

Nuclear measurement techniques. Dosimetry, radiation protection

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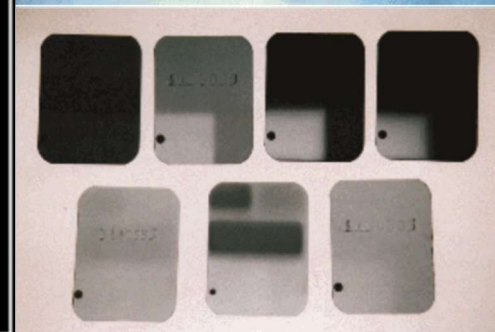
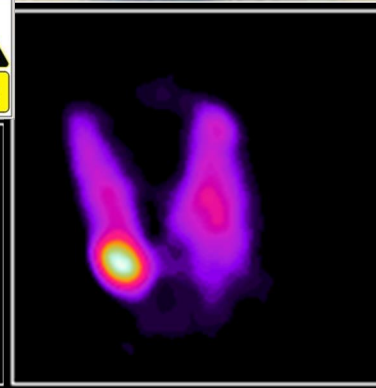
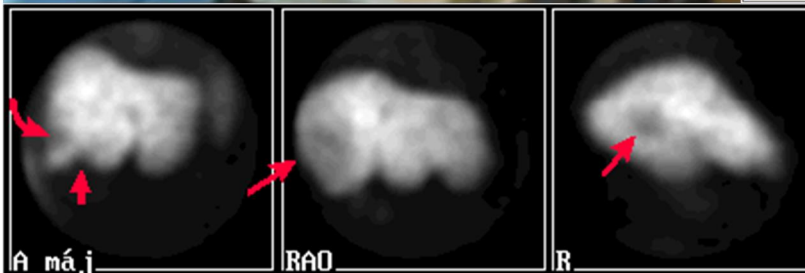
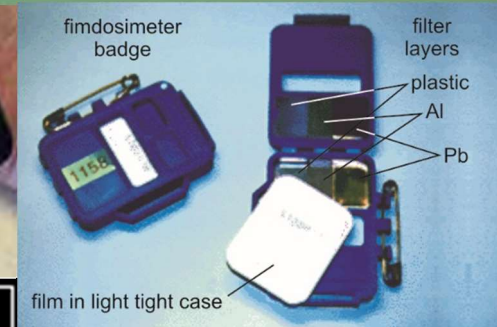
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Nuclear measurement techniques. Dosimetry, radiation protection.

- properties
- measurement
- dosimetry
- medical applications
of the nuclear radiation



1. Detection of the ionizing radiation

1.1. scintillation based methods

1.2. gas-ionization detectors **see practical exc!**

1.3. thermoluminescent dosimeter

1.4. ~~photographic methods (film)~~ **obsolete**

1.5. semiconductor detectors

1.1 Scintillation counter

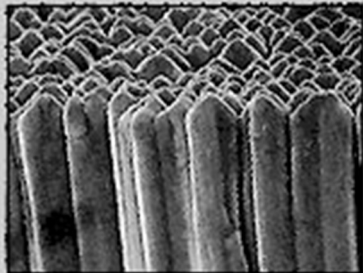
see practical exc.



X-ray image amplifier



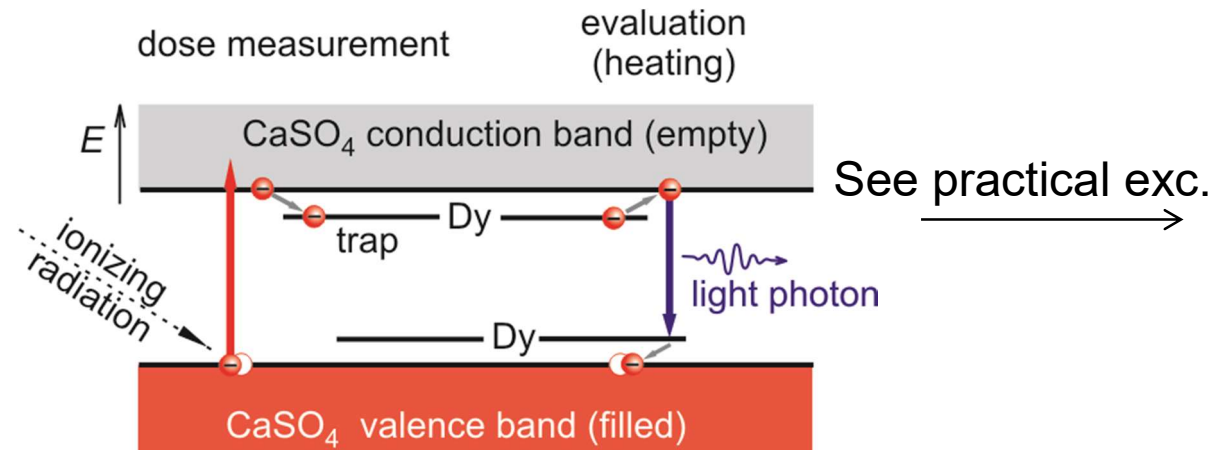
Heart investigation using γ kamera



Needle crystals for imaging



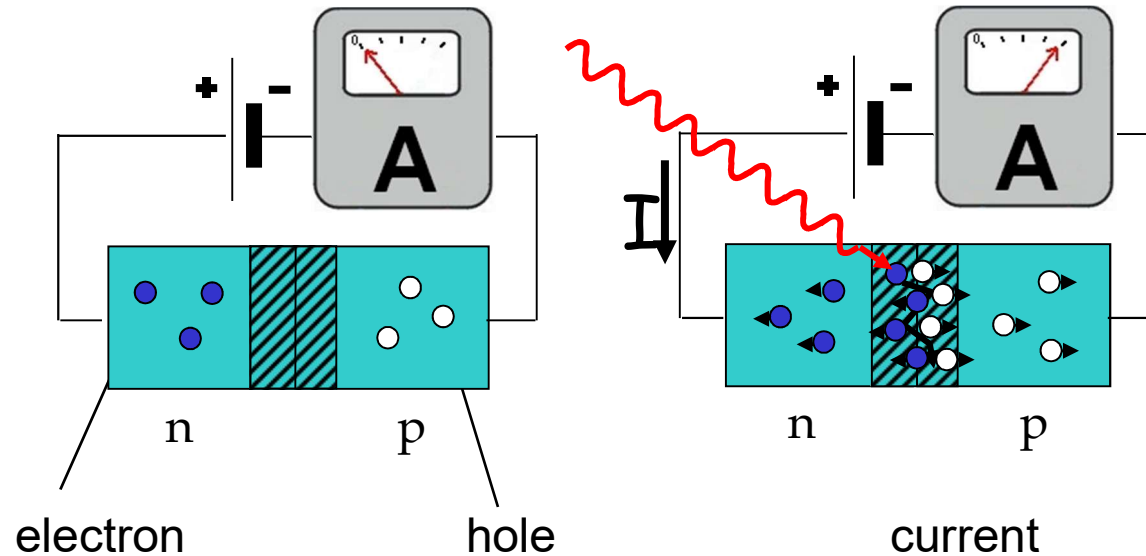
1.3. Thermoluminescent dosimeter (TLD)



1.5. Semiconductor detector

Principle: Semiconductor diode connected reverse biased.

The radiation induces free charges and consequently current.



Diagnostics
Flat panel detector



Dosi-
méter

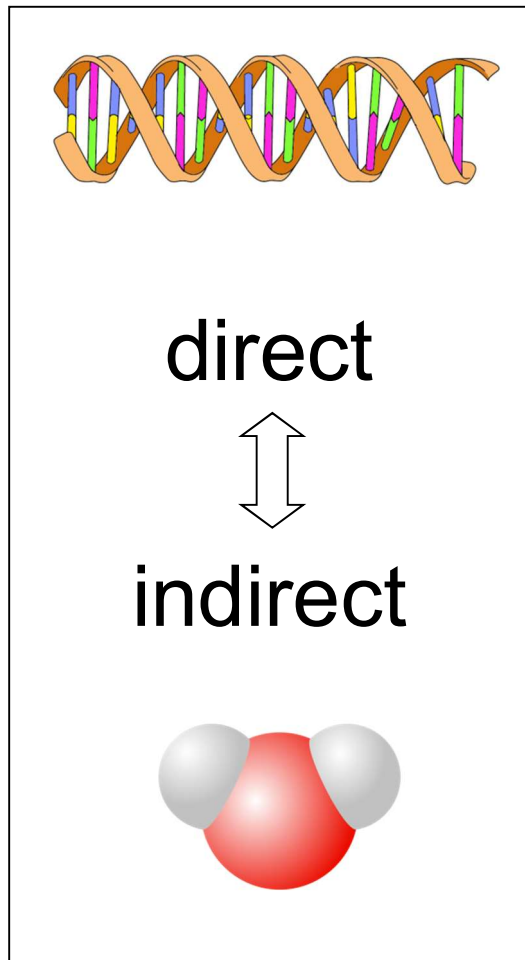


2. Biological effect of the ionizing radiation



- 2.1. Mechanism of the radiation damage
- 2.2. Types of the radiation damages
- 2.3. Dose concepts
- 2.4. Absorbed dose of a γ -emitting isotope
- 2.5. Threshold dose values of deterministic damage
- 2.6. Few characteristic dose values

2.1. The mechanism of the radiation damage



Physical phase:

10^{-17} - 10^{-12} s ionisation

Chemical (biochemical) phase:

10^{-10} - 1s: free radical reactions

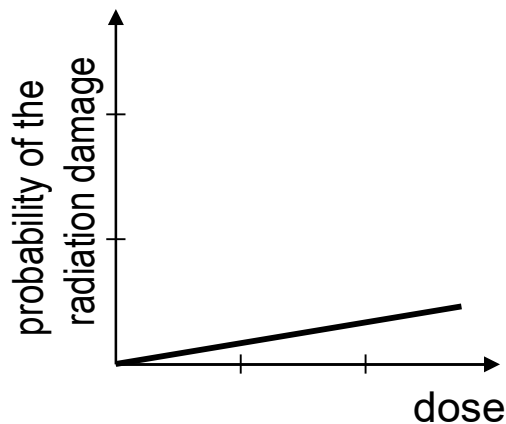
Biological phase:

hours: alteration in the tissues

days-years: stomach-bowel
damage of the
haematogenesis
somatic damage

2.2. Types of the radiation damages

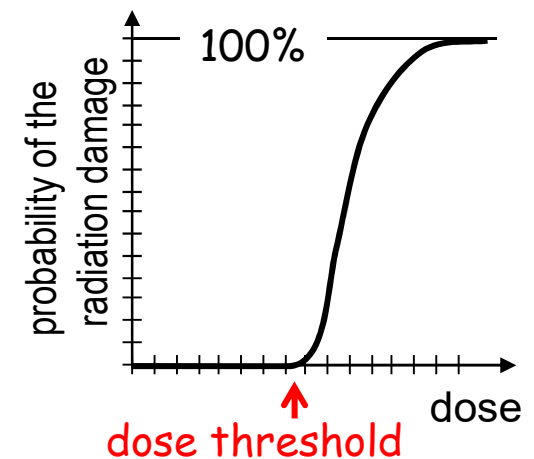
Stochastic



- already at low dose level
- no dose threshold
- severity is independent of the dose
- small number of targets



Deterministic



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



2.3. Dose concepts

2.3.1. Absorbed dose

Absorbed dose:

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

unit J/kg = Gy

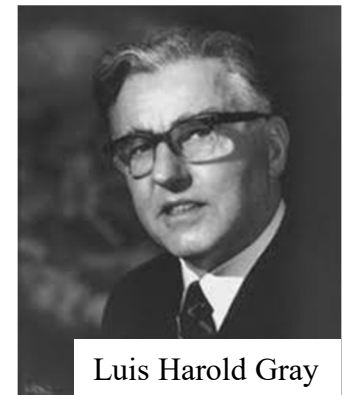
The energy absorbed from the radiation by the mass Δm

absorbed energy by unit mass of absorbing medium

can be used for all types of radiations

How to measure:

- hard to measure directly (unmeasurably small temperature change $\Delta T = 0,0015^\circ\text{C}/\text{Gy}$)
- indirect detection methods:
 - ionisation chamber
 - semiconductor detector
 - thermoluminescent detector
 - ...



2.3.2. Exposure

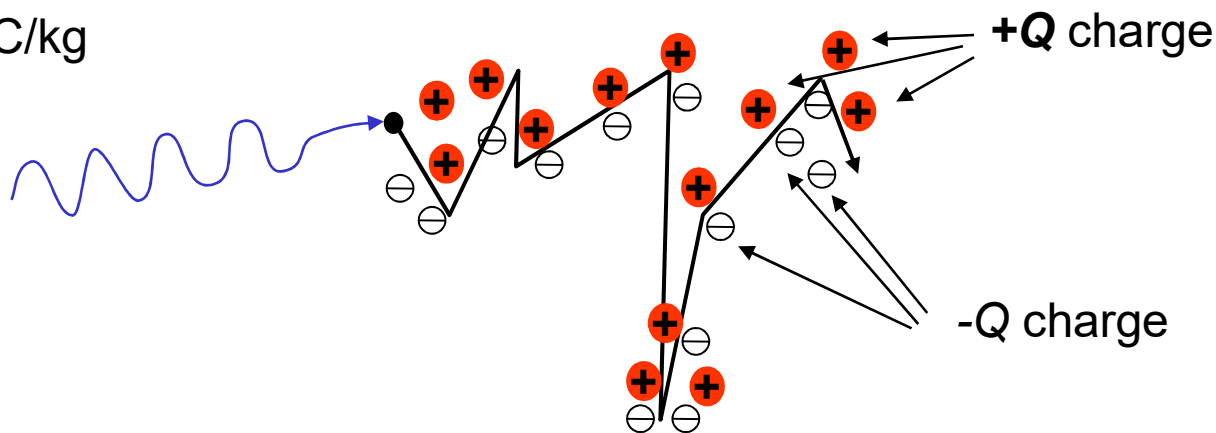
Exposure:

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

*the positive charge produced
in the air of mass Δm*

Only for γ - and x-ray in air!

unit: C/kg



Suitable equipment to measure:

Ionisation chamber.

The produced charges are collected by two electrodes.

2.3.3. Conversion of exposure measured in air to absorbed dose expected in tissue

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

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

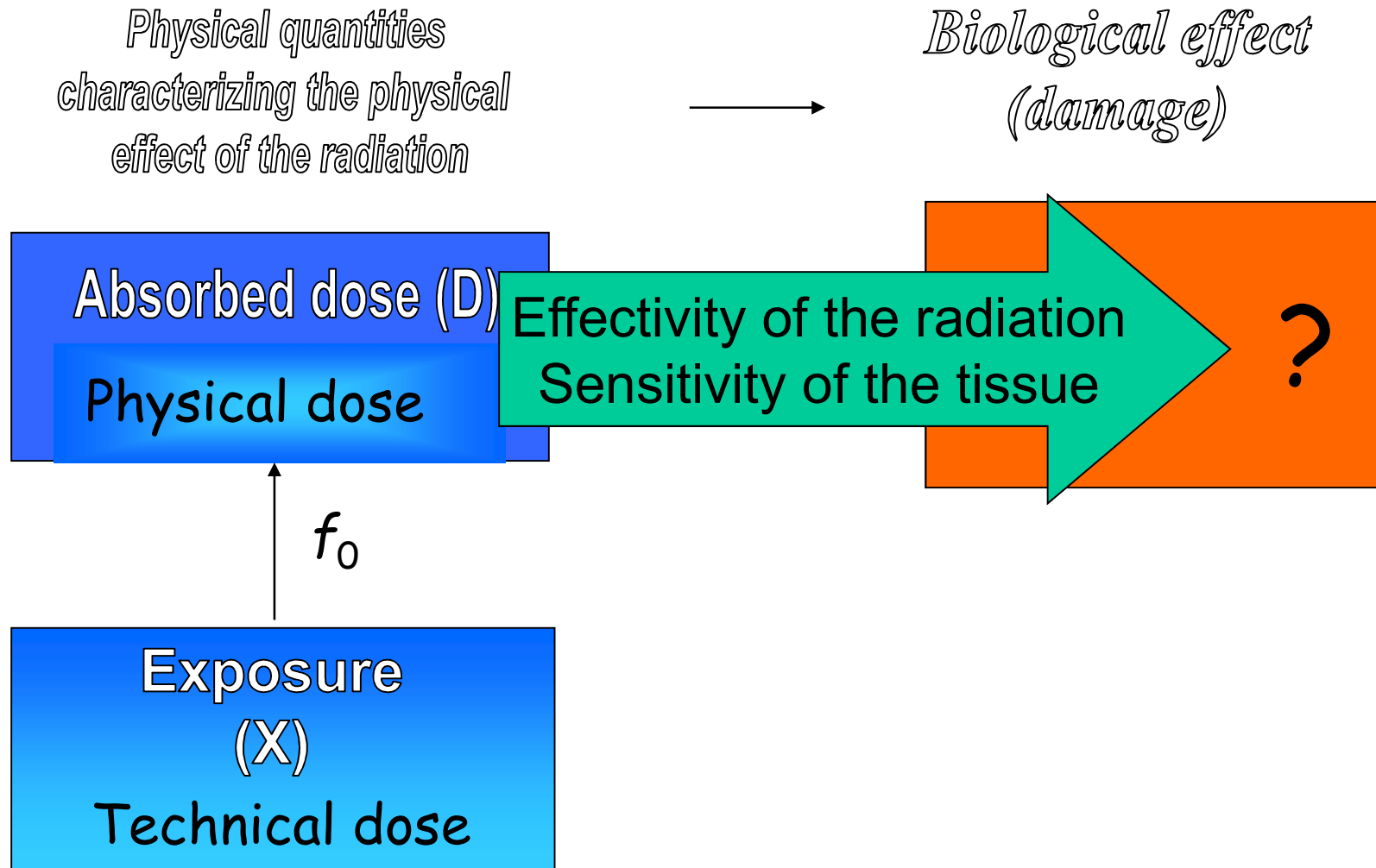
$$1 \frac{\text{C}}{\text{kg}} \Rightarrow 34 \frac{\text{J}}{\text{kg}} = 34 \text{ Gy}_{\text{air}}$$

- Absorption of air and tissue with the same mass will be compared using the mass attenuation coefficients:

$$\frac{D_{\text{tissue}}}{D_{\text{air}}} = \frac{\mu_{m,\text{tissue}}}{\mu_{m,\text{air}}} \quad \longrightarrow \quad D_{\text{tissue}} = \frac{\mu_{m,\text{tissue}}}{\mu_{m,\text{air}}} \overbrace{f_0 X}^{D_{\text{air}}} \quad \text{where} \quad f_0 = 34 \frac{\text{J}}{\text{C}}$$

If $E_{\text{photon}} < 0,6 \text{ MeV}$, for soft tissue: $\frac{\mu_{m,\text{tissue}}}{\mu_{m,\text{air}}} \approx 1,1$

Physical dose concepts and their biological effect



The biological damage can be

→ **Deterministic effect** (e.g. radiotherapy)

typically

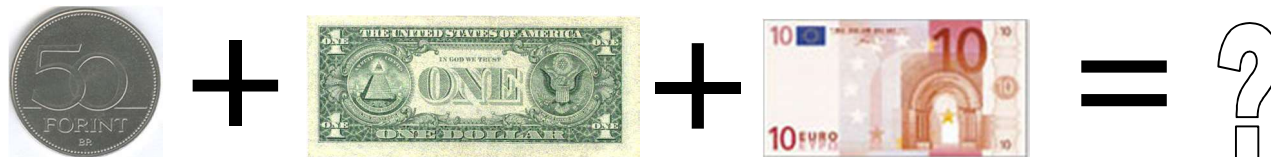
- single type of radiation is used
- single type of tissue is irradiated



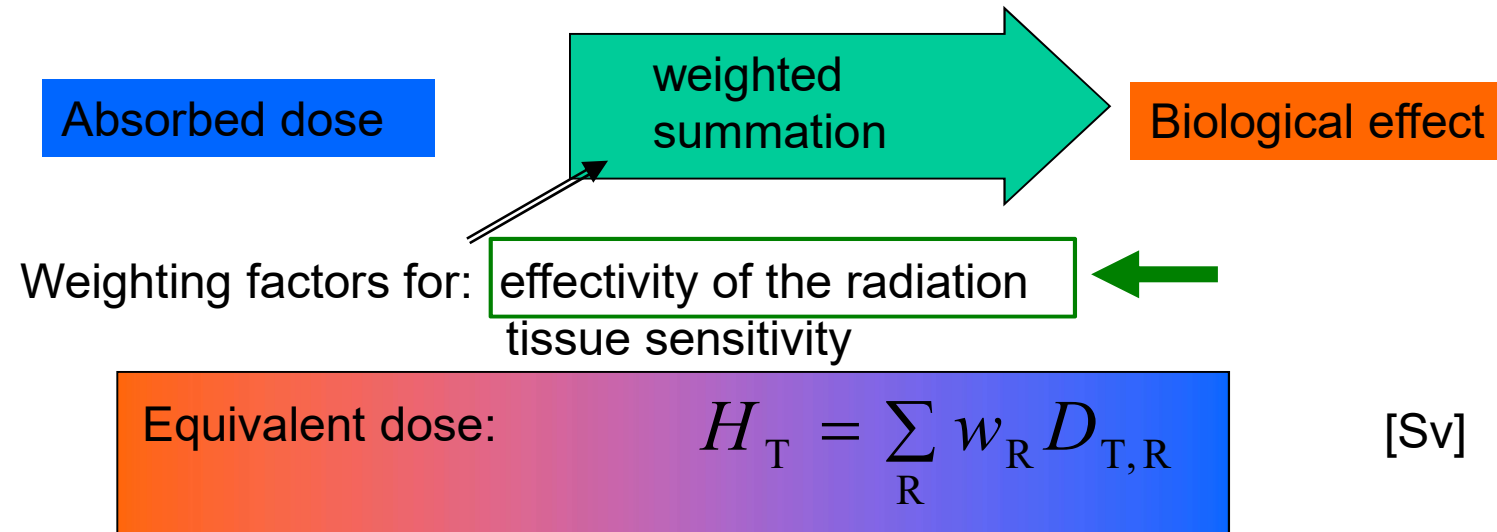
→ **Stochastic effect** (e. g. in diagnostics, radiation protection)

typically

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



2.3.4. Equivalent dose



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

$$\text{E.g.: } H_{\text{skin}} = w_{\alpha} D_{\text{skin},\alpha} + w_{\beta} D_{\text{skin},\beta} + w_{\gamma} D_{\text{skin},\gamma}$$

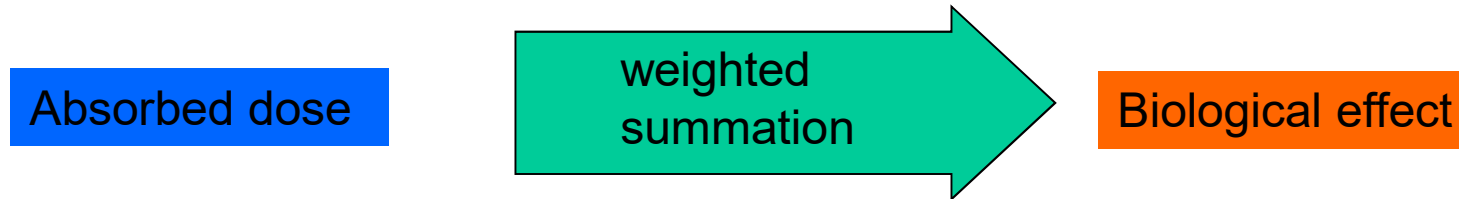
radiation weighting factor (w_R)

How many time higher stochastic biological effect can be expected compared to x-ray or γ -ray with the same absorbed dose.

Radiation	w_R
Photon (γ , x-ray)	1 (def!)
Electron (β)	1
Neutron	Energy dependent
Proton	2
Alpha	20



2.3.5. 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.

For a homogenous irradiation of the whole body: $E = H_T$

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

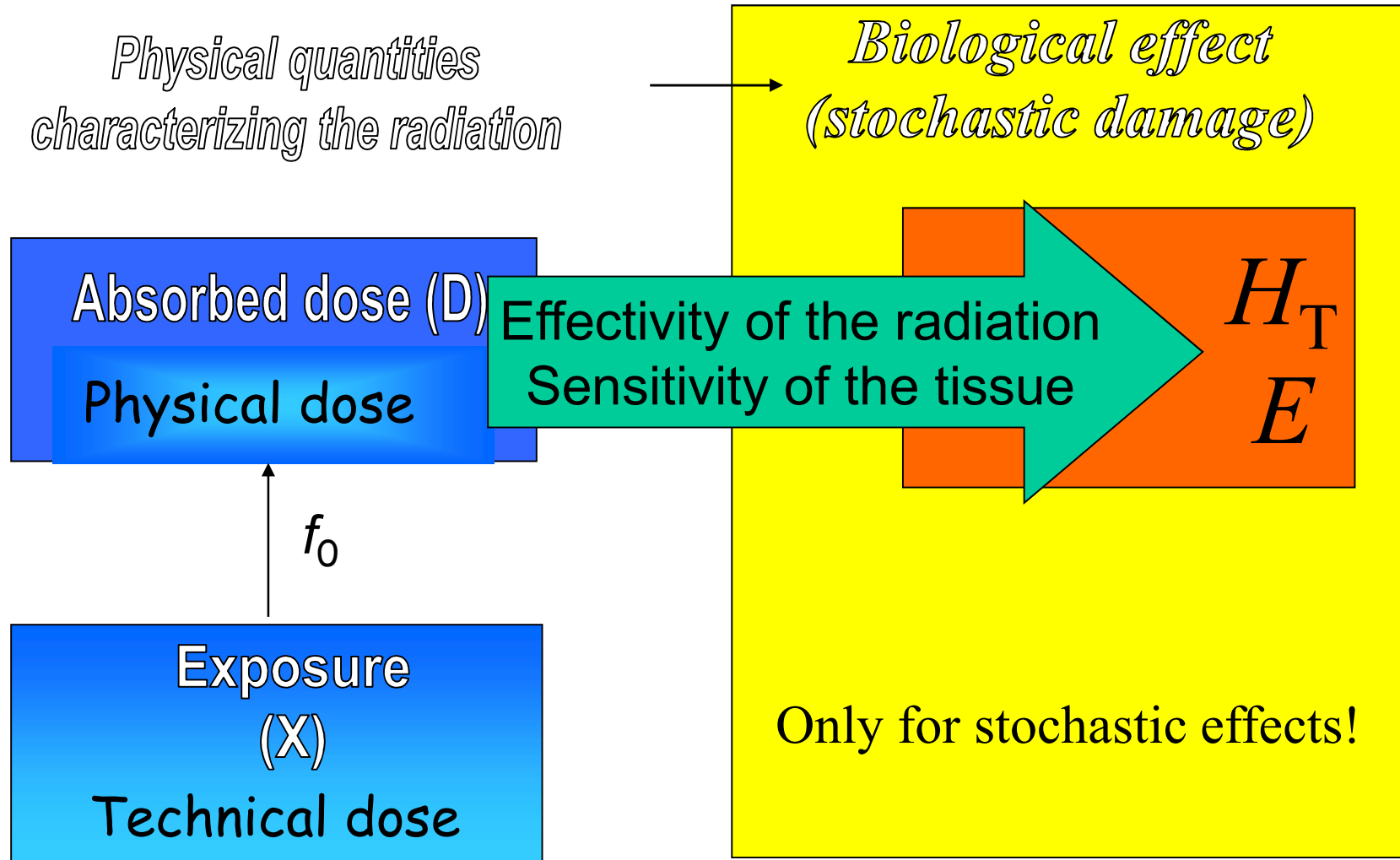
Table 3.4. Weighting factors of various tissues and organs

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		

International Commission on Radiological Protection ICRP Guidelines #116.

*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



Remark: Dose rate = Dose/time e.g.: D/t = absorbed dose rate

2.4. Calculation of absorbed dose of a γ -emitting isotope

In case of point radiator:

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

K_{γ} : dose constant [$\frac{\mu\text{Gy} \cdot \text{m}^2}{\text{h} \cdot \text{GBq}}$]
 Λ : Activity [Bq]
 r : distance from the isotope [m]
 t : time [s,h]

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

⇒ 1GBq ^{137}Cs causes 80 $\mu\text{Gy/h}$
 Absorbed dose rate in 1 m distance

800 x background radiation level

Effective strategies to protect yourself:

Use the least possible activity
 As fast as possible
 Keep distance

2.5.Threshold dose values 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 (LD₅₀) : 4 Gy

lethal dose

6 Gy

2.6. 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: typically 45-60 Gy (in fractions, localized)



3. Radiation protection

3.1. Basic concepts

For personnel:

Justification

Optimization

Reduction of the stochastic effect on an acceptable level

Dose limits

Rule out the deterministic effect

Patients:

Justification

Cost-benefit principle

Optimization

No dose limits!

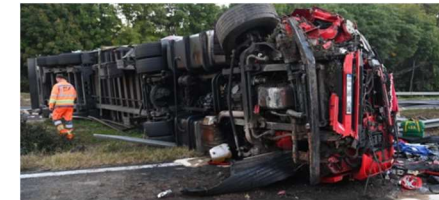
Measurement and documentation of patient dose values

3.2. The concept of dose limitations

- Avoid deterministic damage
- The risk associated to the radioactive work should not exceed the risk of ordinary professional activities. (E.g.: construction work, transport, chemical factory.etc.)

Dose limit \neq allowed dos!

Dose limits: staff
population
~~patient~~ **no limits !**



Patient: cost-benefit principle

diagnose with radiation
risk of radiation damage

without diagnose
risk of progression of an undiagnosed disease

3.3. Dose limits*

≠allowed dose!

3.3.1. For staff members (working with ionizing radiation)

– whole body and eye lens: 20 mSv/ year

(c.a. 10 μSv/working hour)**

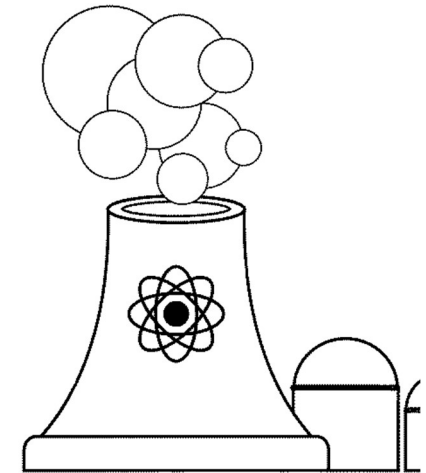
– skin and limb 500 mSv/year

3.3.2. For public***

– whole body 1 mSv/ year****

– eye lens 15 mSv/year

– skin 50 mSv/year



*changed compared to the values in the textbook!!

**compare with background radiation level: $\approx 0,1 \mu\text{Sv/h}$

***only for disis from artificial sources

(excluding the medical use of radiation)

****compare with bacground radiation level : $\approx 2,4 \text{ mSv/év}$