

Dosimetry, radiation protection. Nuclear measurement techniques.



Dr László Smeller Semmelweis University, Dept. Biophysics and Radiation Biology

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, decays, emits radiation)
- Activity ($\text{Bq} = \text{decay/s}$)
- Exponential decay law

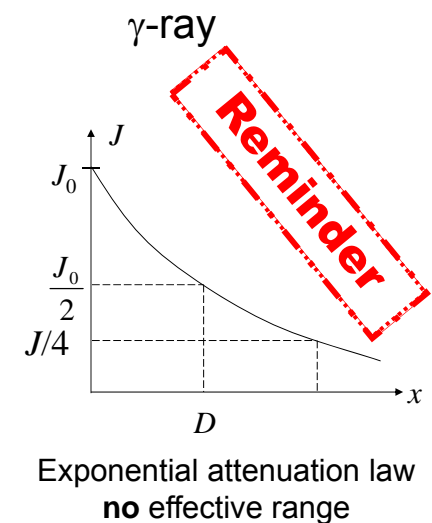
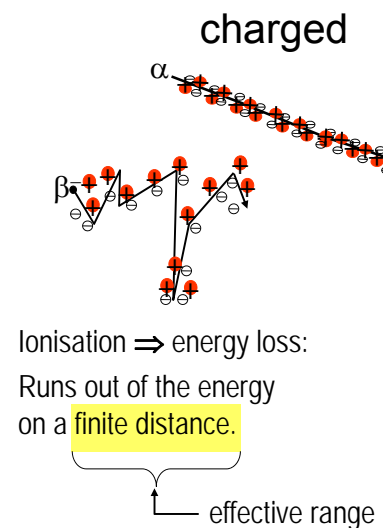
Interaction of the nuclear radiation with the matter

nuclear radiation — absorption
detection
interaction \Rightarrow energy transfer

α	} charged	\rightarrow direct ionisation
β		
γ	} uncharged	\rightarrow indirect ionisation
n		

Reminder

Attenuation of nuclear radiations

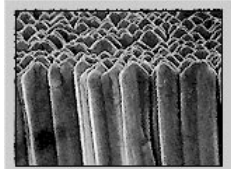
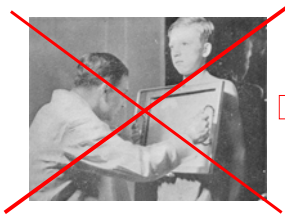


Detection of the ionizing radiation

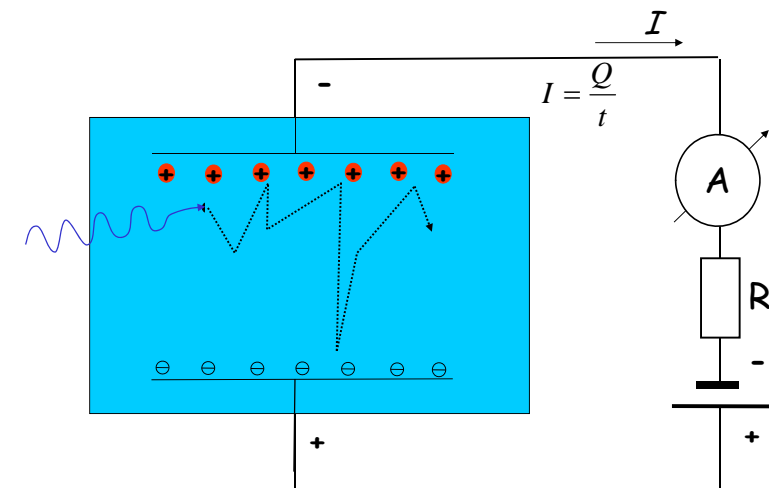
scintillation counter
gas-ionization detectors
thermoluminescent dosimeter
photographic methods (film)
semiconductor detectors

Scintillation counter

see practical exercises!

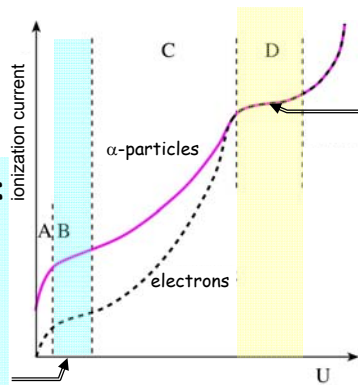


Gas-ionization detectors



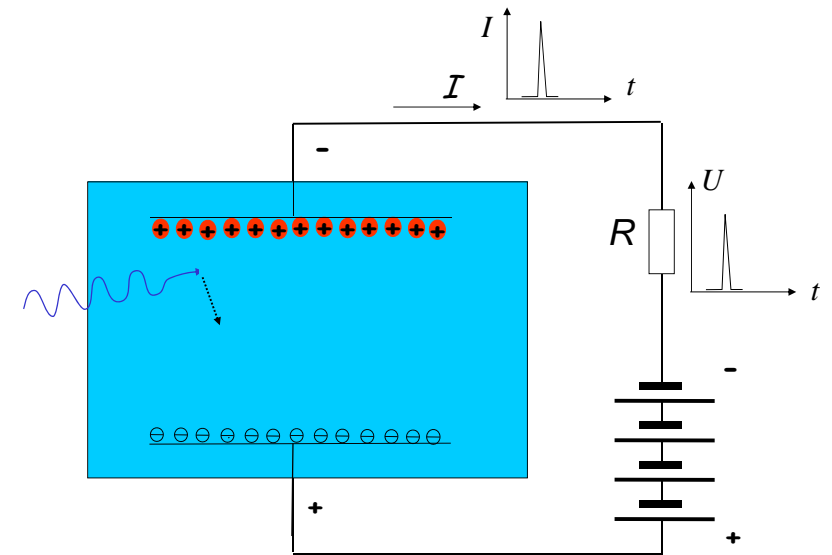
Gas-ionization detectors

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

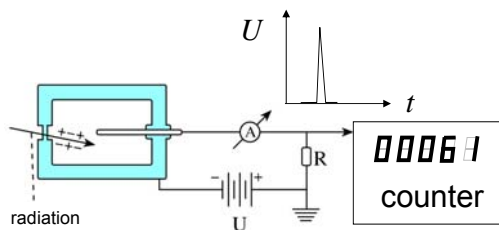


Geiger-Müller
range:
avalanche-
effect:
particle
↓
voltage
pulse

Geiger-Müller tube



G-M tube

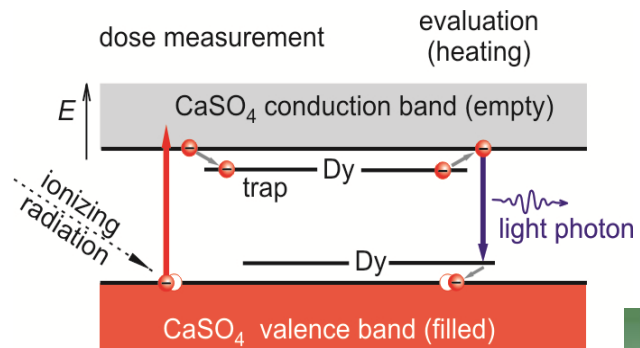


advantage: simple construction,
disadvantage: no energy selectivity,
low efficiency for γ -ray

usage: mainly in dosimetry



Thermoluminescent dosimeter (TLD)



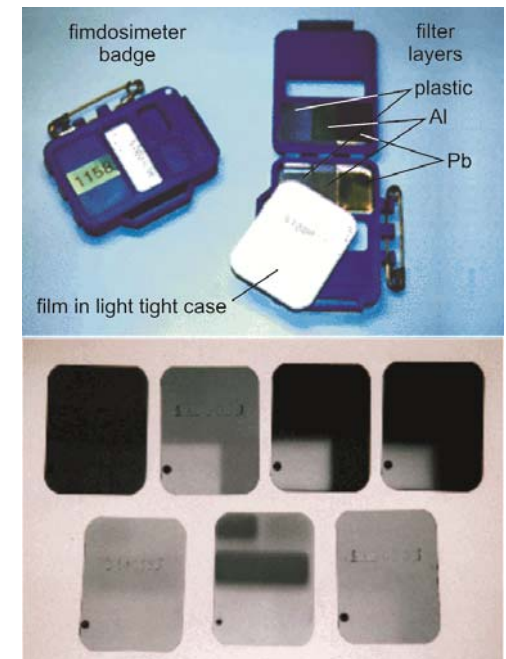
An american astronaut uses the TLD dosimeter „Pille” produced by KFKI
(Photo: NASA ISS002E7814)

Personal dosimeters



Photochemical detection

obsolete

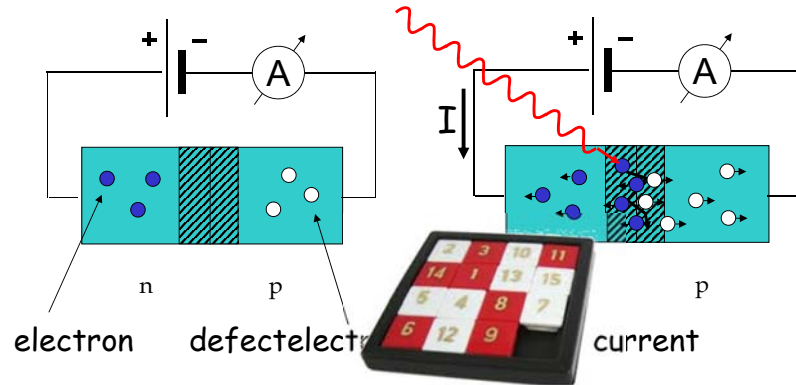


Semiconductor detector

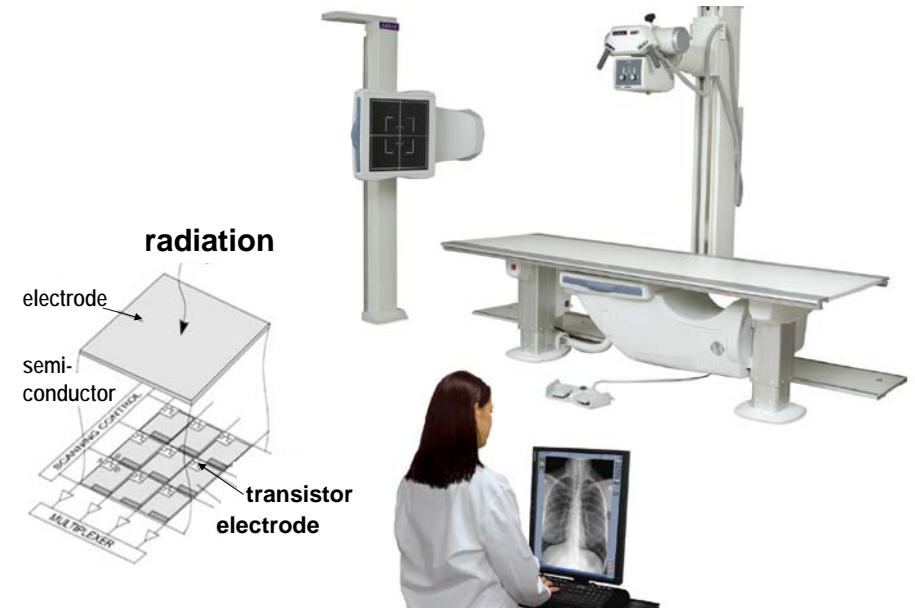
Principle:

Semiconductor diode connected reverse biased

The radiation induces free charges and consequently current



Semiconductor detectors in the diagnostics



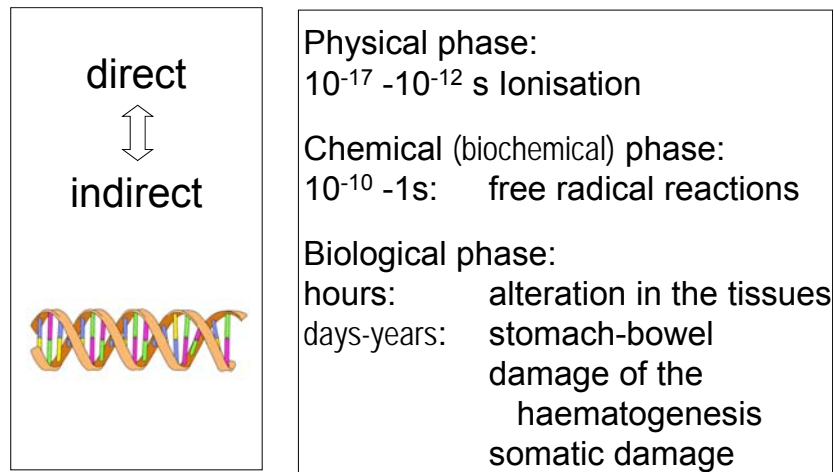
Semiconductor based dosimeters



Biological effect of the ionizing radiation



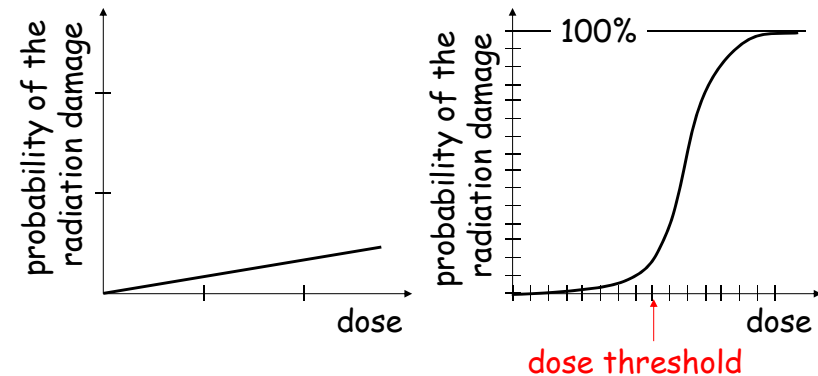
The mechanism of the radiation damage



Radiation damage

Stochastic

Deterministic



Stochastic

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



personnel 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 Δm

unit J/kg = Gy

→ absorbed energy by unit mass of absorbing medium

can be used for all types of radiations

Absorbed dose :

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

How to measure:

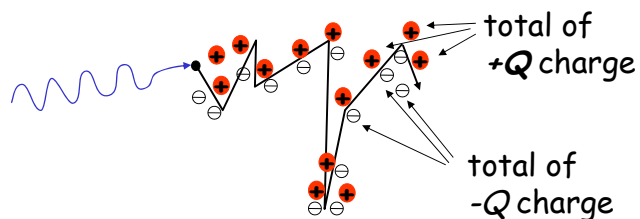
- hard to measure directly (unmeasurably small temperature change $\Delta T = 0,006^\circ\text{C}/4 \text{ Gy}$)
- indirect detection methods:
 - ionisation chamber
 - semiconductor detector
 - thermoluminescent detector
 - ...

Exposure:

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

the positive charge produced in the air of mass Δm

unit: C/kg

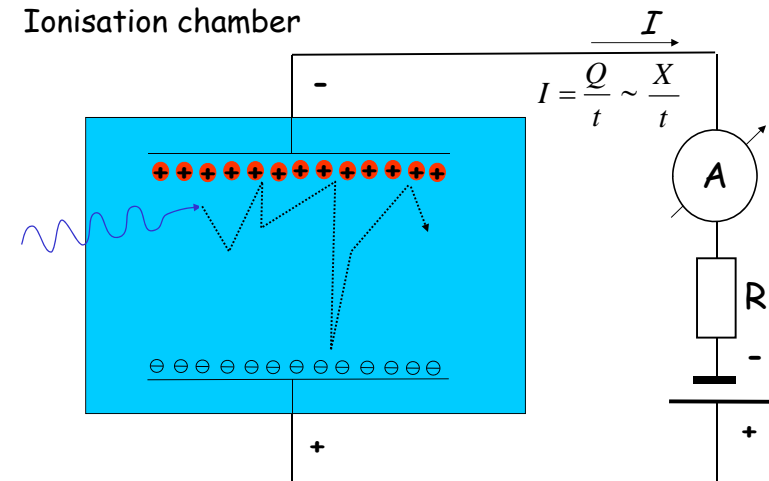


Only for γ - and x-ray in air!

How to measure the exposure:

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

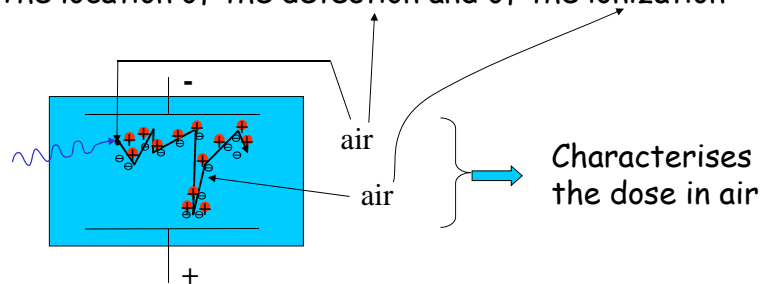
Ionisation chamber



Exposure:

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

The location of the detection and of the ionization



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:

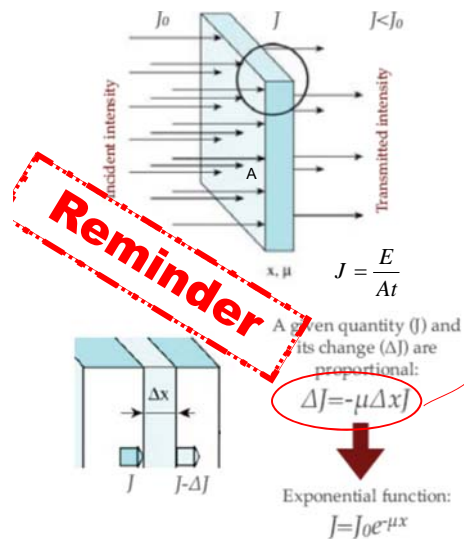
To produce 1 pair of ions one needs 34 eV energy in air*

$$\begin{array}{ll} 34 \text{ eV} = 34 \cdot 1,6 \cdot 10^{-19} \text{ J} & \longrightarrow 1,6 \cdot 10^{-19} \text{ C} \\ 34 \text{ J} & \longrightarrow 1 \text{ C} \end{array}$$

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

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

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

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

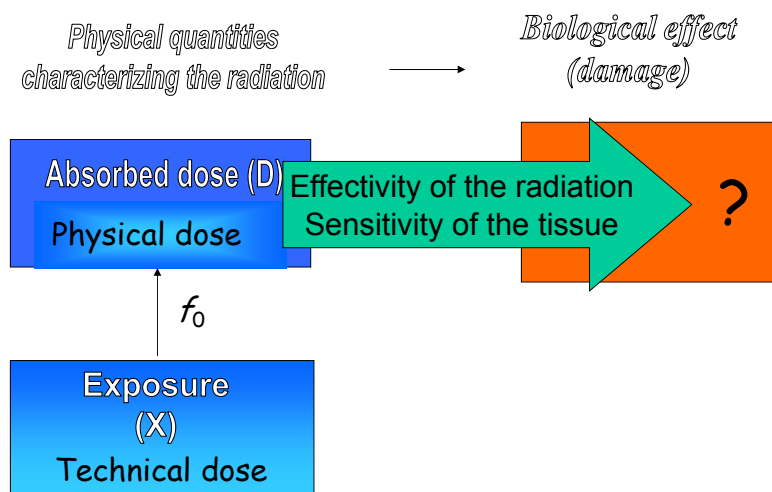


$$D_{\text{tissue}} = \frac{\mu_{m,\text{tissue}}}{\mu_{m,\text{air}}} f_0 X$$

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

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

Dose concepts so far:



Radiotherapy (Deterministic effect)

typically

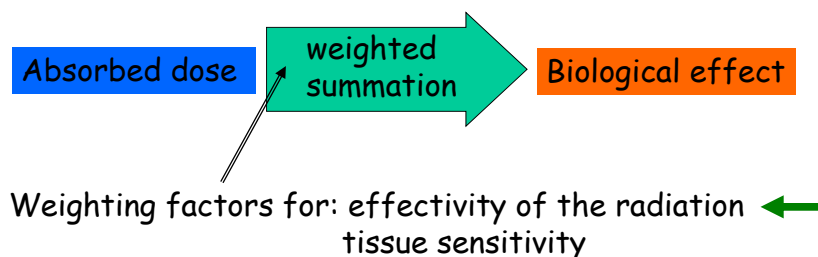
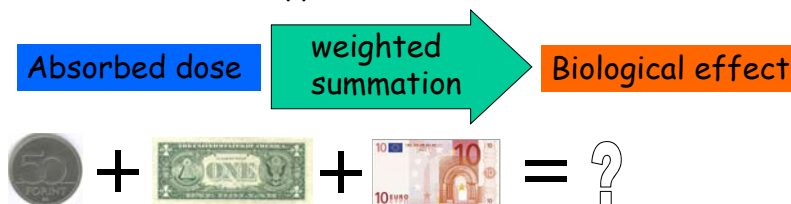
- single type of radiation is used
- single type of tissue is irradiated



Radiation protection (Stochastic effect)

typically

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



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.:

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

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
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.

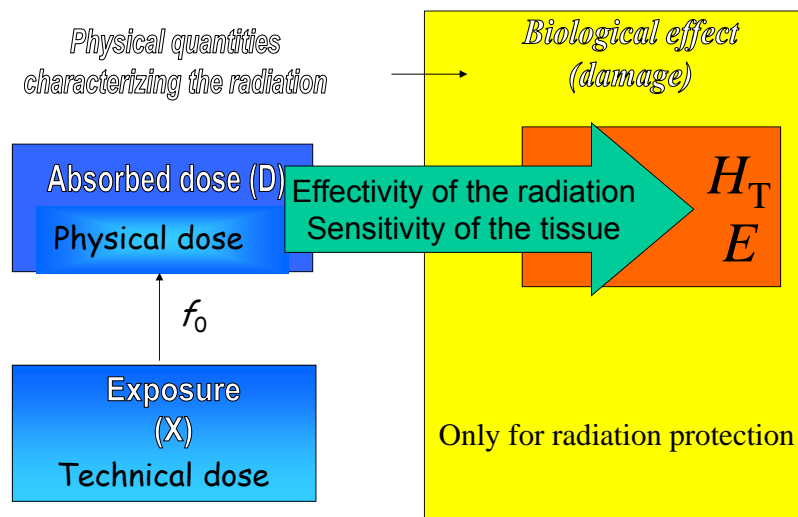
In case of homogenous radiation $E = H_T$

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:

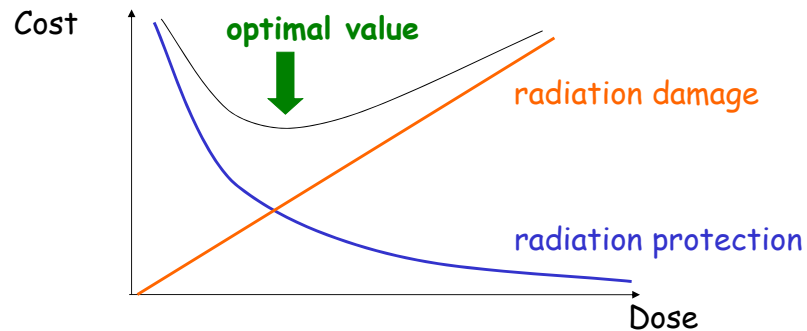
Justification

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. 10 μ Sv/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: $\approx 0,1 \mu$ Sv/h

Threshold doses for deterministic effects

bone-marrow:	
Reduction of blood production	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 values

Background radiation: 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: typically 45-60 Gy (2 Gy fractions.)

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



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 intervenciók radiológia területén.

OSSKI www.sugarvedelem.hu/sugarvedelem/docs/kulonsz/.../szemelyzet.pdf

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