Energy Response

In many TLD applications the main purpose is to determine the dose absorbed in human tissue (see Table 2). For this reason it is desirable that the TLD has an energy response equal or at least proportional to that of human tissue. Suppose a TL material is exposed to photons with a certain fluence Φ and energy E. Under charge particle equilibrium the absorbed dose in that TL material D_{TL} can then be written as

$$D_{\mathrm{TL}} = \Phi E(\mu_{\mathrm{en}}/\rho)_{\mathrm{TL}}, \tag{23}$$

with $(\mu_{\mathrm{en}}/\rho)_{\mathrm{TL}}$ the mass energy absorption coefficient of the TL material. If the TL material is replaced by tissue, i.e. exposed to photons with the same Φ and E then for the absorbed dose in tissue a similar equation can be written. From both equations it follows

$$\frac{D_{\mathrm{TL}}}{D_{\mathrm{tissue}}} = \frac{(\mu_{\mathrm{en}}/\rho)_{\mathrm{TL}}}{(\mu_{\mathrm{en}}/\rho)_{\mathrm{tissue}}}, \tag{24}$$

with $(\mu_{\mathrm{en}}/\rho)_{\mathrm{tissue}}$ the mass energy absorption coefficient of tissue. In Fig. 11 this ratio has been plotted for several TL materials as function of the energy.

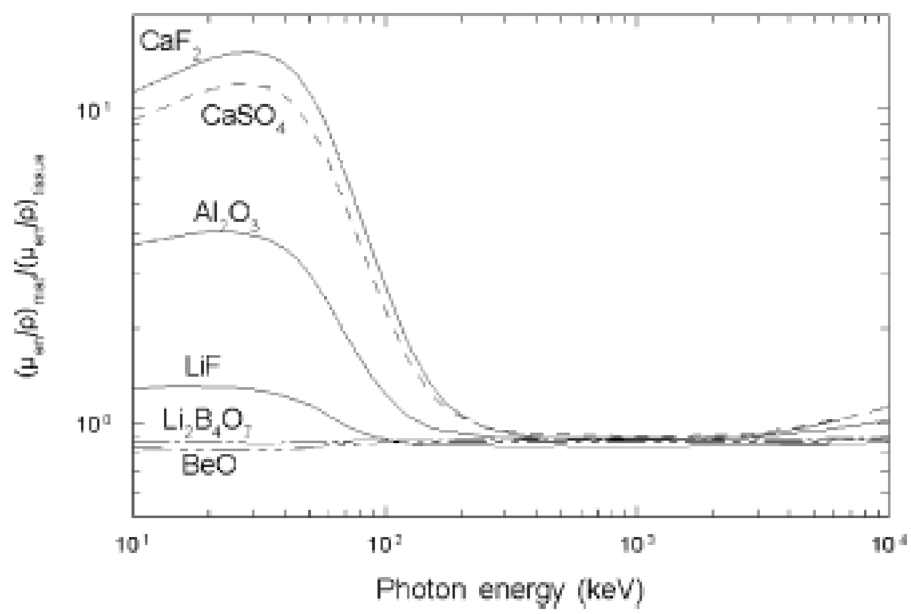

Fig. 11. Photon energy response for a few indicated TLD materials. The reference material is soft tissue with $Z_{\mathrm{eff}} = 7.35$.

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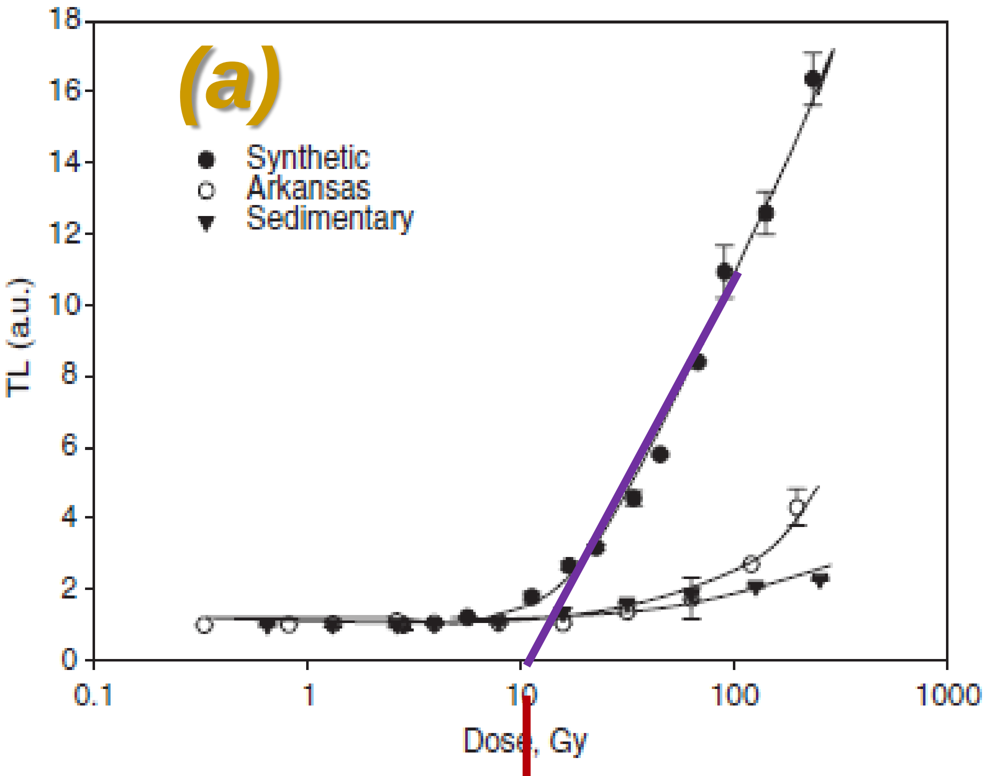
$$Z_{\mathrm{eff}} = \sqrt[m]{\sum_i a_i Z_i^m},$$

Effective atomic numbers of some TLDs

Material	Composition element: mass fraction in %	Z_{eff}
Polyethylene $(C_2H_4)_n$	H: 14.37, C: 85.63	5.53
Fat	H: 11.95, C: 63,72, N: 08; O: 23.23, Na: 0.05, P: 0.02, S: 0.07, Cl: 0.12, K: 0.03, Ca: 0.01	6.38
PMMA $(C_5H_8O_2)_n$	H: 8.05, C: 59.99, O: 31.96	6.56
BeO	Be: 36.0, O: 64.0	7.21
$Li_2B_4O_7$	Li: 8.21, B: 25.57, O: 66.22	7.32
Tissue		
ICRU-sphere	H: 10.1, C: 11.1, N: 2.6, O: 76.2	7.35
ICRU-striated	H: 10.20, C: 12.3, N: 3.5, O: 72.90; Na: 0.08, Mg: 0.02, P: 0.02, S: 0.5, K: 0.3	7.63
ICRP-skeletal	H: 10.06, C: 10.78, N: 2.77, O: 75.48, Na: 0.075, Mg: 0.019, P: 0.18, S: 0.24, Cl: 0.079, K: 0.3, Ca: 0.003, Fe: 0.004, Zn: 0.005	7.65
Water H_2O	H: 11.19, O: 88.81	7.51
Air	C: 0.0124, N: 75.53, O: 23.18, Ar: 1.28	7.77
LiF	Li: 26.75, F: 73.25	8.31
Al_2O_3	Al: 47.08, O: 52.93	11.28
SiO_2	O: 53.3, Si: 46.7	11.75
Compact bone	H: 4.72, C: 14.43, N: 4.2, O: 44.61, Mg: 0.22, P: 10.5, S: 0.32, Ca: 20.99, Zn: 0.01	13.59
$CaSO_4$	O: 47.0, S: 23.6, Ca: 29.4	15.62
CaF_2	Ca: 51.33, F: 48.67	16.90

Detection Limits: Low



(b)

The lower limit of detection is important in low dose measurements where the signal of an irradiated TLD is almost the same as the signal of the background. It is defined as the smallest absorbed dose that according to an analytical process can be detected at a specified confidence level.

BGK measurement, Finding error

$$Error = \sqrt{BGK}$$

Dose corresponding to signal = BGK+3Error

Lowest Detectable Dose Limit Estimation

Detection Limits – Dosimetric applications

Dosimetric requirements in some major application areas

Application area	Dose range (Gy)	Uncertainty, 1 S.D. (%)	Tissue equivalency[a]
Personnel	10^{-5}–5×10^{-1}	−30, +50	+
Environmental	10^{-6}–10^{-2}	±30	-
Clinical			
Radiotherapy	10^{-1}–10^{2}	±3.5	++
Diagnostic radiology	10^{-6}–10	±3.5	+
Radiation processing[b]	10^{1}–10^{6}	±15	-

[a] The more + the more required.

[b] Involves sterilization, food processing, material testing, etc.

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Requirements for TL materials (1)

a high concentration of traps and a high efficiency of light emission associated with the recombination process;

a good storage stability of the trapped charges, as a function of storage time and temperature, so that a negligible fading affects the TL response. This should also be true for opposite extreme temperature values (i.e., tropical or artic climates);

a very simple glow curve (i.e., a simple trap distribution) which allows the interpretation of the readings as simple as possible, without any thermal treatment after irradiation (post irradiation annealing). In case of more or less complex glow curve, the main peak (i.e., the dosimetric peak) should be well resolved among other possible peaks in the glow curve;

a spectrum of the emitted TL light to which the detector system (photomultiplier and associated filters) responds well. A spectrum wavelengths between 300 and 500 nm seems the most desirable since it corresponds to the commercially available detector systems. Furthermore, the black body radiation does not interfer in this spectral range even at relatively high temperatures;

Requirements for TL materials (2)

the main peak should have a peak temperature at the maximum in the range 180°C ÷250°C. At higher temperatures the infrared emission from both TLD sample and TLD holder may interfere giving up to a source of errors in the reading interpretation;

good resistance against disturbing environmental factors as light (optical fading), humidity, organic solvents, gases, moisture;

the TL material should not suffer by radiation damage in the dose range of applications;

the TL material should have a low photon energy dependence of response. For personnel and medical applications, tissue equivalent phosphors (effective atomic number of the tissue Z_{eff} =7.4), or approximated tissue equivalent, should be used to avoid energy corrections;

Requirements for TL materials (3)

a linear TL response over a wide range of doses is a desirable feature for most applications;

the TL material should be non-toxic: this is very important for in-vivo medical applications;

the TL response should be independent of dose rate and of the angle of radiation incidence;

the lower limit of detection should be as low as possible for environmental monitoring;

low self-irradiation due to natural radionuclides in the TLD materials for all kind of applications;

high precision and high accuracy are required characteristics for any kind of applications;

in case of need, the TL detectors should be suitable for postal service.

Sensitivity of TL materials

Reported TL sensitivities of some materials relative to TLD-100

TL material	Relative TL sensitivity		
	Kitis et al. (1999)	Prokert and Sommer (1998)	McKeever et al. (1995)
LiF : Mg, Ti (TLD-100)	1	1	1
LiF : Mg, Cu, P	37.3	20	23–35
Al_2O_3 : C	34.3	30	40–60
$CaSO_4$: Dy	20.4		30–50
$KMgF_3$: Ce	167.3		
CaF_2 : Dy (TLD-200)		20	20–30
CaF_2 : Tm (TLD-300)		10	∼ 3
CaF_2 : Mn (TLD-400)		5	1.7–2.4
CaF_2 : Cu, Ho		160	
BeO			∼ 1

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Dose determination – theoretical aspects

$$D = M \cdot F_c$$

where
M is the TL signal (integral light or peak height), and
F_c is the individual calibration factor of the detector.

Fading? Non linearity? PM tube,

Detection Spectral response

Irradiation type – grain sizes – dose callibration factors

One TL dosimetric system consists of:

- the passive elements: the TL dosimeters (or detectors)
- a TL reader schematically consisting of a heating element, a PM tube, one or more electronic networks.
- an appropriate algorithm to convert the TL signal (response of the reader) to dose.
- ovens and/or furnaces to be used for thermal treatments of the dosimeters (annealing procedures).
- any other complementary instrumentation or facility which can be used for the right setting up and working for the system and/or for the implementation of the system (i.e. calibration sources; programme able to deconvolute the glow-curve, to make an automatic estimation of the background, to calculate the average TL values and so on).

Known TL dosimeters

TL material
TLD-100
TLD-100
PTL-710
LiF (MTS)
LiF (GR-200)
$Al_2O_3 : C$
$CaSO_4 : Dy$
BeO

We measure the TL signal in the corresponding application and then we compare the signal with that of known laboratory dose.