Dosimetry methods

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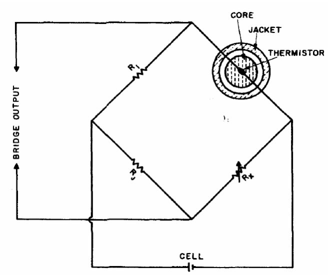
Calorimetry

- Measurement of temperature
- Irradiation causes temperature increase
- 1 Gy in Al gives a temperature increase of 1 mK
- Measurement with thermocouples and thermistors
- The exposed medium must be thermally isolated.
- Non-ionizing radiation must not contribute

Calorimetry

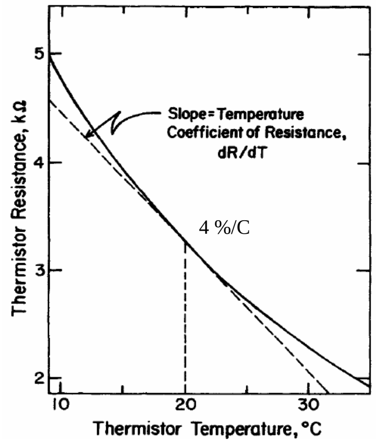
- Use e.g. Wheatstone bridge to measure change in resistance over the thermistor:



Thermistor: semiconductor with temperature-dependent resistance

- Set R_X so that current is zero → $R_C = R_x \times R_1 / R_J$

Thermistor response



Absorbed-dose calorimeters

- Increase in temperature:

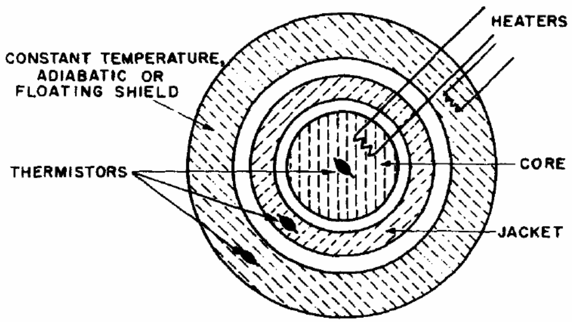
$$\Delta T = \frac{E(1-\delta)}{hm} = \frac{D(1-\delta)}{h}$$

h: heat capacity [J kg^{-1} C^{-1}] (e.g. 900 in Al)

δ: heat defect

- Sensitive volume (*core*) should be water-equivalent (graphite, plastic etc)
- Core surrounded by *jacket* of same material

Absorbed-dose calorimeters



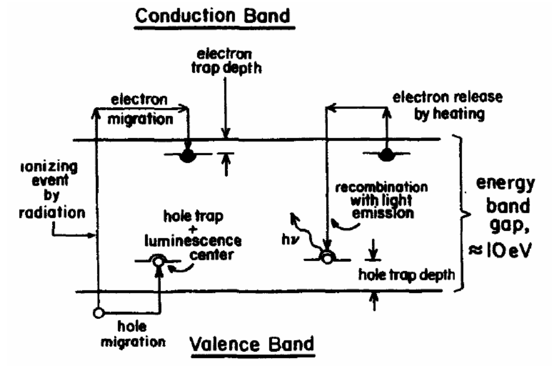
Calorimetry – pros and cons

- Pros
  - Absolute, direct measurement
  - Sensitive volume can be of nearly any material
  - Independent of dose rate
- Cons
  - Minute temperature increase
  - Bulky apparatus

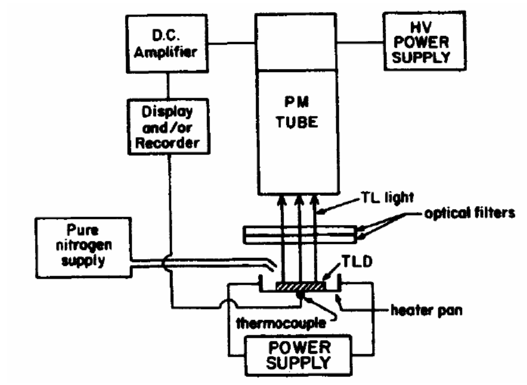
Thermoluminescence dosimetry

- Thermoluminescence (TL): thermally activated luminescence
- Measures the amount of visible light emitted from a crystal when heated
- Crystal contains two types of activators (in trace amounts); traps and luminescence centers

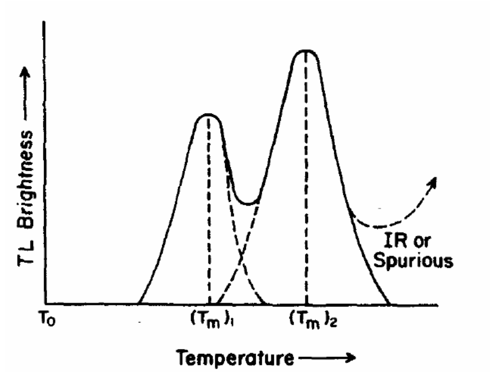
TLD, band structure



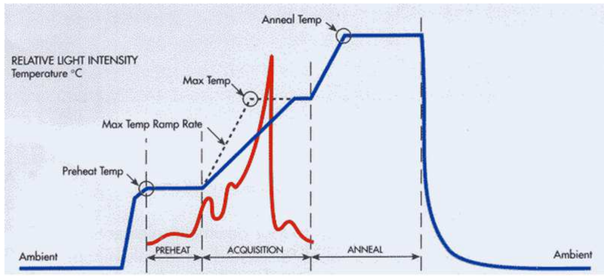
Thermoluminescence detection



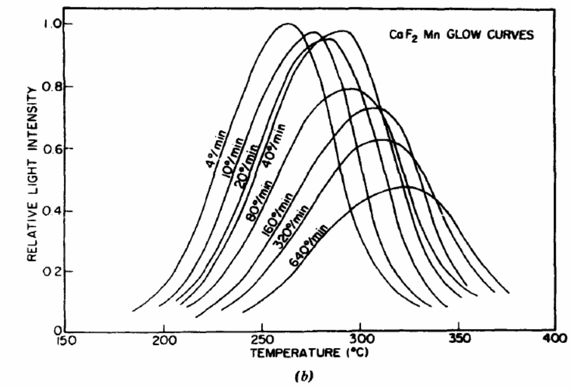
Luminescence spectrum: glow curve



Readout cycle

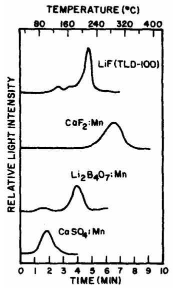


Glow curves



Different TLD materials

Phosphor	LiF:Mg, Ti	CaF_2:Mn	$Li_2B_4O_7$: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



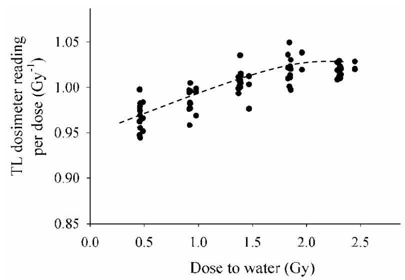
1 R = 0.00877 Gy in air

Trap stability

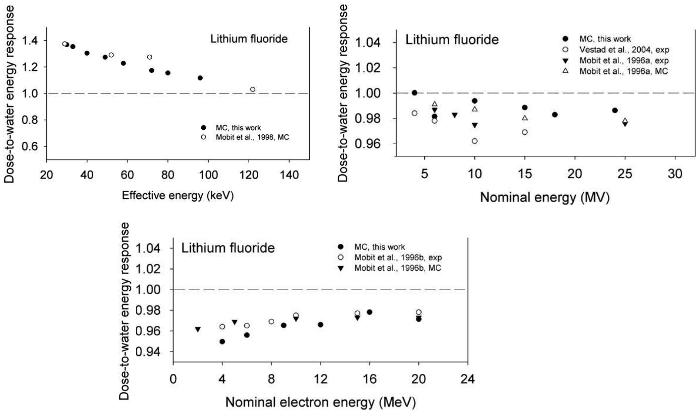
- Signal loss will occur if trapped electrons/ holes are not stable
- Important with reproducible readout procedure
- Glow peaks at > 200°C usually stable
- Peak at 150 °C have half life ~ days

Thermoluminescence dosimetry

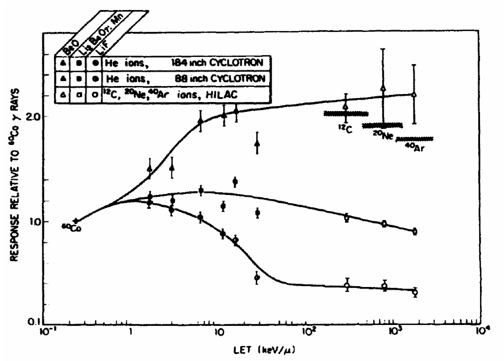
Supralinear dose response



TLD energy dependence



TLD LET dependence



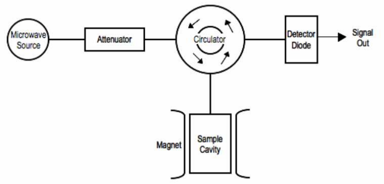
TLD – pros and cons

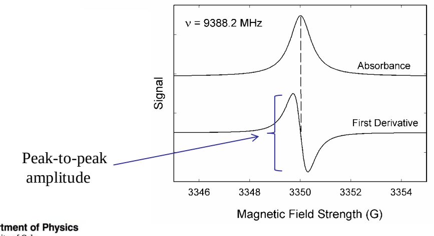
- Pros
  - Very sensitive (μGy)
  - Small size
  - Reusable
  - Rapid readout
  - Different materials available
- Cons
  - Lack of uniformity
  - Suprelinearity
  - Fading, light sensitivity
  - Change in sensitivity with exposure history

EPR dosimetry

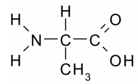
- Radical: compound with unpaired electron
- Most radicals formed in radiation chemistry are short-lived
- Density of radicals is a measure of radiation dose
- EPR dosimetry is an relevant for "historic dosimetry"
- Exploit *Zeeman-effect*, as radicals are paramagnetic
- Materials: alanine, carbohydrates, some rocks, teeth…
- Sensitivity > 40 mGy

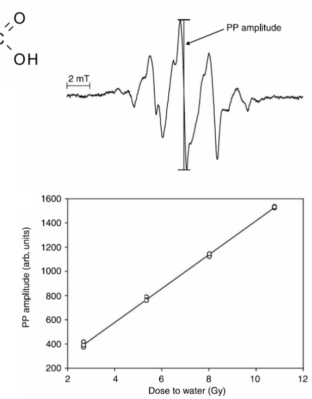
EPR dosimetry

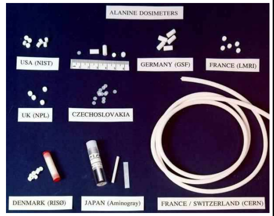




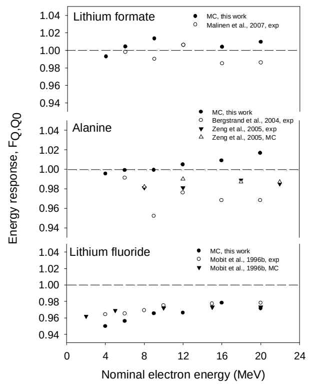
Alanine EPR dosimeters

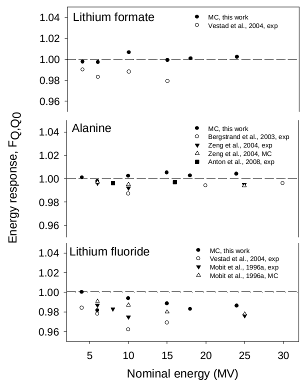






Alanine – energy dependence



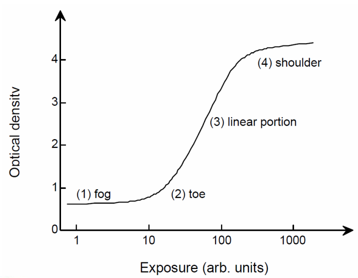


Alanine – pros and cons

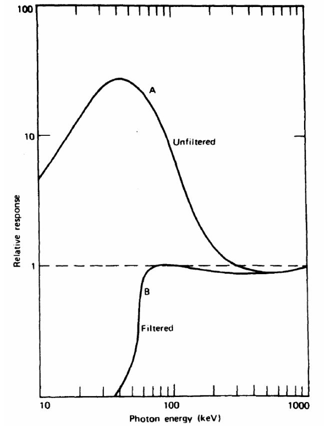
- Pros
  - Non-destructive readout
  - Various shapes and sizes
  - Linear dose response
- Cons
  - Low sensitivity
  - Fading, light sensitivity

Film dosimetry

- Radiographic film: Ionization of photographic emulsion containing AgBr-grains converts Ag^{+} to Ag
- Light transmission is a function of the film opacity and can be measured in terms of optical density (OD) with densitometers



Film dosimetry – energy dependence

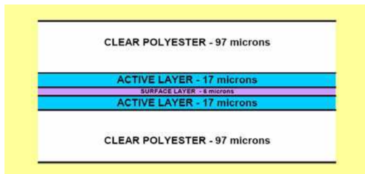


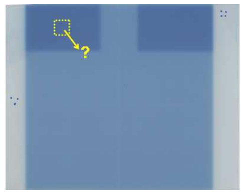
Film dosimetry – pros and cons

- Pros
  - High spatial resolution
  - Signal in prepared film more or less permanent
  - Thin dosimeter
- Cons
  - Wet processing
  - Energy dependence
  - Non-linear dose response

Radiochromic film

- Radiochromic film: special dye gets polymerized upon exposure to radiation. The polymer absorbs light and the transmission of light through the film can be measured with a suitable densitometer





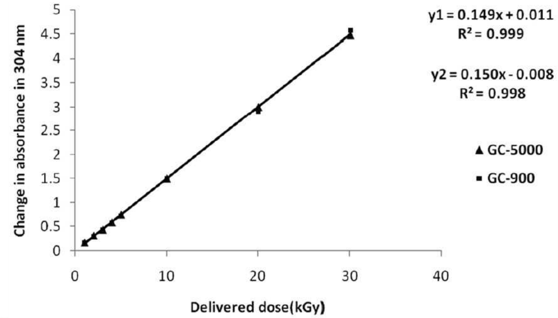
Chemical (Fricke) dosimetry

- Fricke solution of 0.001 M $FeSO_4$
- Oxidation of Fe^{2+} to Fe^{3+}

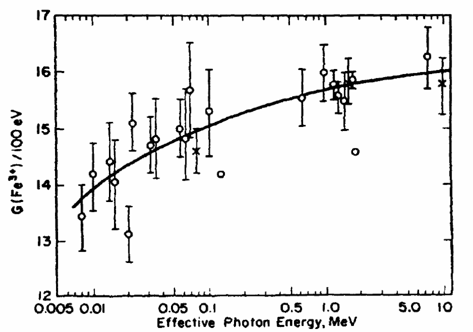
1. $H_2O + \text{rad.} \rightarrow H\bullet + \bullet OH$
2. $\bullet OH + Fe^{2+} \rightarrow Fe^{3+} + OH^-$
3. $\bullet H + O_2 \rightarrow \bullet HO_2$
4. $H^+ + Fe^{2+} + \bullet HO_2 \rightarrow Fe^{3+} + H_2O_2$
5. $H_2O_2 + Fe^{2+} \rightarrow Fe(OH)^{2+} + \bullet OH$
6. $\bullet OH + Fe^{2+} \rightarrow Fe^{3+} + OH-$

Fricke - detection

- Absorption spectroscopy
- 300 nm light source

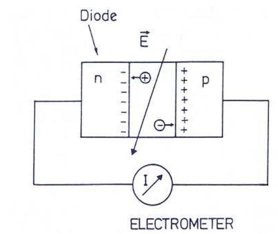


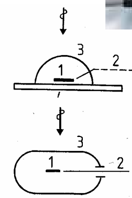
Fricke – energy dependence



Diode dosimetry

- Radiation produces electron-hole (e-h) pairs. The charges (minority carriers) produced in the dosimeter are swept across the depletion region under the action of the electric field. In this way a current is generated in the reverse direction in the diode.



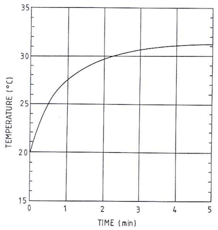


spherical

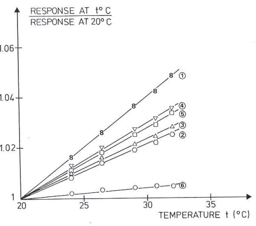
droplet

Diode dosimetry

Detector temperature after placing on patient

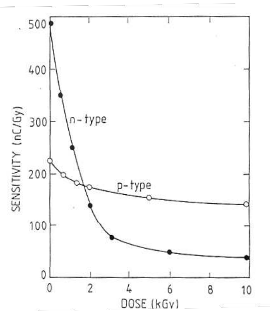


Sensitivity dependence



Diode dosimetry

- Dependence on accumulated dose



Diode dosimetry

- Field size dependence