimum duration of 25 min (Figure 3), while the temperatures during exposure were kept at 30°C, 60°C, 90°C, 120°C and 150°C respectively (within ±1%). The TLDs were evaluated (Steps 3, 4 and 5 of Figure 1) and the re-estimation efficiency $E_r$ is plotted against the corresponding temperature $T_e$ in Figure 4.

**Determination of intrinsic UV background**

It has been found that even the TLDs exposed to UV light only, produce considerable TL glow(6). The exact nature of this phenomenon is not well understood, but it is important to assess the intrinsic UV background in order to re-estimate the net gamma ray dose accurately.

Two batches of dosemeter cards were annealed (Step 1 of Figure 1) and irradiated with $^{137}$Cs gamma rays (Step 2), whilst the first and the second batch received a dose of 2 mSv and 10 mSv respectively, and read out (Steps 3 and 4 of Figure 1). After the first readout the dosemeters were re-assessed five times (Steps 3, 4 and 5 of Figure 1). The re-estimated dose $D_e$ with the corresponding number of the re-estimation $N_e$ are plotted in Figure 5 (see also Table 2).
Table 2. Re-estimated doses for a primary gamma ray dose of 2 mSv (Group a) and 10 mSv (Group b) are shown with the number of the re-estimation.

<table>
<thead>
<tr>
<th>Number of re-estimation, (N_r)</th>
<th>Re-estimated dose (mSv) for Group a</th>
<th>Group b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.66 ± 0.08</td>
<td>2 ± 0.2</td>
</tr>
<tr>
<td>2</td>
<td>0.34 ± 0.09</td>
<td>0.58 ± 0.12</td>
</tr>
<tr>
<td>3</td>
<td>0.26 ± 0.04</td>
<td>0.34 ± 0.10</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>0.32 ± 0.10</td>
</tr>
</tbody>
</table>

Figure 3. Per cent re-estimation efficiency \(E_r\) (\(E_r = (\text{TL output after UV bleaching}/1\text{st TL output}) \times 100\%\), shown with corresponding time \(t_e\) of UV exposure. The error bars indicate the standard deviation of 20 data points.

Table 3. Primary Sv gamma ray doses are shown with the corresponding re-estimated dose after an UV exposure of 25 min at 110°C.

<table>
<thead>
<tr>
<th>Primary absorbed dose (mSv)</th>
<th>Re-estimated dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.66 ± 0.08</td>
</tr>
<tr>
<td>5</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>7.5</td>
<td>1.4 ± 0.3</td>
</tr>
<tr>
<td>10</td>
<td>2 ± 0.2</td>
</tr>
</tbody>
</table>

The calibration curve for dose re-assessment

Four batches of dosemeters were annealed, irradiated with \(^{137}\text{Cs}\) gamma rays and evaluated (Steps 1, 2, 3 and 4 of Figure 1). The 1st, 2nd, 3rd and 4th batch received a dose of 2 mSv, 5 mSv, 7.5 mSv and 10 mSv respectively. After the readout the dosemeters were exposed to UV light for 25 min (Figure 3) at 110°C (Figure 4) and re-evaluated (Steps 5, 3 and 4 of Figure 1). The average re-estimated doses \(D_i\) are plotted with corresponding primary absorbed doses \(D_a\) in Figure 6 (see also Table 3).

RESULTS AND DISCUSSION

The highest value of re-estimation efficiency (11%) at the ambient temperature was achieved after 25 min of UV exposure (Figure 3). An increase of temperature enhances the photocoupled thermoluminescence, consequently the peak value of re-estimation efficiency reaches 19% at 110°C (Figure 4). A further increase of temperature causes a rapid drop in TL output due to thermally induced release and recombination of electrons and holes in the low energy traps\(^{(5)}\).

The lowest detection limit for dose re-estimation depends solely on the intrinsic UV background, which is determined by the repeated UV exposure and readout of the TLDs after a single gamma ray exposure (Steps 3, 4 and 5 of Figure 1). The intrinsic UV background \((^{137}\text{Cs}\) gamma equivalent) extrapolated from the curves in Figure 5 was 0.36 ± 0.08 mSv, which corresponds to the lowest significantly detectable dose (background + 2σ) of 0.52 mSv. The thermal annealing of 300°C for 30 s and 100°C for 24 h (Step 1 of Figure 1) prior to the determination of background dose was sufficient enough to erase the traces of the previous irradiation history completely\(^{(7)}\). In the cases of neutron-gamma mixed field\(^{(8)}\) or charged particle (proton)\(^{(9)}\) irradiation, however, the concentration of deeper traps increases, which is indicated by the shift of main TL glow peak towards a higher temperature. Thus, an annealing treatment of at least 400°C for 1 h must
be performed before using the TLDs again.

The average re-estimated doses from the four batches of dosemeters (Table 3) were plotted against the corresponding primary absorbed dose and fitted by a straight line in Figure 6. It is evident that a primary absorbed dose of the magnitude of 2 mSv could be re-assessed confidently against the lowest detection limit of 0.52 mSv. From a primary absorbed dose higher than 10 mSv the calibration curve starts to be non-linear; this, however, is beyond the aim of the present work.

The high statistical uncertainty of the re-assessed doses in Figures 3, 4, 5 and 6 are due to the fluctuation of the sensitivities of the randomly selected dosemeters. In particular situations, where the authors institution is asked by some of the customers to supply them with the first dose information (primary absorbed dose) of certain TLD cards, the following steps are carried out:

1. The numerically coded TLD cards are read out after UV light treatment (25 min at 110°C).
2. The calibration curve for dose re-estimation of each chip is evaluated (Figure 6).
3. The primary absorbed dose extrapolated from the calibration curve is supplied to the customer.
4. The calibration curves are stored in a computer for future re-use.

Hence, this method of individual calibration of the TLDs reduces considerably the influence of statistical uncertainties on the re-assessed doses and could be effectively integrated in an automated personnel dosimetry system.

REFERENCES


