

Integrating Dosimeters

Integrating dosimeters

- TLD
- Photographic film
- Chemical dosimetry
- Calorimetry

TLD

- Phosphors

The sensitive volume of a TLD consists of a small mass (1 to 100 mg) of crystalline dielectric material containing suitable activators to make it perform as a thermoluminescent phosphor. The activators provides two kinds of centers

- a. Traps for the electron and “holes”, which can capture and hold the charge carriers in a electrical potential well for usefully long periods of time.
- b. Luminescent centers, located at either the electron traps or the hole traps, which emits light when the electrons and holes are permitted to recombine at such a center.

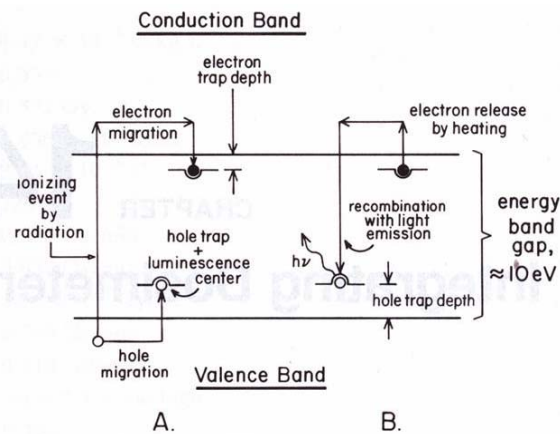
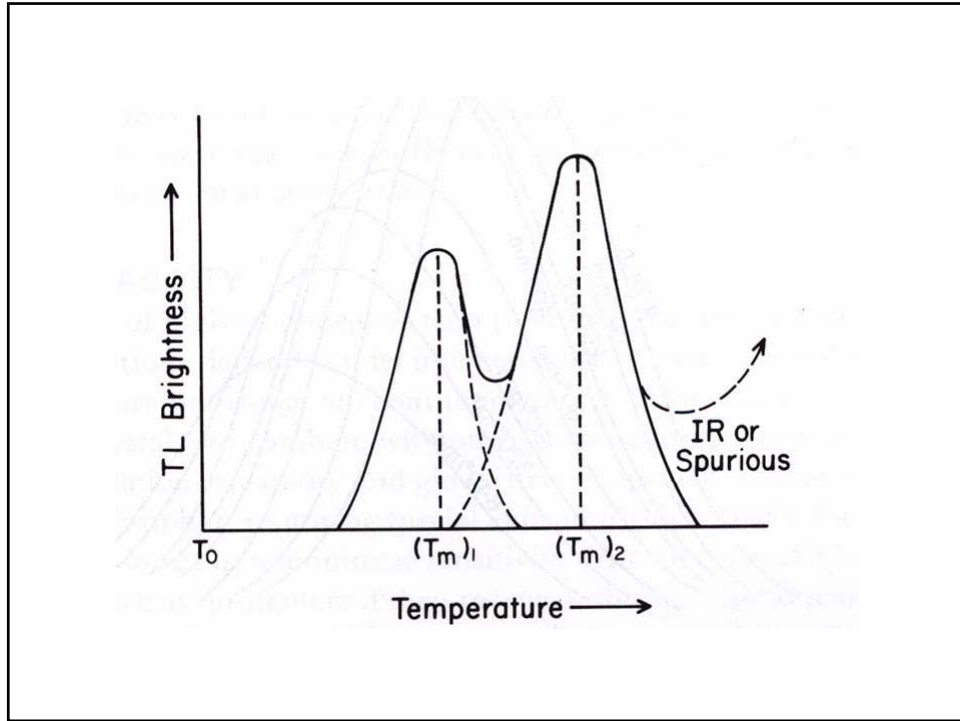
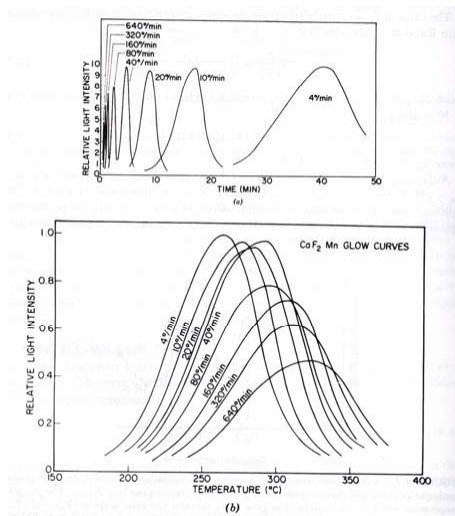


FIGURE 14.1. Energy-level diagram of the thermoluminescence process: (A) ionization by radiation, and trapping of electrons and holes; (B) heating to release electrons, allowing luminescence production.



Gorbics et al
 Dose is inversely proportional to the heating rate
 Maximum TL brightness is constant



Trap stability

- Usefulness depends on its independence of time and ambient conditions
- If traps are not stable in room temperature, it has to be removed by a process called annealing (e.g. 400 oC for 1 h quick cooling and 80 oC for 24 hours).
- Trap leakage → inability of holding charge carriers at ambient temperature. Peaks at 200-225 oC have a half life of months to years. A glow peak at 150 oC has a half life of a few days and a peak of 100 oC has a half life of hours

- Higher temperatures traps than 225oC should be more stable, except for two competing problems
 - Heat (infrared) signal. The phosphor and tray when rising in temperature the short-wavelength of black body radiation begins to extend into the visible region, and produce a signal non-dose related picked up by the PMT
 - Spurious TL signal. The combined effects of adsorbed gases, humidity, dirt and mechanical abrasion of the phosphor surface tend to produce a spurious TL signal, called triboluminescence

Intrinsic efficiency of TLD phosphors

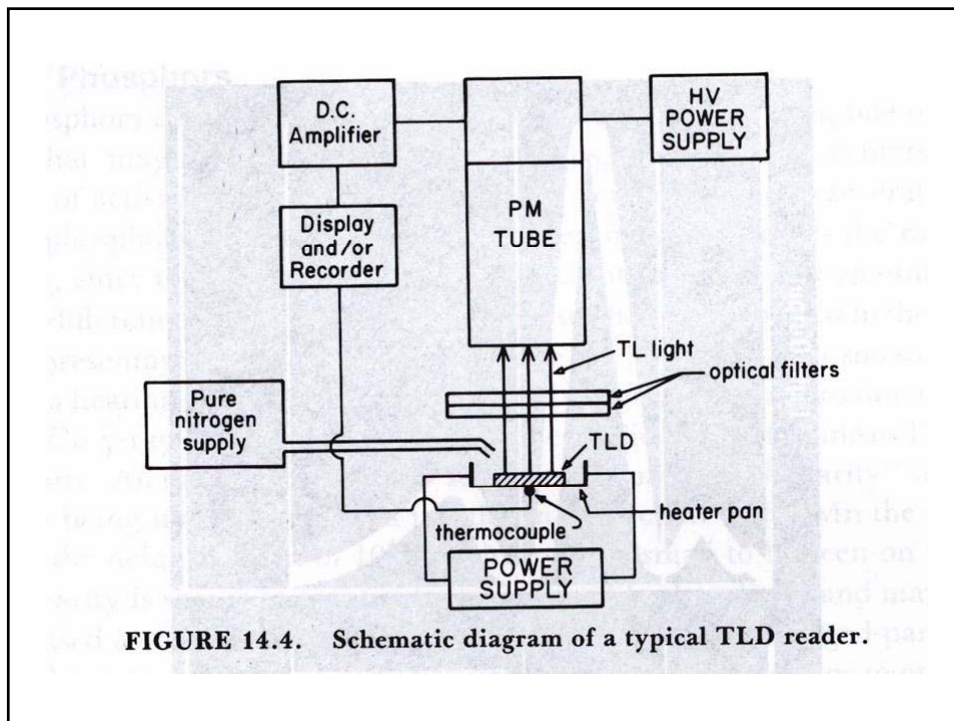
Intrinsic TL efficiency = TL light energy emitted per unit mass/absorbed dose

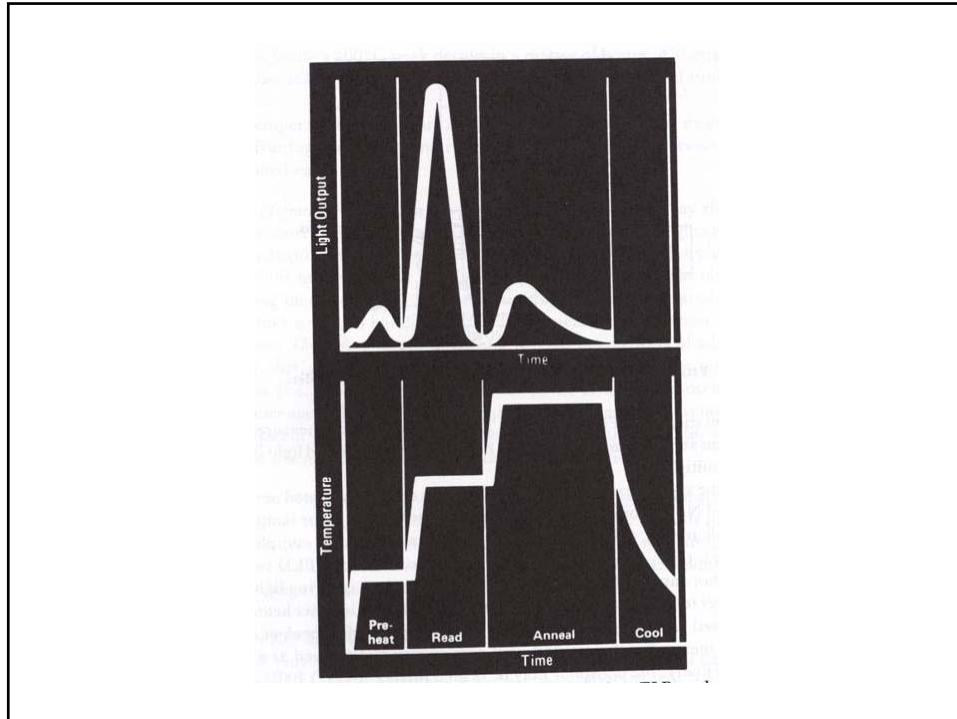
LiF – 0.039%

CaF₂:Mn – 0.44%

CaSO₄:Mn – 1.2%

For LiF 99.96% of energy goes into heat production





TLD phosphors

TABLE 14.1. Characteristics of TL Phosphors

Phosphor	LiF:Mg, Ti	CaF ₂ :Mn	Li ₂ B ₄ O ₇ :Mn	CaSO ₄ :Mn
Density (g/cm ³)	2.64	3.18	2.3	2.61
Effective atomic number	8.2	16.3	7.4	15.3
TL emission spectra (nm):				
Range	350-600	440-600	530-630	450-600
Maximum at	400	500	605	500
Temperature of main TL glow peak at 40°C/min (°C)	215	290	180	100
Approximate relative TL output for ⁶⁰ Co	1.0	≅ 3	≅ 0.3	≅ 70
Energy response without added filter (30 keV/ ⁶⁰ Co)	1.25	≅ 13	≅ 0.9	≅ 10
Useful range	mR-10 ⁵ R	mR-3 × 10 ⁵ R	mR-10 ⁶ R	μR-10 ⁴ R
Fading	Small, <5%/(12 wk)	~10% in first month	~10% in first month	50-60% in first 24 h

TLD Forms

- Bulk granulated
- Compressed pellets or chips
- Teflon matrix containing 5% or 30% by weight of TLD powder
- TLD pellet fastened on an ohmic element
- Single crystal plates
- Powder enclosed in plastic tubing

Calibration of TLDs

- If the incident radiation is completely stopped by the TLD then the incident fluence can be derived by

$$\Psi = \frac{k_{Co} \, m}{A} \quad (\text{J/m}^2)$$

$$k_{Co} = (\bar{D}_{TLD}/r)_{Co} \text{ [Gy/(scale division)]}$$

60Co gamma-ray calibration

- For a free space 60Co gamma-ray exposure X (C/kg) at the point occupied by the center of the TLD in its capsule, the average absorbed dose in the TLD, in grays, under TCPE is

$$\bar{D}_{\text{TLD}} = 33.97a\beta X \left[\frac{(\mu_{\text{en}}/\rho)_{\text{TLD}}}{(\mu_{\text{en}}/\rho)_{\text{air}}} \right]_{\text{Co}}$$

where a is a correction for broad beam attenuation in the capsule wall plus half thickness of the TLD.

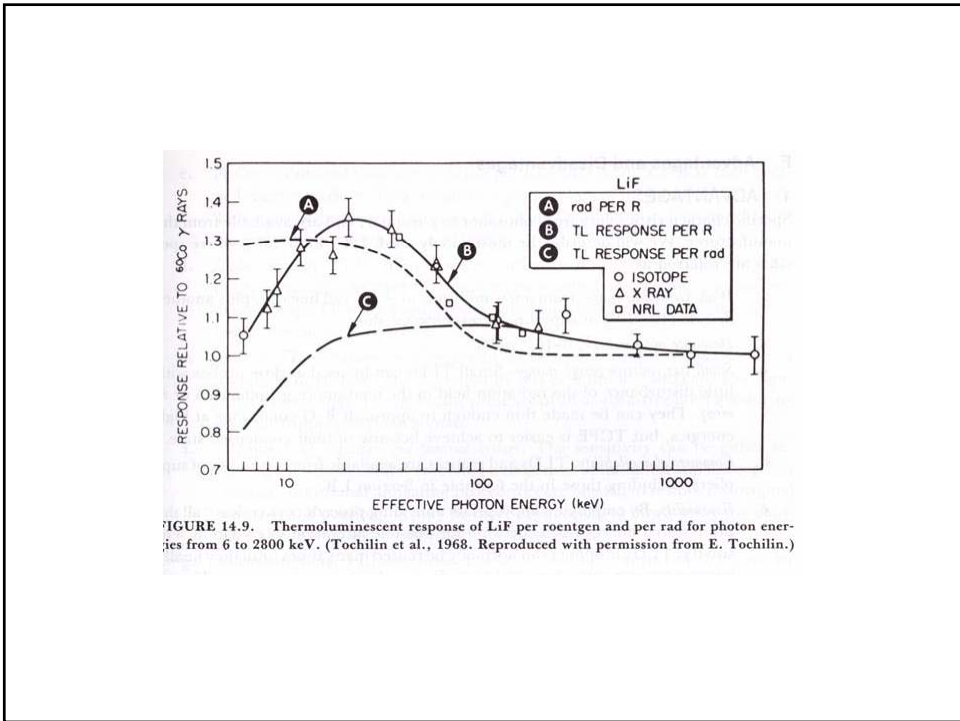
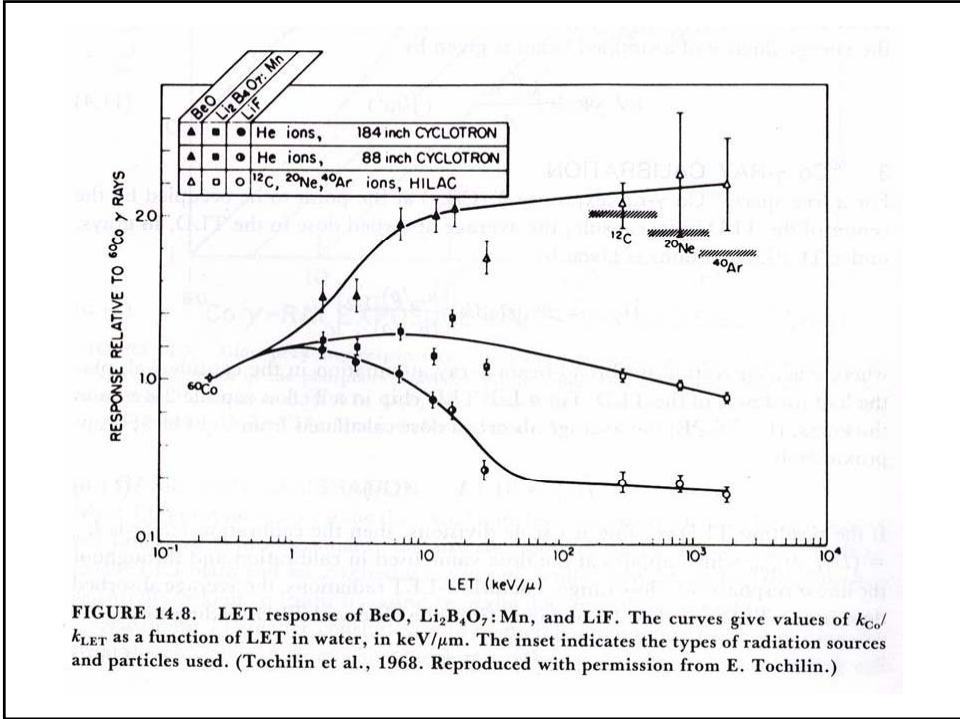
- For a LiF TLD chip in a Teflon capsule 2.8 mm in thickness (for CPE) the average absorbed dose calculated by equation above is

$$\bar{D}_{\text{LiF}} = 31.1X \quad (\text{Gy})$$

- For all low LET radiations, the average absorbed dose in the TLD can be obtained by

$$\bar{D}_{\text{TLD}} = k_{\text{Co}}r$$

$$k_{\text{Co}} = (\bar{D}_{\text{TLD}}/r)_{\text{Co}} [\text{Gy}/(\text{scale division})]$$



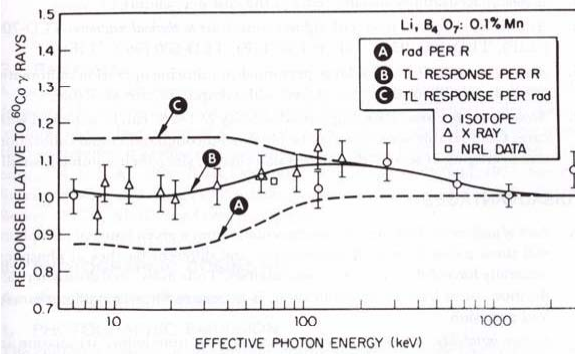


FIGURE 14.10. Thermoluminescent response of $\text{Li}_2\text{B}_4\text{O}_7:\text{Mn}$ per roentgen and per rad for photon energies from 6 to 2800 keV. Tochilin et al., 1968. Reproduced with permission from E. Tochilin.)

Advantages

- Wide useful dose range*, from a few millirads to $\sim 10^3$ rad linearly, plus another decade (10^3 - 10^4) of supralinear response vs. dose.
- Dose-rate independence*, 0 - 10^{11} rad/s.
- Small size; passive energy storage*. Small TLDs can be used as dose probes with little disturbance of the radiation field in the medium (e.g., phantom or *in vivo*). They can be made thin enough to approach B-G conditions at high energies, but TCPE is easier to achieve because of their condensed state.
- Commercial availability*. TLDs and readers are available from a number of suppliers, including those in the footnote in Section I.B.
- Reusability*. By employing appropriate annealing procedures to release all the prior stored energy, and checking for possible alteration in radiation sensitivity, TLD phosphors can normally be reused many times until they finally become permanently damaged by radiation, heat or environment. Thus it is feasible to calibrate individual dosimeters.
- Readout convenience*. TLD readout is fairly rapid (< 30 s) and requires no wet chemistry.
- Economy*. Reusability usually reduces the cost per reading.
- Availability of different types with different sensitivities to thermal neutrons*. TLD-700 (^7LiF), TLD-100 (93% ^7LiF + 7% ^6LiF); TLD-600 (96% ^6LiF).
- Automation compatibility*. For large personnel-monitoring operations automatic readers, capable of being interfaced with computers, are available.
- Accuracy and precision*. Reading reproducibility of 1-2% can be achieved with care. Comparable accuracy may be obtained through individual calibration and averaging of several dosimeters in a cluster, since their volume is small.

Disadvantages

- a. *Lack of uniformity.* Different dosimeters made from a given batch of phosphors still show a distribution of sensitivities, and different batches of phosphor generally have different average sensitivities. Thus individual dosimeter calibration, or at least batch calibration, is necessary for acceptable accuracy and precision.
- b. *Storage instability.* TLD sensitivity can vary with time before irradiation in some phosphors, as a result, for example, of gradual room-temperature migration of trapping centers in the crystals. Controlled annealing of the TLDs can usually restore them to some reference condition again.

Disadvantages

- c. *Fading.* Irradiated dosimeters do not permanently retain 100% of their trapped charge carriers. This results in a gradual loss of the latent TLD signal. This must be corrected for, especially in applications (e.g., personnel monitoring) that involve long time delays.
- d. *Light sensitivity.* TLDs all show some sensitivity to light—especially UV, sunlight, or fluorescent light. This can cause accelerated “fading”, or leakage of filled traps. Or it can produce ionization and the filling of traps, thus giving rise to spurious TL readings.
- e. *Spurious TL.* Scraping or chipping of TLD crystals (e.g., by rough tweezer handling) or surface contamination by dirt or humidity also can cause spurious TL readings. However, the presence of an oxygen-free inert gas during readout suppresses these signals.
- f. *“Memory” of radiation and thermal history.* The sensitivity can be either increased or decreased after receiving a large dose of radiation and undergoing readout. Additional annealing procedures are needed to restore the original sensitivity, if possible. It may be more economical to throw away the phosphor after a single use, especially for large doses.
- g. *Reader instability.* TLD readings depend on the light sensitivity of the reader as well as on the heating rate of the phosphor. Thus reader constancy is difficult to maintain over long time periods.
- h. *Loss of a reading.* The measurement of the light out of a TLD (i.e., by heating it) erases the stored information. Unless special provision is made (e.g., a spare TLD), there is no second chance at getting a reading. Reader malfunction can lose a reading.