Dosimetric measurement methods

- Two different types of methods.
- General methods, i.e. methods also used for other types of measurements
  - Monitors - scintillation detectors
  - Monitors, gas counters
  - “Dose calibrator”, proportional counter (measures current from a source)
- Dedicated methods
  - Thermoluminescence (TLD) crystals
  - ESR methods - radical dosimetry
  - Chemical dosimetry
  - Calorimetry
  - Film
  - Ion chamber (Eirik, next lecture)
  - Track detectors
Band structure

In an isolator, the filled valence band is well separated (~10 eV) from the conduction band.

Particle/hole states are formed when the crystal is irradiated.

The material must contain impurities inorder to create trapping states!!
Thermoluminescence dosimetry

Principle:
1. Radiation creates metastable, excited states in a solid crystal.
2. When the crystal is to be “read”, it is heated. Some of the metastable excited states deexcite by photon emission. This light is detected.

Condition: The life-time of the excited states at moderate (room) temperature is very long compared to the time passing between start and reading.

Deexcitation of metastable states in solid media follows the Randall-Wilkins law: $p(T) = \tau^{-1} = \alpha e^{-(E/kT)}$

$E$ - trapp depth; $\alpha$ - frequency factor
Reading of TLD crystals

When the crystal is heated, light is emitted and detected by a photomultiplier tube. In routine labs, this is done automatically. Only the most intense light peak is used for calculation of the radiation dose.
Reading apparatus for TLD

Diagram showing the components of a reading apparatus for TLD, including DC amplifier, display and/or recorder, power supply, PM tube, pure nitrogen supply, optical filters, thermocouple, heater, and TL light.
Heating sequence for TLD
Different TLD materials

![Graph showing different TLD materials](image)

- LiF (TLD-100)
- CaF$_2$:Mn
- Li$_2$B$_4$O$_7$:Mn
- CaSO$_4$:Mn
TLD-detection

The heating of TLD crystals must be optimised with respect to temperature and temperature gradient.

For every crystal, there is a particular temperature $T_m$ where optimal signal ("brightness") is achieved for the emitted light.

Roughly: $T_m = 489 \, \text{E}$, where $E$ is the depth of the trap in eV.

Typical TLD materials:
- LiF (Mg,Ti) (**most common**)
- CaF$_2$(Mn)
- Li$_2$B$_4$O$_7$(Mn)
- CaSO$_4$ (Mn)
TLD-detection

TLD crystals have a very broad range of sensitivity, from several Gy down to 10 μGy.

Hence, these crystals are excellent for personnel dosimetry, but also for “tougher” applications.

When the reading is done, the crystals can be used again several times. Since the reading is non-destructive it is a very economic method, compared to film.

TLD is today dominating in personnel dosimetry.
Dose-response curves

![Graph showing dose-response curves for different materials: LiF:Mg,Ti, Li$_2$B$_4$O$_7$:Mn, CaSO$_4$:Mn, CaF$_2$:Mn. The x-axis represents the $\gamma$-ray exposure in units of R or $2.58 \times 10^{-4}$ C/kg, and the y-axis represents the TL light output in arbitrary units.]
Radical dosimetry (ESR)

Radical: compound with unpaired electron

Most radicals formed in radiation chemistry are short-lived (to be discussed later), but some special ones have very long half-lives.

Since density of radicals in a compound is a measurement of the radiation dose, they can be used to measure such doses.

Radical dosimetry is an important method for “historic dosimetry, i.e. to measure dose in situations that were not prepared for (bombs, reactor accidents etc.)
Radical dosimetry

Materials useful for radical dosimetry: alanin, carboglydrates, some rocks, teeth, everything creating something long-lived.

ESR on sugar and teeth can be used in evaluation of cancer patients doses; bomb victims; doses to people living in areas with high natural background; contaminated areas etc.

Many materials can be used, they must also produce a useful ESR signal from the long-lived radical.

Sensitivity > 40 mGy
ESR (electron spin resonance) apparatus

Figure 3-14. Physical arrangement for irradiation in ESR cavity. Vector model is superimposed on cavity.

either by absorption or emission, are defined by

\[ \Delta E = E_{+1/2} - E_{-1/2} = 2\beta H \]  \hspace{1cm} (3-7)

and will take place if, when bathed in radiation of frequency \( \nu \), \( H_0 \) is adjusted to the resonance condition

\[ h\nu = \Delta E = 2\beta H_0 \]  \hspace{1cm} (3-8)
Radical dosimetry
Radical dosimetry

![Graph showing the relationship between tissue absorbed dose (Gy) and relative ESR intensity for lactose sugar with Mn²⁺. The graph includes a linear relationship between dose and intensity.]
Dose profile, Hiroshima
Radical dosimetry

Materials useful for radical dosimetry: alanin, carboghydrates, some rocks, teeth, everything creating something long-lived.

ESR on sugar and teeth can be used in evaluation of cancer patients doses; bomb victims; doses to people living in areas with high natural background; contaminated areas etc.

Sensitivity > 40 mGy
Chemical dosimetry

Fricke solution.
Sour FeSO₄ solution with air
0.001 M FeSO₄
0.4 M H₂SO₄

Principle: Oxidation of Fe²⁺ to Fe³⁺

1. H₂O + rad. → H• + •OH
2. •OH + Fe²⁺ → Fe³⁺ + OH⁻
3. •H + O₂ → •HO₂
4. H⁺ + Fe²⁺ + •HO₂ → Fe³⁺ + H₂O₂
5. H₂O₂ + Fe²⁺ → Fe(OH)²⁺ + •OH
6. •OH + Fe²⁺ → Fe³⁺ + OH⁻

Total in sour solution:
4 Fe²⁺ + 4 H⁺ + O₂ → 4Fe³⁺ + 2H₂O
Good linearity

Linearity of the Fricke solution

Range: ~40 - ~400 Gy
Chemical dosimetry

Other chemical compounds can also be used as dosimeters
Calorimetry

Calorimetric methods measure the dose by measuring the temperature increase in a medium.

1 Gy in Al metal corresponds to a temperature increase of 1 mK. Can be measured with thermocouples and thermistors.

Important requirements:

1. The exposed medium must be extremely well thermally isolated.

2. Non-ionising radiation must not contribute.

Range: Very high doses (>~10 Gy) Calorimetry is the only dosimetric method measuring dose directly.
Thermistor temperature

The graph shows the relationship between thermistor resistance (kΩ) and thermistor temperature (°C). The slope of the line represents the temperature coefficient of resistance, dR/dT.
Wheatstone bridge for exact reading of resistance
Track dosimetry

Track dosimetry measures only high LET radiation, and is developed in particular for radon measurements.

A “close-to perfect” surface will receive tracks from high LET particles impinging on it. If the right type of surface (i.e. one allowing detection) is used, these tracks can be applied to measure the Rn content in the gas immediately above the surface.

Several different types of surfaces may be used, combined with different detection techniques.
Track dosimetry

Followed by etching and reading with sparking or laser-detection.
Track techniques

Media sensitive to different types of tracks have been developed. Track dosimetry may also be used to detect fissions and neutrons (inducing fission in media doped with $^{235}\text{U}$).