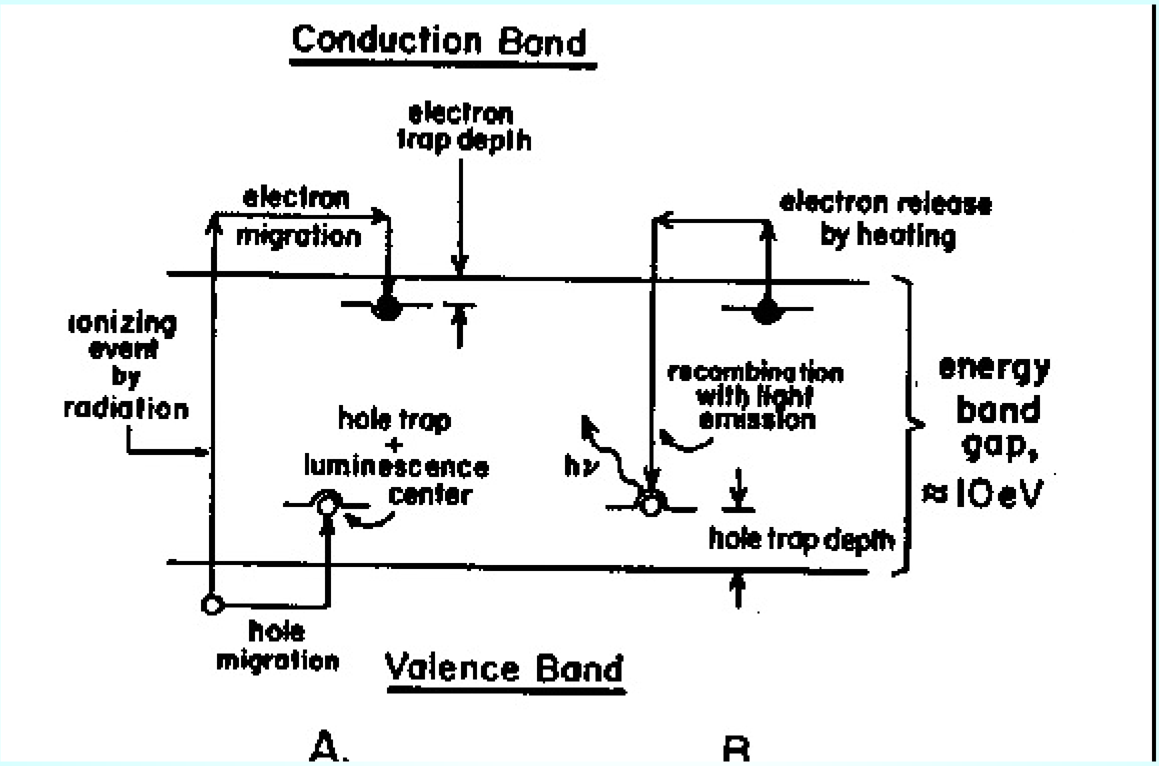
Dosimetric measurement methods

- 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)
  - Semiconductor detectors (measure particle/hole excitations in a semiconductor)
- Dedicated methods
  - Thermoluminescence (TLD) crystals
  - ESR methods - radical dosimetry
  - Chemical dosimetry
  - Calorimetry
  - Film
  - Ion chamber (Eirik)
  - Track detectors
  - Optically Stimulated Luminescence (OSL)
  - Gafchromic® (polymer chemistry)
  - FISH (fluorescent in-situ-hybridization, individual chromosome painting)

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 in order to create trapping states !!

Thermoluminescence dosimetry

Principle:

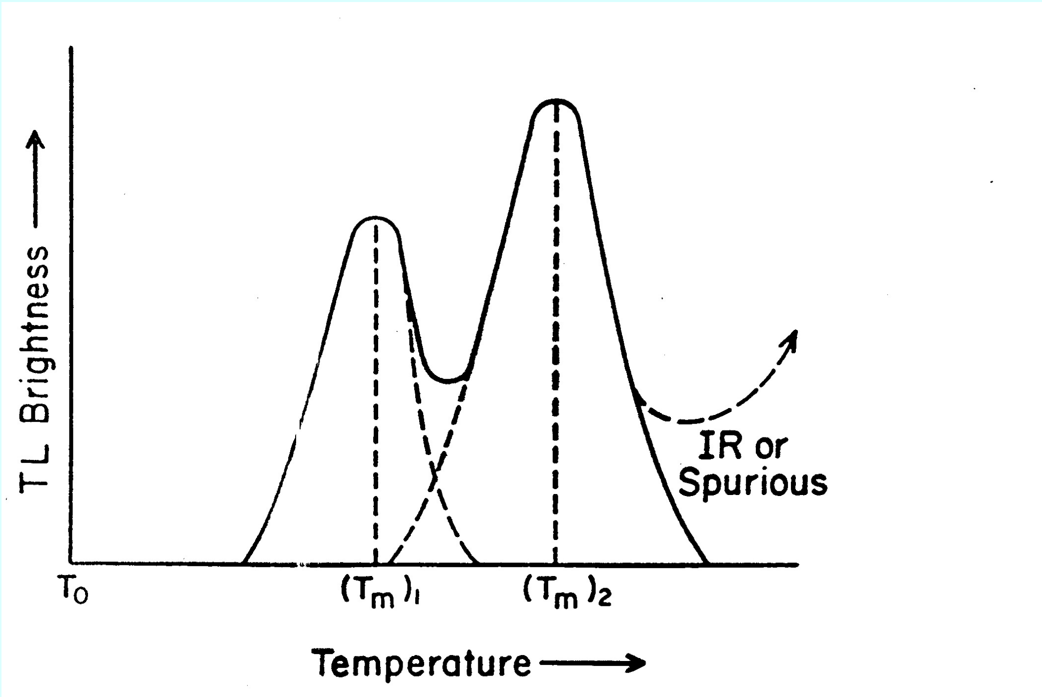
1. Radiation creates metastable, excited states in a solid crystal.
2. When the crystal is to be "read", it is heated. Some of the metastable excited states deexcite by photon emission. This light is detected.

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; α - frequency factor

Reading of TLD crystals



When the crystal i 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.

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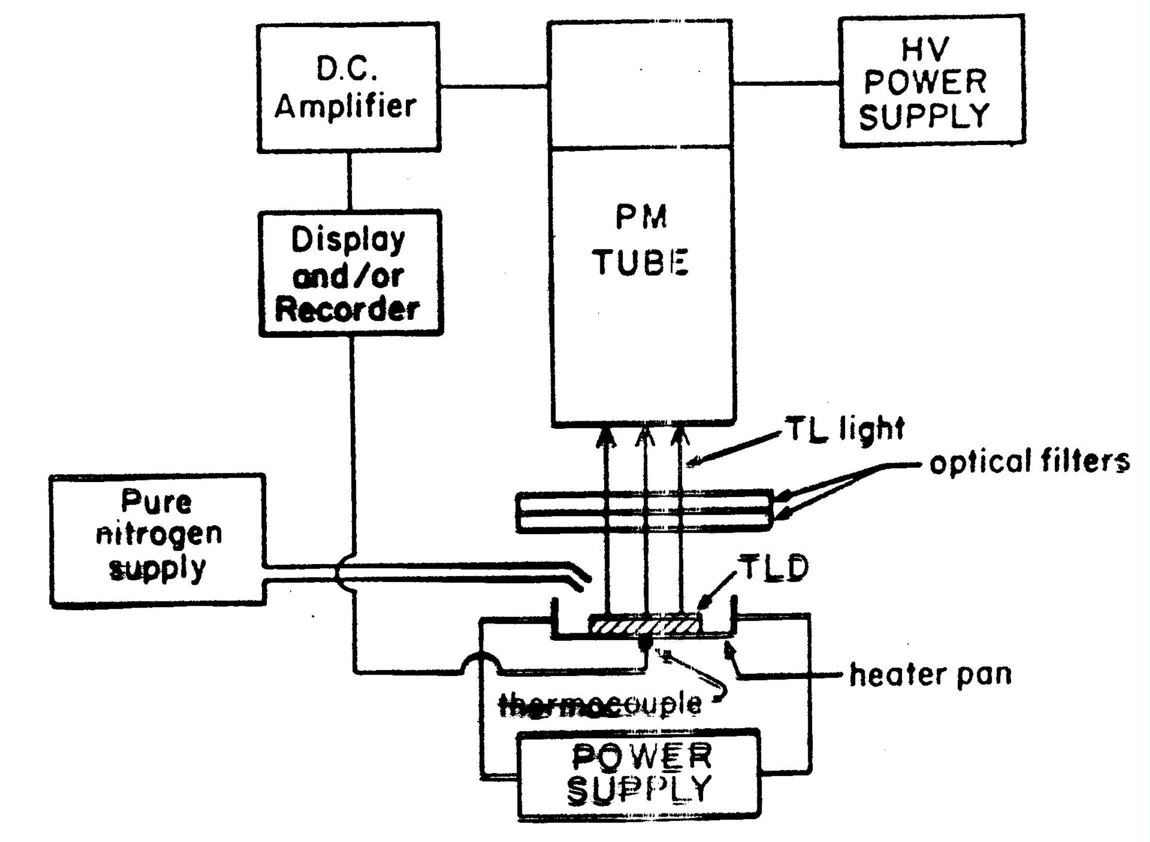
Reading aparatus for TLD



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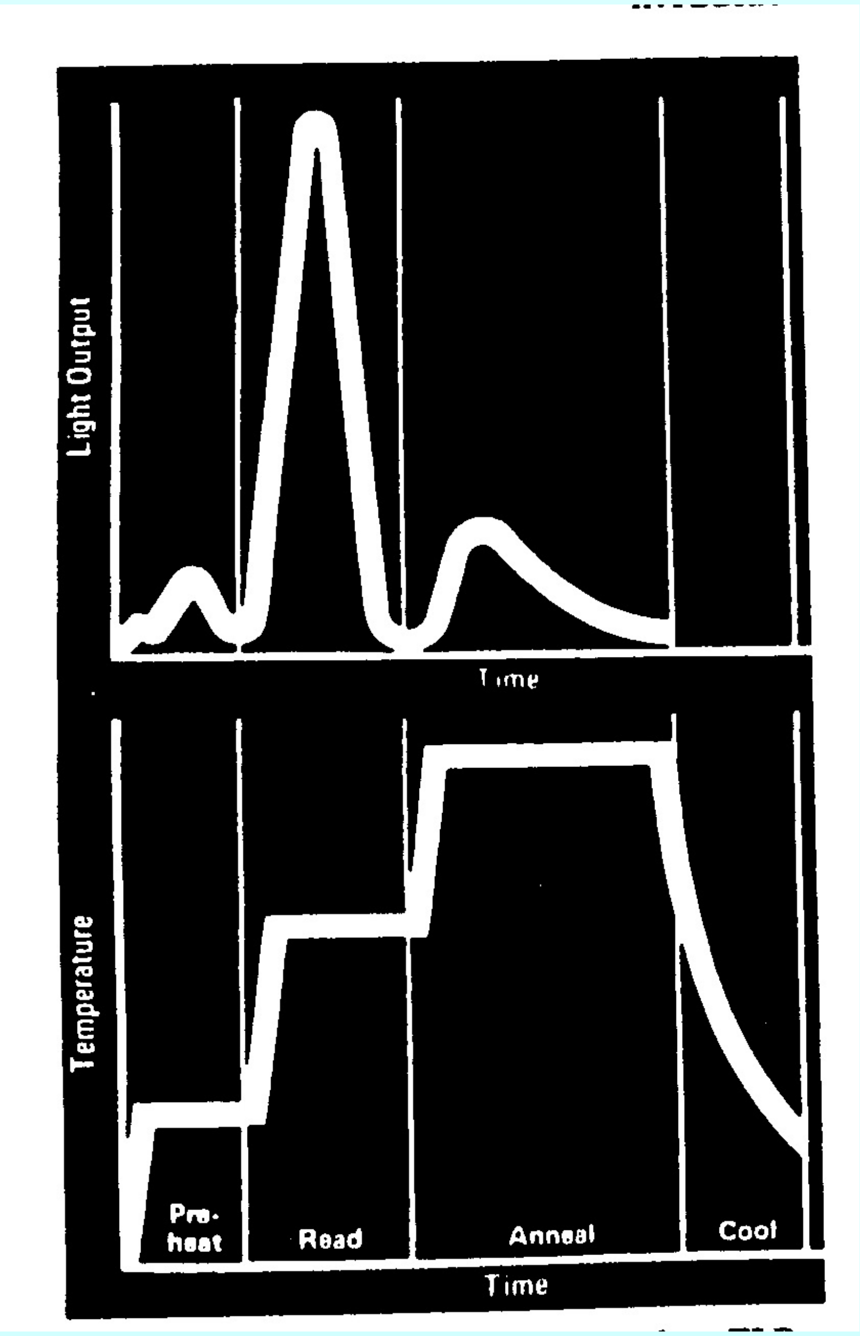
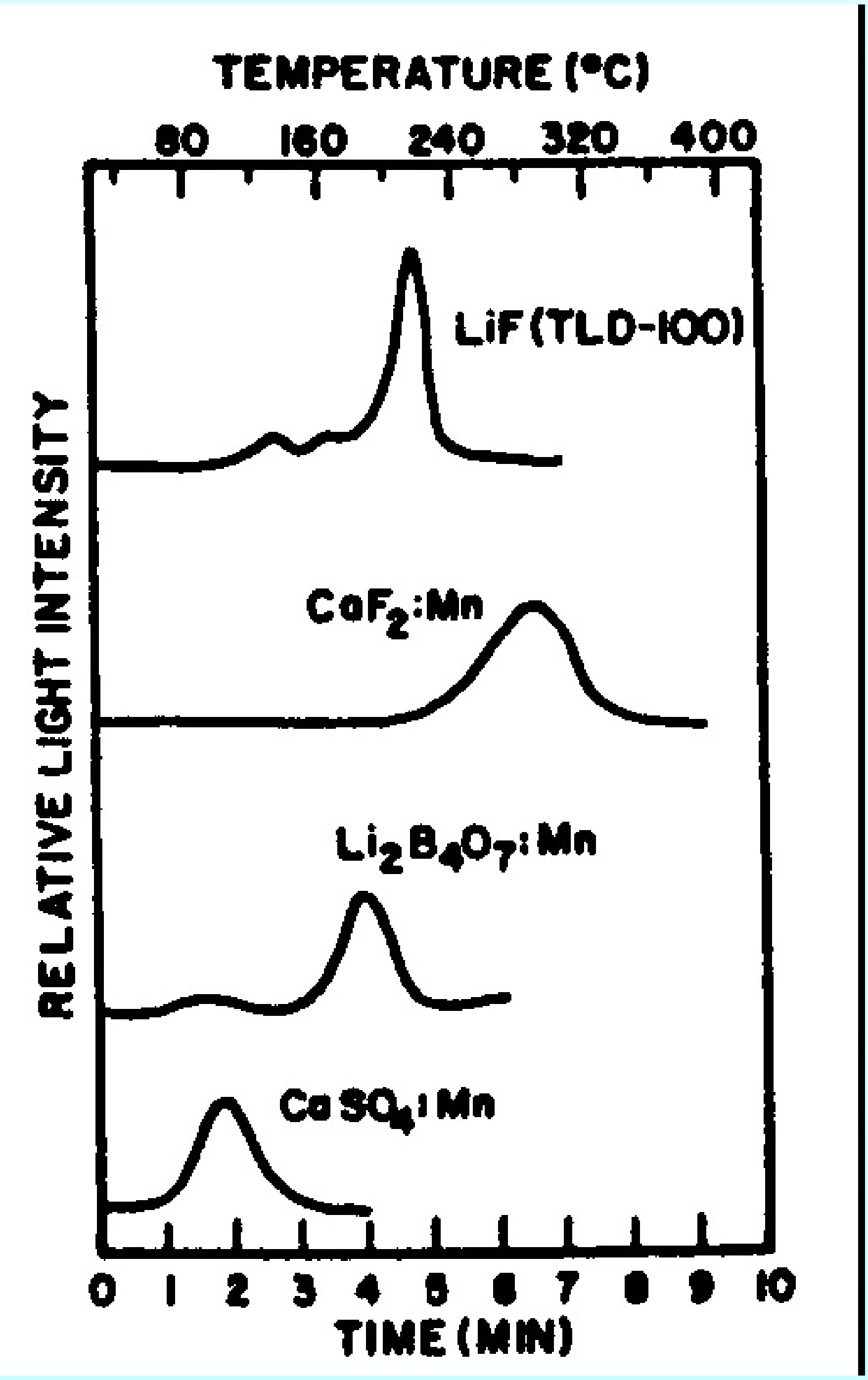
Heating sequence for TLD



Different TLD materials



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 achived for the emitted light.

Roughly: T_m = 489 E, where E is the depth of the trap in eV.

Typical TLD materials:
LiF (Mg,Ti) (most common)
CaF_2(Mn)
$Li_2B_4O_7$(Mn)
$CaSO_4$ (Mn)

TLD-detection

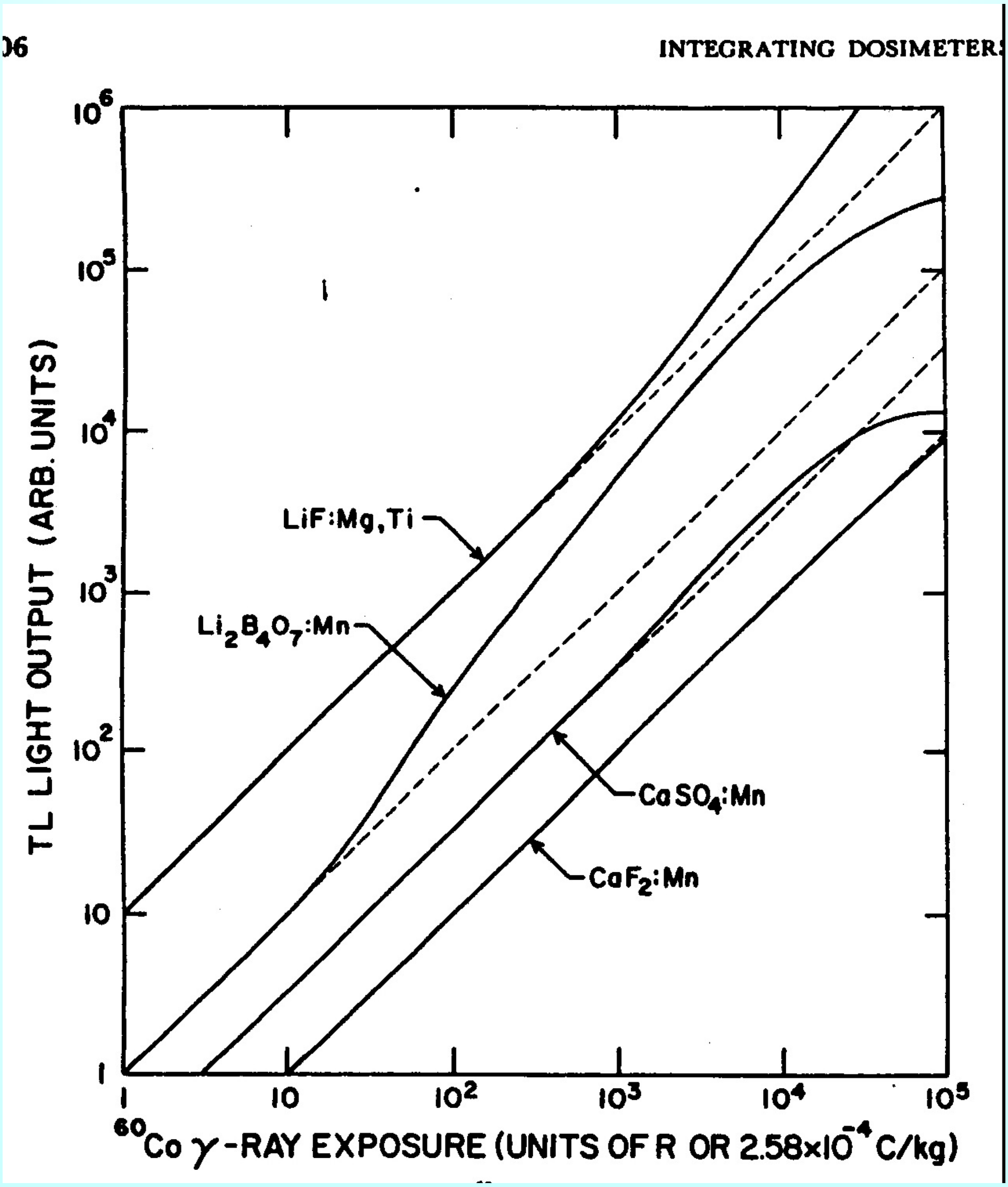
TLD crystals have a very broad range of sensitivity, from several Gy down to 10 μGy.

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

When the reading is done, the crystals can be used agein 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



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 situation which were not prepared for (bombs, reactor accidents etc.)

Radical dosimetry

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

ESR on sugar and teeth can be used in evaluation of cancer patiens doses; bomb victims; doses to people living in areas with high natural background; contanimated 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) aparatus

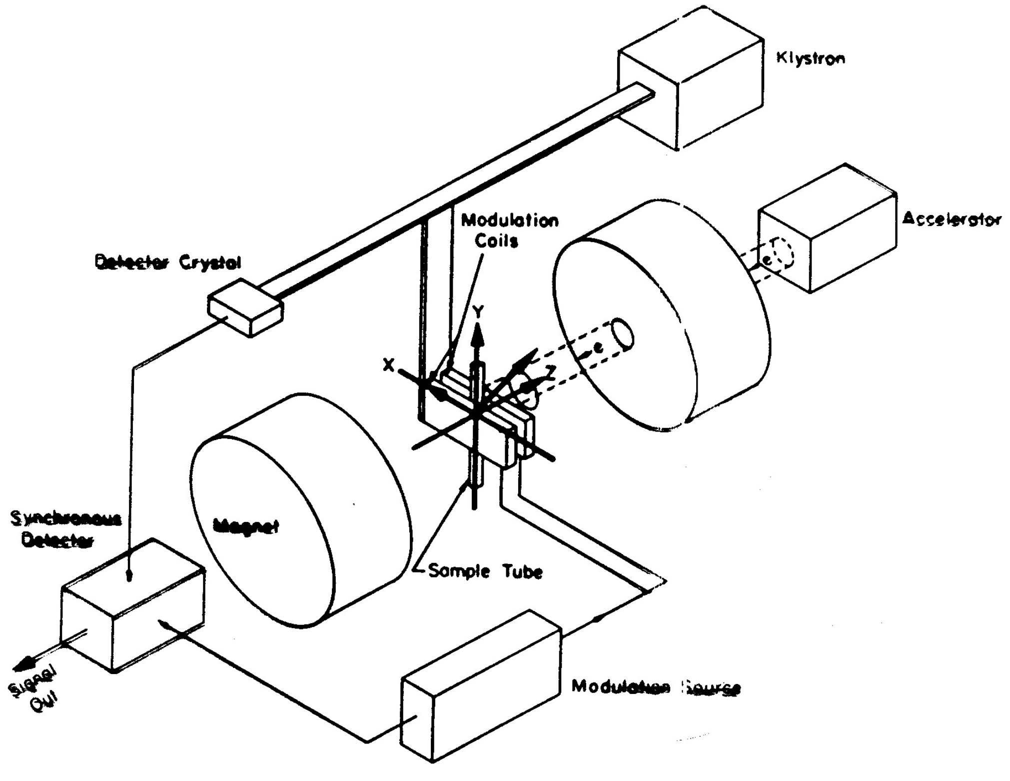


Figure 3-14. Physical arrangement for irradiation in ESR cavity. Vector model is superimposed on cavity.

either by absorption or emission, are defined by

$$\Delta E = E_{+1/2} - E_{-1/2} = 2\beta H \qquad (3\text{-}7)$$

and will take place if, when bathed in radiation of frequency ν, H_0 is adjusted to the resonance condition

$$h\nu = \Delta E = 2\beta H_0 \qquad (3\text{-}8)$$

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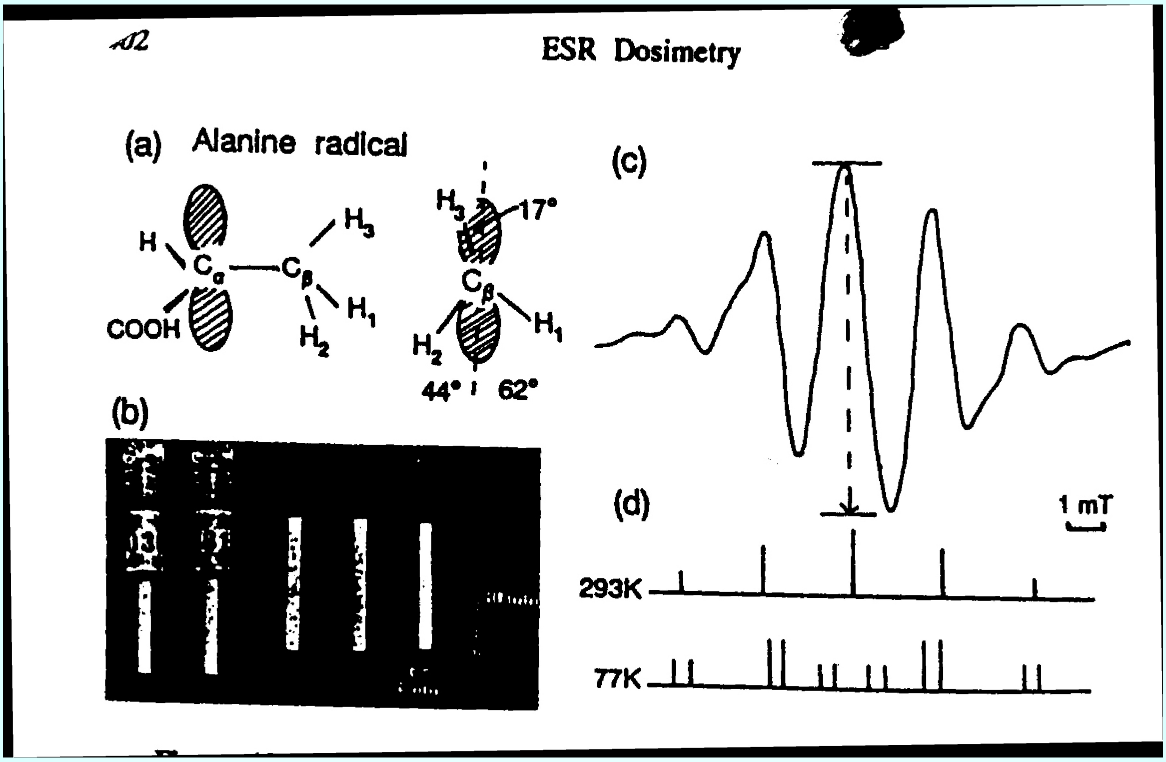
Radical dosimetry



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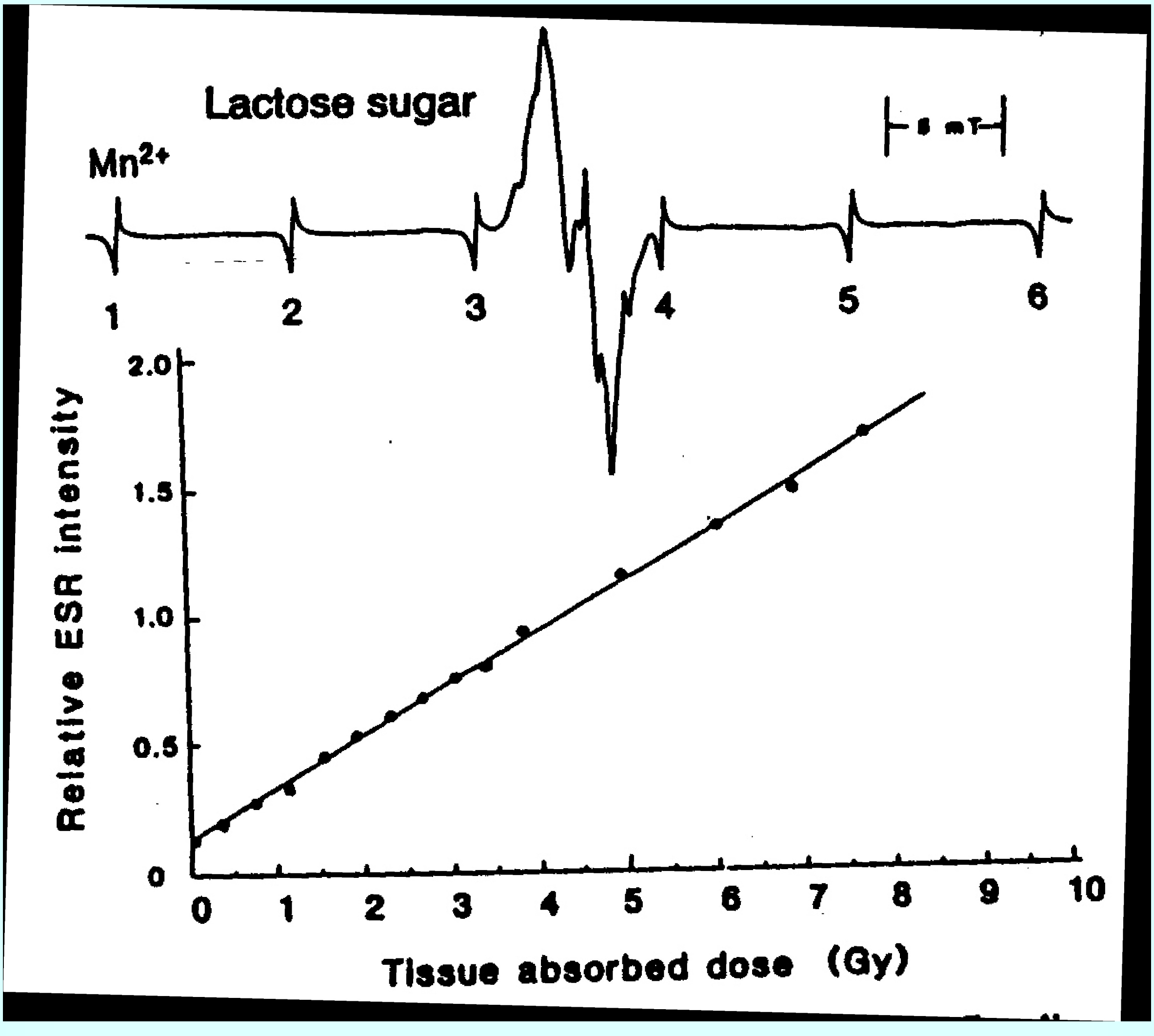
Radical dosimetry



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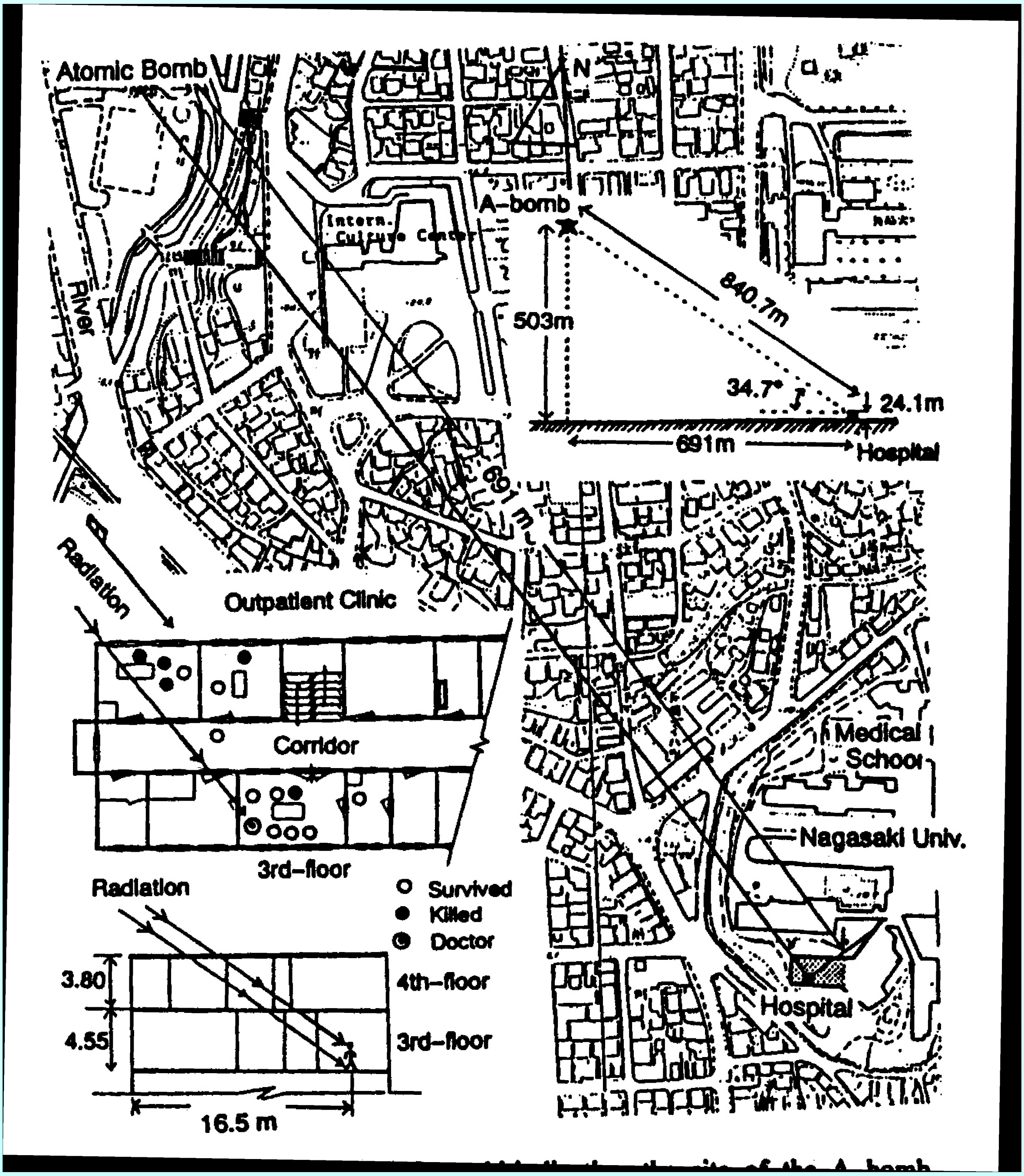
Dose profile, Hiroshima



Radical dosimetry

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

Sensitivity > 40 mGy

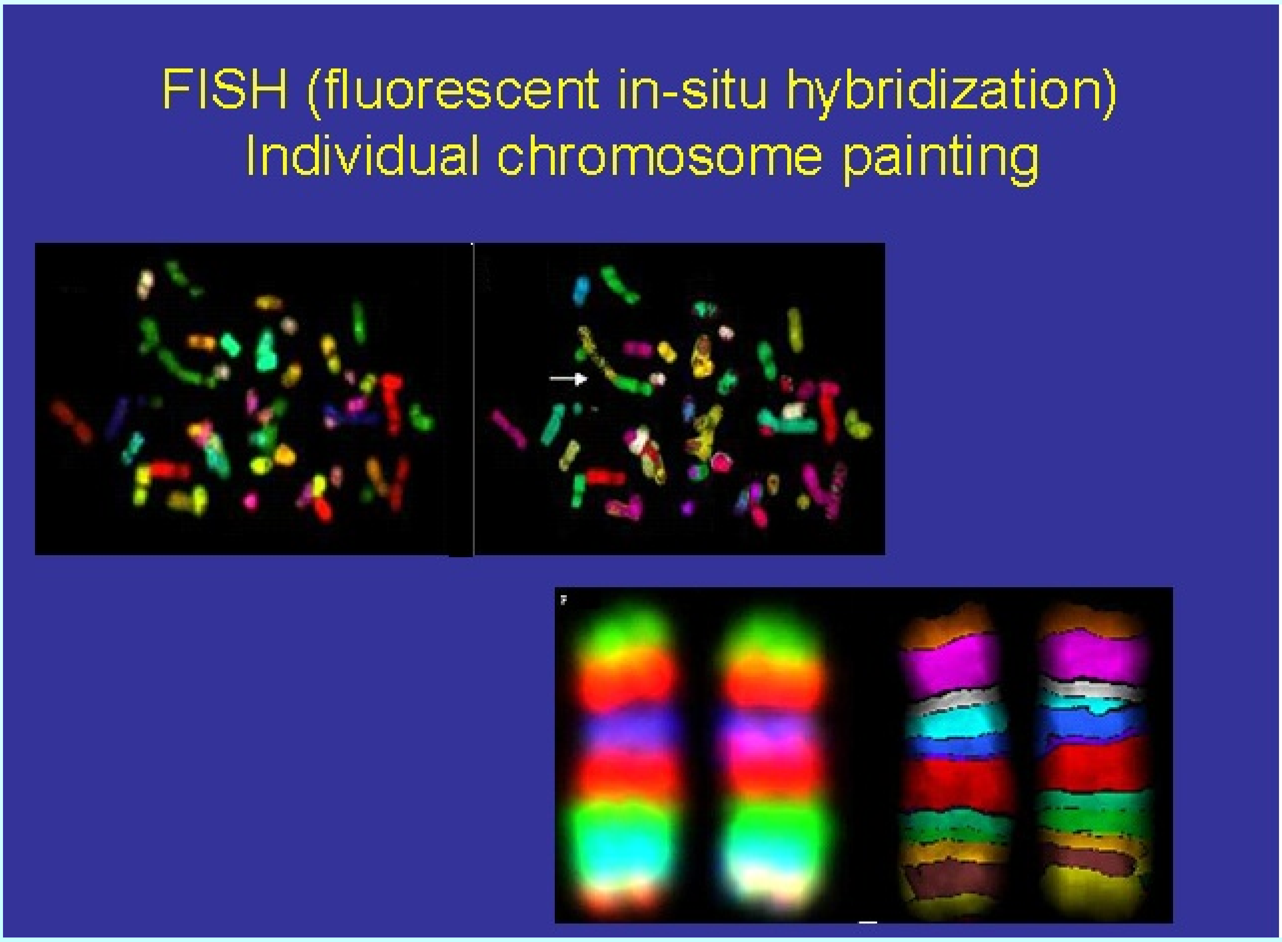
Historic dosimetry

Strong radiation exposure gives rise to chromosome abberations which may me detected. The number of such abberations represents a measurement of the radiation dose. (More details on this later)

A high number of abberations does not necessarily imply that the individual in question is ill or at higher risk than others.

FISH -fluorescent in-situ hybridization

FISH is a general method for selective colouring of DNA sequences with chromophores. One of the applications is the detection of radiation induced chromosome abberations. Limit ~250 mGy



Chemical dosimetry

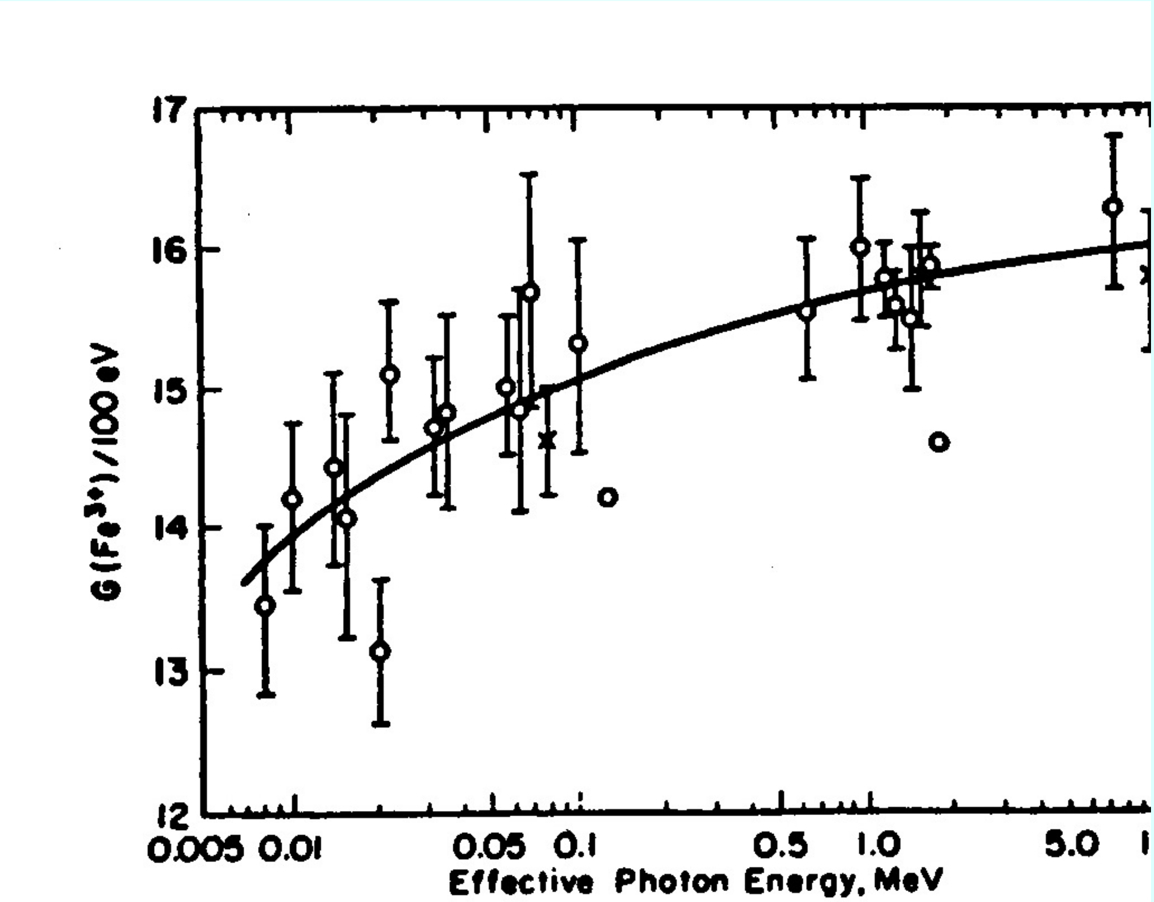
Fricke solution.
Sour $FeSO_4$ solution with air
0.001 M $FeSO_4$
0.4 M H_2SO_4

Principle: Oxidation of Fe^{2+} to Fe^{3+}

1. H_2O + rad. → H• + •OH
2. •OH + Fe^{2+} → Fe^{3+} + OH^-
3. •H + O_2 → •HO_2
4. H^+ + Fe^{2+} + •HO_2 → Fe^{3+} + H_2O_2
5. H_2O_2 + Fe^{2+} → $Fe(OH)^{2+}$ + •OH
6. •OH + Fe^{2+} → Fe^{3+} + OH-

Total in sour solution:
$4\,Fe^{2+} + 4\,H^+ + O_2 \rightarrow 4Fe^{3+} + 2H_2O$

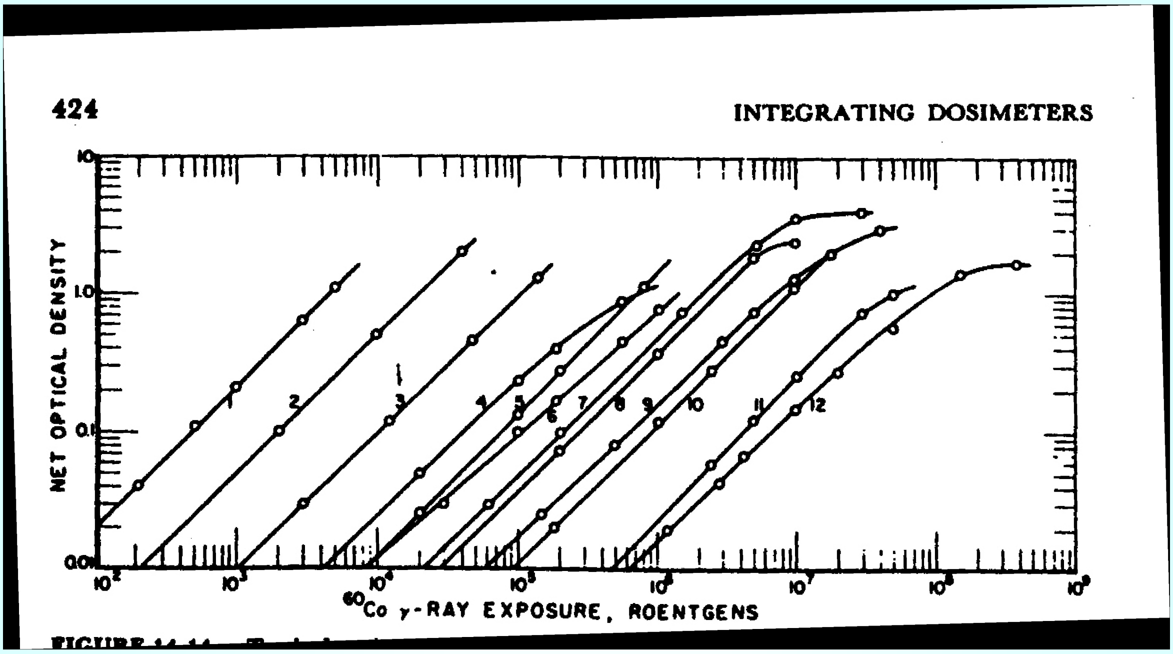
Good linearity



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 temeperature increase in a medium.

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

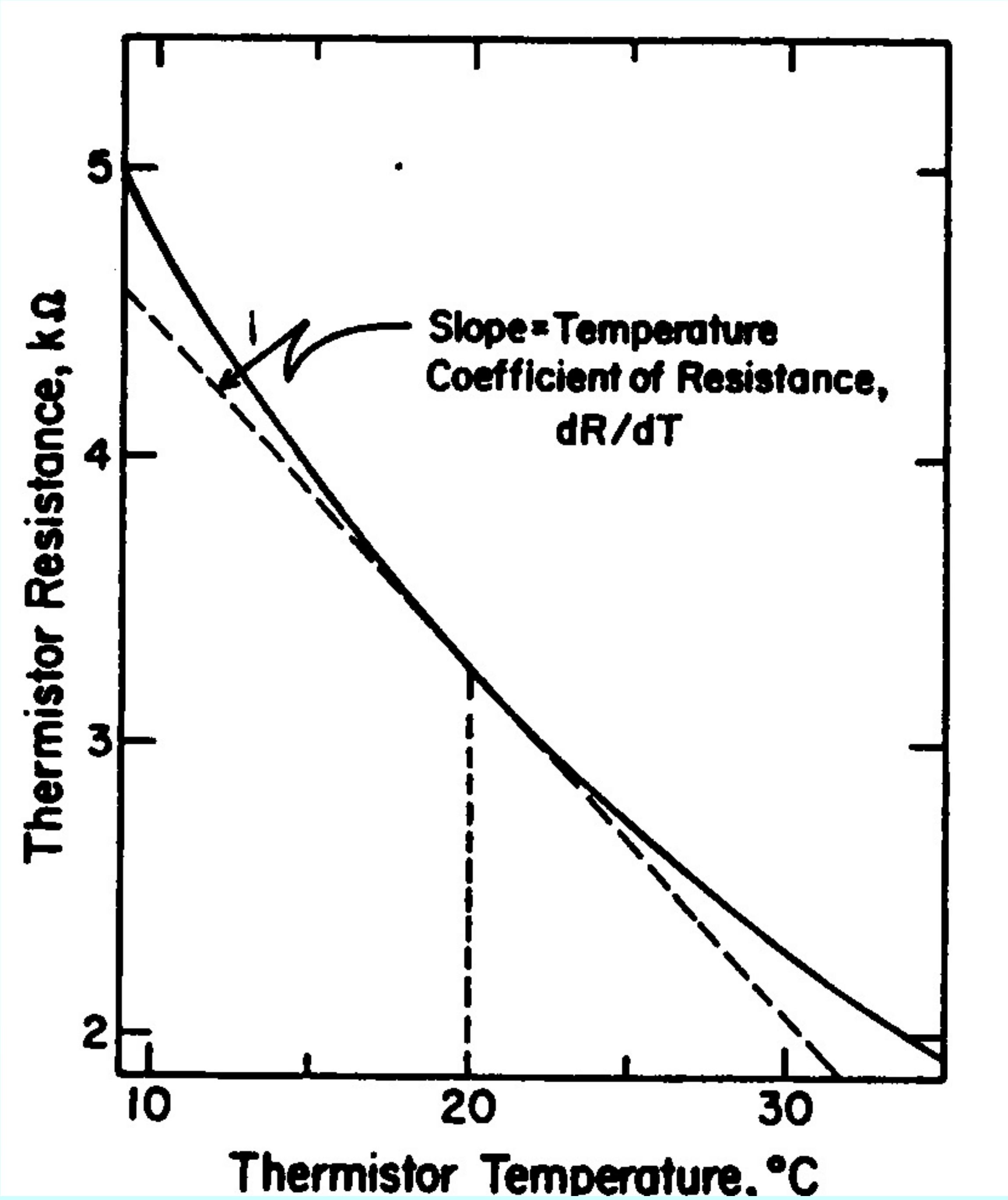
Important requirements:

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



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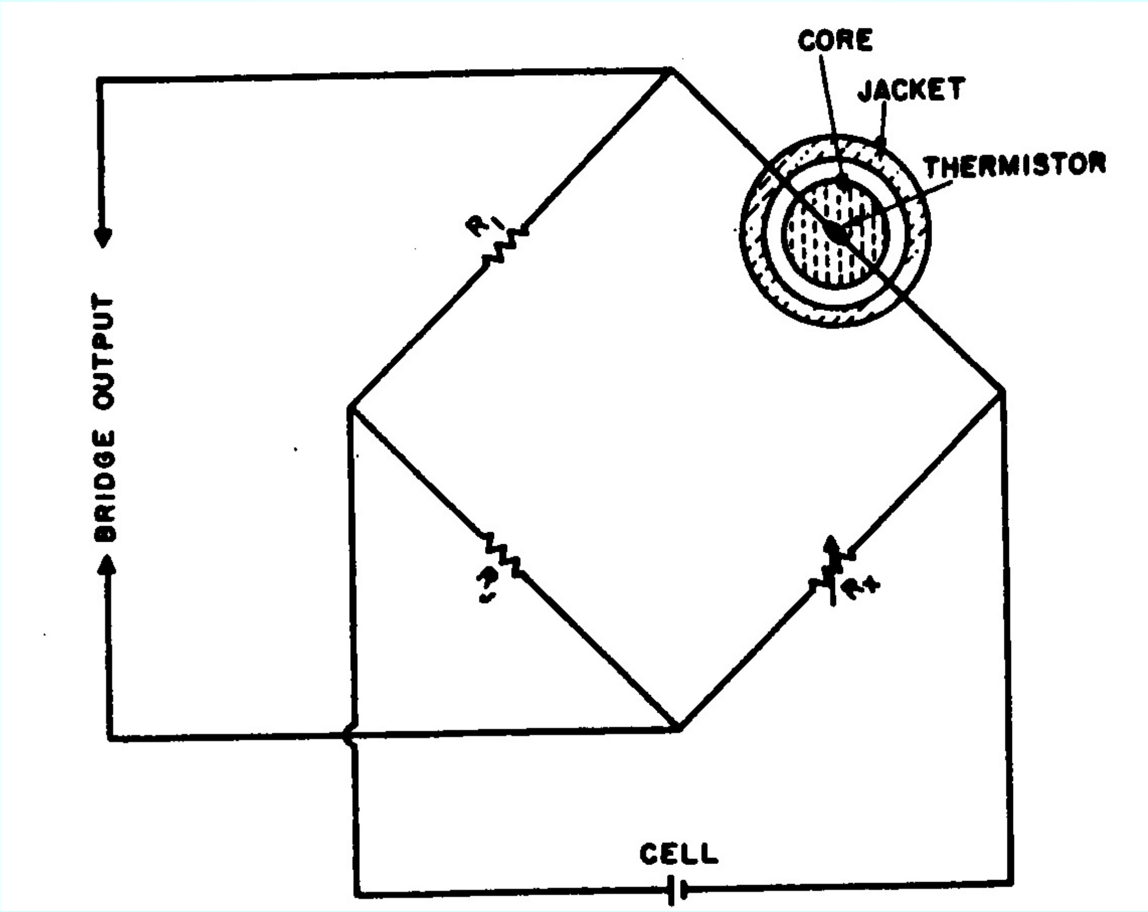
Wheatstone bridge for exact reading of resistance



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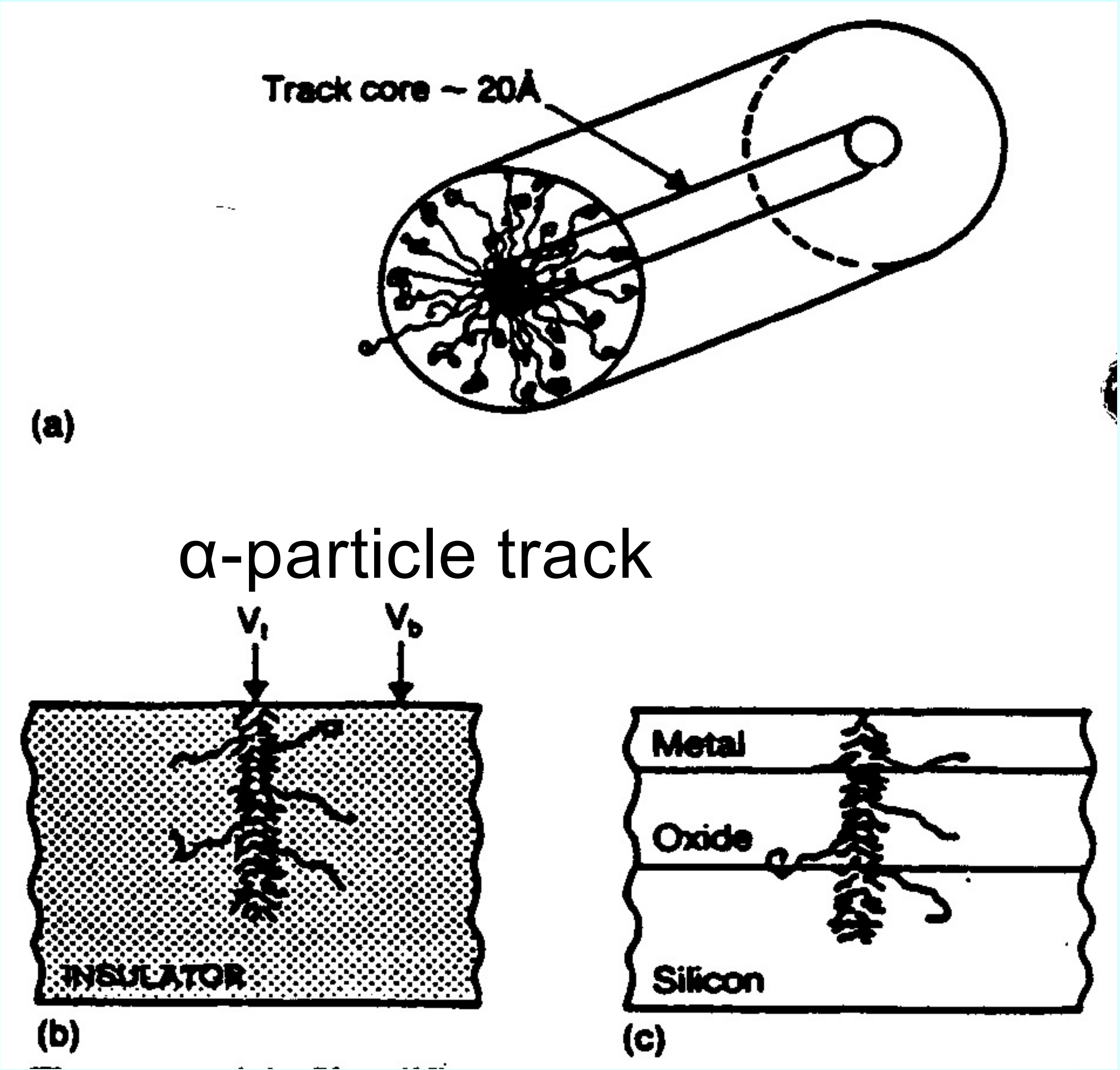
Track dosimetry

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 sifferent types of surfaces may be used, combined with different detection techniques.

Track dosimetry



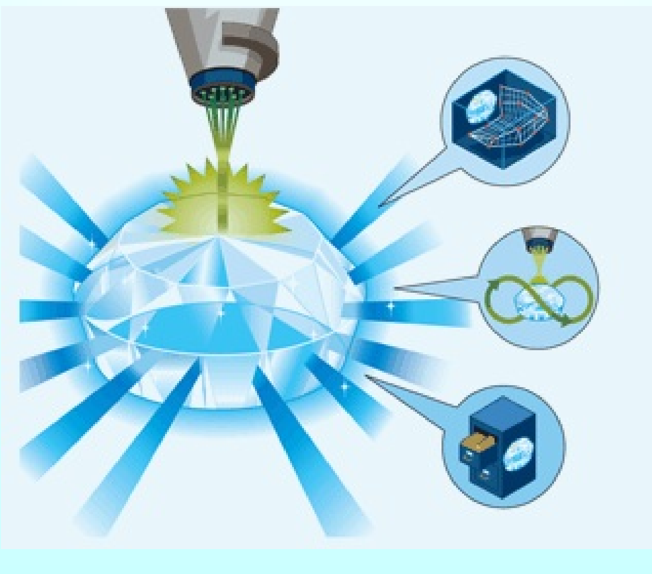
Followed by etching and reading with sparking or laser-detection.

Track techniques

Media sentitive 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}U)

Optically stimulated luminescence (OSL)

The key to the optically stimulated luminescence technology is the detector material, aluminum oxide crystals (Al_2O_3:C). Aluminum oxide can be grown in a variety of crystal configurations depending on its intended application.
In OSL, an irradiated crystal is exposed to green light from some source, leading to emission of blue light. The intensity av the blue light is proportional to the radiation dose received by the crystal.



Range: 10 µGy - 100 Gy

Gafchromic®

Gafchromic® is a system utilising radiation induced polymerisation to measure radiation dose. The basis of the system is a radiation sensitive non-coloured monomer. When this compound is exposed to ionising radiation, a polymerisation reaction starts, forming a coloured polymer. The amount of polymer is proportional to the radiation dose received.

The compound may be formed into different shapes and "films", containing different amounts of monomer. It is particularly useful for measurement of dose distributions and profiles.

Range (according to the company) 50 µGy - 400 Gy