Nuclear measurement techniques. Dosimetry, radiation protection.

- properties
- measurement
- dosimetry
- medical applications

of the nuclear radiation

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Detection methods for the ionizing radiation

scintillation based methods

gas-ionization detectors

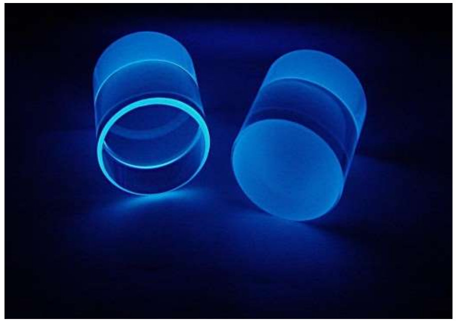
thermoluminescent dosimeter

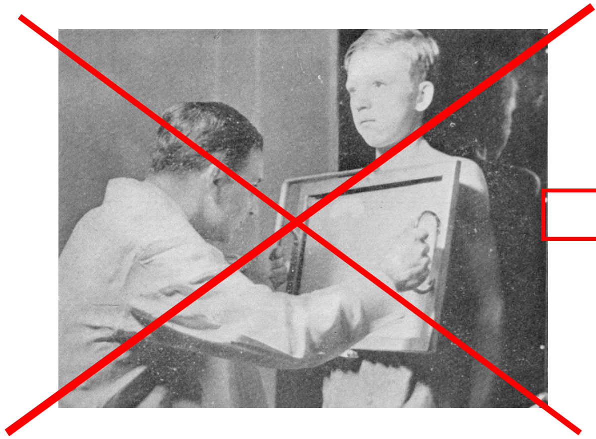
~~photographic methods (film)~~

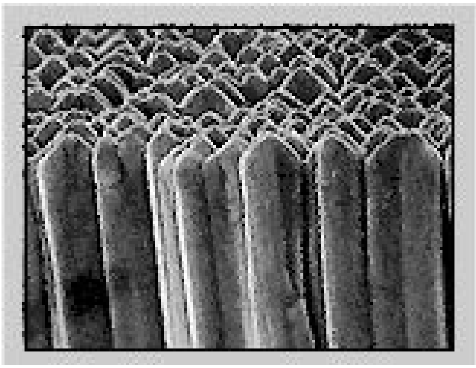
semiconductor detectors

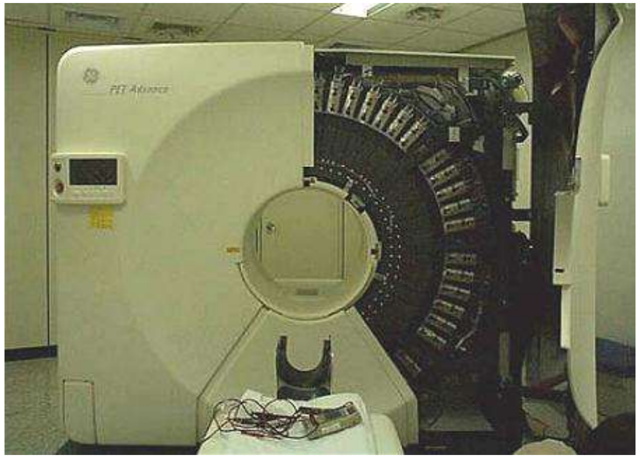
Scintillation counter

see practical exercises!

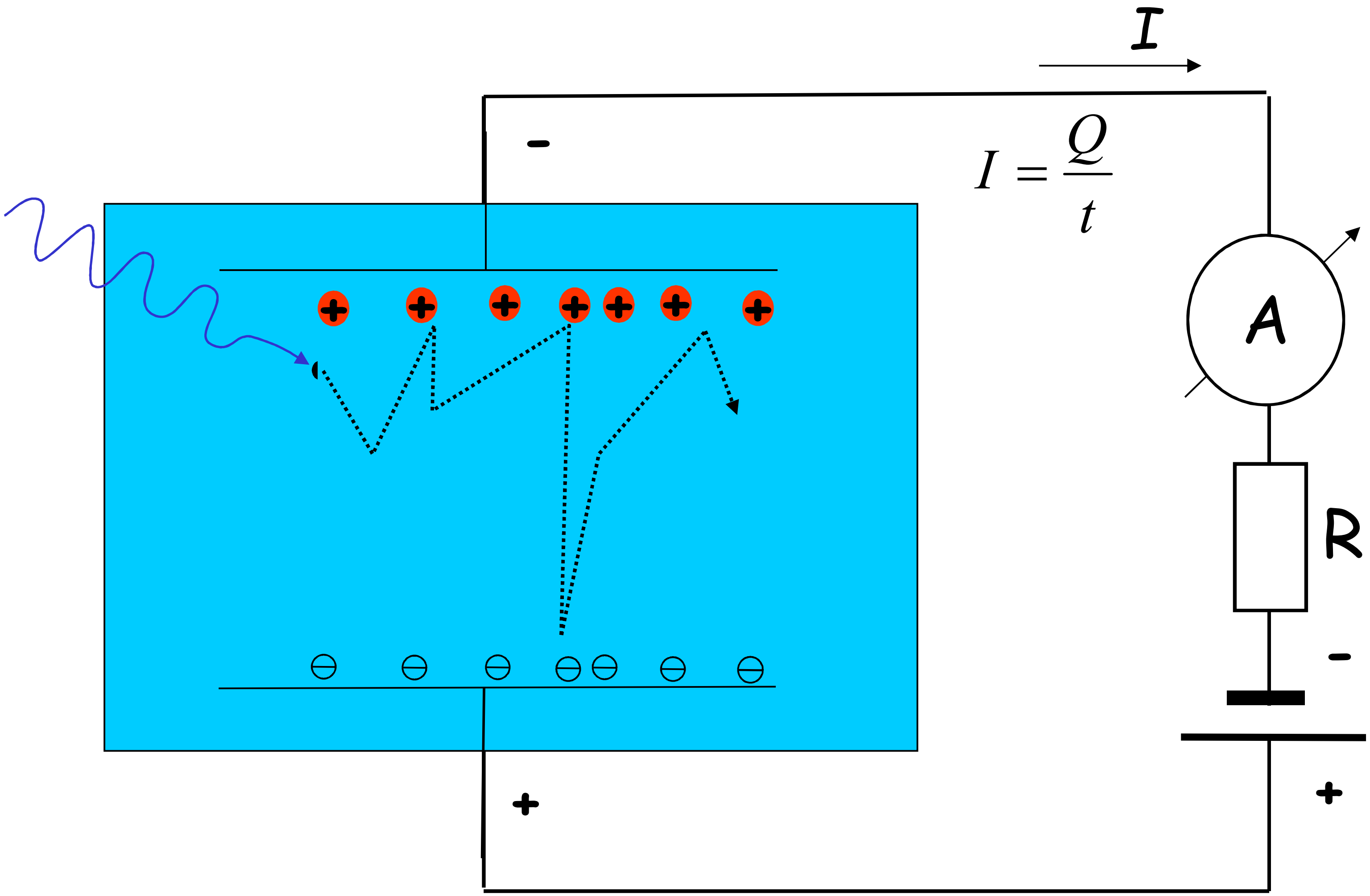




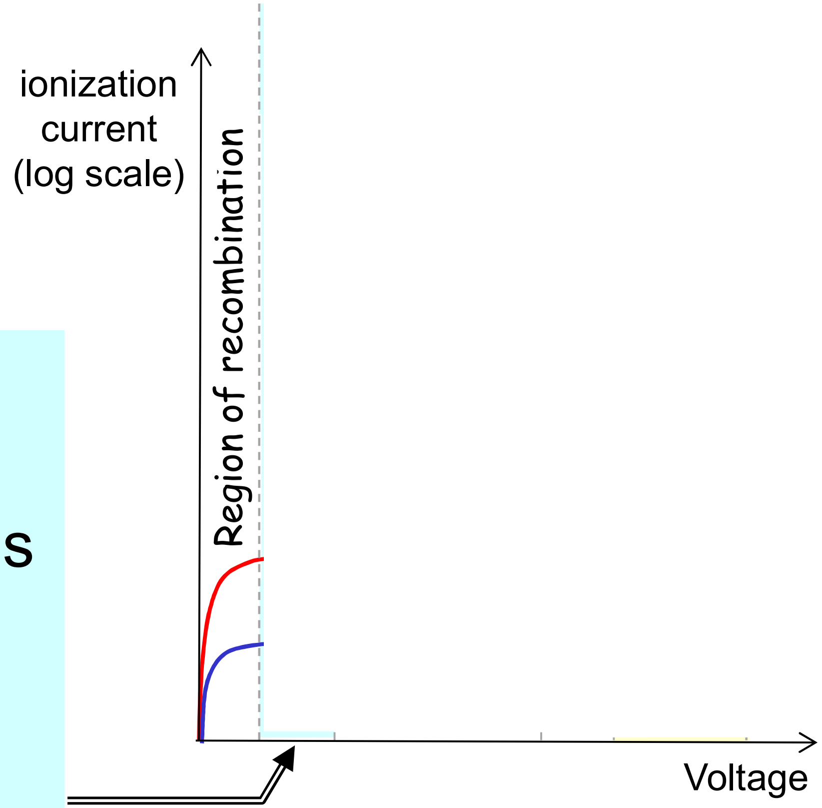




Gas-ionization detectors

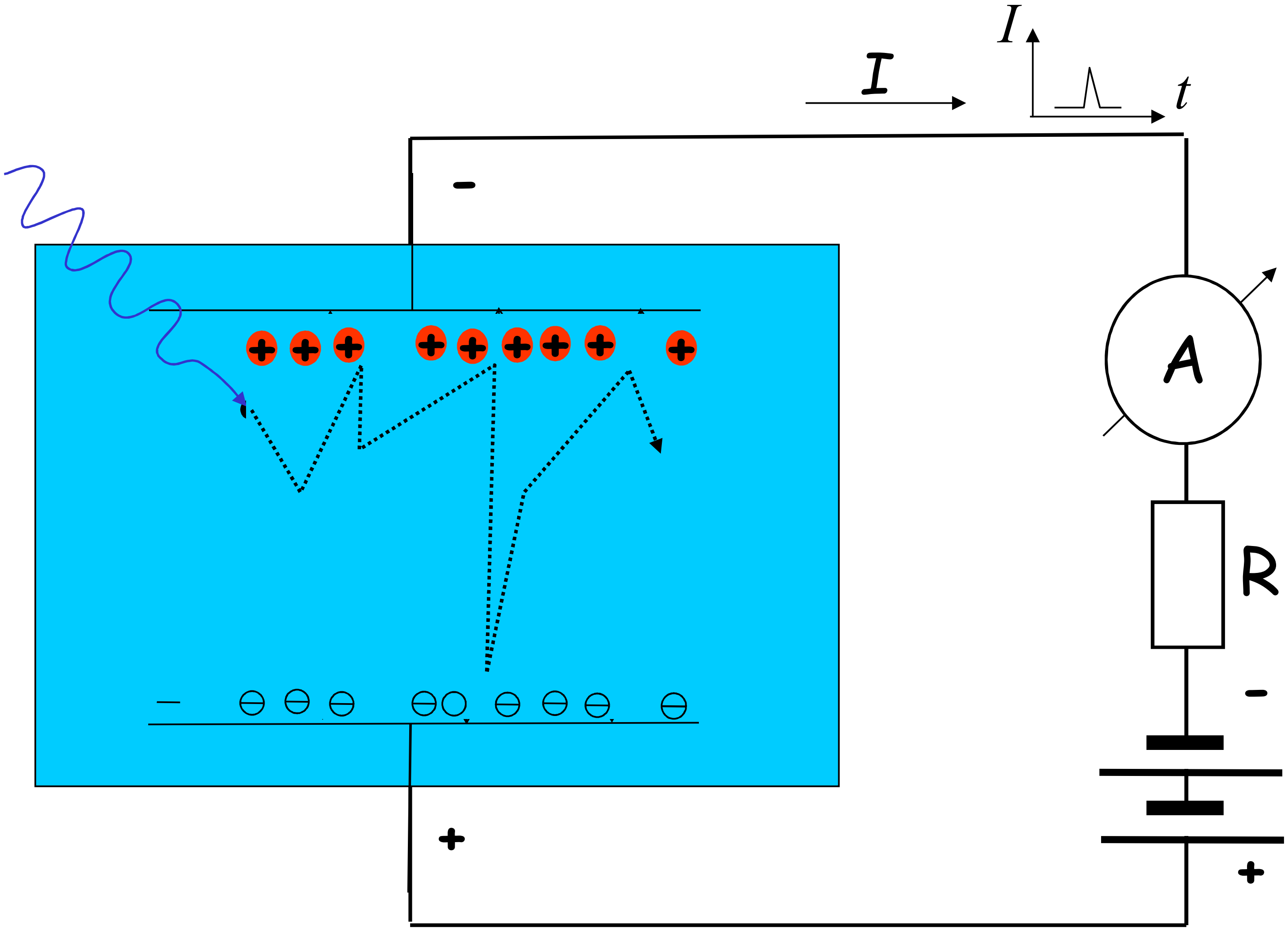


Gas-ionization detectors

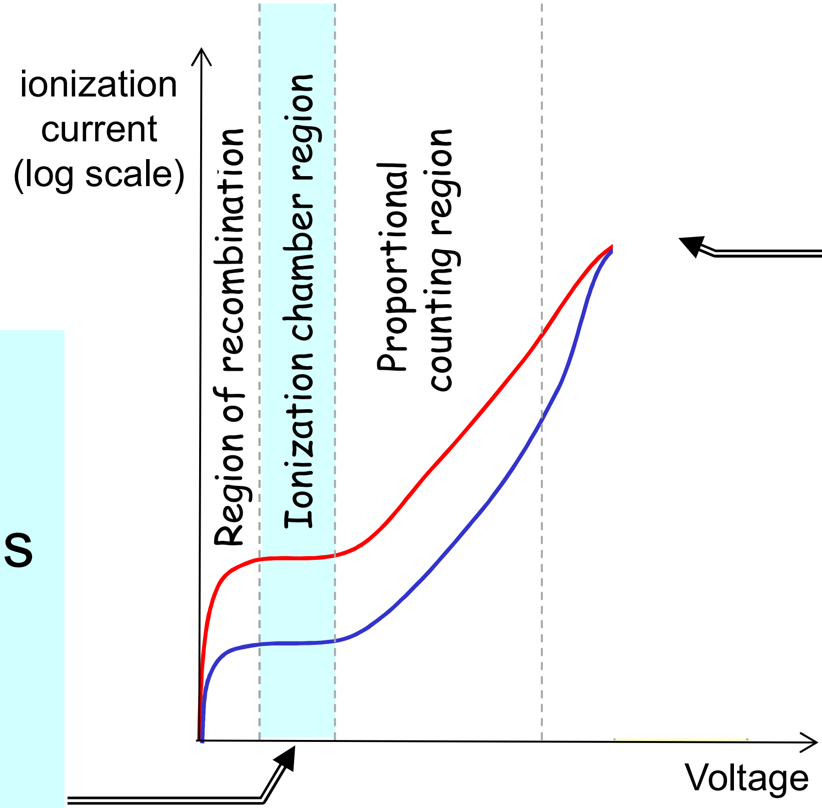


Ionization chamber:
collects all the ions
Measures the
ionizing effect
of the radiation
see: dosimetry

Gas-ionization detectors



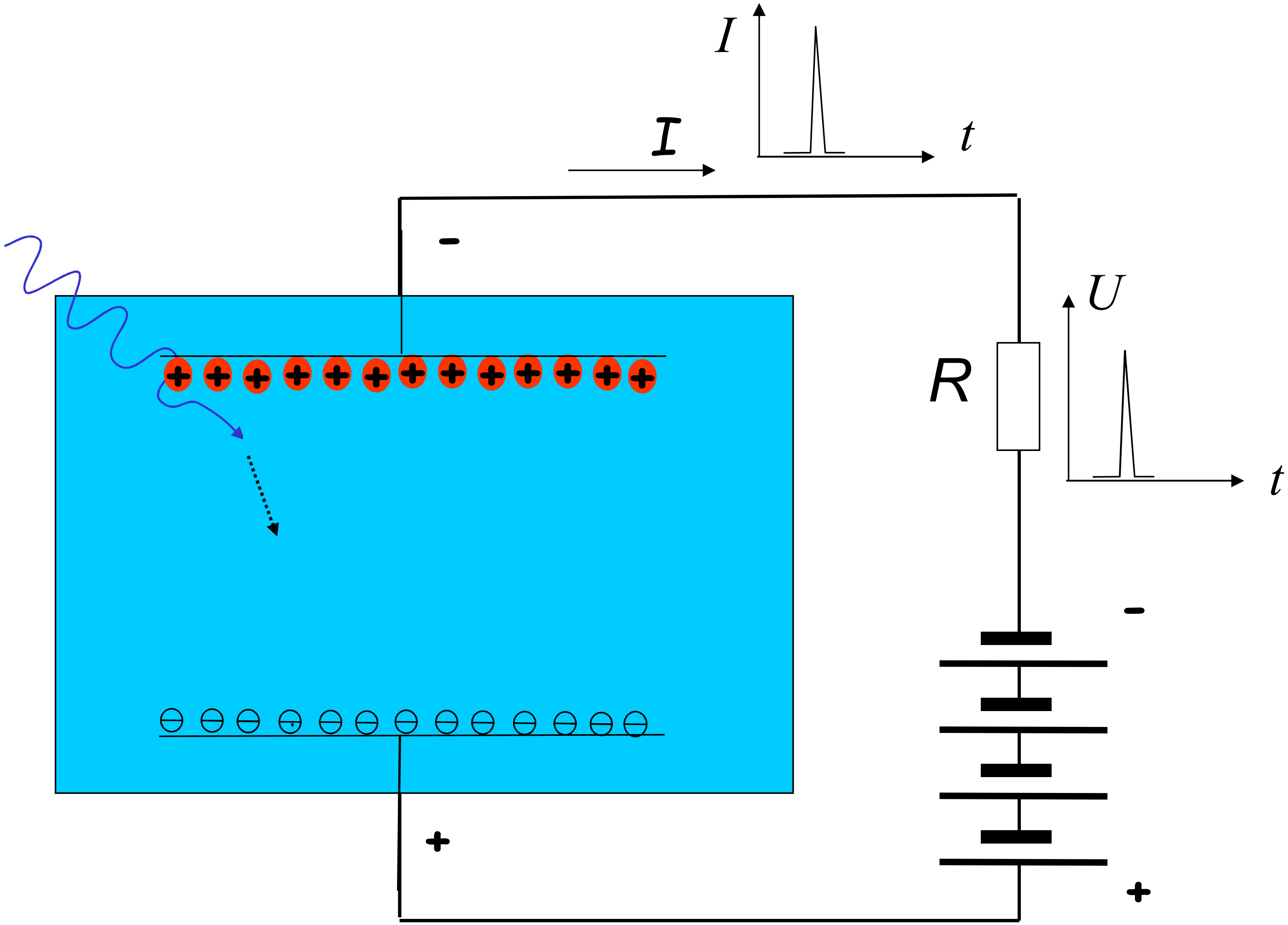
Gas-ionization detectors



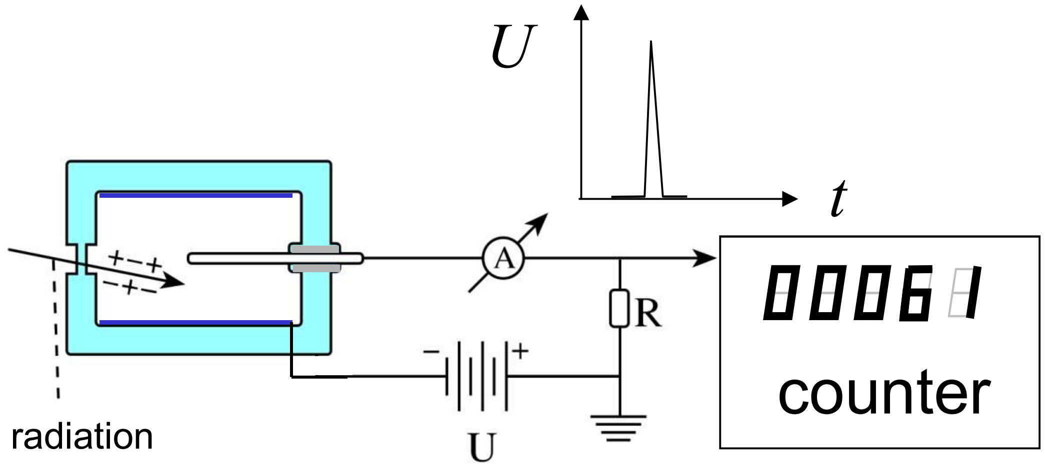
Ionization chamber:
collects all the ions
Measures the ionizing effect of the radiation
see: dosimetry

Geiger-Müller range:
avalanche-effect:
particle
⇓
voltage pulse

Geiger-Müller tube



Geiger-Müller counter



advantage: simple construction,

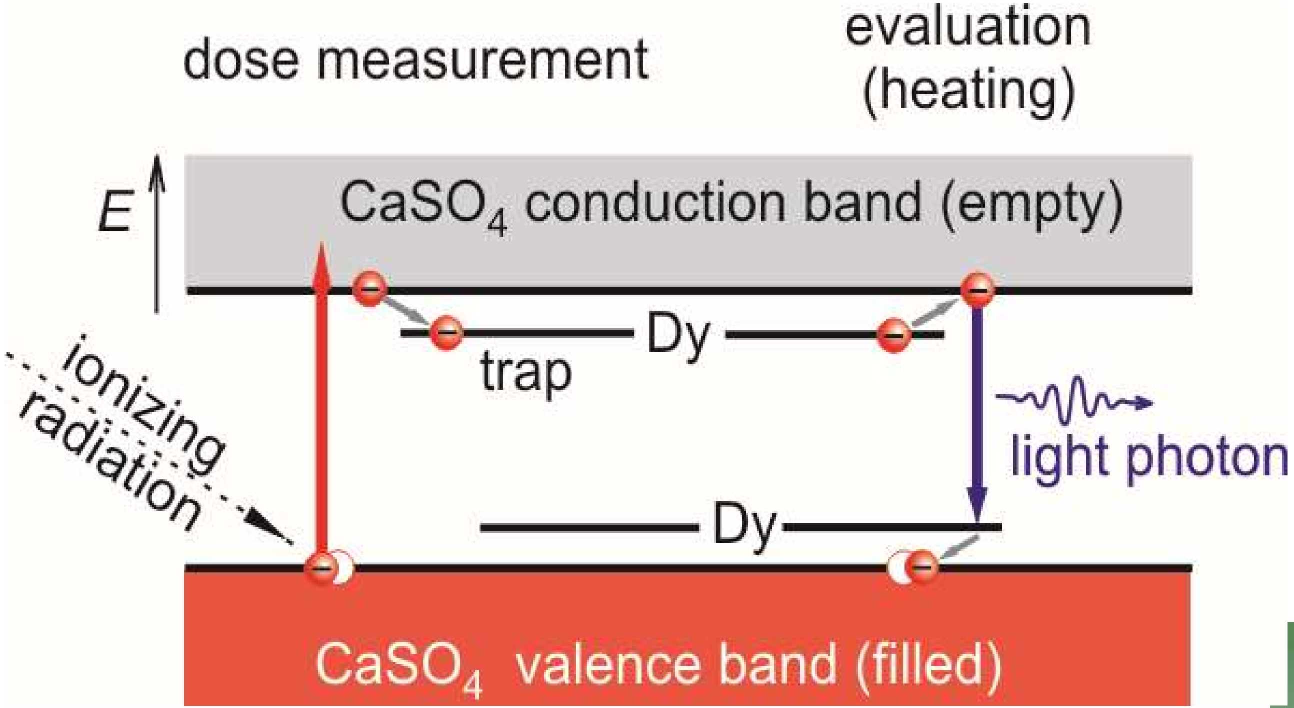
disadvantage: no energy selectivity,
low efficiency for γ-ray

usage: mainly in dosimetry


counts per second
series 900 mini-monitor
MINI


2.302
Inspector

Thermoluminescent dosimeter (TLD)

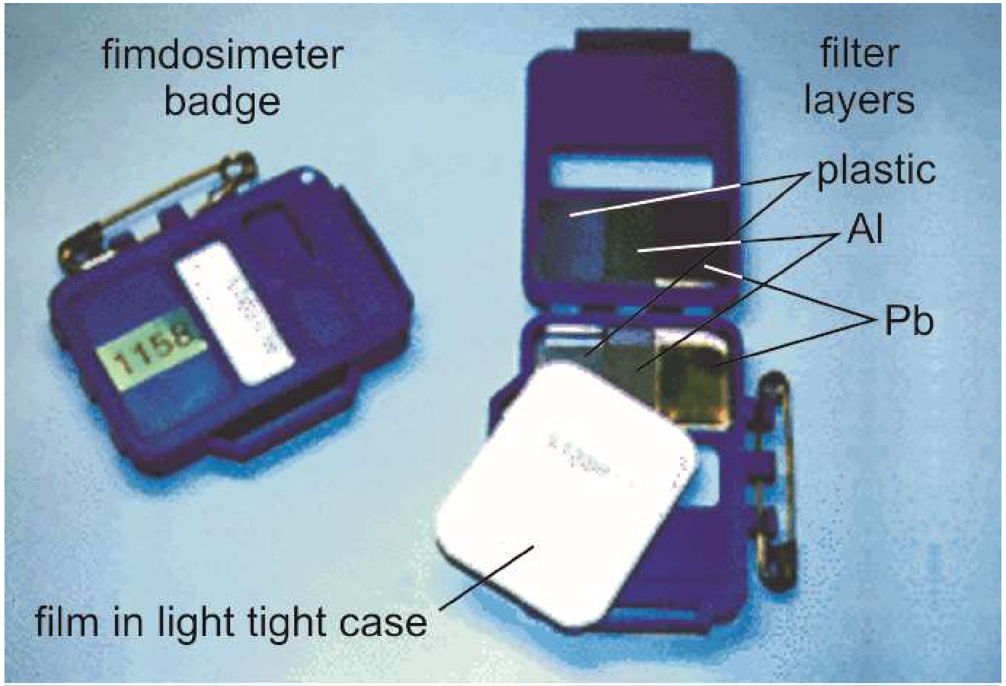


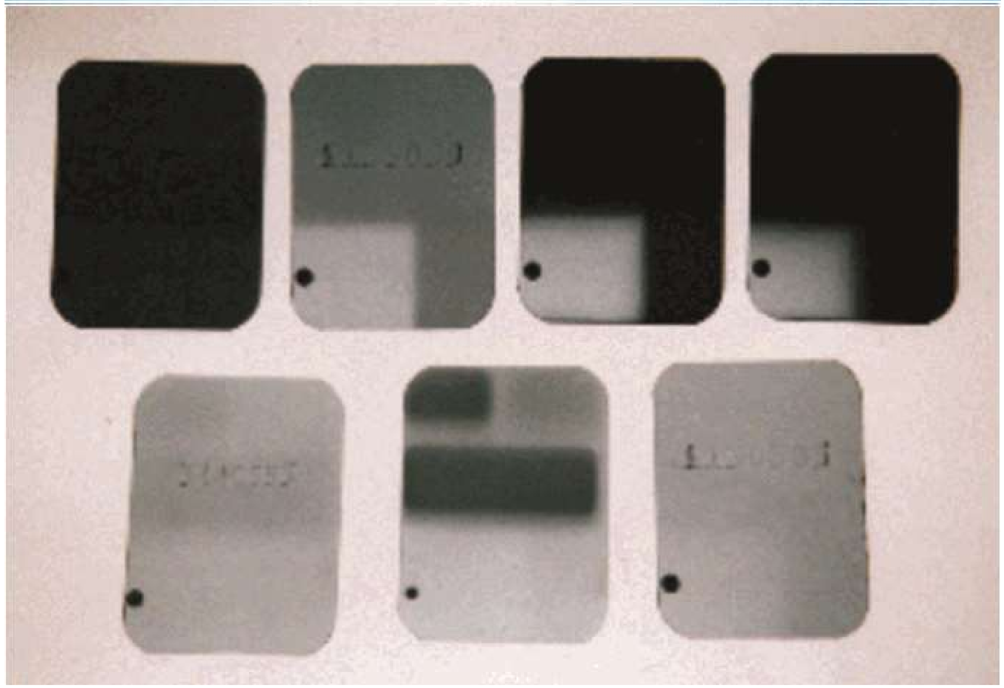
An american astronaut uses the TLD dosimeter „Pille" produced by KFKI Budapest (Photo: NASA ISS002E7814)

Personal dosimeters

Photochemical detection

obsolete



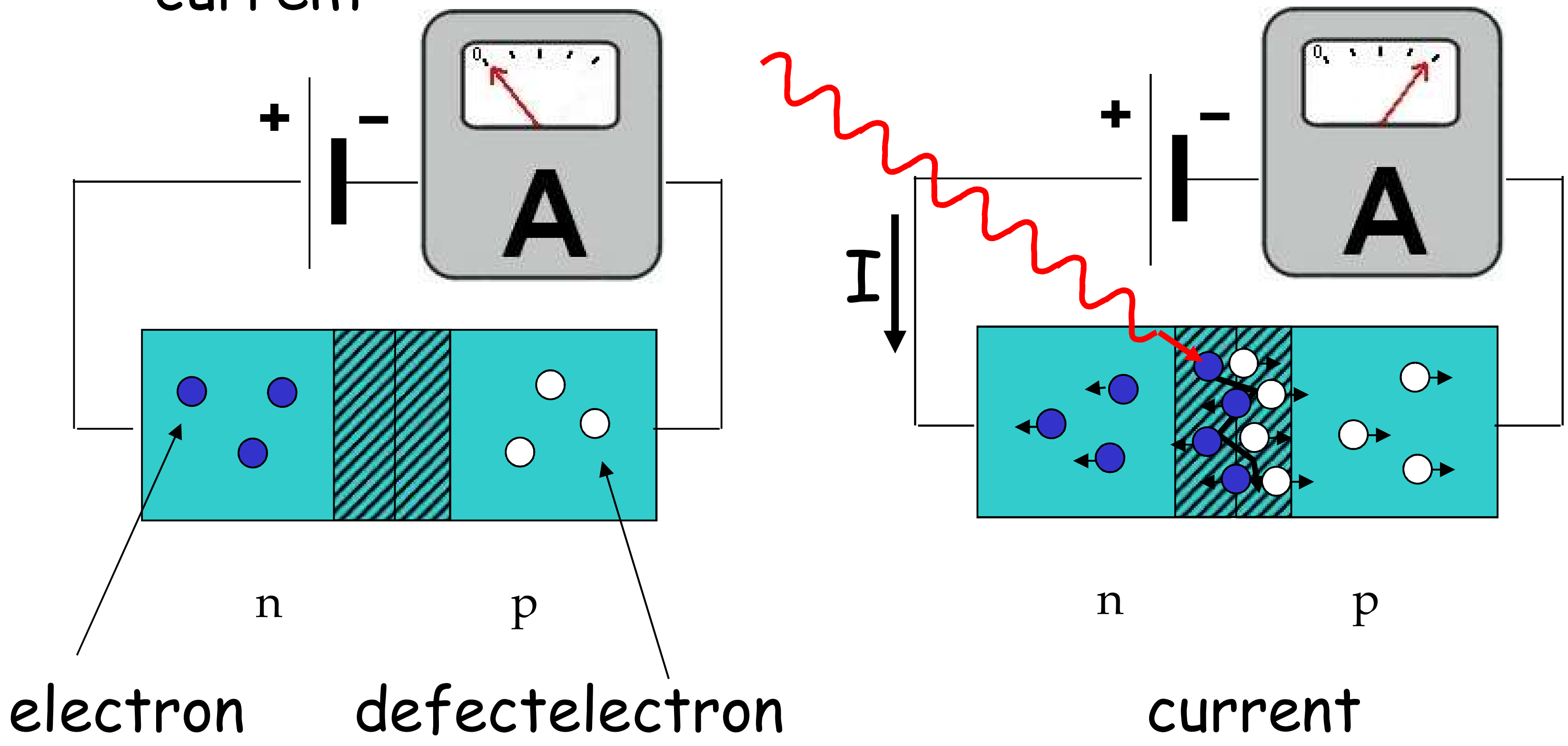


Semiconductor detector

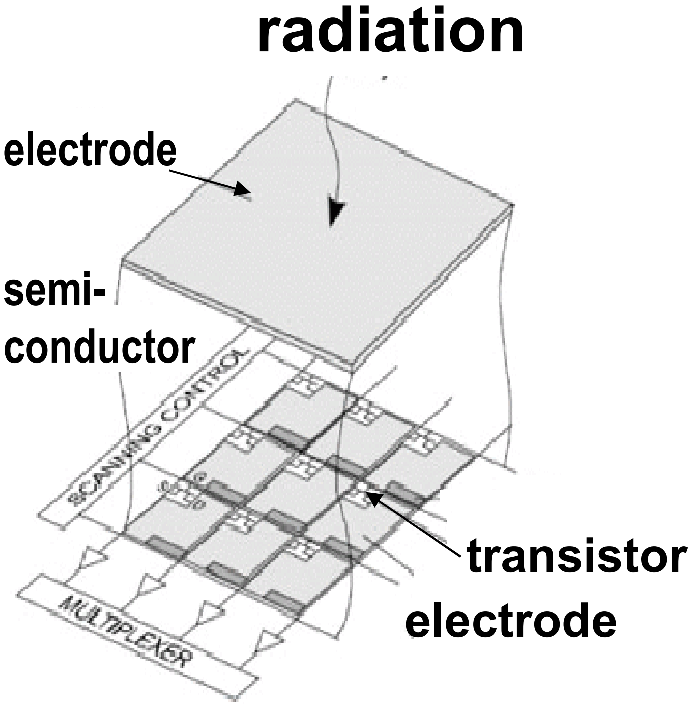
Principle:

Semiconductor diode connected reverse biased

The radiation induces free charges and consequently current

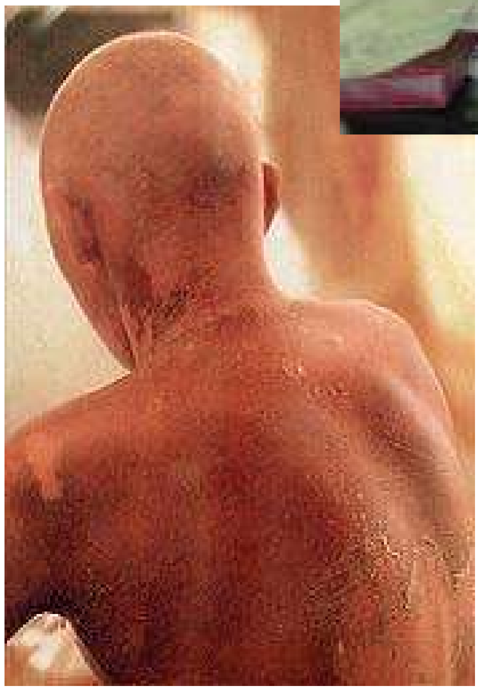


Semiconductor detectors in the diagnostics

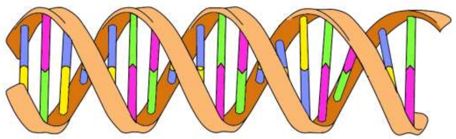


Semiconductor based dosimeters

Biological effect of the ionizing radiation

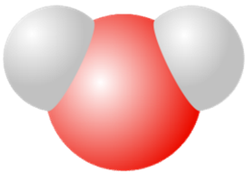


The mechanism of the radiation damage



direct

indirect



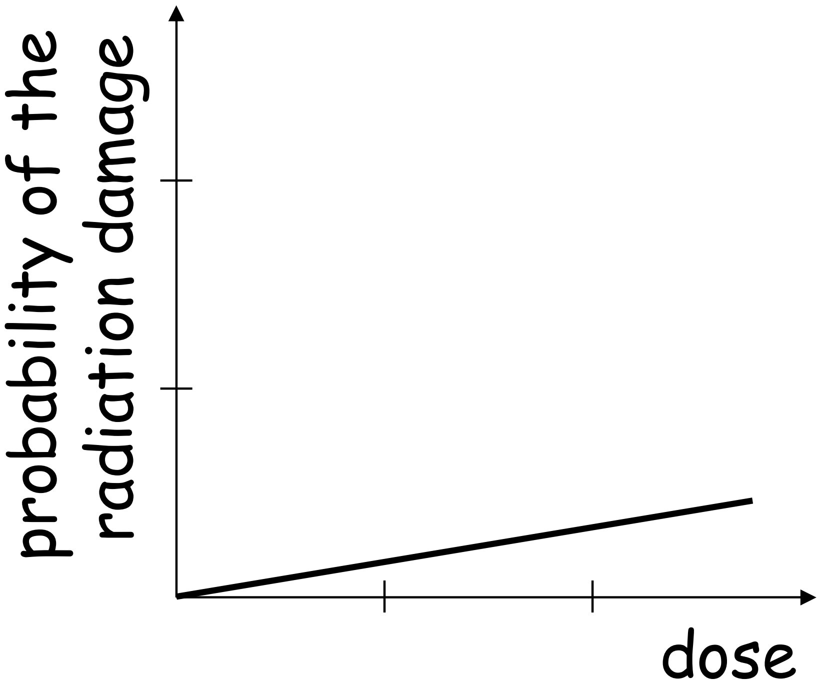
Physical phase:
10^{-17} -10^{-12} s ionisation

Chemical (biochemical) phase:
10^{-10} -1s: free radical reactions

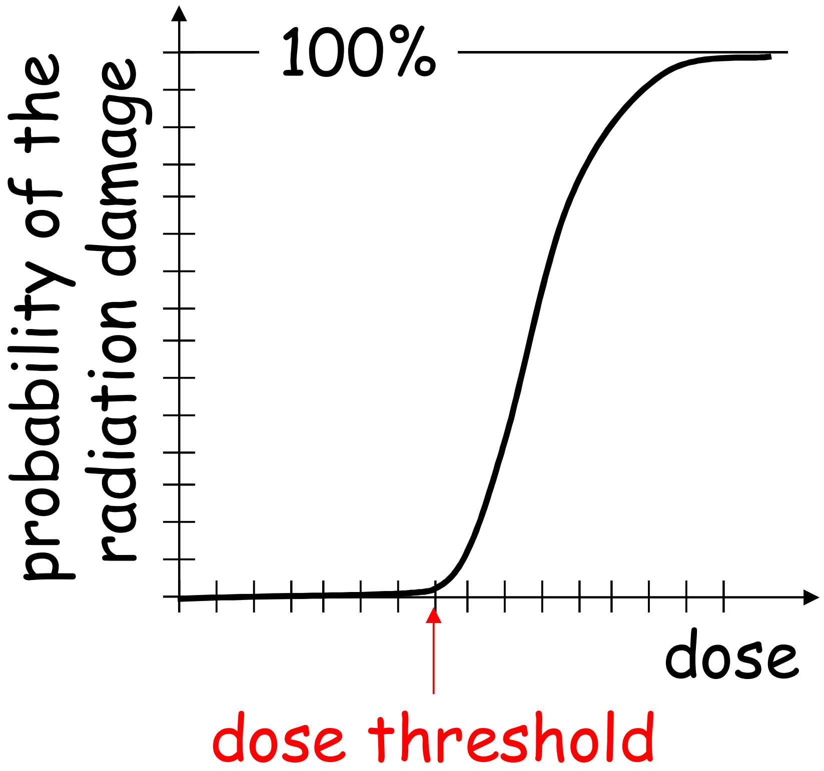
Biological phase:
hours: alteration in the tissues
days-years: stomach-bowel
damage of the haematogenesis
somatic damage

Mechanism of radiation damage

Stochastic



Deterministic



Stochastic	Deterministic
already at low dose level small number of targets **no** dose threshold severity is **in**dependent of the dose	High dose (>threshold) many targets should be hit only above the threshold severity increases with the increasing dose
⇩	⇩
personnel at workplaces using ionisation radiation, patients of X-ray and nuclear imaging investigations	accidents Radiotherapy

Dose concepts

Absorbed dose:

$$D = \frac{\Delta E}{\Delta m}$$

The energy absorbed from the radiation by the mass Δm

unit J/kg = Gy

→ absorbed energy by unit mass of absorbing medium

Luis Harold Gray

can be used for all types of radiations

Absorbed dose :

$$D = \frac{\Delta E}{\Delta m} \qquad [Gy]$$

How to measure:

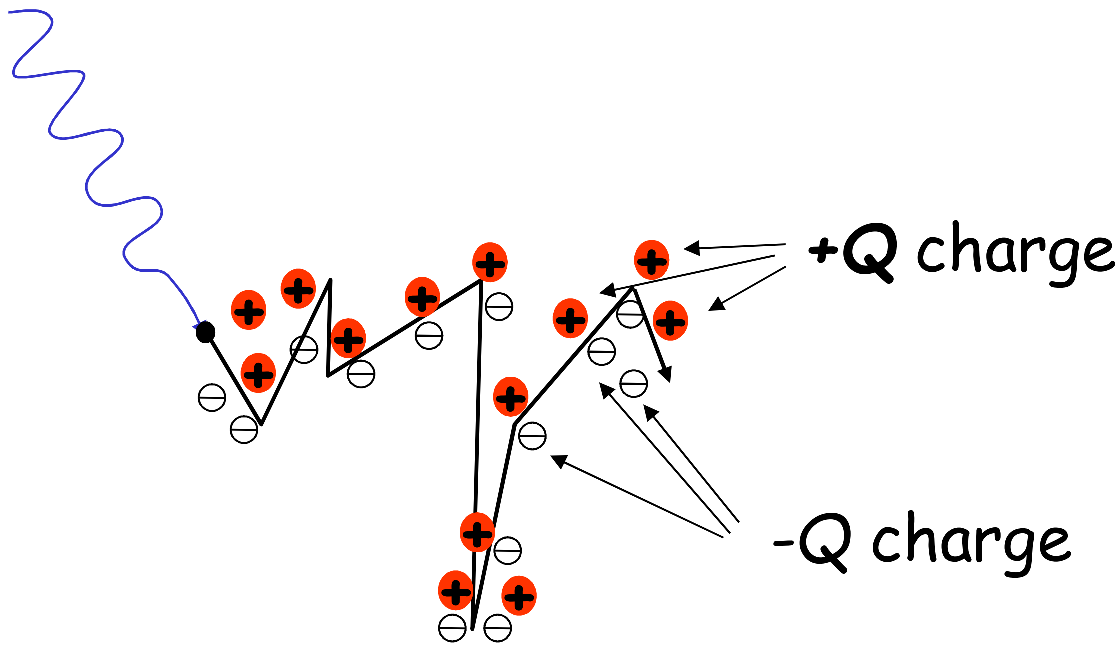
- hard to measure directly (unmeasurably small temperature change ΔT = 0,006°C/4 Gy)
- indirect detection methods:
  - ionisation chamber
  - semiconductor detector
  - thermoluminescent detector
  - ...

Exposure:

$$X = \frac{\Delta Q}{\Delta m}$$

the positive charge produced in the air of mass Δm

unit: C/kg

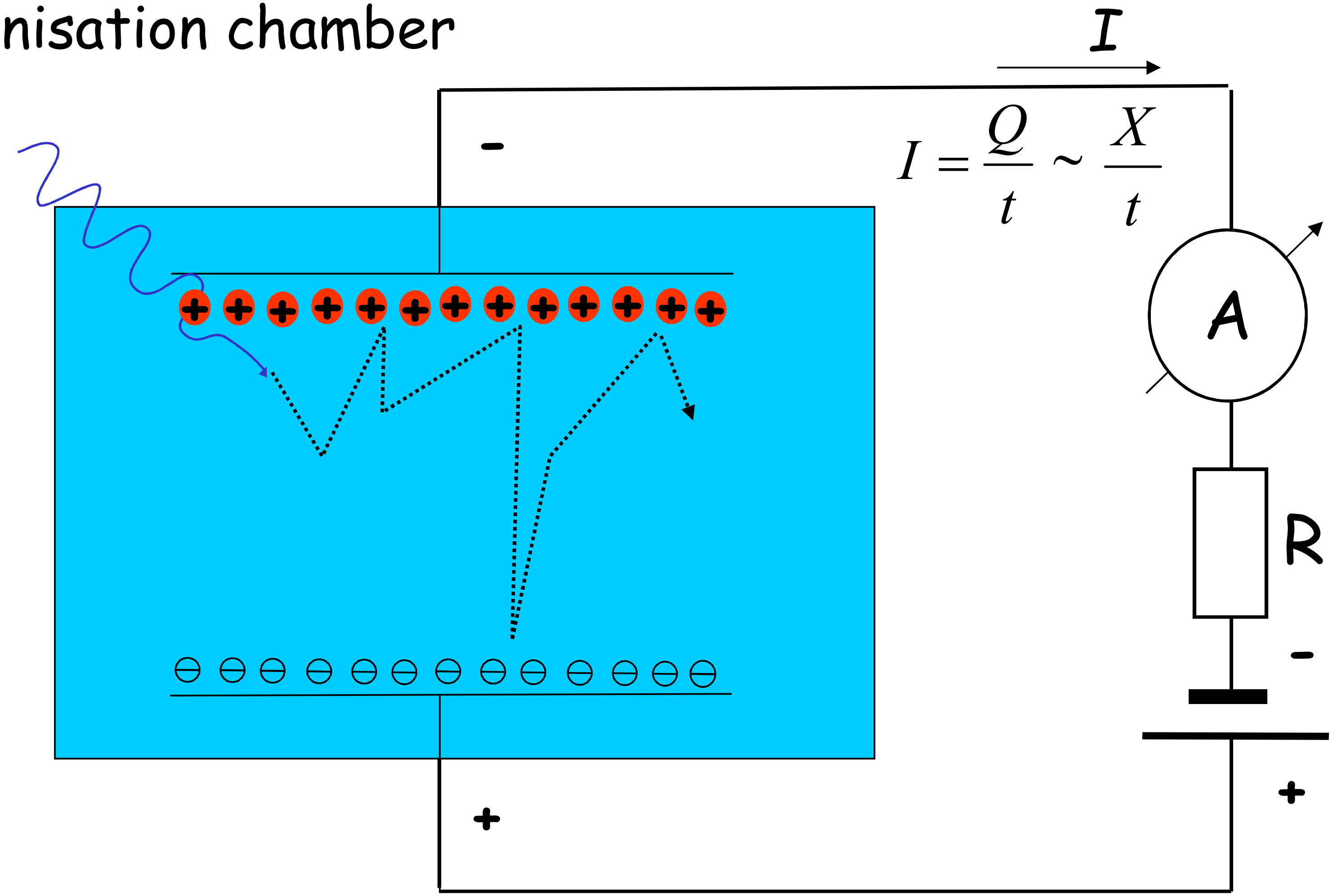


Olny for $\gamma-$ and x-ray in air!

How to measure the exposure:

$$X = \frac{\Delta Q}{\Delta m}$$

Ionisation chamber

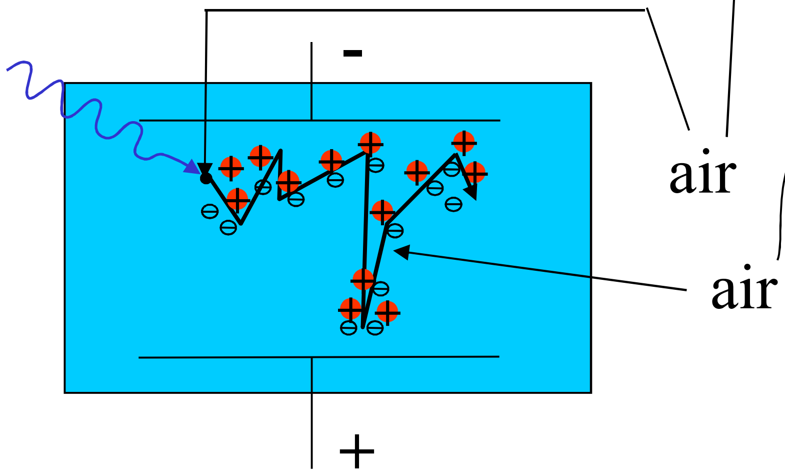


$$I = \frac{Q}{t} \sim \frac{X}{t}$$

Exposure:

$$X = \frac{\Delta Q}{\Delta m}$$

The location of the detection and of the ionization



Characterises the dose in air

How to convert it to absorbed dose?
Exposure was measured in air
  how to convert it to the dose in the tissue?

Exposure:

$$X = \frac{\Delta Q}{\Delta m}$$

Conversion to absorbed dose:

To produce 1 pair of ions one needs 34 eV energy in air*

$34\ \text{eV} = 34 \cdot 1.6 \cdot 10^{-19}\ \text{J} \longrightarrow 1.6 \cdot 10^{-19}\ C$

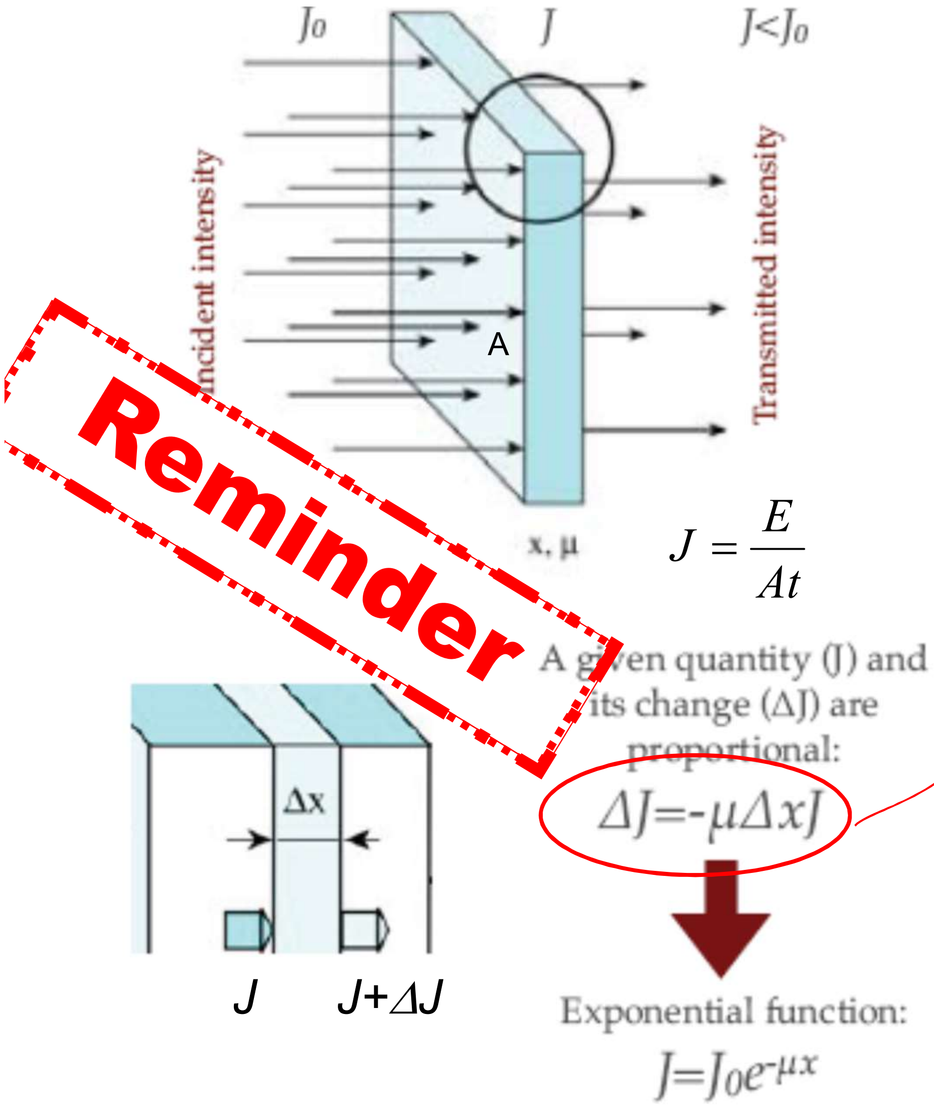
$34\ \text{J} \longrightarrow 1\ C$

$$1\frac{\text{C}}{\text{kg}} \Rightarrow 34\frac{\text{J}}{\text{kg}} = 34\,\text{Gy}_{\text{air}}$$

f_0

* In case of electrons. For protons and α particles $\approx$35 eV

Conversion of absorbed dose measured in air to absorbed dose expected in tissue



$$\Delta J = -\mu \Delta x J$$

$$J = \frac{E}{At}$$

$$\Delta E = |\Delta J| At$$

$$D = \frac{\Delta E}{\Delta m} = \frac{|\Delta J| At}{\rho A \Delta x} =$$

$$= \frac{\mu \Delta x J t}{\rho \Delta x} = \mu_m J t$$

μ_m

$$\boxed{D \sim \mu_m}$$

Conversion of absorbed dose measured in air to absorbed dose expected in tissue

$$\frac{D_{tissue}}{D_{air}} = \frac{\mu_{m,tissue}}{\mu_{m,air}} \Rightarrow D_{tissue} = \frac{\mu_{m,tissue}}{\mu_{m,air}} D_{air}$$

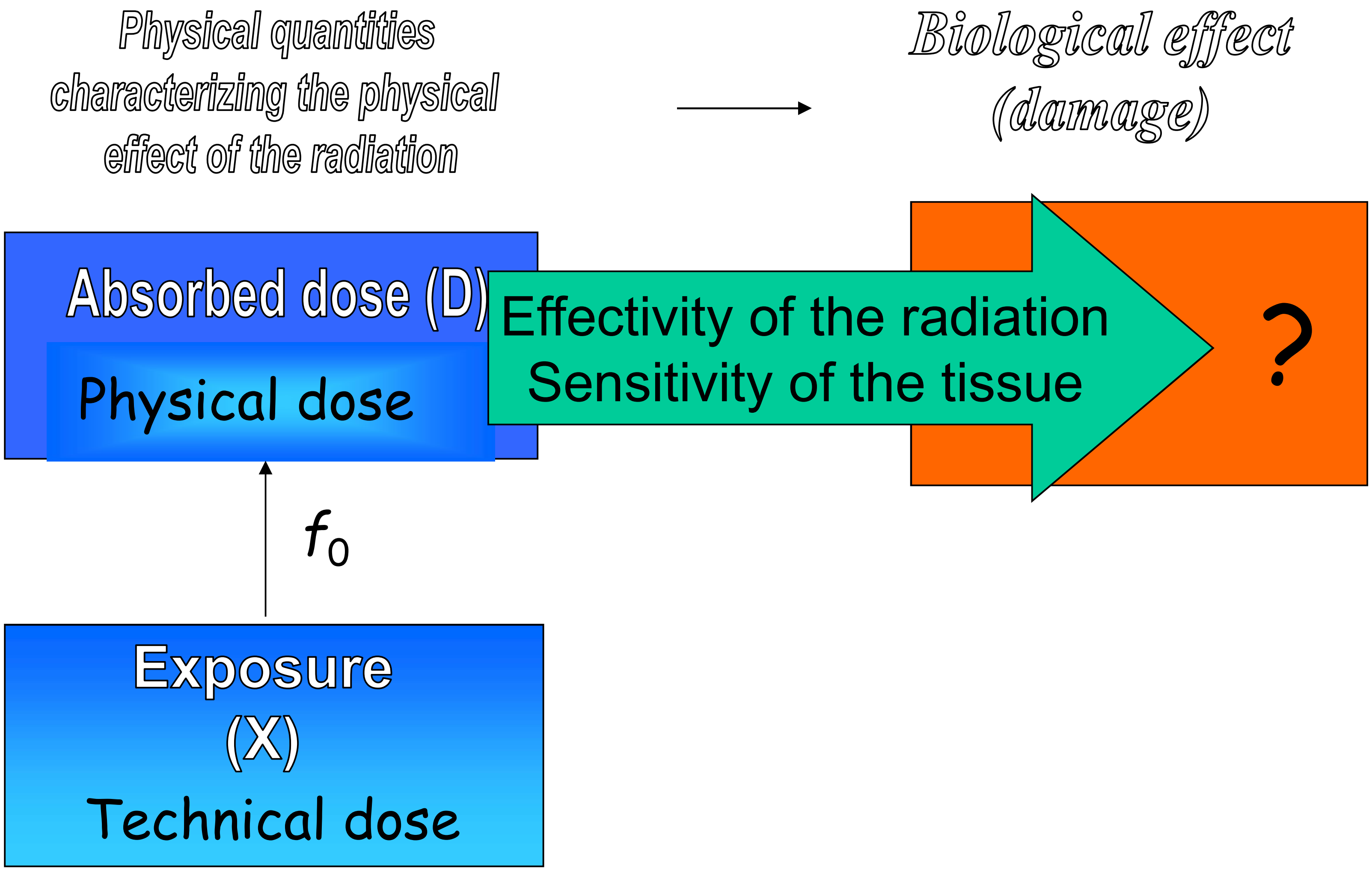
$$\Downarrow$$

$$D_{tissue} = \frac{\mu_{m,tissue}}{\mu_{m,air}} f_0 X$$

$$f_0 = 34 \frac{J}{C}$$

If E_{photon}<0,6 MeV, for soft tissue: $\dfrac{\mu_{m,tissue}}{\mu_{m,air}} \approx 1.1$

Dose concepts so far:



In case of…

→ Deterministic effect (e.g. radiotherapy)

typically

- single type of radiation is used
- single type of tissue is irradiated

Absorbed dose → proportional → Biological effect

→ Stochastic effect (e. g. in diagnostics, radiation protection)

typically

- several types of radiations are absorbed
- several different tissues are irradiated

Absorbed dose → weighted summation → Biological effect

+


+


= ?

Equivalent dose

Absorbed dose → weighted summation → Biological effect

Weighting factors for: $\boxed{\text{effectivity of the radiation}}$

tissue sensitivity

$$\text{Equivalent dose:} \qquad H_T = \sum_R w_R D_{T,R} \qquad [\mathrm{Sv}]$$

Weighted sum of the absorbed doses from the different radiations (R) in a *given* tissue (T).

w_R: radiation weighting factor

E.g.:

$$H_{\text{skin}} = w_\alpha D_{\text{skin},\alpha} + w_\beta D_{\text{skin},\beta} + w_\gamma D_{\text{skin},\gamma}$$

The w_R radiation weighting factors

How many times greater is the effectivity (considering stochastic effects) of the given radiation compared to the x-ray or γ-radiation.

Radiation and energy range		Radiation weighting factor	
Photons, at every energy		1	by definition
Electrons, muons, at every energy		1	
Neutrons, if the energy is	~~<10 keV~~	~~5~~	
	~~10 keV–100 keV~~	~~10~~	
	~~100 keV–2 MeV~~	~~20~~	
	~~2 MeV–20 MeV~~	~~10~~	
	~~> 20 MeV~~	~~5~~	
Protons, if the energy is	> 2 MeV	~~5~~ 2	
α-particles, nuclear fission products, heavy nuclei		20	

Continous function for neutrons

For γ-radiation: 1Gy = 1Sv

Effective dose:

Absorbed dose → weighted summation → Biological effect

Weighting factors for: effectivity of the radiation

$\boxed{\text{tissue sensitivity}}$ ←

Effective dose: $E = \sum_{\mathrm{T}} w_{\mathrm{T}} H_{\mathrm{T}}$ [Sv]

Weighted sum of the equivalent doses of the irradiated tissues (T)

$$\sum_{\mathrm{T}} w_{\mathrm{T}} = 1$$

$w_{\mathrm{T}} H_{\mathrm{T}}$ gives the contribution of the H_{T} dose to the damage of the whole body.

In case of homogenous irradiation $E = H_{\mathrm{T}}$

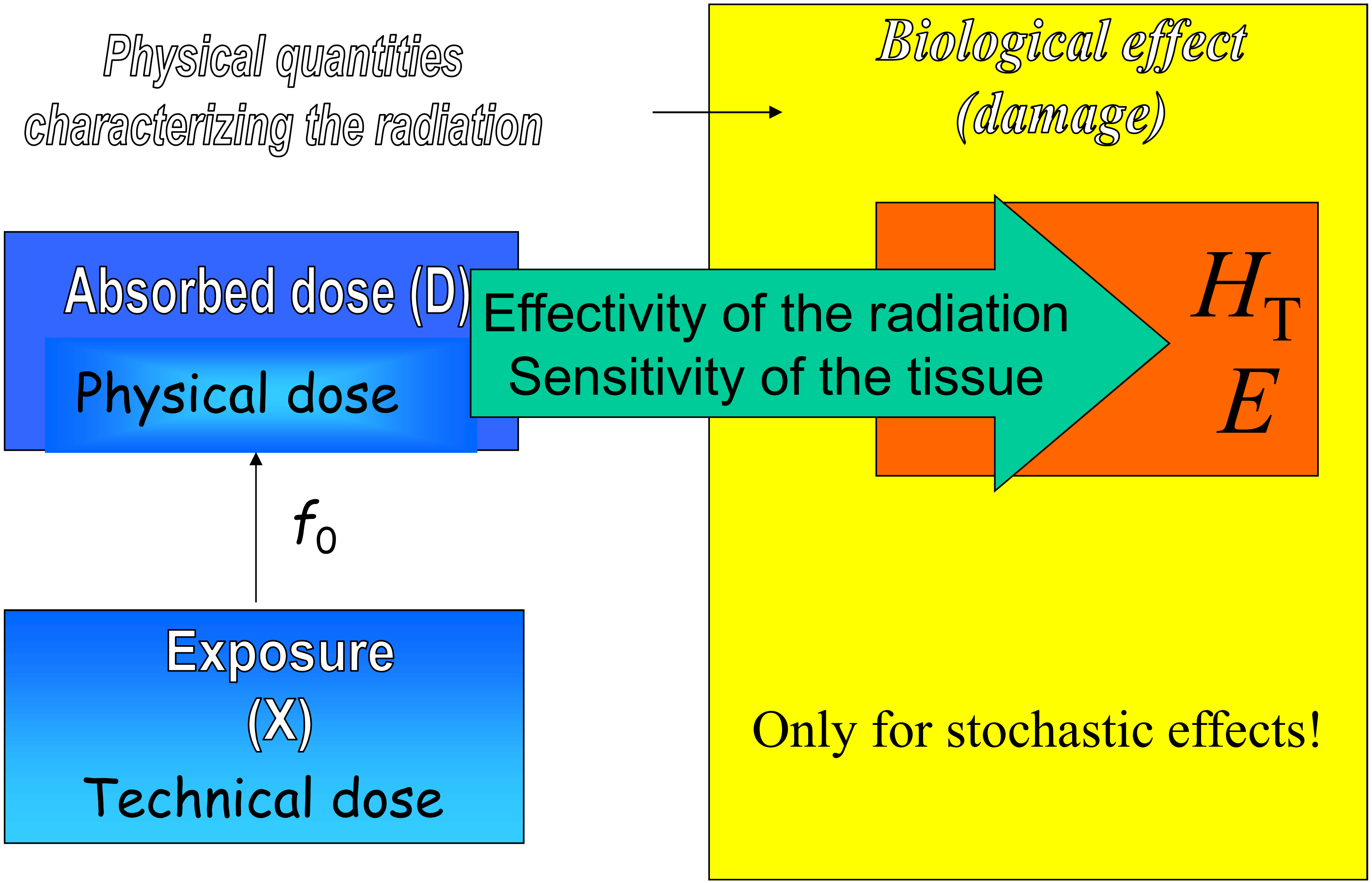
The w_T weighting factor

represents the relative contribution of that organ or tissue to the total damage in case of stochastic effects resulting from uniform irradiation of the whole body

Tissue	w_T	Tissue	w_T
Red bone marrow	0,12	Oesophagus	0,04
Large intestine	0,12	Liver	0,04
Lungs	0,12	Thyroid gland	0,04
Stomach	0,12	Surface of the bones	0,01
Breast	0,12	Brain	0,01
Other tissues*	0,12	Salivary glands	0,01
Gonads	0,08	Skin	0,01
Bladder	0,04		

*Other tissues: adrenal glands, upper respiratory tracts, gall-bladder, heart, kidney, lymp nodes, muscle, mucus membrane ,pancreas, prostate, small intestine,spleen, thymus, uterus.

Summary of dose concepts



Radiation protection

For personnel:

- Justification
- Rule out the deterministic effect
- Dose limits
- Reduction of the stochastic effect on a rationally acceptable level

Patients:

- Justification
- Cost-benefit principle
- Measurement and documentation of patient dose values

Calculation of absorbed dose from γ radiation of an isotope

In case of point radiator:

$$D = \frac{K_\gamma \Lambda t}{r^2}$$

K_γ: dose constant $\left[\frac{\mu Gy \cdot m^2}{h \cdot GBq}\right]$

Λ: Activity [Bq]

r: distance from the isotope [m]

t: time [s,h]

E.g K_γ=80 $\frac{\mu Gy \cdot m^2}{h \cdot GBq}$ for ^{137}Cs

1GBq ^{137}Cs gives 80 μGy/h in 1 m distance

800 x backgroud radiation level

Dose limits

(≠ allowed dose!)

For personnel at radiation workplace

- whole body: $\boxed{\text{20 mSv/year}}$

(c.a.10μSv/working hour)*

- eye lens: 20 mSv/year
- skin: 500 mSv/year
- limb: 500 mSv/year

*compare: background dose rate: ≈ 0,1 μSv/h

Threshold doses for deterministic effects

bone-marrow:	
Reduction of blood production	$\boxed{0,5\ Gy}$
Testis:	
temporary sterility	0,15 Gy
permanent sterility	3,5-6 Gy
Eye lens	
obscurity	0,5-2 Gy
Cataracta	5 Gy
Skin:	
temporary erythema	2 Gy
erythema	6 Gy
temporary epilation	3 Gy

For whole-body irradiation: median lethal dose (LD_{50}) : 4 Gy
lethal dose 6 Gy

A few characteristic dose values

Background raditaion: 2,4 mSv/year
half of it from Radon.

Medical investigations (patient dose)
conventional x-ray image: 0,2-1 mSv
CT scan: 2-8 mSv

Treatment:
Intervention radiology
doctor: hand: 100 mSv/2 month
eye: 30 msv/2 month
knee: 20 mSv/2 month
gonad (under the lead apparel): 0,5 mSv/2 month
Patient: up to 1 Gy!!

Radiotherapy: tipically 45-60 Gy (in fractions, localized)

Dose limits and risks

Dose limit $\neq$ allowed dose

= dose with acceptable level of risk

Stochastic effects cannot be avoided even below the dose limit!

But! everything is dangerous!

life is dangerous!

risk $\leftrightarrow$ benefit