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Optimization of the Readout Procedures for the Harshaw 8800 TL Dosimetry System

Chwei-jeng (James) Liu
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T. A. Rhea

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Environmental and Health Protection

OPTIMIZATION OF THE READOUT PROCEDURES FOR THE HARSHAW 8800 TL DOSIMETRY SYSTEM

Chwei-jeng (James) Liu
C. S. Sims
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ABSTRACT

The optimization of the readout procedures for Harshaw's LiF-TLDs and its 8800 automatic TLD reader were studied. The optimization was based on the TLD sensitivity stability during 8-10 recycling uses. Three types of TLDs under several exposure conditions (gamma and neutron, low and high doses, and different fading times), five different types of TL light signals, and three different heating time-temperature-profiles (TTPs) were involved in the stability performance studies. The results show that the optimum readout procedures for all exposure cases can be achieved by using the Harshaw-suggested TTP heating methods and the TL light signals of some certain carefully-chosen regions of interest and peaks 3+4+5. The practical experience gained from using the computerized glow curve deconvolution (CGCD) program in the reader is also discussed.

1. INTRODUCTION

Today automatic thermoluminescent (TL) dosimetry systems have become prevalent in personnel monitoring. Many automatic TL dosimetry systems with different designs are commercially available[1]. Broadly speaking, such systems are composed of five main components: the thermoluminescent dosimeters (TLDs), dosimeter transport system, TLD heating system, TL light detection system, and TL signal processing system. Any changes in the TLD or the four instrumentation parts influence the accuracy of the final dose evaluation. Martin Marietta Energy Systems, Inc. has recently installed three Harshaw/Filtrol* model 8800 TLD Workstations and Harshaw's beta-gamma and neutron personnel dosimeters for personnel radiation dosimetry. A detailed description of the Harshaw TL dosimetry system can be found in their training manuals[2-4]. The Harshaw dosimeter has four holes in an aluminum card to contain TLD-600 and TLD-700 chips which are encapsulated between two thin sheets of Teflon. The 8800 TLD Workstation has an automatic TLD card reader and the TLD Radiation Evaluation and Management System (TLDREMS), which includes an 80286-based personal computer and relevant software programs. The TLD card reader uses hot nitrogen gas for a non-contact linear heating method and has ten programmable time-temperature-profiles (TTPs). The four TLD elements on each card can be read simultaneously and different TTPs can be applied to each chip. The output signals of the reader include the integrated TL light, the TL lights of selectable regions of interest (ROIs), and two-hundred-channel digitized glow curves to the PC. TLDREMS has a computerized glow curve deconvolution (CGCD) program[4-6] that allows the elimination of the constant background noise and infrared radiation noise and the unfolding of the remaining glow curve into individual dosimetric glow peaks by assuming first order TL kinetics for LiF-TLD.

It is well-known that the sensitivity of LiF-TLD is greatly affected by many factors, with the thermal procedures involved in the use of the TLD being a prime one. Recommended pre-irradiation oven anneal procedures for LiF-TLD are: 400°C-1 hour, followed by 80°C-24 hour or 100°C-10 minute, inert dry nitrogen or argon gas or vacuum are preferred to air[7]. The maximum readout temperature should ideally empty the high temperature peaks (peaks 6+7) and induce only tolerable infrared noise. The effect of maximum temperature on the TL sensitivity is related to the radiation type, dose level, heating rate, etc. High reproducibility of the heating and cooling rates are also crucial to good precision and accuracy of the readouts.

Since high-temperature and long low-temperature oven anneals are sometimes impractical, the reader anneal or the unannealed TLD[7] may be more appropriate, especially in highly automated TLD systems. Many

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*Harshaw/Filtrol Partnership, Crystal and Electronic Products, 6801 Cochran Rd., Solon, Ohio 44139.

authors have studied the effects of conventional oven anneal, different heating and readout procedures, reader anneal, and unannealed TLD on LiF-TLD characteristics[7-15]. Knowing that their experiments are different and the results are system-specific, it is quite difficult to compare the results and generate common conclusions. However, some general findings are as follows:

1. Oven anneal gives less sensitivity variation (<10%) over reuse[9,10,12]. Reader anneal or unannealed TLD can give as high as 20% sensitivity variation[10,12,14].

2. Reader anneal and unannealed TLD are acceptable in low dose, low linear energy transfer (LET) radiation situations[10,14,15].

3. The optimized anneal and readout procedures may vary with different LET radiations, different LiF-TLD materials, dose levels and reader systems[8,11,13].

The purpose of this study was to optimize the readout procedures of our automated TL dosimetry system. Readout procedures here refer to both the TTP heating method and the TL signal processing method. Since the reusability of the TLD is most important in the TLD monitoring technique, the optimization criterion was based on the consideration of TLD sensitivity stability during reuse. Other factors such as the sensitivity, the residual effect, glow curve reproducibility, and the speed of the readout process were also considered. Because there are many interrelated variables involved, it is difficult, if not impossible, to isolate and determine the individual affecting factors. This study was designed to investigate TLD stability performance by doing experiments that simulate the real exposure situations as closely as possible. The studies were done by using three types of LiF-TLDs exposed to low and high doses of low LET radiation (gamma) and high LET radiation (neutron). The exposed TLDs were read with different TTPs after a certain storage time and there was no oven anneal between readouts. The above process was repeated 8-10 times and the TTP and TL signals (integrated TL light, TL light of ROI, peaks area 3+4+5, peaks 4+5, or peak 5) which gave the best performance for sensitivity stability for each LiF-TLD material and exposure category was determined.

2. MATERIALS AND METHODS

2.1 LIF-TLD MATERIALS

The Harshaw beta-gamma dosimeter card has two TLD-700 chips ($3.2*3.2*0.38\ mm^3$), one TLD-700 thin chip ($3.2*3.2*0.09\ mm^3$), and one TLD-600 chip ($3.2*3.2*0.38\ mm^3$) (see Fig. 1a). Two TLD-700 chips are in element positions 1 and 2. The thin TLD-700 chip and TLD-600 are in element positions 3 and 4, respectively. The Harshaw albedo neutron dosimeter card (see Fig. 1b) has two pairs of TLD-600 and TLD-700 chips. Since the optimization criteria depend on the TL material, not on the card holder, only beta-gamma cards were used and the cards were irradiated without the holders. Thus three types of TLDs were under study: TLD-700, TLD-600, and thin TLD-700. TLD-700 is the LiF-TLD with ^{7}Li enriched to 99.93%. TLD-600 is the LiF-TLD with ^{6}Li enriched to 95.62%.

2.2 IRRADIATION

The beta-gamma cards were exposed to a ^{137}Cs source in free air for photon radiation and to a ^{238}Pu-Be neutron source on a standard Lucite slab phantom for high LET radiation. The neutron irradiations followed the standard procedures recommended by the National Bureau of Standards[16]. Low and high deep dose equivalent levels were 1 mSv (100 mrem) and 15 mSv (1500 mrem), respectively. The low dose level was picked to represent the typical quarterly dose equivalent range received by radiation workers in routine radiation protection situations. The high dose tests simulate calibration situations and accidental exposures. To simulate real exposure situations, the storage time before irradiation varied from 1 to 5 days and the storage time between irradiation and readout (fading time) varied from 1 to 37 days. The irradiation and storage environmental conditions were ambient temperatures and humidities, and in the dark. To minimize the source irradiation error, the irradiation times were made much longer than the source on-off time and the irradiation set-ups were never moved throughout the whole experiment. The irradiation variations were believed to be within 0.5% for gamma and 1% for neutron.

2.3 TL SIGNAL MEASUREMENTS

Harshaw Model 8800 reader was used to read the TLDs. The hot nitrogen gas research cycle is fast-heating and ideal for glow curve analysis[7,17]. Three TTPs in these research heating cycles were used for the study of TLD sensitivity stability. All four TLD elements in each card had the same TTP in these experiments. The following conditions were the same for all TTPs: preheat temperature (50°C), no preheat time, linear heating rate (25°C sec^{-1}), and maximum temperature (300°C). The hold time at the maximum temperature was 3.33 sec for TTP1 and 6.67 sec for TTP2. Therefore, the TL light acquisition time (AT) is 13.33 sec for

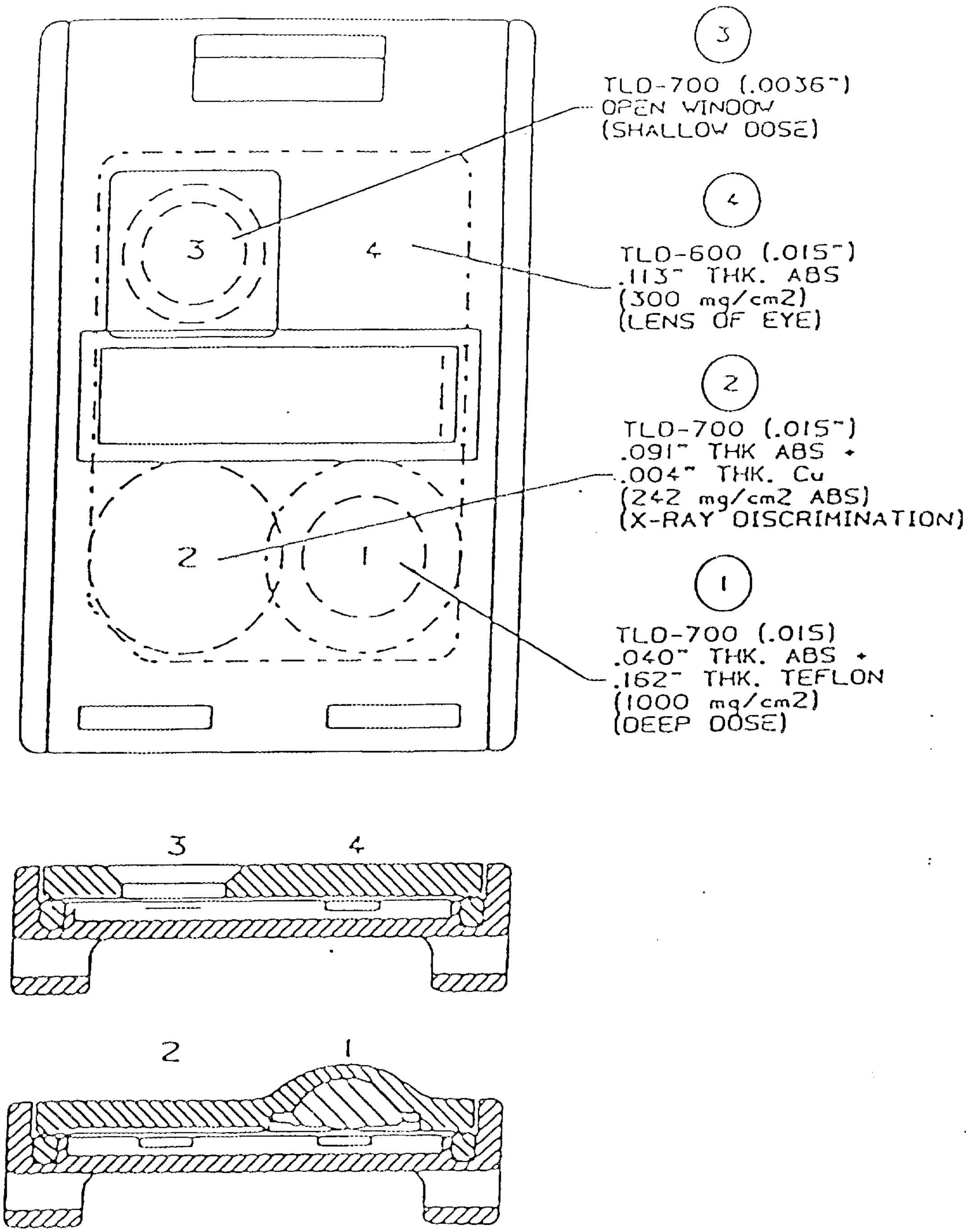


Fig. 1a. The Harshaw beta-gamma TL dosimeter design.

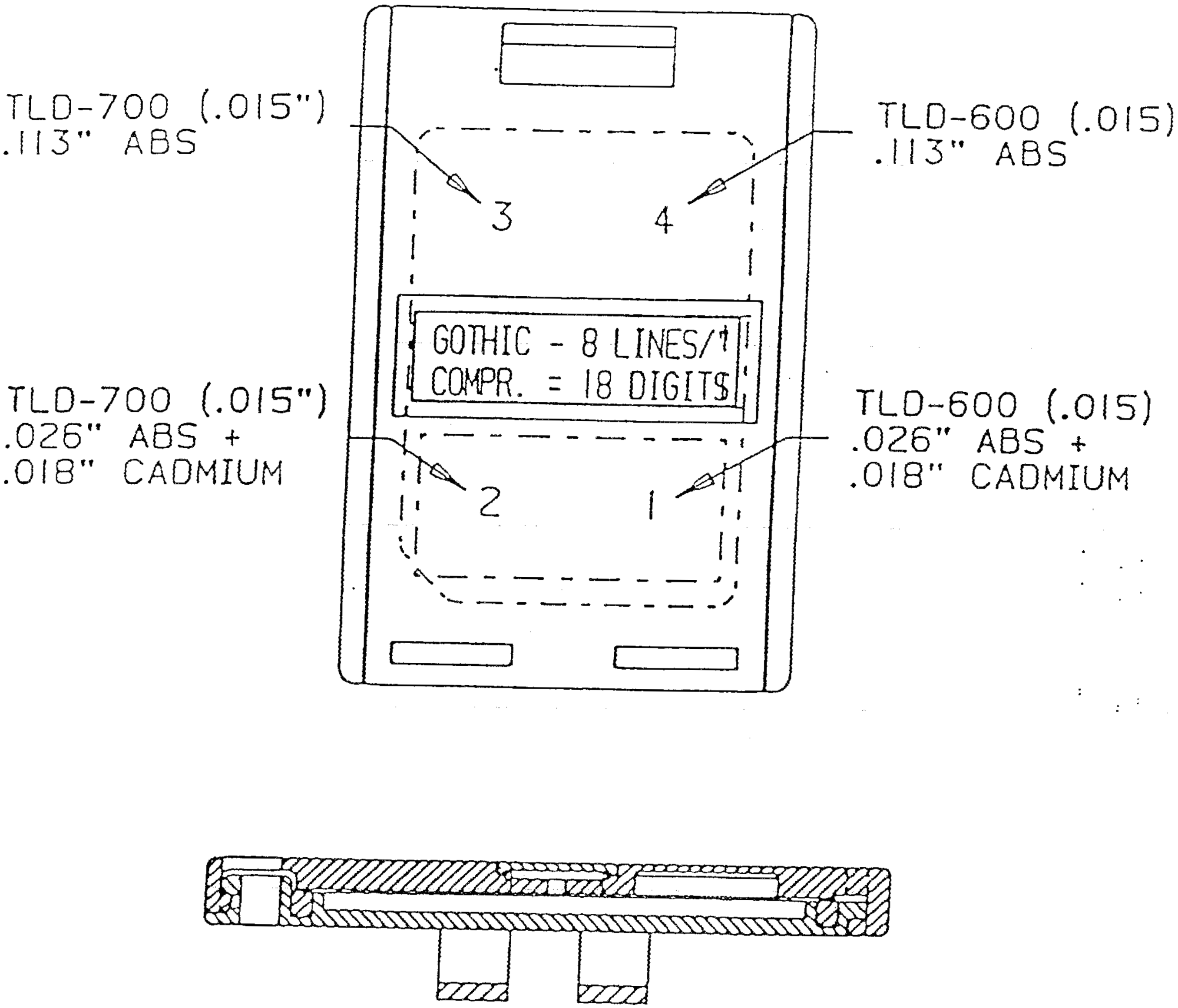


Fig. 1b. The Harshaw albedo neutron TL dosimeter design.

TTP1 and 16.67 sec for TTP 2. TTP1 and TTP2 are the TTPs specified inthe Harshaw manual[2] for reading TLD chips that are exposed to gamma and neutron radiations, respectively. The maximum temperature is set at 300°C to prevent melting the Teflon sheets. Since this temperature and the hold time does not empty the high temperature traps completely, there are some residual signals, especially in neutron exposures. To study the residual effect, TTP3 was set to read the cards twice with the same TTP1. The second reading was compared to the first reading in TTP3 heating to estimate the residual.

A total of 57 cards were used in this study (12 TLD groups with 4 cards in each TLD group and 3 background TLD cards for each TTP). Each TLD group was exposed to a low or high dose of gamma or neutron radiation and then read with one TTP. The noise and reference light signals of the four photomultiplier tubes (PMTs) were monitored every ten card readouts. The reference light measurements served to check both the short-term variation and long-term stability of the TL light detection system and also to estimate its contribution to the TLD sensitivity variation. Non-radiation induced TL signals (dirt-induced, oxygen and water vapor chemiluminescence) were minimized by the use of high purity (99.997%) nitrogen heating gas and the Teflon-encapsulated TLD chips.

2.4 TL SIGNAL EVALUATION

The integrated TL signal output of LiF-TLD measured as described above includes peak 2, the main dosimetry peaks (3+4+5), high temperature peaks (6+7) in neutron exposure, and noise. Peak 2 fades quickly with a half-time of approximately 10 hours. Infrared radiation from TL phosphors should increase the noise in the glow curve tail at temperatures greater than 250°C. However, infrared noise was not found in the readouts. By processing the digitized glow curve with the CGCD program, the noise and peak 2 can be eliminated and the dosimetry peaks can be obtained, which theoretically should be the better TL signals. Therefore, five different TL signals for the TLD sensitivity response were used:

1. Integrated TL signal with background TLD signals subtracted,

2. TL signal of a certain selected ROI,

3. Peaks 3+4+5 with noise and/or peak 2 eliminated by the CGCD program,

4. Peaks 4+5 from the peak separation option of the CGCD program,

5. Peak 5 from the peak separation option of the CGCD program.

3. RESULTS AND DISCUSSION

The bar code label glued to the aluminum card posed some limits on the heating time and temperature applied. At first several TTPs with different heating rates (5 to 50°C sec^{-1}) and longer acquisition times (up to 63.3 sec) were tried. Unfortunately, these TTPs caused the bar code label to peel off the aluminum substrate. Because this problem greatly influenced the speed of the automatic readout process, the study was restricted to the three TTPs (TTP 1, 2, and 3) in the main experiment. The results from that preliminary work and the main experiment are presented and discussed in the following text.

3.1 INDIVIDUAL TLD CHIP SENSITIVITY

The TLD chips used were not specially screened for uniform sensitivity. The typical sensitivity variation of a group read by the same PMT is ~5% (1σ) and 10% high is not rare. Therefore, the use of the Element Correction Factor (ECF) concept[17] to correct for the individual TLD chip sensitivity difference is strongly recommended for improved precision. However, the sensitivity stability study here is a self-comparison, so we used the mean response of a TLD group. This was justified by demonstrating that, in any two runs, the change of the mean response of a TLD group was close to the individual response change of any TLD chip in the group. The relative gamma sensitivity of TLD-600 to TLD-700 also depends on the PMTs of the reader system and the mean value is about unity. However, the variation of mean value (1σ = 22%) again is so large that individual sensitivity corrections by ECC and Reader Correction Factor (RCF)[2-3] are necessary in the albedo neutron dosimeters. The relative thermal neutron sensitivity of TLD-700 to TLD-600 is estimated to be negligible. The mean relative gamma sensitivity of thin TLD-700 to thick TLD-700 is about 0.27 (1σ = 26%) in this reader system, which is close to their nominal thickness ratio (0.24). All the TLD chips were verified to be in their proper positions from the test results, e.g., TLD-600 is in the element 4 position.

3.2 GLOW CURVE AND RESIDUAL CHARACTERISTICS

To study the glow curve and residual characteristics, the 200 channels of a glow curve were seperated into four identical areas with consecutive 50 channels for each area. For TTP1 heating, peak 2 is in the second area. Most main dosimetry peaks are in area 3 (channels 101-150). Peaks 6+7 are in area four. From the typical glow curves outputs shown in Figs. 2, 3, and 4, the following observations were made:

1. TLD-600 and TLD-700 have different glow curve responses to gamma radiation. TLD-600 has higher peak 3 response (see Fig. 2, elements i and iv of card 1043 or Fig. 3, card 1007).

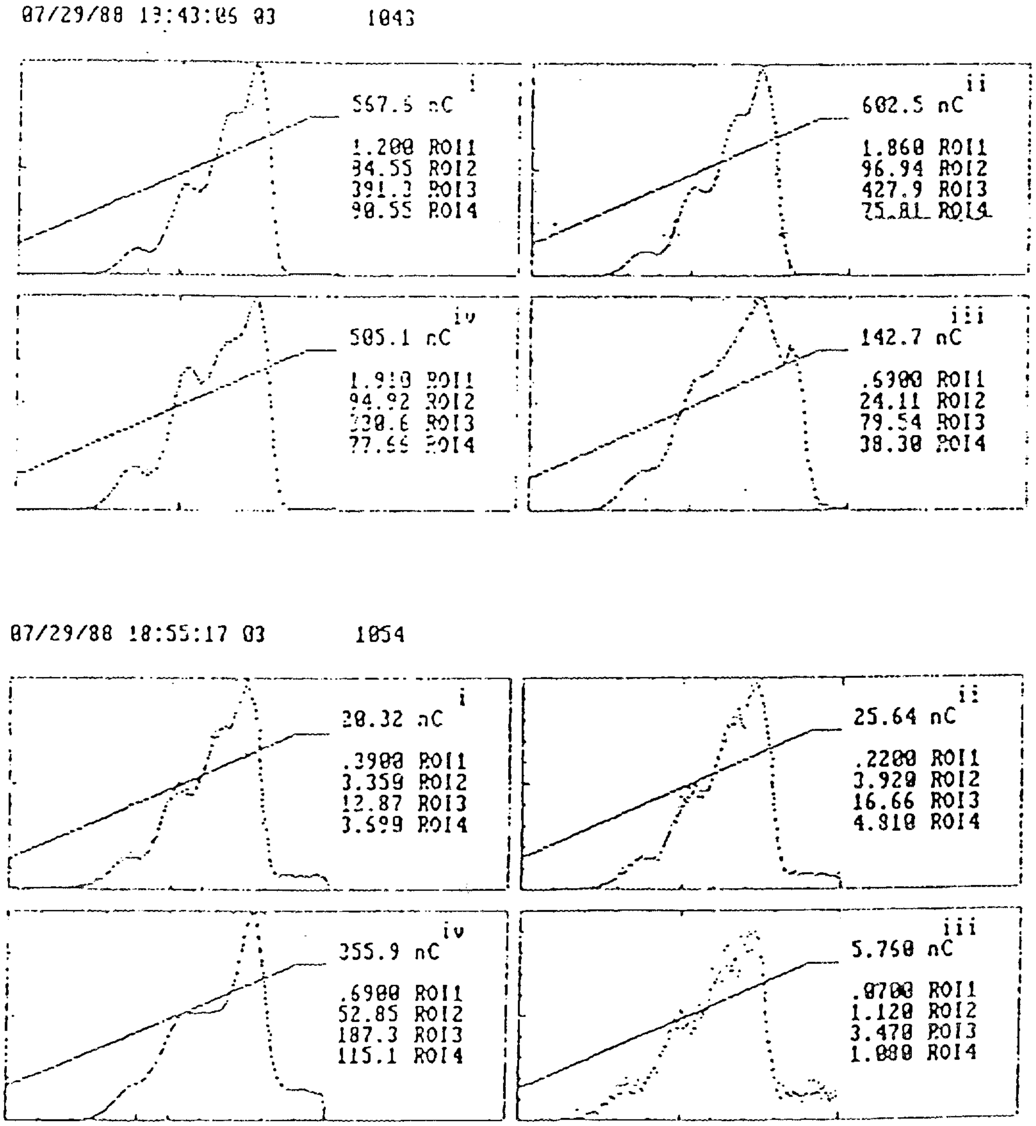


Fig. 2. Glow curve outputs: card 1043 to photon and card 1054 to neutron. Both are high dose exposure and little fading.

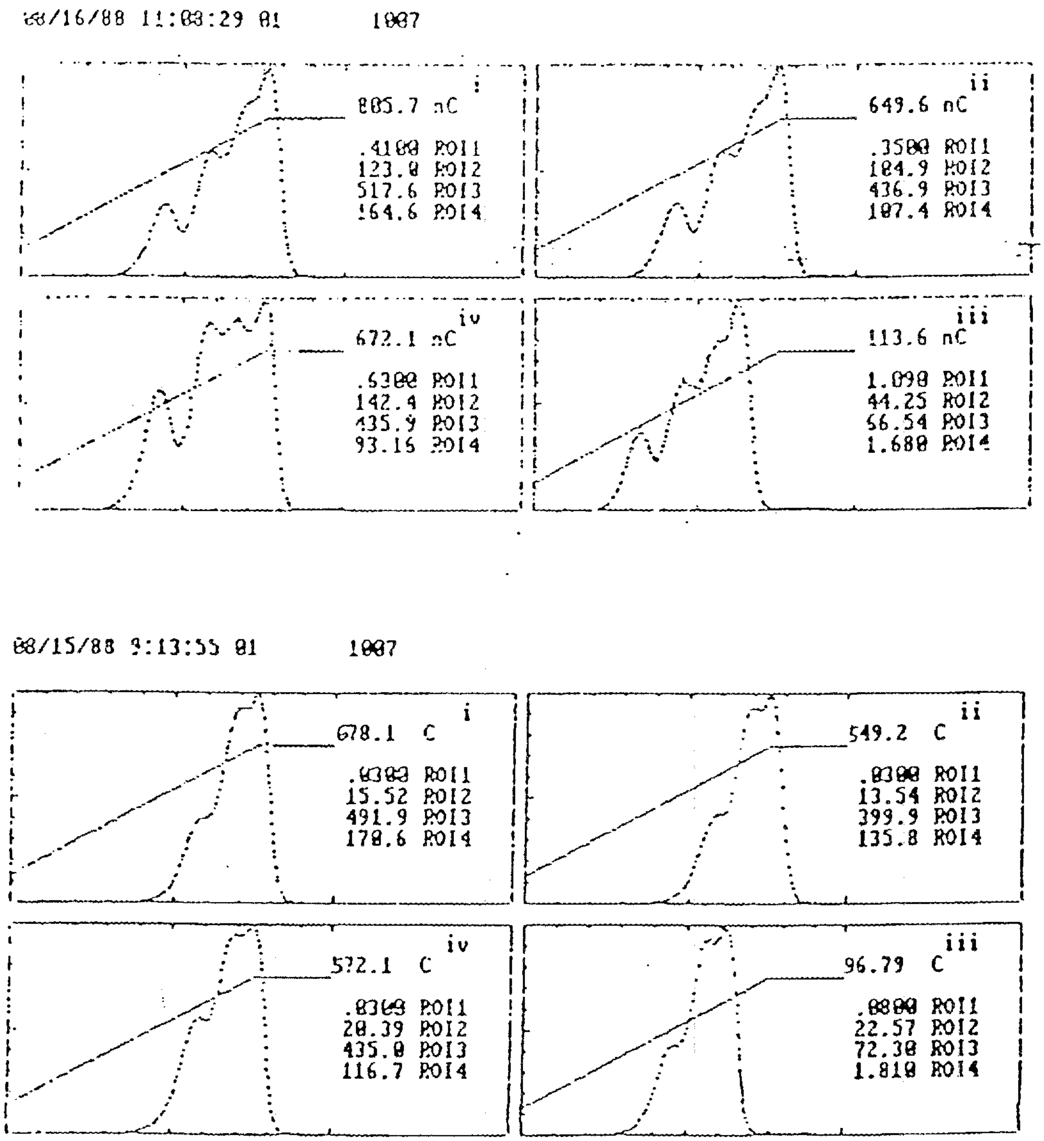


Fig. 3. Glow curve outputs: card 1007 to high photon dose exposure and TTP1 in two fading situations = top (short-term fading), bottom (long-term fading).

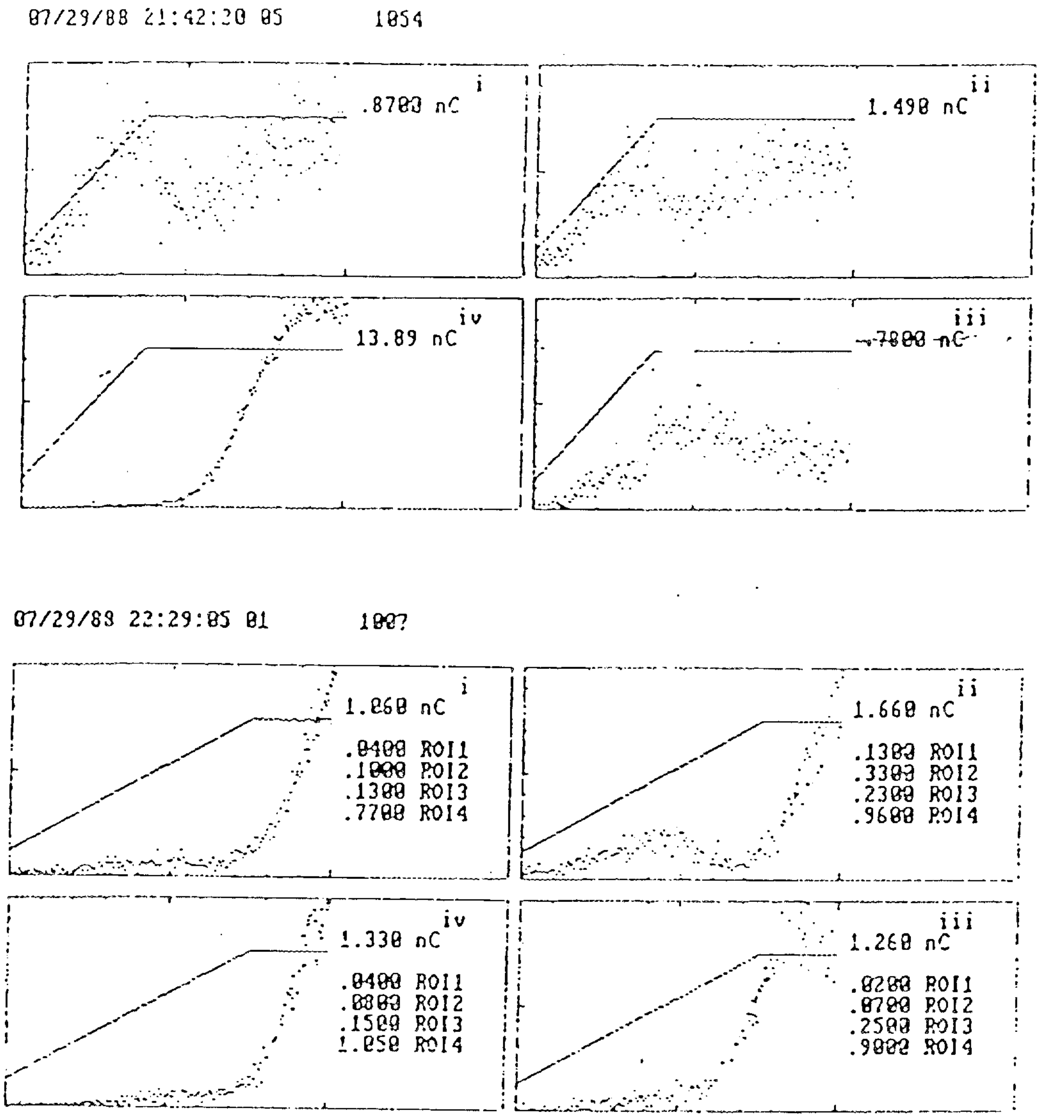


Fig. 4. Glow curve outputs from the second rereads: card 1054 to neutron and TTP4, and card 1007 to high gamma dose and TTP1.

2. TLD-600 has different glow curve responses to photon and neutron. Neutron induces higher peaks 6+7 and lower peaks 3+4 (see Fig. 2, elements iv of cards 1043 and 1054)

3. Peak 2 fades completely within a few days while peak 3 fades little during this period. The fading of peak 3 in TLD-600 is more severe than TLD-700 (see Fig. 3, card 1007 in two runs of different storage time after irradiation).

4. The glow curve output is reproducible for TLD-700 and TLD-600. This proved the stability of the TTP heating process. However, the glow curve reproducibility is not as good for thin TLD-700 due to its thinness (an irregular glow curve of thin TLD-700 can be seen in Fig. 2, element iii of card 1043). More variations in the peak positions of the thin TLD-700 were observed than for the other elements.

5. Very little residual was found for low gamma dose exposure. The second to first reading ratios from TTP3 heating for all TLDs were found to be ~0.2% for high gamma dose exposure (see card 1007 in Figs. 3 and 4). This agreed with King's results[13]. The residual from high temperature peaks was estimated to be 0.4% by reread with TTP4 (50°C sec^{-1}, AT = 13.3 sec, maximum temperature 300°C). The negligible residual indicated that no peaks 6+7 exist in photon exposure of TLD-700.

6. The second-to-first reading ratios from TTP3 heating for TLD-600 in low and high neutron dose exposures were ~2%. The residual should be more than 4% from the reread result with TTP4 (see element iv of card 1054 in Figs. 2 and 4). TTP5 (25°C sec^{-1}, AT = 30 sec, maximum temperature 300°C) was found to be able to empty all the high temperature peaks and the residual of TLD-600 for neutron with TTP1 heating was found to be ~10%. Because there was no light irradiation, the sensitivity transfer phenomenon[7] was not found during the 3-month experimental period.

3.3 SENSITIVITY STABILITY WITH TTP1

The sensitivity stability was first studied by deciding which TL signal is the best for each TLD material in each exposure condition. TTP1 was used for this study. The stability performance results are summarized in Tables 1-5. The reference light (RL) responses were monitored as an index of the reader stability and the mean responses and their variations (expressed as 1σ) for the four PMT channels of every run were recorded. Because one PMT broke after second run, the whole PMT assembly was replaced. All the signals in the first two runs were normalized to the mean RL response, so the RLs for all the first two runs are the same as the mean RL (see note a in all Tables). In the TLD-700 cases, the mean signal responses from both element 1 and element 2 were used, and no σ was given to the RLs since it involved two PMTs.

Table 1. Sensitivity stability of thick TLD-700 over reuse for low gamma dose exposure as a function of different TL signals (nC)

Run no.	Day (t1,t2)[c]	RL[a]	IL	ROI	Peaks 3+4+5	Peaks 4+5	Peak 5
1	(?, 2)	228	46.0	44.6	45.3	35.9	24.8
			5.0%	4.5%	2.5%	4.5%	6%
2	(3, 1)	228	47.3	45.9	44.9	36.9	27.3
			5.0%	5.0%	5.5%	4.5%	8%
3#	(3,10)	228	44.1	44.5	42.8	37.5	26.8
			18%	19%	18%	19%	22%
4	(1,<1)	223	52.1	44.9	44.5	35.8	24.6
			18%	19%	18%	18%	23%
5	(1,<1)	224	51.4	44.0	43.5	34.8	25.2
			17%	19%	17%	18%	24%
6	(<1,<1)	226	50.4	42.1	42.3	34.0	24.5
			18%	20%	18%	17%	24%
7	(1,<1)	226	49.5	43.4	42.6	34.8	25.0
			17%	18%	17%	18%	24%
8#	(1, 7)	232	43.6	43.2	42.3	33.3	25.4
			17%	18%	17%	16%	21%
9#	(4,37)	238	41.5	43.4	41.7	38.7	30.1
			18%	18%	18%	19%	25%
mean		228	47.3	44.0	43.3	35.7	26.0
σ of mean		2.3%	8.0%	2.5%	3.0%	4.8%	7.0%
max. varia.		6.7%	26%	9.0%	8.6%	16%	23%

Symbol # designated the runs of large fading.

Note a: Reference Light signals (RLs) of runs 1-2 were normalized to the mean RL value.

Note c: t1 is storage time before exposure, t2 is fading time after exposure.

Integrated Light (IL): channels 1-200.

Region of Interest (ROI): channels 101-200.

Table 2. Sensitivity stability of thick TLD-700 over reuse for high gamma dose exposure as a function of different TL signals (nC)

Run no.	Day (t1,t2)[c]	RL[a]	IL	ROI	Peaks 3+4+5	Peaks 4+5	Peak 5
1	(?, 1)	229	678 8%	628 8%	653 8%	484 14%	346 10%
2	(4,<1)	229	732 9%	662 9%	653 9%	545 9%	379 9%
3#	(3,10)	228	633 17%	616 17%	603 17%	527 17%	369 17.5%
4	(1,<1)	223	743 17%	628 18%	631 17%	514 17%	339 17.5%
5	(1,<1)	224	724 17%	627 19%	627 17%	509 16%	339 21%
6	(1,<1)	226	720 16%	616 17%	615 16%	500 15%	334 18%
7#	(1, 7)	232	628 16%	608 17%	600 16%	490 14%	357 19%
8#	(4,37)	238	599 16%	593 16%	574 16%	529 16%	390 18%
mean		229	682	622	620	512	357
σ of mean		2.5%	8.2%	3.2%	4.4%	4.1%	5.8%
max. varia.		6.7%	24%	12%	14%	13%	17%

Symbol # designated the runs of large fading.
Note a: Reference Light signals (RLs) of runs 1-2 were normalized to the mean RL value.
Note c: t1 is storage time before exposure, t2 is fading time after exposure.
Integrated Light (IL): channels 1-200.
Region of Interest (ROI): channels 101-200.

Table 3. Sensitivity stability of thin TLD-700 over reuse for high gamma dose exposure as a function of different TL signals (nC)

Run no.	Day (t1,t2)[c]	RL[a]	IL	ROI	Peaks 3+4+5	Peaks 4+5	Peak 5
1	(?, 1)	175 2.5%	124 13%	95 17%	120 13%	96 13%	69 20%
2	(4, <1)	175 1.2%	136 14%	99 17%	120 14%	102 13%	76 27%
3#	(3,10)	178 0.7%	119 14%	100 17%	113 14%	100 13%	76 23%
4	(1,<1)	175 0.8%	140 14%	94 19%	118 14%	96 15%	69 19%
5	(1,<1)	176 0.9%	139 14%	92 18%	119 14%	93 25%	67 24%
6	(1,<1)	177 1.8%	138 14%	91 19%	116 14%	95 13%	65 17%
7#	(1,7)	172 0.7%	115 14%	92 18%	110 14%	94 13%	69 21%
8#	(4,37)	173 0.8%	108 14%	95 17%	104 14%	98 15%	77 20%
mean		175	127	95	115	97	71
σ of mean		1.3%	9.8%	3.5%	4.9%	3.2%	6.5%
max. varia.		3.5%	30%	9.9%	15%	9.7%	18%

Symbol # designated the runs of large fading.
Note a: Reference Light signals (RLs) of runs 1-2 were normalized to the mean RL value.
Note c: t1 is storage time before exposure, t2 is fading time after exposure.
Integrated Light (IL): channels 1-200.
Region of Interest (ROI): channels 101-200.

Table 4. Sensitivity stability of TLD-600 over reuse for low neutron dose exposure as a function of different TL signals (nC)

Run no.	Day (t1,t2)[c]	RL[a]	IL	ROI[b]	Peaks 3+4+5	Peaks 4+5	Peak 5
1	(?, 2)	245 2%	30.8 6.0%	30.3 4.3%	29.6 10%	18.9 9%	14.6 8%
2	(3, 1)	245 0.8%	32.2 5.0%	30.8 3.6%	26.5 11%	18.1 6%	14.4 3.5%
3#	(1,12)	248 1%	25.8 6.2%	26.1 5.2%	23.9 5%	19.0 2%	16.5 7%
4	(<1,<1)	243 0.7%	31.9 5.2%	29.1 3.3%	27.3 5%	21.6 19%	14.6 10%
5	(<1,<1)	244 0.8%	33.5 3%	29.1 3.8%	26.2 1%	16.1 8%	12.5 10%
6	(<1,<1)	244 0.8%	34.1 7%	26.2[b] 2.4%	28.0 7%	17.6 12%	13.0 7%
7	(<1,<1)	243 0.6%	34.0 4.8%	25.6 2%	25.3 9%	19.4 25%	13.0 14%
8	(<1,<1)	243 0.6%	32.5 6.4%	25.2 1.8%	25.6 9%	16.4 1%	12.2 10%
9#	(1, 7)	245 0.9%	27.4 6.7%	24.4 1.2%	22.2 14%	16.7 7%	13.9 6%
10#	(4,37)	246 0.7%	22.3 8%	23.1 4.3%	20.5 3%	16.7 13%	14.5 15%
mean		245	30.5	24.9	25.5	18.1	13.9
σ of mean		0.7%	13%	4.8%	11%	9.5%	9.2%
max. varia.		2.1%	53%	13%	44%	34%	35%

Symbol # designated the runs of large fading.

Note a: Reference Light signals (RLs) of runs 1-2 were normalized to the mean RL value.

Note b: Region of Interest (ROI) changed from channels 101-200 to channels 116-200 after run no. 5.

Note c: t1 is storage time before exposure, t2 is fading time after exposure.

Integrated Light (IL): channels 1-200.

Table 5. Sensitivity stability of TLD-600 over reuse for high neutron dose exposure as a function of different TL signals (nC)

Run no.	Day (t1,t2)[c]	RL[a]	IL	ROI[b]	Peaks 3+4+5	Peaks 4+5	Peak 5
1	(?, 2)	245 2%	461 3.8%	426 3.5%	396 7%	260 4%	212 2%
2	(3, 1)	245 0.8%	485 3.7%	439 3.1%	375 5%	272 6%	221 1.5%
3#	(1,12)	248 1%	390 4.4%	376 4.4%	314 3%	262 2%	206 5%
4	(<1,<1)	243 0.7%	489 3.9%	427 4.1%	360 7%	241 3%	178 11%
5	(<1,1)	244 0.8%	495 4%	380[b] 4%	378 3%	233 8%	187 5%
6	(<1,1)	243 0.6%	482 4%	369 4%	366 5%	228 5%	184 8%
7#	(5, 3)	245 0.9%	440 4.3%	370 4%	344 3.5%	247 6.5%	208 8%
8#	(4,37)	246 0.7%	339 4%	312 4%	255 4%	232 4%	202 5%
mean		245	448	358	349	247	200
σ of mean		0.8%	12%	8.6%	13%	6.6%	7.6%
max. varia.		2.1%	46%	22%	55%	19%	24%

Symbol # designated the runs of large fading.
Note a: Reference Light signals (RLs) of runs 1-2 were normalized to the mean RL value.
Note b: Region of Interest (ROI) changed from channels 101-200 to channels 116-200 after run no. 4.
Note c: t1 is storage time before exposure, t2 is fading time after exposure.
Integrated Light (IL): channels 1-200.

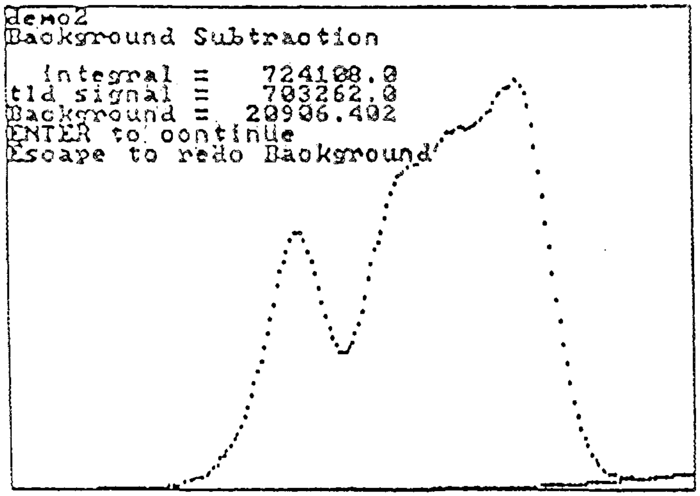
The storage time before irradiation (t1) and the storage time after irradiation (t2) in units of days are in column 2 of Tables 1-5. Those runs with t2 longer than 2 days (runs no. marked with symbol #) can be regarded having long fading times and peak 2 can not be seen or easily identified in those glow curve outputs. Peak 3 of some glow curves in the last run were also not distinct due to its 37-day fading.

The five TL signals used for stability performance comparison in the TTP1 can be clearly seen in Fig. 5. Figure 5a shows a typical digitized gamma-exposed LiF glow curve with 200 channels. The integrated TL light covers all 200 channels. The fourth column in Tables 1-5 gives the integrated TL signals (channels 1-200) with background TLDs signals subtracted (IL). The IL signal should give the worst performance. In practical TLD dosimetry it is necessary that the low temperature peaks fading effect be eliminated, without significantly affecting the response of the dosimetry peaks. Although no preheat was applied to remove peak 2 in the readouts, we can still resort to the use of the carefully-chosen ROI, which covers only peaks 3, 4, and 5, or to the use of the CGCD program to cope with the fading problem. The ROI signal chosen is given in the fifth column of all Tables. The ROI for gamma exposure (Tables 1, 2, and 3) is from channel 101 to channel 200. The ROI for neutron exposure was also between channels 101 and 200 for the first few runs. However, a new ROI from channel 116 to 200 was later found to be more appropriate due to the more severe fading in peak 3 for neutron exposure. Consequently, a change of ROI was made in neutron cases (see note b in Tables 4 and 5). The mean of ROI signal was based on the signals of final ROI setting only, e.g., the mean ROI signal in Table 5 was derived from the ROI signals of runs 5 through 8 only. The best ROI setting can be adjusted by matching the ROI signal with the IL signal of a large fading one (e.g., see Tables 1, the mean ROI signal is close to the IL signal of run 3, 8, or 9).

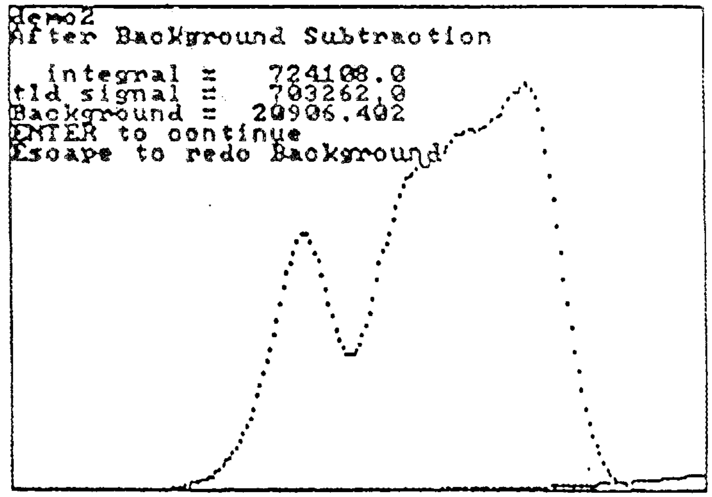
The sum of peak areas 3, 4, and 5 in column 6 (peaks 3+4+5) of Tables 1-5 was derived in two different ways. For the small-fading runs, peak 2 and the noises (constant noise and peaks 6+7) were removed by the peak 2 elimination option in the CGCD program and the peaks 3+4+5 signals were obtained (see Fig. 5c). For those large-fading runs (marked with # after run no.), the peak 2 elimination option did not work well due to unclear peak 2 identification and then only the background subtraction option in the CGCD program could be used (see Fig. 5b). The signals of peaks 4+5 and peak 5 are listed in columns 7 and 8, respectively. They were derived by the peak separation option of the CGCD program in either the production mode or the research mode (see Fig. 5d). The maximum variation in the last row of all Tables refers to the percentage difference between the maximum and the minimum TL signals in that column.

From Tables 1-5 and the experience with the CGCD program, we made the following conclusions can be drawn:

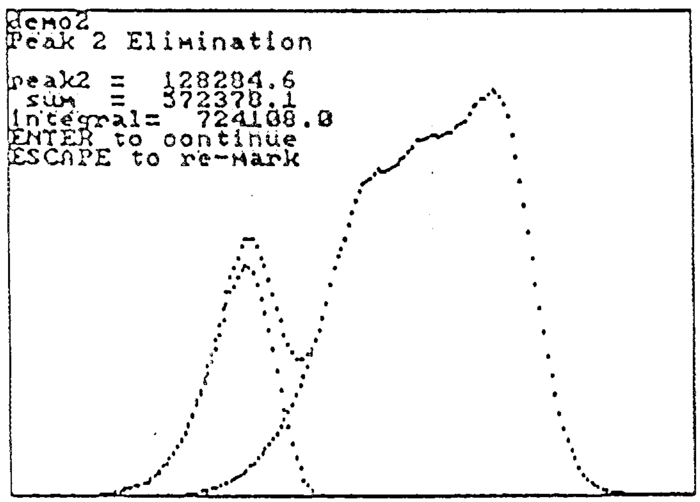
1. The RL variations (i.e. the reader PMTs instability) contributed 0.7% to 2.5% (1σ) and 2.1% to 6.7% (maximum variation) to the TLD sensitivity variation during reuse (see column 3 in Tables 1-5).



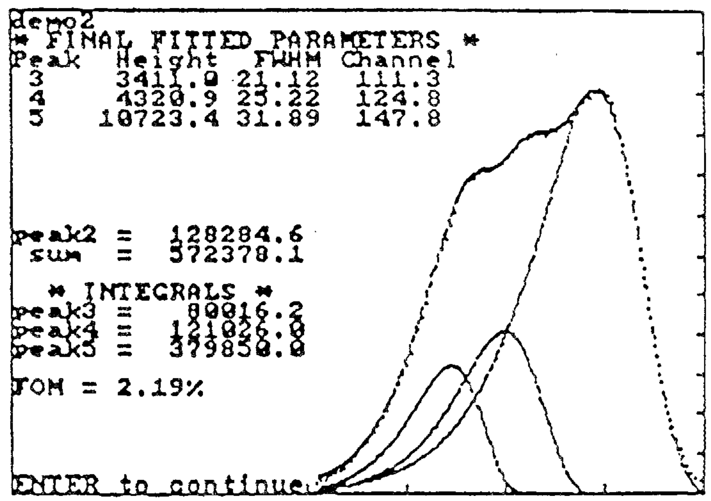
a. Typical gamma-exposed LiF-TLD glow curve



b. Background subtraction



c. Peak 2 elimination



d. Dosimetry peaks deconvolution

Fig. 5. The digitized glow curve ouptut of LiF-TLD, the CGCD options, and the five TL light signals.

However, the RL variation within a run could be as high as 3%. This is why the contribution from the RL variation was estimated instead of normalizing the TL signals of all runs to the mean RL value.

2. The IL signal had the worst sensitivity stability performance in almost all cases, as expected. One standard deviation is about 10% and the maximum variations ranged from 24% to 53%. This is due to the fading effects of peak 2 and peak 3 and the background TLD signal subtraction method. However, the IL signals variations are within 15% if small fading runs and large fading runs are considered separately. For example, see Table 1 the ILs from runs 4-7 are similar and the ILs of runs 3, 8, and 9 are similar. Therefore, the IL signal (channels 1-200) can give a first order dose approximation without too much error (<50%) in routine chronic exposures that have similar fading times.

3. The ROI signal between channels 101 and 200 gave the best stability performance in all TLD-700 with TTP1 heating cases (σ of mean <3.5% and maximum variation <12%). The ROI signal between channels 116 and 200 is better for the low neutron dose case and good for the high neutron dose case. The fact that the ROI signal of the last run in the neutron exposure is the smallest indicates that, at the expense of reduced sensitivity, the channels of the ROI can be chosen smaller to reduce the peak 3 fading effect and better stability can be expected. However, the ROI signal level is close to the peaks 3+4+5 signal and the ROI signal performance is still the best (see the mean values in Tables 1-5). This showed that if the appropriate ROI is chosen, both the stability and the sensitivity can be optimum. The ROI signal can be very easily derived from setting the calibration region in the reader, so it is also very practical to use the ROI signal in routine TLD readouts. The 1σ of the mean ROI in the thin TLD-700 case is slightly higher than other TLD cases, but it is still good (see Table 3). This is due to the previously-mentioned problem of irregular glow curves of the thin TLD-700s. This confirmed the above mentioned observation number 4.

4. The signal of peaks 3+4+5 or the signal of peaks 4+5 gave the second best stability performance in the thick TLD-700 cases. The peaks 4+5 signal performs slightly better than the peaks 3+4+5 signal in thin TLD-700 and TLD-600 cases. Since the signals of peaks 3+4+5 were derived in two ways, they lie in two levels. The signals derived by the background subtraction option (marked with #) give lower signal levels than the signals derived by the peak 2 elimination option (e.g., see Table 1-5, column 6, and Table 6). This is more obvious in neutron cases. The reason for this is the peak 3 fading in the large fading runs, especially in neutron exposure (see the last runs in all Tables which have the smallest peaks 3+4+5 signals). This also confirmed observation number 3. Again, in routine radiation protection situations where one program

option can deconvolute all glow curves, the signals of peaks 3+4+5 and peaks 4+5 should give performance comparable to the ROI signal.

5. The signal of peak 5 from the peak separation option did not give satisfactory stability performance in all cases, as expected. It exhibited varied standard deviation, high standard deviation of mean, and high maximum variation. This is because the production mode of the CGCD program performs well only for very similar glow curves. The performance is even worse in neutron exposure situations where the glow curves have higher temperature peaks and more irregularities. The excellent performance stated in reference 15 occurred because of their high reproducibility of glow curves due to the fixed beta irradiation and short fading time[15], which do not happen in routine personnel dosimetry. The big statistical fluctuation nature of the peak 5 signal from the deconvolution results and the time-consuming deconvolution process make the peak separation option of the CGCD program impractical, especially in neutron exposure cases.

6. The signal's standard deviation of each TLD group in each run did not change during reuse in gamma cases. The abrupt increase of 1σ in TLD-700 after the second run (see runs 2 and 3 in Tables 1 and 2) was due to the replacement of the PMTs. As compared with the gamma case, the 1σ of signals of peaks 3+4+5, peaks 4+5, and peak 5 varied by an order of magnitude between runs for neutron exposures. This again reflects the failure of using the CGCD program in the neutron case. The reason may be that the first order TL kinetics assumption is not correct for neutron exposures.

7. In using the peak separation option of the CGCD program in the production mode, the choice of initial glow curve parameters is important. Experience has shown that there were always some glow curves that were unable to be deconvoluted in the production mode, no matter what initial choice was made. In those cases the research mode, which requires manual handling and is more time-consuming, was used. A composite glow curve may have several combinations of separated dosimetry peaks. To ensure the proper deconvolution process, the Figure of Merit (FOM) should first be checked to be within a certain value and, then, the propriety of the separated peak areas and positions be checked, e.g., peak 5 should be the largest. The smallest FOM does not necessarily guarantee the best deconvolution result.

8. The FOM value and the speed of the deconvolution process depend on the glow curve shape and the dose level. The speed is faster and the FOM is smaller for gamma exposure and higher dose. Typically it takes only about ten seconds to deconvolute a good gamma glow curve on the PC. By contrast, it takes 30 seconds to 1.5 minute for a low dose neutron glow curve.

Table 6. TLD sensitivity stability comparison for different TTPs

TTP	TLD-700		TLD-600		
	1	3	1	2*	3*
run 1	653	---	396	480	434
run 2	653	632	375	487	432
run 3#	603	588	314	417	394
run 4	631	614	360	491	455
run 5	627	604	378	499	462
run 6	615	597	366	481	444
run 7#	600	585	344	---	419
run 8#	574	566	255	355	343
mean	620	598	349	459	423
σ of mean	4.4%	3.6%	13%	12%	9%
max. varia.	14%	12%	55%	41%	35%

note: The TL signals (nC) are the peaks 3+4+5 from the CGCD program.

The signals in these three rows were derived in the background subtraction option. The other runs were from the peak 2 elimination option in the CGCD program.

* The TL signals in these two columns were derived from the research mode, most of the rest were from the production mode.

9. The sensitivity stability of TLD-700 and TLD-600 does not significantly depend on the dose level. This is because the low dose level (1 mSv) used in the study is much higher than the lowerlimits of detection of the TLDs, and both the high and low dose levels are within the TLD linear response region. The deviations from linearity for TLD-700 for gamma exposures (see the mean ROIs in Tables 1 and 2) and TLD-600 for neutron exposures (see the mean ROIs in Tables 4 and 5) are both within about 5%.

10. The ROI signal and peaks 3+4+5 signal gave better sensitivity stability performance than Driscoll's unannealed-TLD-100 system[14].

11. Omitting the results of last run (37 days fading), all the TL signals perform better, especially the signals of ROIs and peaks 3+4+5. However, the signal performance comparison is still the same, i.e., the ROI signal is still the best.

3.4 STABILITY COMPARISON WITH DIFFERENT TTPS

The sensitivity stability of TLD-700 in TTP1 and TTP3 were studied by comparing their peaks 3+4+5 signals for high gamma dose exposures. For TLD-600 the peaks 3+4+5 signals from TTP1, TTP2, and TTP3 were compared for stability performance. However, the signals of TLD-600 in TTP2 and TTP3 were derived by the research mode. Most of the rest were derived by the production mode. Again, for different runs, the peaks 3+4+5 signals were derived with two different CGCD program options, depending on the fading condition, as stated earlier. From the comparison results in Table 6, TTP3 is slightly better than TTP1, but both TTP1 and TTP3 are good for TLD-700. For TLD-600 it seems that TTP3 and TTP2 are better than TTP1. However, this better stability may be partly due to the TTP used to reduce the residual effect and partly due to the research mode applied. Therefore, one can conclude that the three TTPs heating methods perform about the same for all LiF-TLD materials in all irradiation situations.

4. SUMMARY AND CONCLUSION

The readout procedures of the Harshaw 8800 automatic reader and its associated LiF-TLDs were optimized. Three types of LiF-TLDs (TLD-700, thin TLD-700, and TLD-600), three time-temperature-profiles heating methods, and five TL light signals (total integral area, ROIs, peaks 3+4+5 area, peaks 4+5 area, and peak 5 area) were used. The optimization was based mainly on the TLD sensitivity stability performance during reuse, under low and high doses, gamma and neutron exposure situations. The results show that the Harshaw-suggested TTPs, the carefully-chosen ROI signals, and peaks 3+4+5 signals can achieve the optimum conditions in all cases, regarding the stability, sensitivity, and the readout speed. The standard deviation (1σ) and the maximum variation of the TLD responses during reuse under the optimum readout conditions can be within 5% and 10%, respectively.

In routine personnel dosimetry, using TTP1 to heat thick and thin TLD-700 chips and using TTP2 to heat TLD-600 chips (especially in neutron exposure) is recommended. Only reader anneal with the same TTPs before the issue of the TLDs is necessary. The ROI signal is the recommended TL signal, due to its best stability and fast readout. For thick and thin TLD-700 chips in TTP1 heating, the appropriate ROI is channels 101-200. For TLD-600, the appropriate ROI is channels 116-200 in TTP1 heating and channels 96-200 in TTP2 heating.

The peak separation option of the CGCD program is of limited utility in the TLD readouts for routine personnel dosimetry. However, it is a useful tool for research and problem diagnosis. Some suggestions to improve the performance of the CGCD program are:

1. To have a better peak separation function in the production mode, the peak identification method should be improved. The reflection point method is not as good in identifying unclear peaks of large-fading and/or low dose exposed TLD glow curves. An alternative is to allow the user to store and apply the fixed peak parameters (peak width, peak channel) in the production mode.

2. Adding a peak 3 elimination option to derive the peaks 4+5 signal may be quite helpful in relieving the peak 3 fading problem in the neutron case. Theoretically, the peaks 4+5 signal should be the most stable TL signal.

3. The worse CGCD performance problem for neutrons should be studied. The assumption of first order TL kinetics, may not be valid for high LET readiations.

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