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 thermostors
- 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:

\[ R_C = \frac{R_X \times R_I}{R_J} \]

Thermistor: semiconductor with temperature-dependent resistance

Thermistor response

- Set \( R_X \) so that current is zero
- Slope = Temperature Coefficient of Resistance, \( \frac{dR}{dT} \)
- \( 4 \%/C \)
Absorbed-dose calorimeters

- Increase in temperature:
  \[ \Delta T = \frac{E(1-\delta)}{h \cdot m} = \frac{D(1-\delta)}{h} \]
  
  \( h \): heat capacity [J kg\(^{-1} \) C\(^{-1} \)] (e.g. 900 in Al)
  \( \delta \): heat defect

- Sensitive volume (core) should be water-equivalent (graphite, plastic etc)

- Core surrounded by jacket of same material

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

<table>
<thead>
<tr>
<th>Material</th>
<th>QP (MeV)</th>
<th>Cp (MeV)</th>
<th>Cu(0.5 MeV)</th>
<th>Cu(10 MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaF₂</td>
<td>1.84</td>
<td>2.18</td>
<td>1.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Ca₂Al₂Si₂O₇F₂</td>
<td>0.2</td>
<td>1.3</td>
<td>2.4</td>
<td>1.8</td>
</tr>
<tr>
<td>LiF</td>
<td>230-400</td>
<td>100-400</td>
<td>250-400</td>
<td>250-400</td>
</tr>
<tr>
<td>Half-life (s)</td>
<td>400</td>
<td>500</td>
<td>800</td>
<td>2000</td>
</tr>
<tr>
<td>Temperature of main TL glow peak at 90°C (°C)</td>
<td>315</td>
<td>255</td>
<td>200</td>
<td>150</td>
</tr>
<tr>
<td>Repetitive nature of TL</td>
<td>Supralinear dose response</td>
<td>Supralinear dose response</td>
<td>Supralinear dose response</td>
<td>Supralinear dose response</td>
</tr>
<tr>
<td>Half-life (s)</td>
<td>~10-6</td>
<td>~10-7</td>
<td>~10-8</td>
<td>~10-10</td>
</tr>
<tr>
<td>TL sensitivity</td>
<td>~10-7</td>
<td>~10-8</td>
<td>~10-9</td>
<td>~10-10</td>
</tr>
</tbody>
</table>

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

TL-Dose sensitivity (Gy)

Dose to water (Gy)
**TLD energy dependence**

- Lithium fluoride

**TLD LET dependence**

- Lithium fluoride

**TLD – pros and cons**

- **Pros**
  - Very sensitive ($\mu$Gy)
  - 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

![Graph showing the relationship between optical density and exposure](image)

**Film dosimetry – energy dependence**

![Graph showing the energy dependence of film dosimetry](image)

**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

![Diagram showing radiochromic film structure](image)
**Chemical (Fricke) dosimetry**

- Fricke solution of 0.001 M FeSO$_4$
- Oxidation of Fe$^{2+}$ to Fe$^{3+}$

\[
egin{align*}
1. & \quad H_2O + \text{rad.} \rightarrow H^+ + \text{•OH} \\
2. & \quad \text{•OH} + Fe^{2+} \rightarrow Fe^{3+} + OH^- \\
3. & \quad H + O_2 \rightarrow \text{•HO}_2 \\
4. & \quad H^+ + Fe^{2+} + \text{•HO}_2 \rightarrow Fe^{3+} + H_2O_2 \\
5. & \quad H_2O_2 + Fe^{2+} \rightarrow Fe(OH)^{2+} + \text{•OH} \\
6. & \quad \text{•OH} + Fe^{2+} \rightarrow Fe^{3+} + OH^- \\
\end{align*}
\]

**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.
Diode dosimetry

Detector temperature after placing on patient

Sensitivity dependence

Diode dosimetry

- Dependence on accumulated dose

Diode dosimetry

- Field size dependence