Nuclear measurement techniques. Dosimetry, radiation protection.

- properties
- measurement
- dosimetry
- medical applications

of the nuclear radiation

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1. Detection of the ionizing radiation

1.1. scintillation based methods

1.2. gas-ionization detectors see prectical exc!

1.3. thermoluminescent dosimeter

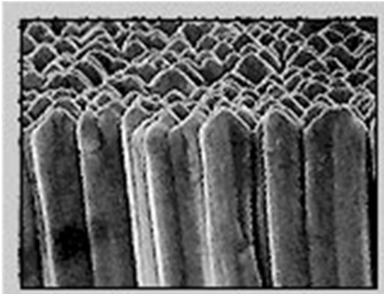
1.4. ~~photographic methods (film)~~ obsolete

1.5. semiconductor detectors

1.1 Scintillation counter

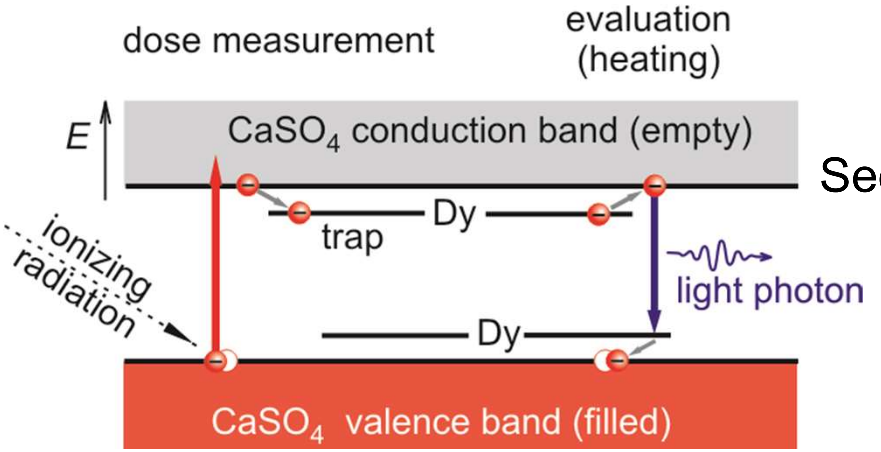
see practical exc.

Heart investigation using γ kamera



Needle crystals for imaging

1.3. Thermoluminescent dosimeter (TLD)

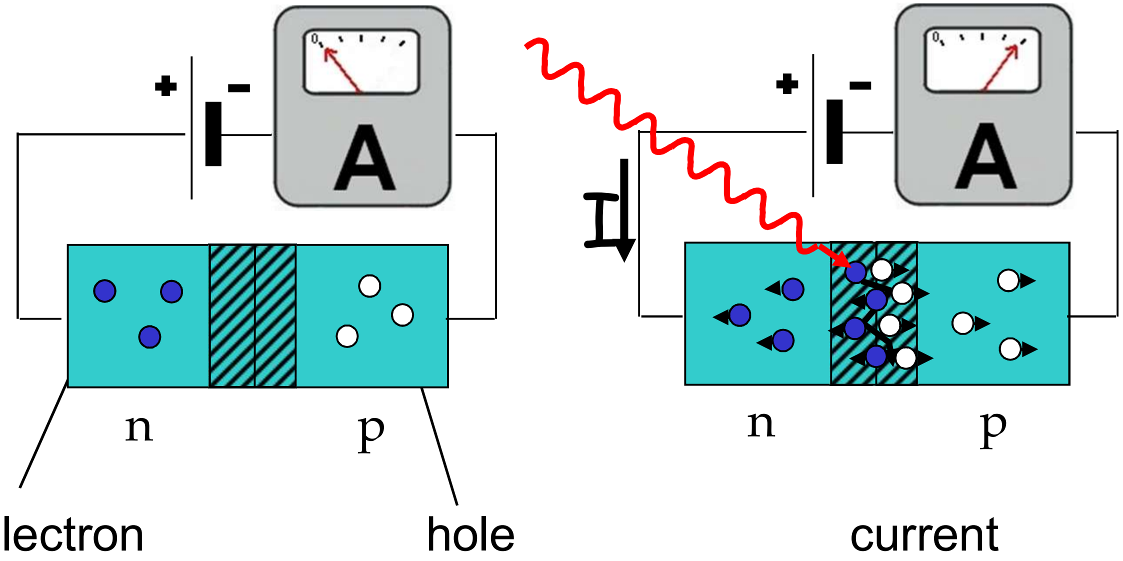


See practical exc. →

1.5. Semiconductor detector

Principle: Semiconductor diode connected reverse biased.

The radiation induces free charges and consequently current.

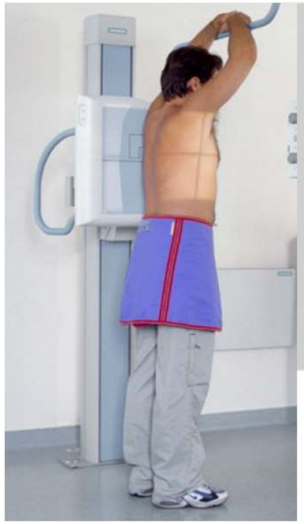


Diagnostics

Flat panel detektor

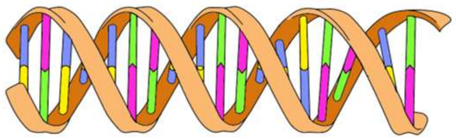
Dosi-
méter

2. Biological effect of the ionizing radiation




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

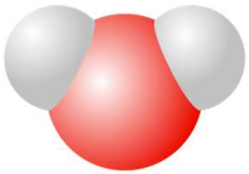
2.1. The mechanism of the radiation damage



direct

⇕

indirect



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

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

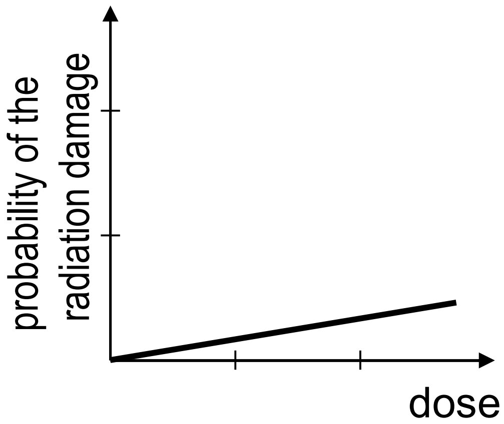
Biological phase:

hours: alteration in the tissues

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

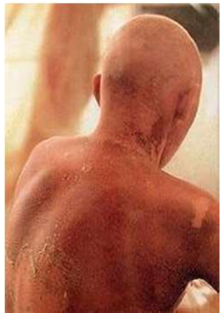
2.2. Types of the radiation damages

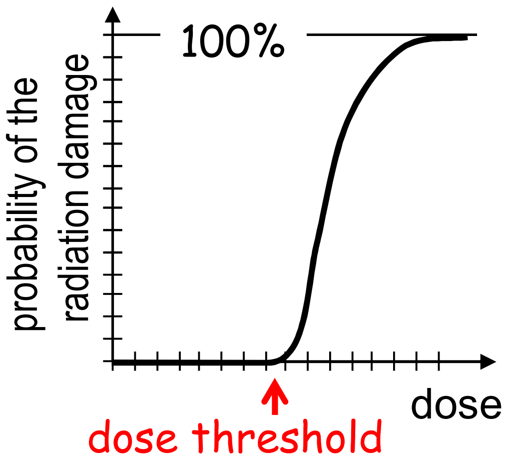
Stochastic



- 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:

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

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

How to measure:

- hard to measure directly (unmeasurably small temperature change ΔT = 0,0015°C/Gy)
- indirect detection methods:
  - ➢ionisation chamber
  - ➢semiconductor detector
  - ➢thermoluminescent detector
  - ➢...


Luis Harold Gray

2.3.2. Exposure

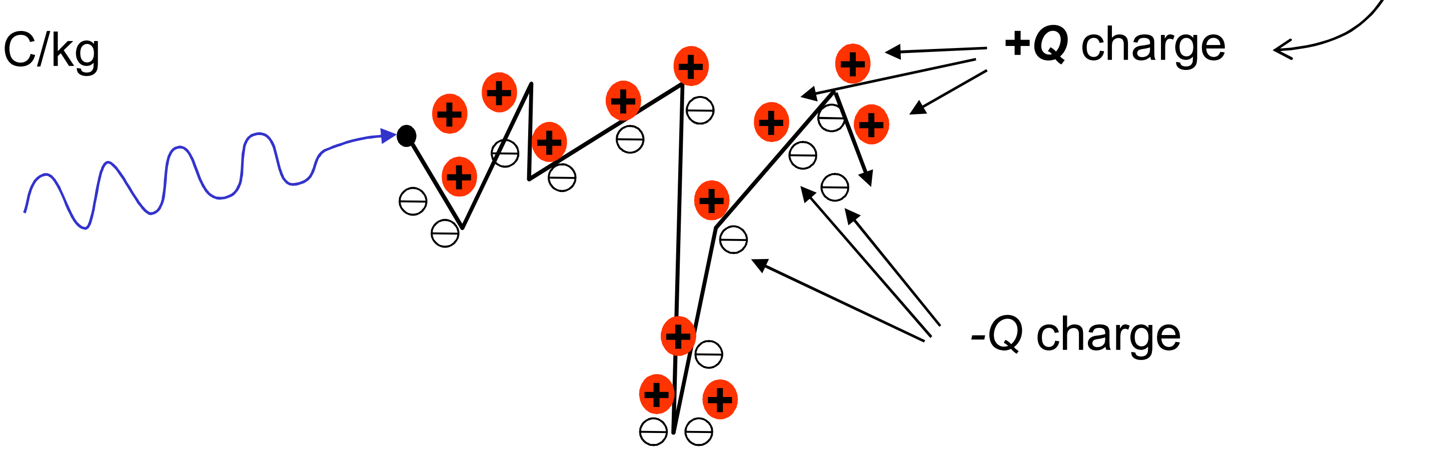
Exposure:

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

the positive charge produced in the air of mass Δm

Olny 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:

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

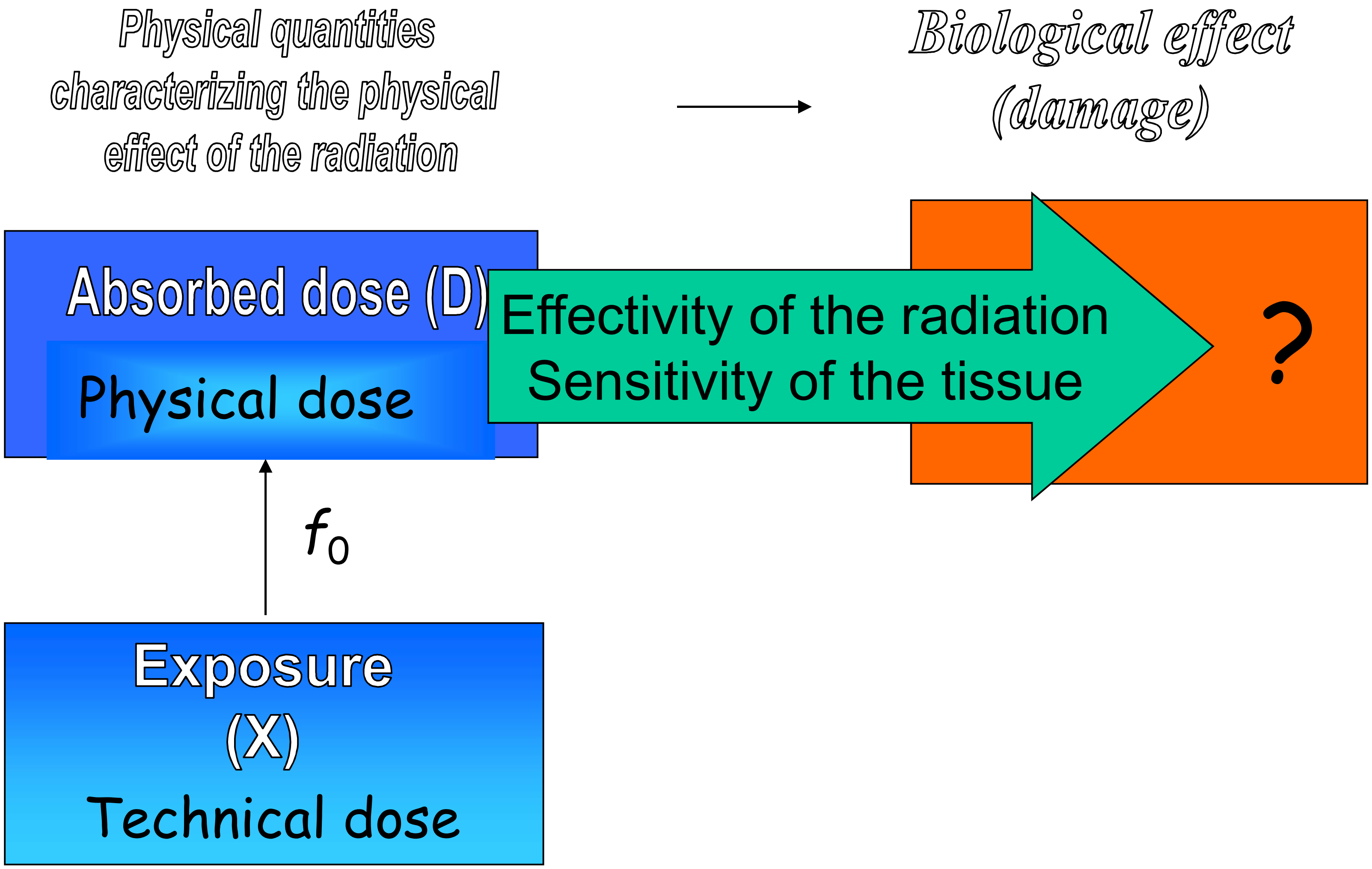
$$1\frac{\mathrm{C}}{\mathrm{kg}} \Rightarrow 34\frac{\mathrm{J}}{\mathrm{kg}} = 34\,\mathrm{Gy}_{\mathrm{air}}$$

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

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

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

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

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

2.3.4. Equivalent dose

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.

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

radiation weighting factor (w_R)

How many time higher stochastic biologcal 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:

Absorbed dose → weighted summation → Biological effect

Weighting factors for: effectivity of the radiation

tissue sensitivity ←

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

Weighted sum of the equvivalent 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 irraditation 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

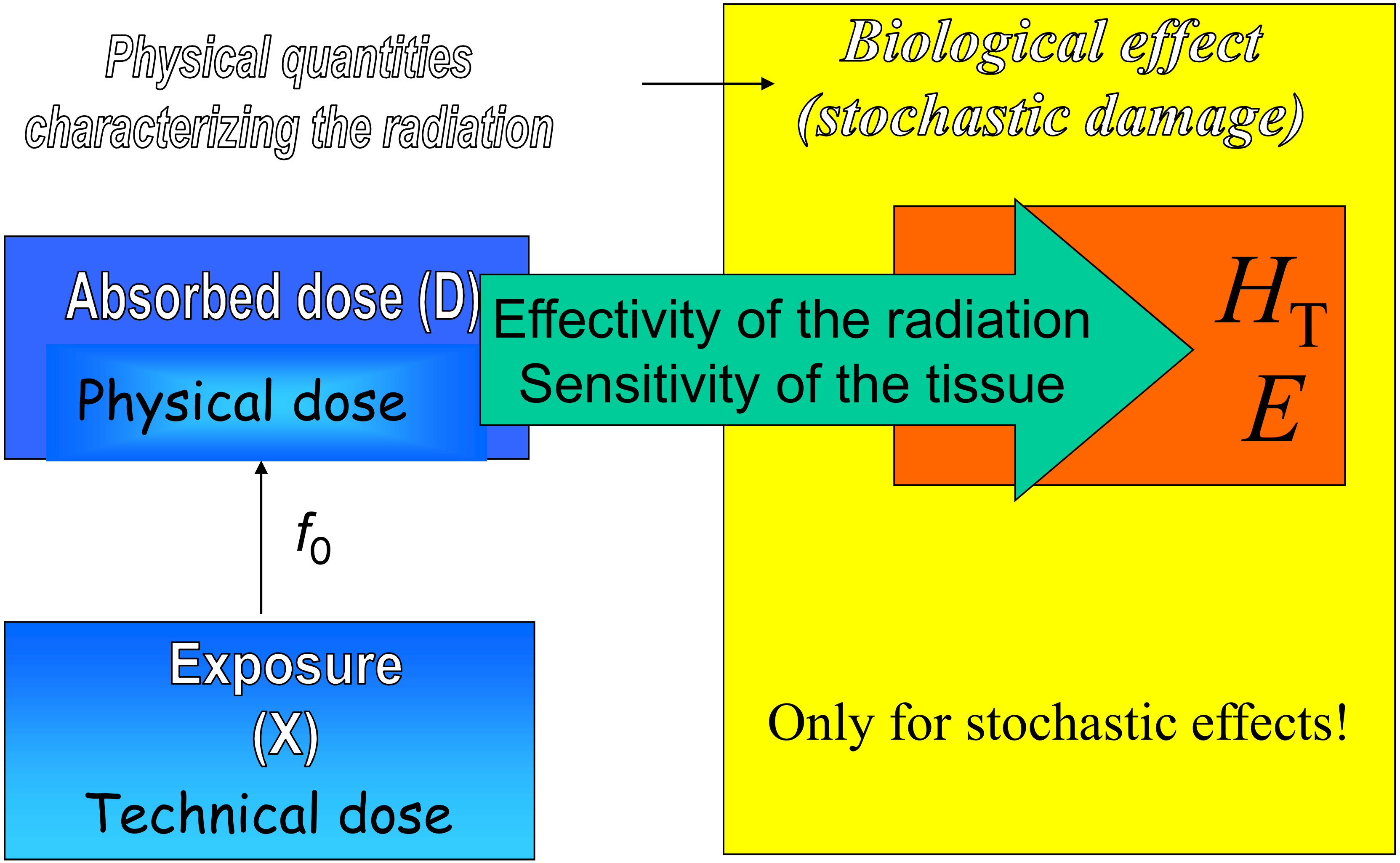
Table 3.4. Weighting factors of various tissues and organs

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 Guidlines #116.

*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



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

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

$\Rightarrow$ 1GBq ^{137}Cs causes 80 μGy/h
Absorbed dose rate in 1 m distance

800 x backgroud 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 (LD_{50}) : 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: tipically 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 exced the risk of ordinary professonal activites. (E.g.: constuction work, transport, chemical factory.etc.)

Dose limit ≠ 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.10μSv/working hour)**

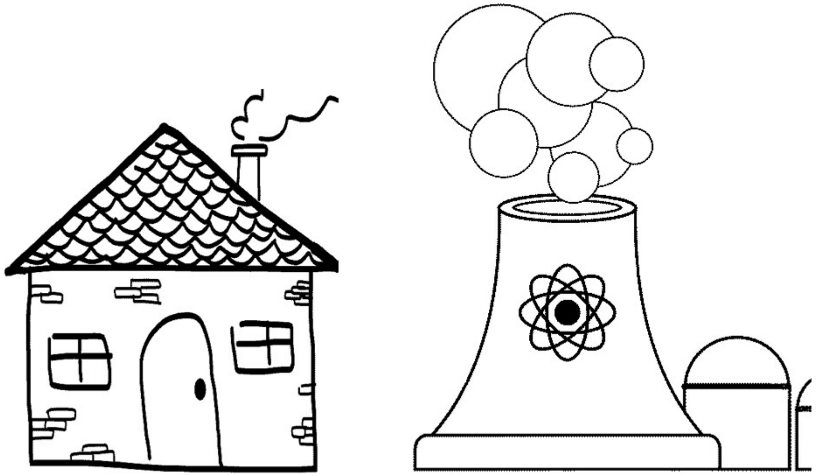
– skin and limb 500 mSv/year

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: ≈ 0,1 μSv/h

***only for disis from artificial sources
(excluding the medical use of radiation)

****compare with bacground radiation level : ≈ 2,4 mSv/év

Few important remarks:dose limits and risks

Life is dangerous!

Risk cannot be avoided, but it can be reduced to a rationally acceptable level.

risk ↔ benefit