

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

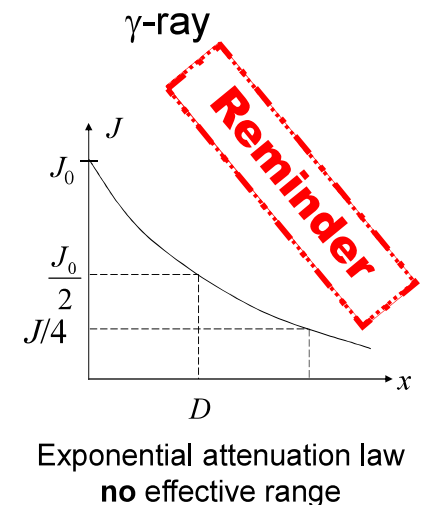
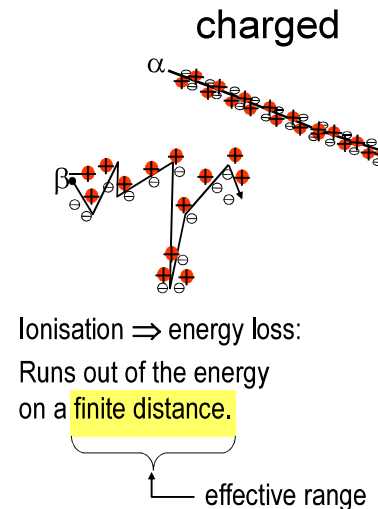
Interaction of the nuclear radiation with the matter

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

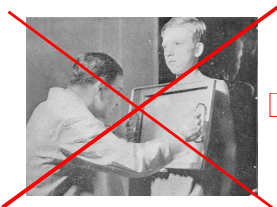


Detection of the ionizing radiation

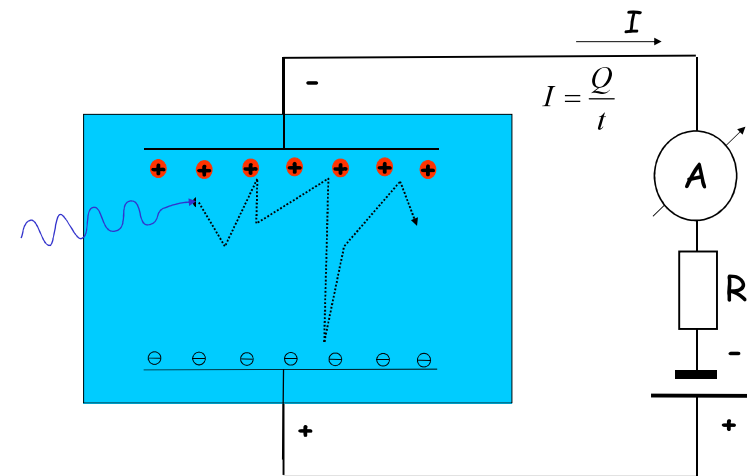
scintillation counter
gas-ionization detectors
thermoluminescent dosimeter
photographic methods (film)
semiconductor detectors

Scintillation counter

see practical
exercises!

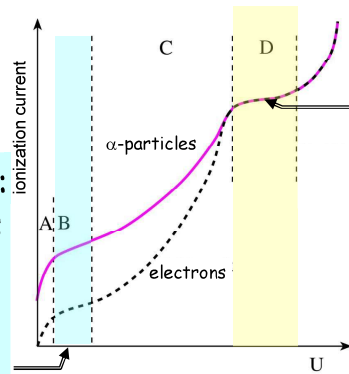


Gas-ionization detectors



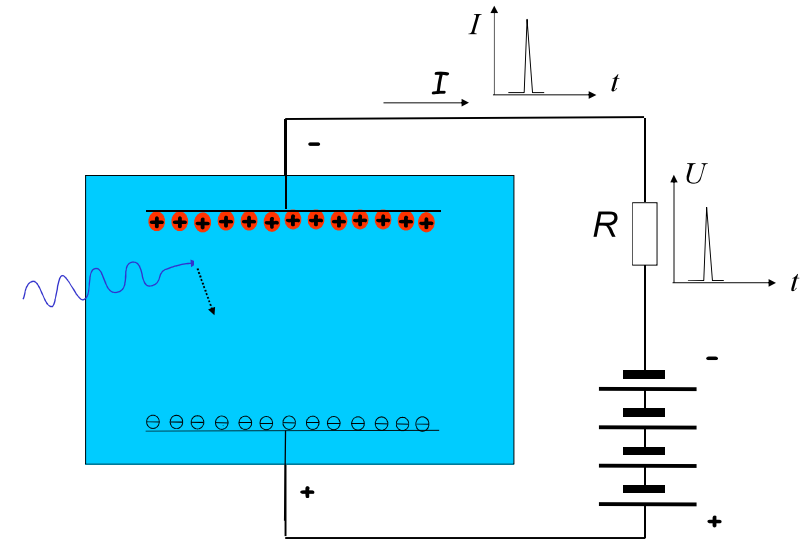
Gas-ionization detectors

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

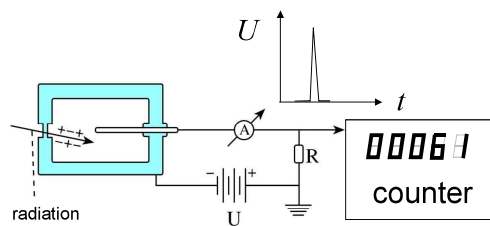


Geiger-Müller
range:
avalanche-
effect:
particle
↓
voltage
pulse

Geiger-Müller tube



G-M tube

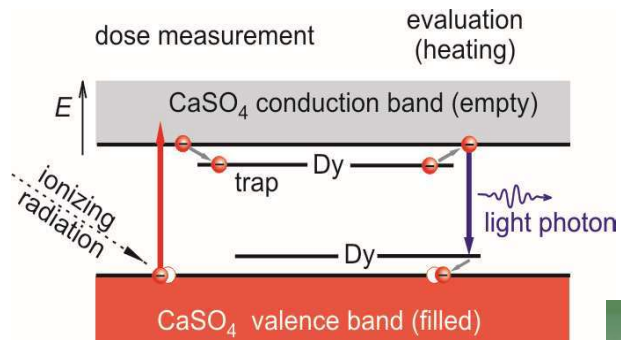


advantage: simple construction,
disadvantage: no energy selectivity,
low efficiency for γ -ray

usage: mainly in dosimetry



Thermoluminescent dosimeter (TLD)



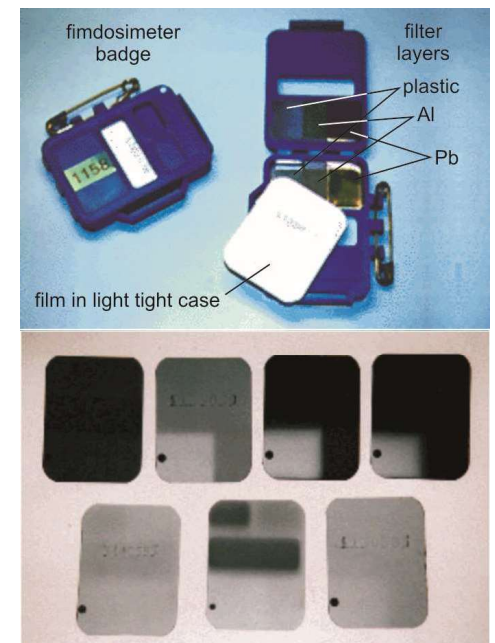
An american astronaut uses the TLD dosimeter „Pille” produced by KFKI Budapest (Photo: NASA ISS002E7814)

Personal dosimeters



Photochemical detection

obsolete

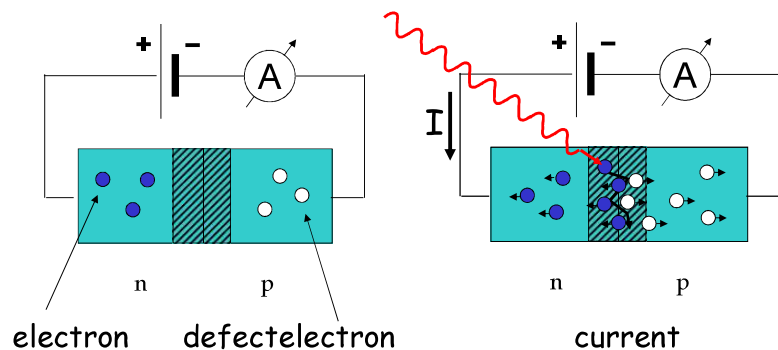


Semiconductor detector

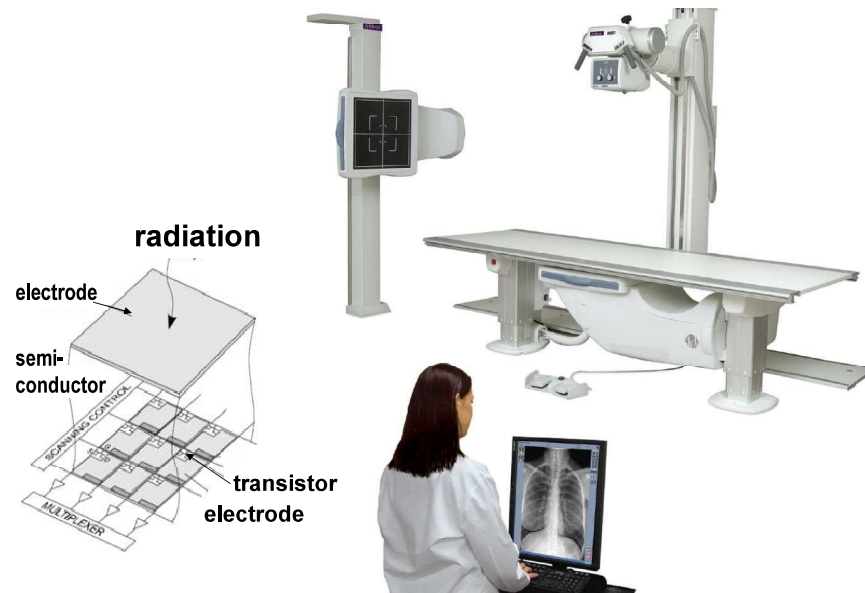
Principle:

Semiconductor diode connected reverse biased

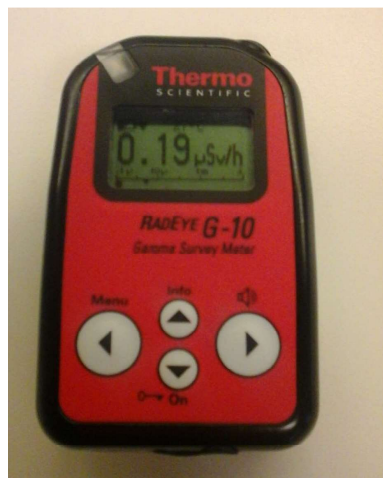
The radiation induces free charges and consequently current



Semiconductor detectors in the diagnostics



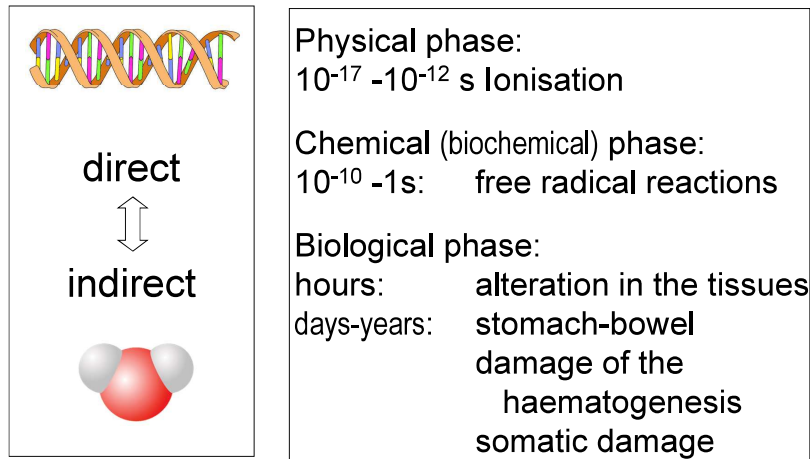
Semiconductor based dosimeters



Biological effect of the ionizing radiation



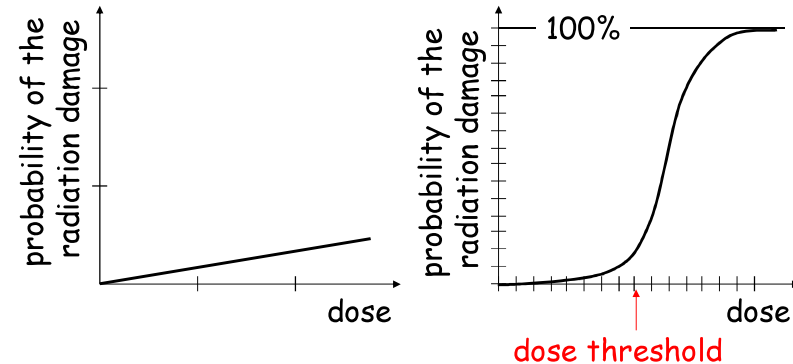
The mechanism of the radiation damage



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:

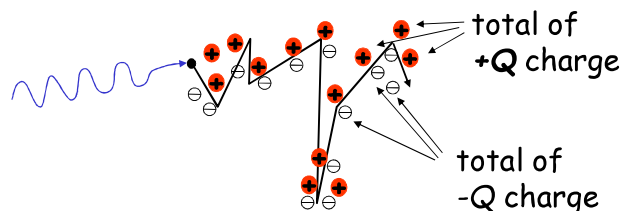
- hard to measure directly (unmeasurably small temperature change $\Delta T = 0,006^\circ\text{C}/4 \text{ Gy}$)
- indirect detection methods:
 - ionisation chamber
 - semiconductor detector
 - thermoluminescent detector
 - ...

Exposure:

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

the positive charge produced in the air of mass Δm

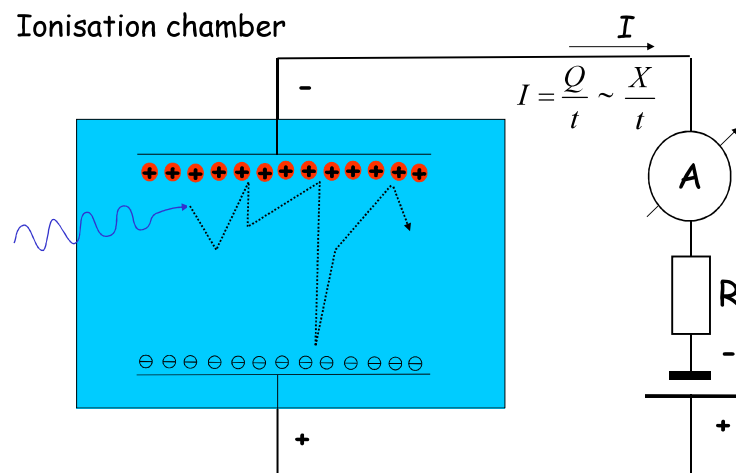
unit: C/kg



Only for γ - and x-ray in air!

How to measure the exposure:

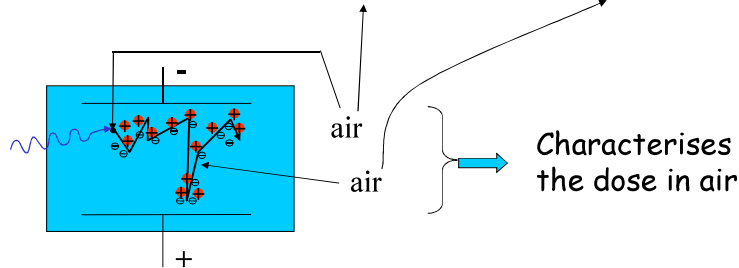
$$X = \frac{\Delta Q}{\Delta m}$$



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

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

Reminder

A given quantity (J) and its change (ΔJ) are proportional:

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

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

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

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

Exponential function:

$$J = J_0 e^{-\mu x}$$

$D \sim \mu_m$

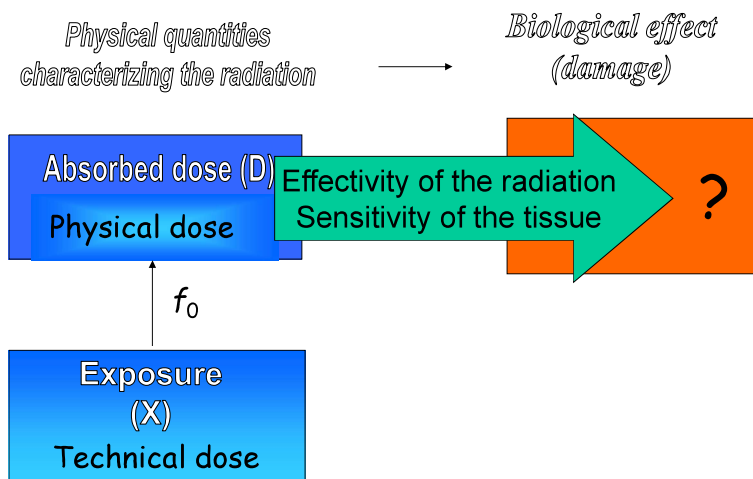
$$\frac{D_{\text{tissue}}}{D_{\text{air}}} = \frac{\mu_{m,\text{tissue}}}{\mu_{m,\text{air}}} \Rightarrow D_{\text{tissue}} = \frac{\mu_{m,\text{tissue}}}{\mu_{m,\text{air}}} D_{\text{air}}$$

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

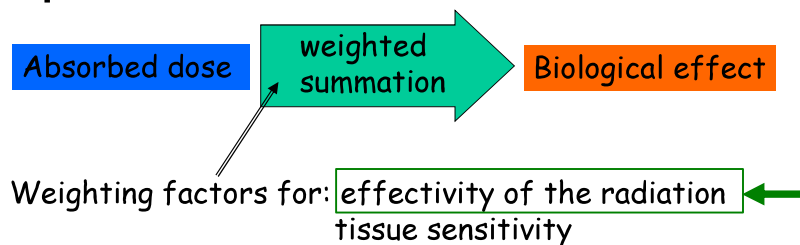
$f_0 = 34 \frac{\text{J}}{\text{C}}$

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:



Equivalent dose



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.:

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

Biological damage in...

→ **Radiotherapy** (Deterministic effect)

typically

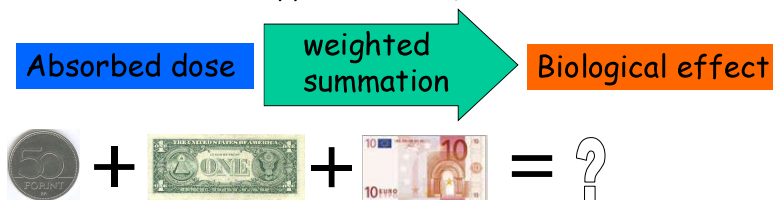
- single type of radiation is used
- single type of tissue is irradiated



→ **Radiation protection** (Stochastic effect)

typically

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



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	5
Continuous function for neutrons	10 keV
	10 keV–100 keV
	100 keV–2 MeV
	2 MeV–20 MeV
	> 20 MeV
Protons, if the energy is	2
α -particles, nuclear fission products, heavy nuclei	20

Effective dose:



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 $E = H_T$

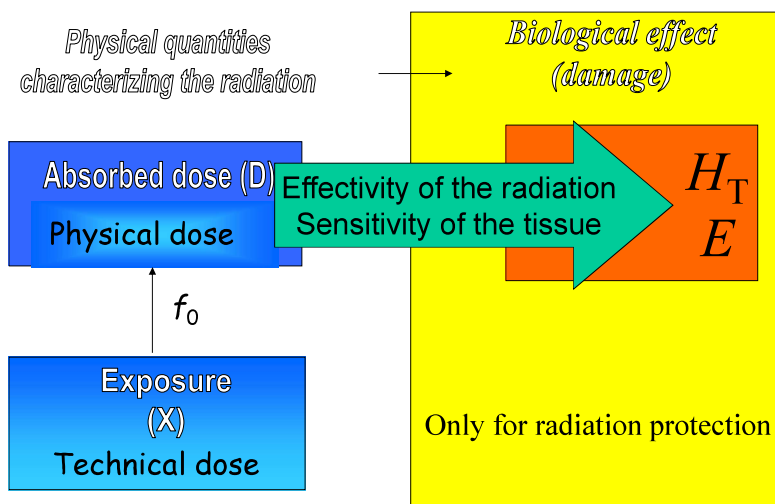
The w_T weighting factor

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	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, lymph nodes, muscle, mucus membrane, pancreas, prostate, small intestine, spleen, thymus, uterus.

Summary of dose concepts



Radiation protection

For personnel:

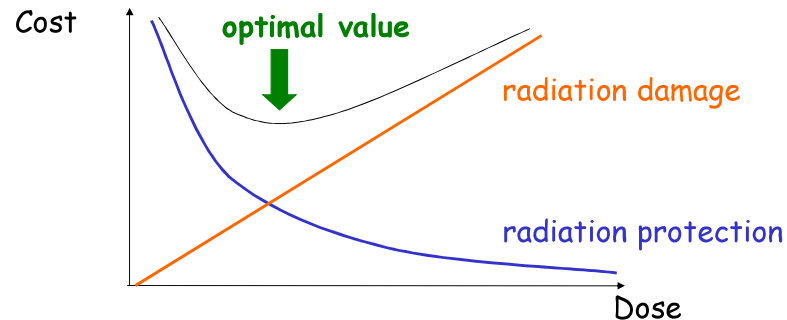
- Justification
- Rule out the deterministic effect
- Reduction of the stochastic effect on a rationally acceptable level:
- ALARA principle
- Dose limits

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: **20 mSv/year**

(c.a. 10 μ Sv/working hour)*

- eye lens: 20 mSv/year

- skin: 150 mSv/year

- limb: 150 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	
obscure	0,5-2 Gy
Cataract	5 Gy
Skin:	
temporary erythema	2 Gy
erythema	6 Gy
temporary epilation	3 Gy

For whole-body irradiation: median lethal dose (LD₅₀): **4 Gy**
lethal dose **6 Gy**

A few characteristic dose 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 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.