Influence of Time Temperature Profiles on the Minimum Detectable Dose of Thermoluminescent Dosimeters

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Introduction and Motivation

Determination of optimal time temperature profile (TTP) for thermoluminescent dosimeters (TLDs) based on minimum detectable dose (MDD)

- Improved accuracy in personnel & environmental dose measurements
- Precision in radiation health effects research
- Characterization of the lowest dose a system is capable of measuring
- Discrimination of small experimental changes

Mission Relevance

Monitoring dose rates for radiation protection

- Occupational radiation protection
- Quality assurance of radiation facilities
- Low level radioactive waste monitoring
- Public safety enhanced by establishing confidence in the accuracy of low level natural background radiation measurements
- Improved ability to counter nuclear smuggling through detection of radioactive and nuclear materials at low dose rates

Technical Approach

Experimental Overview

Irradiate and measure dose response of thermoluminescent dosimeters (TLD)

- LiF:Mg,Ti Harshaw TLD-100
- 236 GBq Cs-137 Irradiator
- Irradiate TLD-100 batches to 15 mGy
- Rexon UL-320 TLD Reader
- Limit of detection and limit of determination calculations

Figure 1. *Cs-137 Irradiator experimental set up*

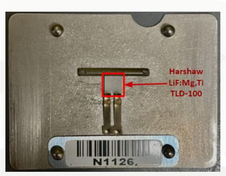

Figure 2. *Planchet set up for Rexon UL-320 TLD Reader*

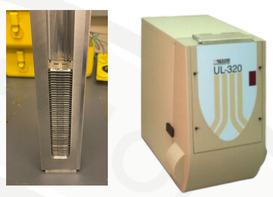

Figure 3. *Planchet sleeve (left) and Rexon UL-320 TLD Reader (right)*

Theory of Thermoluminescent Dosimeters

Irradiate and measure dose response of thermoluminescent dosimeters (TLD)

- Ionizing radiation excites electrons of TLD crystal into trap states
- Energy is stored in crystal lattice trap states
- When heated, TLD releases stored energy in the form of thermoluminescent photons
- Number of photons emitted by the TLD is proportional to the dose received by ionizing radiation

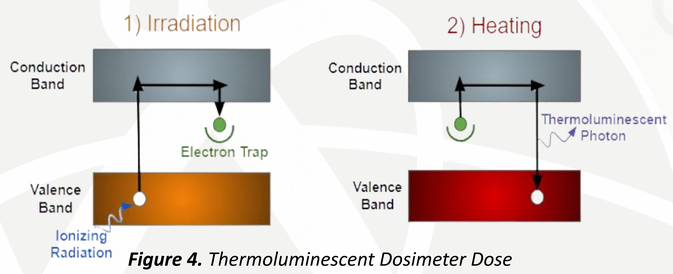

Figure 4. *Thermoluminescent Dosimeter Dose Collection Process*

Calculation Methods

Detection & Determination Limits

Statistical quantities used to represent detection limit of Rexon UL-320 TLD Reader for each TTP

- Limit of Detection (LD): Minimum dose that can easily be distinguished from the background blank measurement
- Limit of Determination (LQ): Minimum dose measured at a given precision satisfactory for quantitative detection

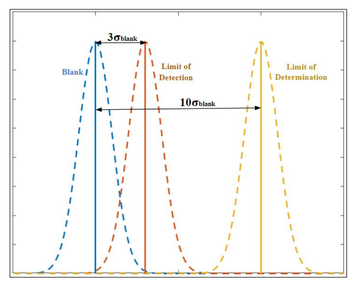

Figure 5. *Limit of Detection and Limit of Determination Schematic*

Limit of Detection: Equation

$$L_D = \frac{2\left(t_n s_b + t_m^2 s_\mu^2 \overline{K}_b\right)}{\left(1 - t_m^2 s_\mu^2\right)}$$

Limit of Determination: Equation

$$L_Q = \frac{k_Q^2 s_\mu^2 \overline{K}_b + \left[k_Q^4 s_\mu^2 \overline{K}_b^2 + k_Q^2 s_b^2 \left(1 - k_Q^2 s_\mu^2\right)\right]^{1/2}}{\left(1 - k_Q^2 s_\mu^2\right)}$$

Results

TTP	Preheat Temp (°C)	Preheat Time (s)	Acquire Heating Rate (°C s⁻¹)	Acquire Temp (°C)	Acquire Time (s)	Anneal Temp (°C)	Anneal Time (s)	Lower Detection Limit (mGy)	Lower Determination Limit (mGy)
1	50	0	15	300	20	300	0	0.93	3.38±0.27
2	50	10	15	300	20	300	0	0.91	3.26±0.26
3	50	0	15	300	20	300	10	2.48	9.42±0.72
4	50	10	15	300	20	300	10	0.58	1.81±0.17
5	50	10	12	260	26.7	300	10	1.05	3.35±0.31
6	50	10	12	260	20	300	10	0.58	1.75±0.17
7	50	0	5	300	60	300	0	0.71	2.16±0.21
8	50	0	15	300	20	300	20	1.28	4.51±0.37

Table 1. *Time Temperature Profiles (TTPs) Corresponding to Various Minimum Detectable Doses (MDDs)*

Table 1 displays eight different TTPs which were created in order to test the influence of preheat time, acquire heating rate, acquire temperature, acquire time, and anneal time on the Lower Detection & Lower Determination Limits.

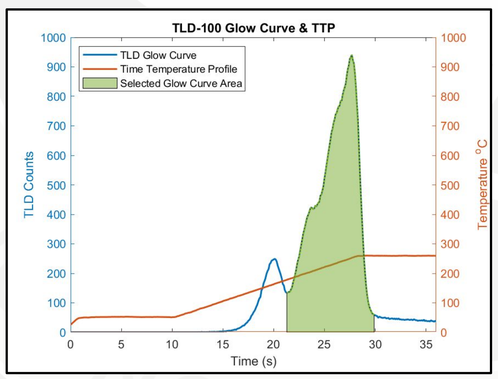

Figure 6. *TLD-100 Selected Glow Curve Region and Corresponding Time Temperature Profile*

Figure 3 displays a TLD-100 glow curve overlayed on its respective TTP. The selected region minimizes the effect of fading which occurs in the first peak.

Conclusion

Time temperature profiles directly impact the minimum detectable dose of thermoluminescent dosimeters

- MDD is optimized with an increase in preheat time and decrease in acquire time
- MDD fluctuates with changes in acquire heating rate and acquire temperature
- Small changes of one TTP parameter can significantly influence the minimum detectable dose

MTV Impact

Gained research experience in radiation measurements

- Trained to safely operate a 236 GBq Cs-137 irradiator
- Performed occupational radiation protection training
- Financial support for research and project materials
- Improved writing and public speaking skills through developing abstracts and delivering presentations
- Provided a mentor who was supported throughout the duration of the research project

Expected Impact

Optimized detector readout processes for personnel and environmental radiation measurements

- Optimized Rexon UL-320 process for all TLD types
- Consistent dose measurements during collaboration with other University of Michigan laboratories
- Precise dose measurements for radiation experiments
- Understanding of each TTP parameters specific degree of influence on minimum detectable dose

Next Steps

Further verification and future applications

- Verification of optimized TTPs through additional tests of specific parameters
- Further testing on parameters that led to fluctuations in the minimum detectable dose
- Determine optimal TTPs for all thermoluminescent dosimeter types

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