Thermoluminescence Dosimetry System

Date of experiment: 18 September 2025

Medical Physics Laboratory I

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Date of submission: November 13, 2025

Contents

1 | Objective

- To study the characteristics of CaSO4: Dy.
- To calibrate the TL/OSL research Reader in terms of absorbed dose and find out the unknown dose from a sample.

2 | Apparatus

- Annealed TLD samples (CaSO4: Dy)
- Slab phantoms
- TL/OSL Research reader
- TLD Annealing Oven
- Radiation-generating equipment

3 | Theory

In a perfect crystalline insulator, the conduction and valence bands are separated by an energy difference of several eV, and there are no intermediate energy levels within the band gap. Lumininescence detectors are created by adding impurities (activators) to the crystal structure that create energy levels within the band gap. When ionizing radiation interacts with the crystal, it excites electrons from the valence band to the conduction band(Fig. 3.1a), leaving behind holes in the valence band. Some of these electrons and holes become trapped at the impurity levels, creating metastable states. The trapped electrons and holes can later be released by providing energy, such as heat (thermoluminescence) or light (optically stimulated luminescence). In the absence of external stimulation, the trapped charges can remain in their metastable states for extended periods, ranging from hours to years, depending on the stability of the traps.

During the readout process [Fig. 3.1(b)], stimulation by heat (TL) or light (OSL) releases the trapped charges. Once the trapped electron is released, it can recombine with the trapped hole, creating a defect in the excited state. TL or OSL results from the relaxation of these defects to return to the ground state by light emission. One should keep in mind that this model is simplified. Actual TL and OSL materials have many defects that may not give rise to observable TL/OSL signals but may act as competitors for the transitions represented in Fig. 3.1, causing changes in the TL/OSL properties. These competitors give rise to phenomena such as supralinearity of the dose response and sensitivity changes with detector's dose and annealing history.

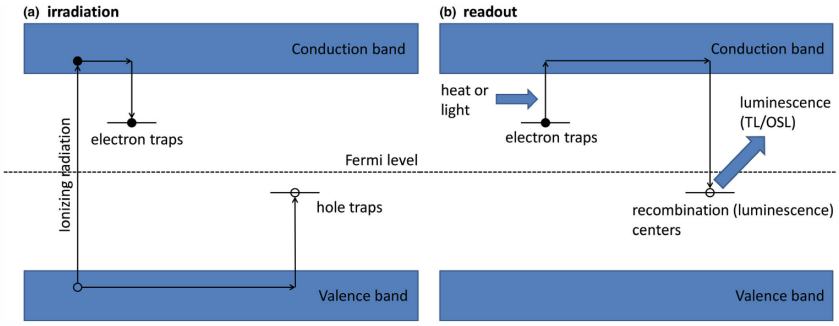

Figure 3.1: Simplified energy level diagram representing the delocalized bands (valence band and conduction band) and the electronic transitions in Thermolumines- cent/optically stimulated luminescent material during irradiation (a) and readout (b) where stimulation is provided by heat or light. In this illustration, the hole trap is more stable than the electron trap. Therefore, the electron trap is said to act as a trapping center, whereas the hole trap is said to act as a recombination center.[1]

Thermoluminescent dosimeters are read by increasing the temperature of the detector while monitoring the TL emitted, either creating a glow curve graph of signal vs temperature or by recording the total

signal for a portion of the heating pro- cess. In the former, the TL signal can be defined as the maxi- mum intensity of a TL peak or the integrated TL intensity over a region of interest. Figure 3.2 illustrates a glow curve for LiF:Mg,Ti (TLD-100). Different trapping centers have different depths within the bandgap that require different tem- peratures for release. As the detector is heated, these trapping centers are stimulated sequentially, giving rise to a series of peaks.

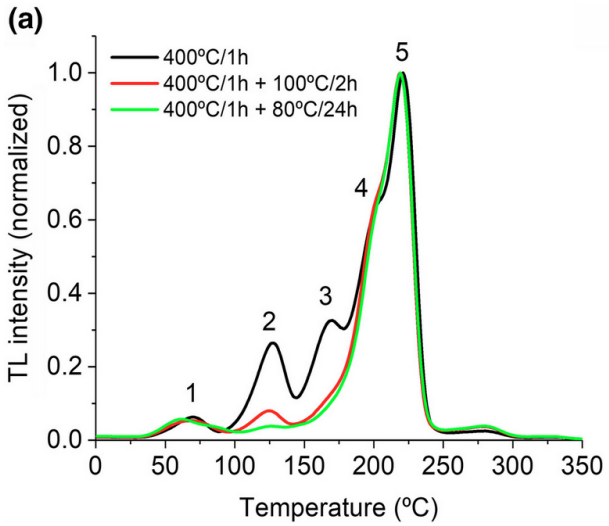

Figure 3.2: Thermoluminescent curves of LiF:Mg,Ti (TLD-100) subjected to different preirradiation annealing treatments. Peaks 1–5 correspond to different trapping centers (which yield signal at different temperatures); peak 5 occurs at the temperature of maximum signal.[1]

Both the temperature of the maximum peak and the maximum TL signal depend on the heating rate. To minimize the effect of heating rate fluctuations, the integral of the TL signal rather than its maximum is typically used to determine the dose. TL peaks with maxima around 200-225°C are best for dosimetry because of their stability at room temperature (Peak 5 in Fig. 3.2). TL peaks at lower temperatures are due to shallow trapping levels in the band gap and may be unstable at room temperature. TL peaks appearing at higher temperatures may suffer interference from infrared black-body radiation and spurious signals. These effects are mitigated by using a bandpass filter to eliminate the infrared signals and by flowing an inert gas such as N_2 or Ar over the TL phosphor during heating to reduce spurious signals. The relative importance of these peaks and the sensitivity of the detector will depend on annealing regimens before irradiation. Because the TL readout depletes the majority of the trapping centers, less than 1% of the original signal should be observed if the material is read again without irradiation.

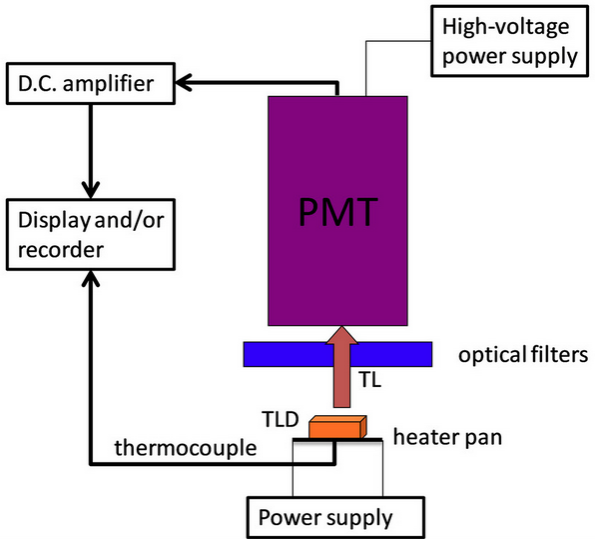

Figure 3.3: Schematic diagram of a typical thermoluminescent dosimeter (TLD) reader.[1]

While different peaks can include different information about the irradiation, in clinical practice the standard practice is to simply integrate the entire glow curve to yield the overall signal. To ensure reproducible results, a consistent heating cycle should be used.

Figure 3.3 presents a typical configuration for a TLD reader. The heating source can be an ohmically heated pan, preheated N_2 gas, or an infrared light source. A typical heating cycle consists of a rapid increase to a moderate temperature during which the signal, primarily from unstable traps, is not recorded, followed by a linear temperature increase during which the TL glow curve is measured (e.g., peak 5 in Fig. 3.2). The final step is heating the crystal to a high temperature to anneal the TLD, emptying the deep traps that were untouched at lower temperatures.

3.1 | Types of TLD/OSLD

Thermoluminescent dosimeter (TLD) and optically stimulated luminescent dosimeter (OSLD) materials available commercially along with example commercial names, density ρ, effective atomic number Zeff, temperature of the main TL peak, and typical emission wavelength, sensitivity relative to LiF and fading.

Material	Commercial Name	ρ	Z_{eff}	Glow Peak (°C)	Emission (nm)	TL Sens.	Fading
LiF:Mg,Ti (TL)	TLD-100	2.6	8.31	~235	~410	Referent	5% in 3–12 months
^{6}LiF:Mg,Ti (TL)	TLD-600	2.6	8.31	~235	~410	1.0	5% in 3–12 months
^{7}LiF:Mg,Ti (TL)	TLD-700	2.6	8.31	~235	~410	1.0	5% in 3–12 months
LiF:Mg,Cu,P (TL)	TLD-100H	2.5	8.31	~200	~370	30	2% in 3 months
$Li_2B_4O_7$:Mn (TL)	TLD-800	2.3	7.32	~185	~600	0.3	5–10% in 3 months
CaF_2:Dy (TL)	TLD-200	3.18	16.90	~160,185,245,290	480,575,660,750	30	25% in 4 weeks
CaF_2:Mn (TL)	TLD-400	3.18	16.90	~300	~495	10	15% in 2–4 weeks
$CaSO_4$:Dy (TL)	**TLD-900**	**2.61**	**15.62**	~220	**480,575,660,750**	**15**	**6% in 6 months**
Al_2O_3:C (OSL)	nanoDot	3.95	11.28	~200	~410	N/A	4% in 3 months
BeO (OSL)	Thermolox 995	2.85	7.21	~210,330	~335,390	N/A	5–10% in 3 months

3.2 | TLD forms

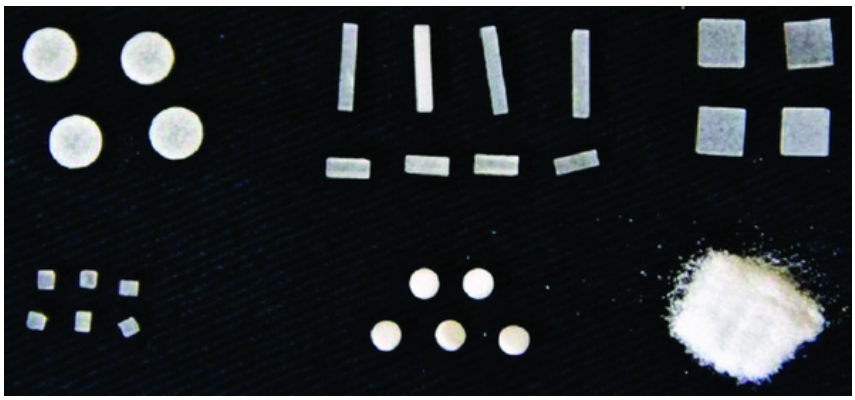

Figure 3.4: Different forms of TLDs [1]

Thermoluminescent dosimeters can be purchased in different forms that offer different advantages and disadvantages. The main forms are powder and solid (Fig. 3.4), including rods, chips, disks, and microcubes. With powder it is possible to generate a large number of TLD with uniform characteristics. However, powder is challenging to use in terms of loading, handling, and annealing. Powder form is also sensitive to mass and powder distribution during readout. The mass of the powder is important: if the mass is too large, excessive self-attenuation of the TL occurs, which decreases the apparent sensitivity. Problems also arise for small masses. For masses < 18 mg, the signal/mass becomes dependent on the mass; therefore, only masses > 20 mg should be used. The distribution of powder on the heating pan also requires attention, as the centering and distribution of the powder can affect the signal/mass by several percent. In contrast to a powder form, solid forms can readily be annealed and reused indefinitely if

appropriate procedures are followed. However, because each detector is unique, each will show variability in sensitivity that needs to be accounted for. Solid forms are also sensitive to being scratched or chipped, and additional care is required in their handling.

4 | Observation

Table 4.1: Intensity values for different doses

Dose (Gy)	A	B	C	D	E	Net Intensity
Background	842326	8401365	7377735	1443072	12047312	0
0.5	42366729	46893479	36180595	48441922	54392237	39632630.4
1	72423155	80360004	73245158	82007274	73189478	70222651.8
2	94610261	93586371	99646954	94782233	91800276	88862857
3	97315644	10255814	110922831	111687756	108736283	100221763.6
4	118198629	117279687	121895156	112600457	117156973	111403818.4
6	129900901	129918209	134048179	127953661	126380141	123474018.2
Unknown A	105077687	107876926	107610287	99717134	104853017	99004648.2
Unknown B	119925678	120381880	116170288	118524838	120983219	113174818.6

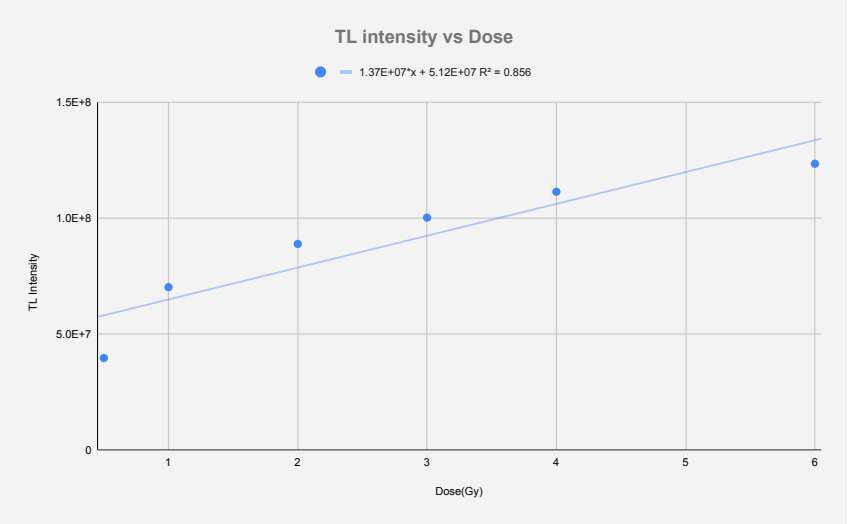

Figure 4.1: Dose vs Average Intensity graph for CaSO4: Dy TLD.

From the graph, we can see that the relationship between dose and intensity is linear. Using the linear fit equation, we can calculate the unknown doses. Using the linear fit equation:

$$\boxed{\text{Dose} = \frac{I - 5.12 \times 10^7}{1.37 \times 10^7}}$$

Where I = Intensity. So for unknown A: the intensity is 99004648.2

$$\text{Dose} = \frac{99004648.2 - 5.12 \times 10^7}{1.37 \times 10^7} = \boxed{3.489}\ \text{Gy}$$

Similarly, for unknown B: the intensity is 113174818.6

$$\text{Dose} = \frac{113174818.6 - 5.12 \times 10^7}{1.37 \times 10^7} = \boxed{4.524}\ \text{Gy}$$

So the relative errors in the calculated doses are: For unknown A:

4.1 | Heating rate analysis

Table 4.2: Intensity values for different doses

Heating rate(°C/s)	A	B	C	Bg A	Bg B	Net Intensity
1	128731197	156087955	130975226	4211945	28177825	122403241
1.5	91896493	106535449	111177232	5737988	34929935	82869096.5
2	97266471	77432993	109717659	17155082	2693598	84881367.67
2.5	93535507	81280319	87006715	15384092	23027192	68068538.33
3	88523949	75226109	72113909	7197779	16678551	66683157.33
4	69037517	63641046	65486040	69037517	307269	31382474.67

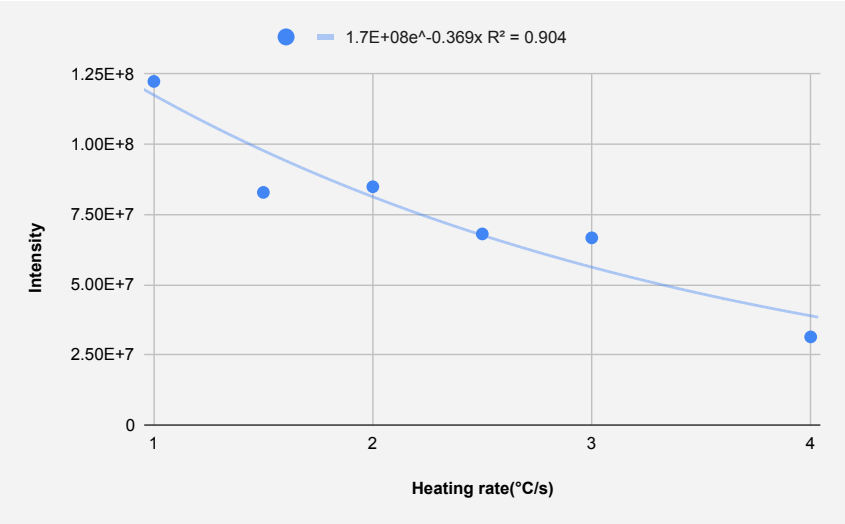

Figure 4.2: Average Intensity graph for CaSO4: Dy TLD vs Heating rate

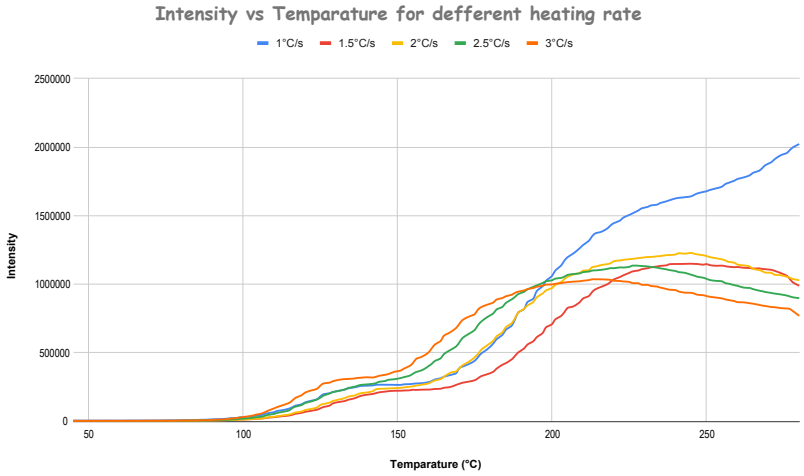

Figure 4.3: Glow Curve for different heating rates

5 | Applications

6 | Conclusion

7 | References

[1] Stephen F. Kry, Paola Alvarez, Joanna E. Cygler, Larry A. DeWerd, Rebecca M. Howell, Sanford Meeks, Jennifer O'Daniel, Chester Reft, Gabriel Sawakuchi, Eduardo G. Yukihara, and Dimitris Mihailidis. Aapm tg 191: Clinical use of luminescent dosimeters: Tlds and oslds. *Medical Physics*, 47(2):e19–e51, 2020.