Dosimetry, radiation protection. Nuclear measurement techniques.

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Basic definitions

Reminder

- Nuclear radiation:
  - Produced in the transition of the nucleus
  - α (He^{2+}), β (e^-,e^+), γ (em.), n … radiation
- Isotope (same atomic number, different mass number)
- Radioactive isotope (unstable, decay, emits radiation)
- Activity (Bq = decay/s)
- Exponential decay law

Interaction of the nuclear radiation with the matter

Reminder

nuclear radiation — absorption
nuclear radiation — detection

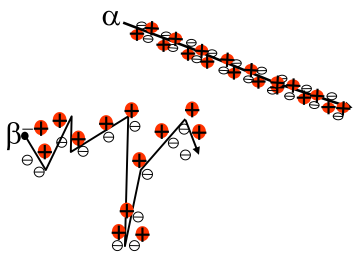
interaction ⇒ energy trasfer

α, β	charged	➡	direct ionisation
γ, n	uncharged	➡	indirect ionisation

Attenuation of nuclear radiations

Reminder

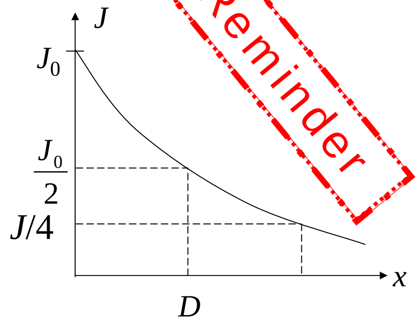
charged



Ionisation ⇒ energy loss:
Runs out of the energy on a finite distance.

effective range

γ-ray



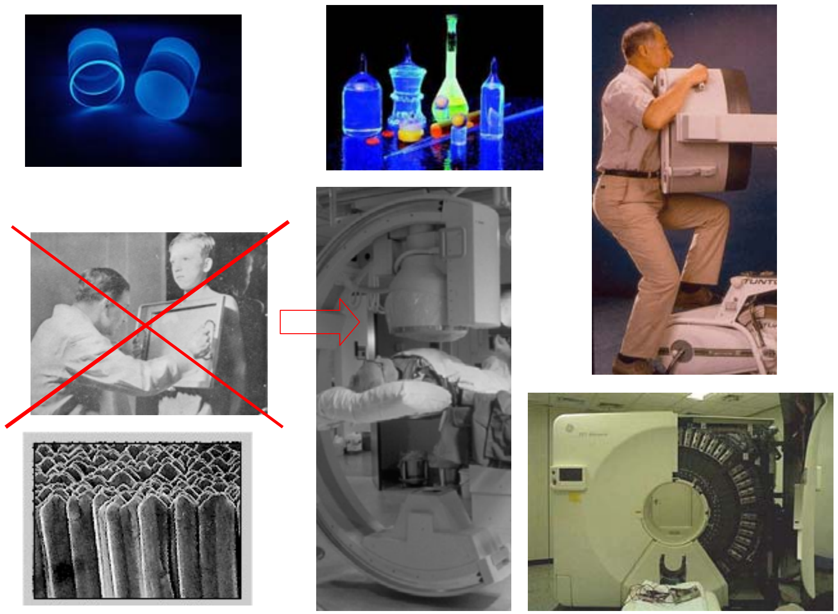
Exponential attenuation law
no effective range

Detection of the ionizing raditaion

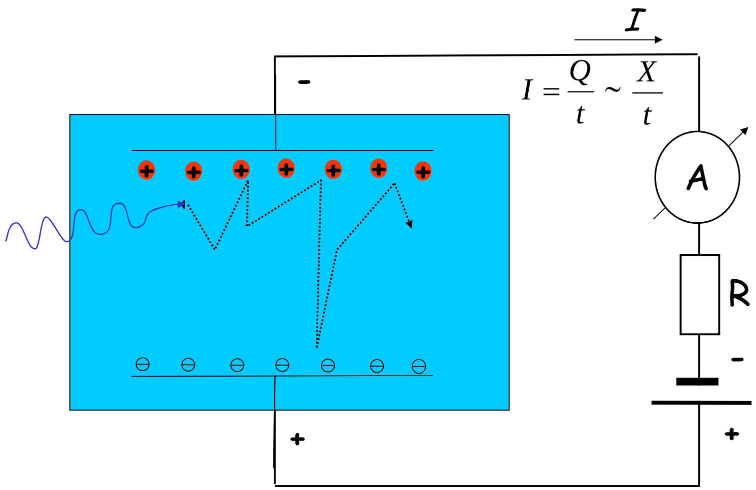
scintillation counter
gas-ionization detectors
thermoluminescent dosimeter
photographic methods (film)
semiconductor detectors

Scintillation counter

see practical exercises!

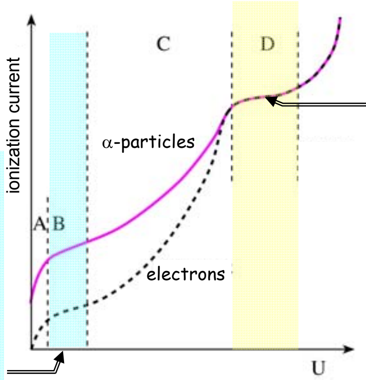


Gas-ionization detectors



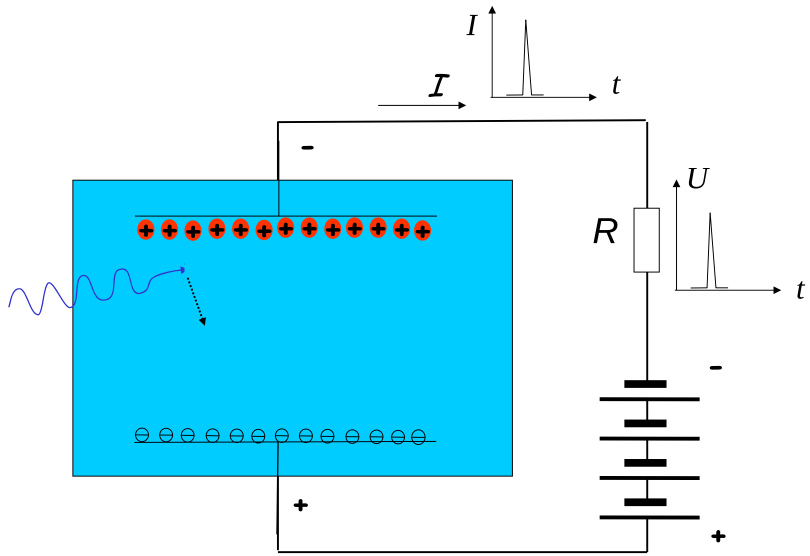
Gas-ionization detectors

Ionization chamber:
collects all the ions
Measurees the
inonizating effect
of the radiation
see: dosimetry

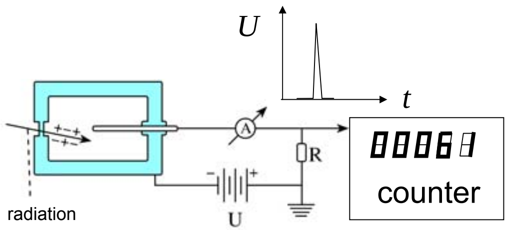


Geiger-
Müller
range:
avalanche-
effect:
particle
⇩
voltage
pulse

Geiger-Müller tube



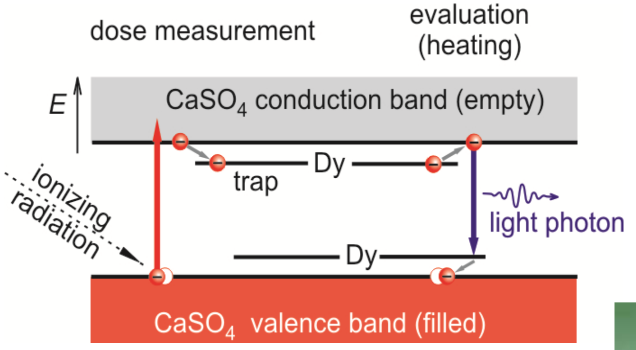
G-M tube



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

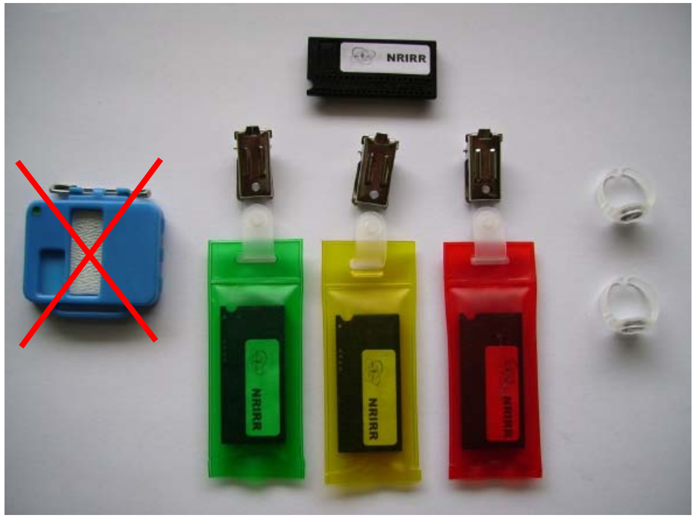
usage: mainly in dosimetry

Thermoluminescent dosimeter (TLD)



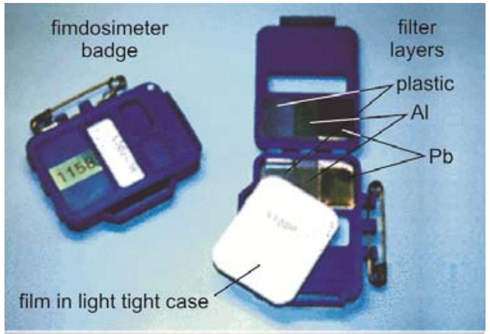
An american astronaut uses the TLD dosimeter „Pille" produced by KFKI
(Photo: NASA ISS002E7814)

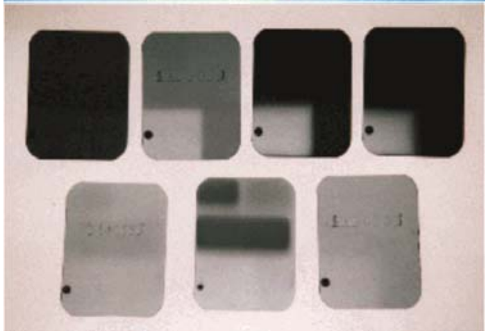
Personal dosimeters



Photochemical detection

obsolete

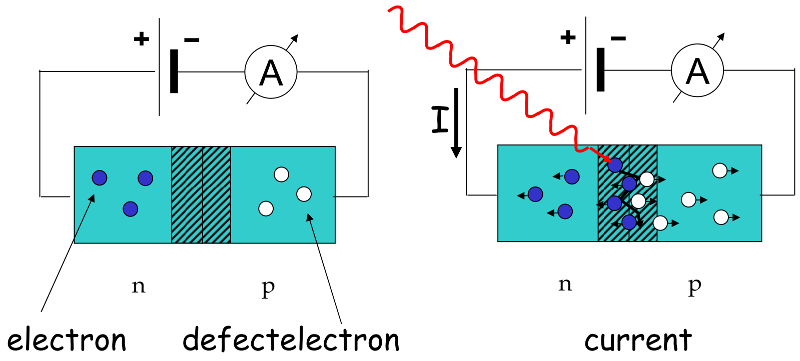




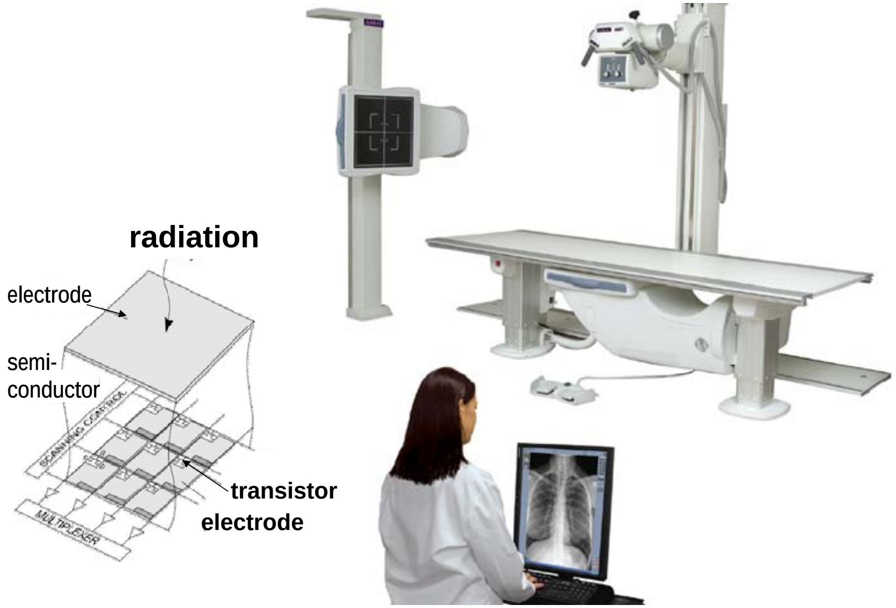
Semiconductor detector

Principle:

- Semiconductor diode connected reverse biased
- The radiation induces free charges and consequently current

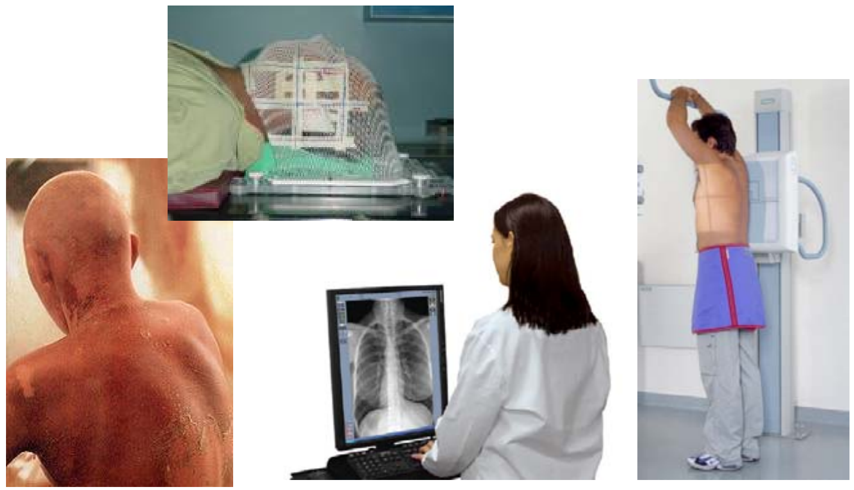


Semiconductor detectors in the diagnostics



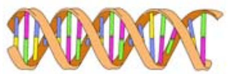
Semiconductor based dosimeters

Biological effect of the ionizing radiation



The mechanism of the radiation damage

direct
⇕
indirect



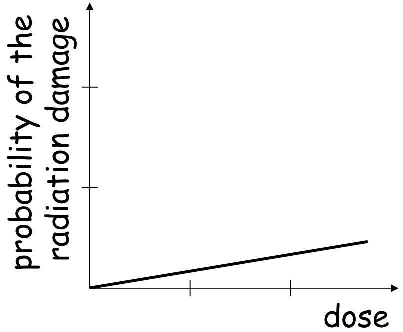
Physical phase:
10^{-17} -10^{-12} s Ionisation

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

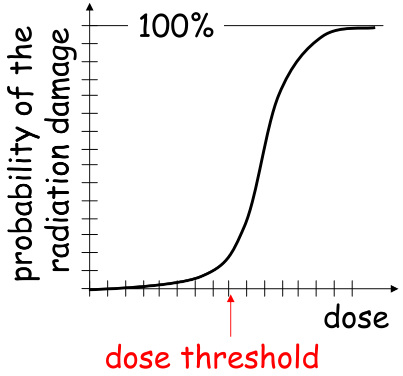
Biological phase:
hours: alteration in the tissues
days-years: stomach-bowel
damage of the haematogenesis
somatic damage

Radiation damage

Stochastic



Deterministic



Stochastic

already in case of low dose
small number of targets
no dose threshold
severity is independent of the dose

⇩

parsonnel at workplaces using ionisation radiation,

patients of X-ray and nuclear imaging investigations

Deterministic

Large dose (>threshold)
many targets should be hit
only above the threshold
severity increases with the increasing dose

⇩

accidents

Radiotherapy

Radiation protection and dosimetry

Main tasks in radiation protection:

- measurement of the dose rate
- detection of the pollution
- measurement and control of the personal dose

Dose concepts

absorbed dose:

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

The energy absorbed from the radiation by the mass *dm*

unit J/kg = Gy

➡ absorbed energy by unit mass of absorbing medium

can be used for all types of radiations

Absorbed dose : $D = \frac{\Delta E}{\Delta m}$ [Gy]

How to measure:

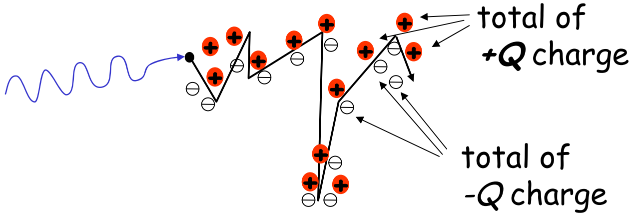
- hard to measure directly (unmeasurably small temperature change ΔT = 0,006°C/4 Gy)
- indirect detection methods:
  - ionisation chamber
  - semiconductor detector
  - thermoluminescent detector
  - ...

Exposure:

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

the positive charge produced in the air of mass Δm

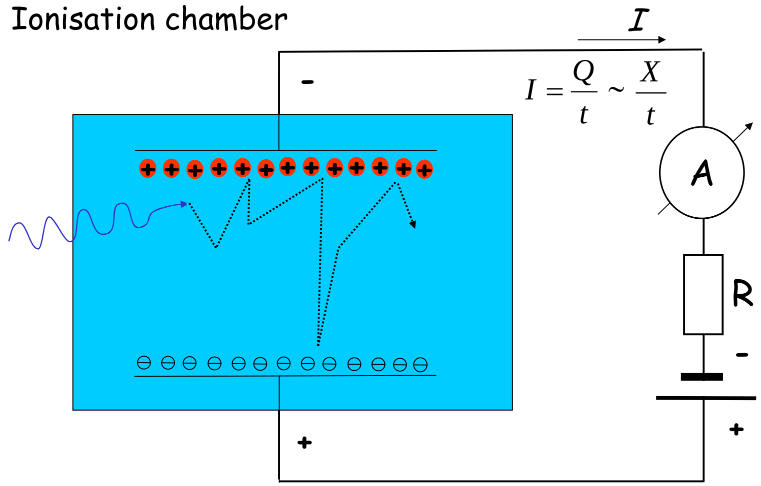
unit: C/kg



Olny for γ– and x-ray in air!

How to measure the exposure: $X = \frac{\Delta Q}{\Delta m}$

Ionisation chamber

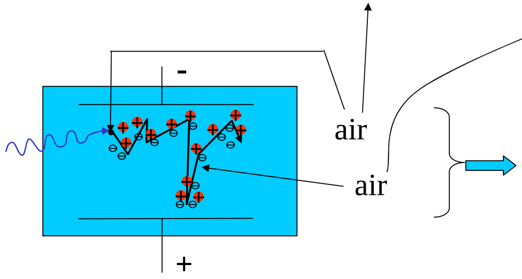


$$I = \frac{Q}{t} \sim \frac{X}{t}$$

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:

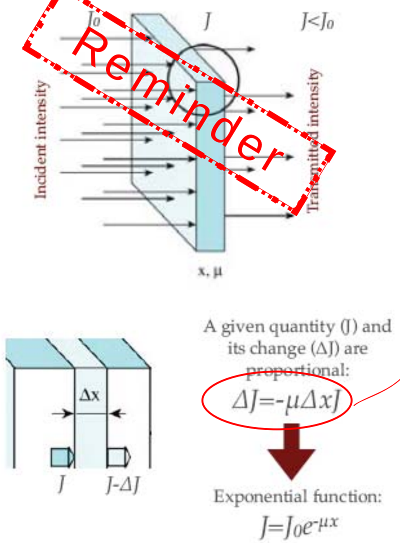
To produce 1 pair of ions one needs 34 eV energy in air*

34 eV= 34 · 1,6 ·10^{-19} J ⟶ 1,6 ·10^{-19} C
34 J ⟶ 1 C

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

* In case of electrons. For protons and α particles ≈35 eV

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



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

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

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

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

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

$$D \sim \mu_m$$

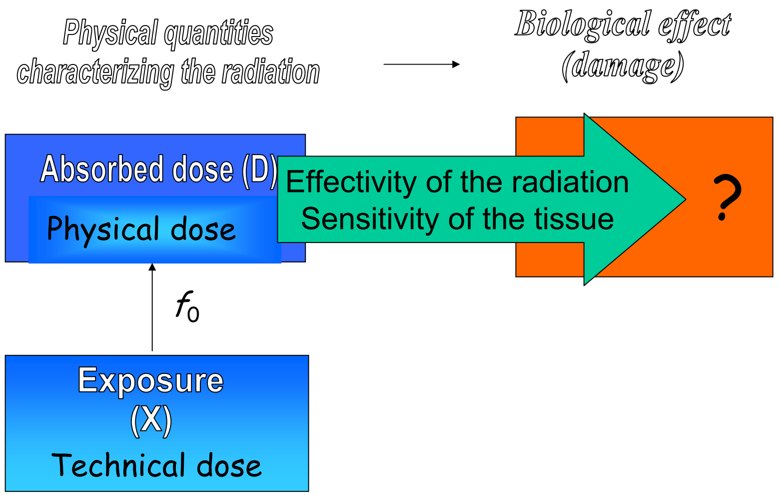
Conversion of absorbed dose measured in air to absorbed dose expected in tissue

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

$$D_{tissue} = \frac{\mu_{m,tissue}}{\mu_{m,air}} f_0 X \qquad f_0 = 34\frac{J}{C}$$

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

Dose concepts so far:



Radiotherapy (Deterministic effect)

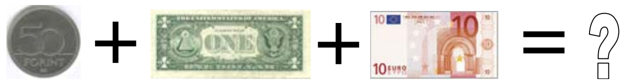
Usually
- single type of radiation is used
- single type of tissue is irradiated

Absorbed dose → proportional → Biological effect

Radiation protection (Stochastic effect)

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

Absorbed dose → weighted summation → Biological effect



Absorbed dose → weighted summation → Biological effect

Weighting factors for: effectivity of the radiation ←
tissue sensitivity

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

Weighted sum of the absorbed doses from the different radiations (R) in a given tissue (T).
w_R: radiation weighting factor

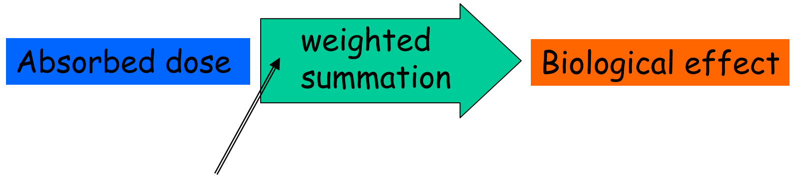
E.g.:

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

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
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
α-particles, nuclear fission products, heavy nuclei		20



Weighting factors for: effectivity of the radiation
tissue sensitivity ←

Effective dose: $E = \sum_{T} w_T H_T$ [Sv]

Weighted sum of the equivalent doses of the irradiated tissues (T) $\sum_{T} w_T = 1$

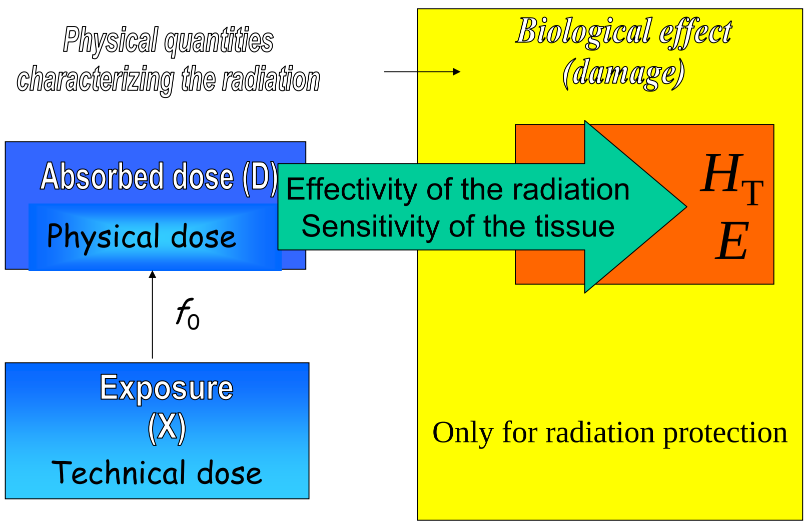
$w_T H_T$ gives the contribution of the H_T dose to the damage of the whole body.
In case of homogenous radiation $E = H_T$

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/Organ	Weighting factor, w_T
Gonads	0.20
Red bone marrow	0.12
Large intestine	0.12
Lungs	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid gland	0.05
Skin	0.01
Surface of the bones	0.01
Other	0.05

Summary of dose concepts



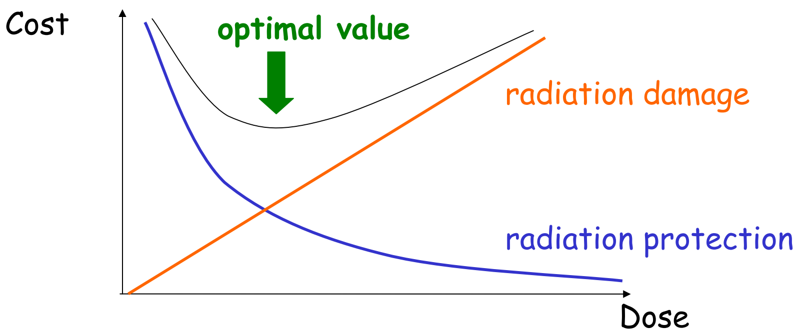
Radiation protection

For personnel:
- Justification
- Rule out the deterministic effect
- Reduction of the stochastic effect on a rationally acceptable level:
  - ALARA principle
  - Dose limits

Patients:
- Justificatio
- Cost-benefit principle
- Measurement and documentation of patient dose values

ALARA principle

- As Low As Reasonably Achievable



Dose limits

(≠ allowed dose!)

For personnel at radiation workplace

- whole body: 100 mSv/5 year
  and 50 mSv/year
  (c.a.10μSv/working hour)*
- eye lens: 150 mSv/year
  (will be smaller in the future!)
- 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 blod production	0,5 Gy
Testis:	
temprary 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 values

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

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 (2 Gy fractions.)

Dose limits and risks

Dose limit ≠ 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 ↔ benefit

Some of the above presented values are taken from:

Damjanovich et al.: Medical Biophysics

Köteles György: Sugáregészségtan (Medicina)

Fehér István, DemeSándor: Sugárvédelem (ELTE Eötvös kiadó)

Turák O., Osvay M.: A személyzet dózisa az intervenciós radiológia területén. OSSKI www.sugarvedelem.hu/sugarvedelem/docs/kulonsz/.../szemelyzet.pdf

Pellet Sándor, Giczi Ferenc, Gáspárdy Géza, Temesi Alfréda: Az intervenciós radiológia sugár-egészségügyi vonatkozásai. Magyar Radiológia 81 (2007) 32–39.