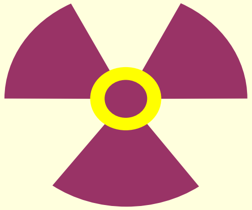
# Dosimetry

# of

# ionizing radiation



## Ionizing radiation

Classification according to the primary effect

↙ ↘

*Direct ionization*

Incoming particles already held charges. E.g. α- and β- particles.

*Indirect ionization*

Primary electrons ejected by the photons and secondary electrons present charges. e.g. γ-radiation, X.ray.

## Ionizing radiation

Discovery
(X-ray, radioactivity etc.)

↓

Application
(enjoy benefits)

☺

↓

Dosimetry
(optimization of benefits, estimation of risk and hazard)

☹

## Task for dosimetry

Estimation of health risk for prevention.

Estimation of biological damages.

Design of therapeutic procedures.

*Definition of quantities*

↓

*Design of measuring techniques*

↓

*Estimation of consequences*

## *1. Dose values sholud be*

- proportional to the damagas and expected risk !
- additiv
- independent of other factors!?

## *Dose concepts*

**Physical dose concepts:**
Absorbed dose,
Exposure

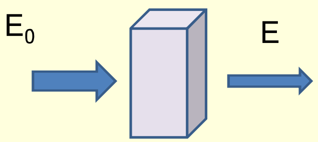
**Biological dose concepts:**
Equivalent dose,
Effective dose

**Derived dose concepts:**
Collective dose,
Dose rate

## 1. Absorbed dose

**measures the absorbed energy in a unit mass**

$\Delta E = E_0 - E$




$$D = \frac{\Delta E}{\Delta m}[J/kg]$$

*Validity*: for any kind of material and any type of radiation without restriction

*Unit:* $[J/kg] \equiv Gy$

Louis Harold Gray (1905-1965).

*How to be measured ????*

$^{131}$I of 0.2 GBq activity is accumulated in 80 g thyroid glands. The effective half-life is 7.5 days . Average β-particle energy is 0.18 MeV. Assume that the particles are fully absorbed in the thyroid glands . What is the absorbed dose in the given tisssue?

$$\Lambda = \frac{\ln 2}{T} N$$

$$N = \frac{0{,}2 * 10^9 [Bq] * 6{,}48 * 10^5 [s]}{0{,}693} = 1{,}87 * 10^{14}$$

$$E_{sum} = N * E$$

$$E = 0{,}18 * 10^6 [eV] = 2{,}88 * 10^{-14} [J]$$

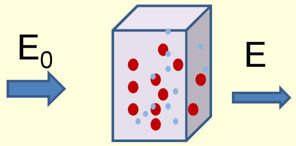
$$E_{össz} = 1{,}87 * 10^{14} * 2{,}88 * 10^{-14} = 5{,}38 [J]$$

$$D = \frac{E_{sum}}{m}$$

$$D = \frac{5{,}38}{0{,}08} = 67{,}28 \left[\frac{J}{kg}\right]$$

## 2. Exposure

**measures the amount of positive or negative charges generated by the radiation in a unit mass.**



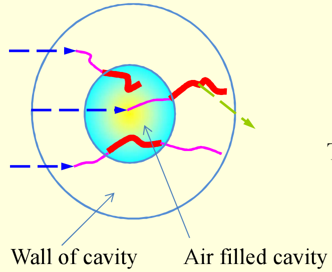

$$X = \frac{\Delta Q}{\Delta m}[C/kg]$$

*Validity*: in the air, only $\gamma$ and X –rays, measured in electron equilibrium*

$$X = \frac{\Delta Q}{\Delta m}[C/kg]$$

$\Delta Q$ – secondary electrons!!

***Electron-equilibrium :*** net number of the secondary electrons living and entering volume of the cavity are equal.




To be considered:

- composition of surrounding material (chamber wall) – **air-equivalent wall!**
- thickness of the wall
- Photon energy: E< 0.6 MeV

## Calculation of the absorbed dose from the exposure

$$X = \frac{\Delta Q}{\Delta m}[C/kg] \qquad D_{air} = f_0 X \qquad D = \frac{\Delta E}{\Delta m}[J/kg]$$

~ 34 J/C

Average ionization energy in air

~ 34 eV.

## Absorbed dose in tissue

$$\frac{\Delta E}{\Delta m} \approx \mu_m \cdot J$$

$$D_{air} = \frac{\Delta E}{\Delta m}[J/kg]$$

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

| Photon energy (MeV) | $\mu_{m,air.}/\mu_{m,tissue}$ (soft tissues) | $\mu_{m,air.}/\mu_{m,tissue}$ (bones) |
|---|---|---|
| 0,1 | 1,07 | 3,54 |
| 0,2 | 1,08 | 2,04 |
| 0,4 | 1,10 | 1,24 |

## *Biological dose concepts*

Equivalent dose

Effective dose

The absorbed energy (absorbed dose) is not sufficient to measure the possible biological consequences.

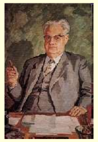
The biological consequences are influenced by :

*the type of radiation.* → radiation weighting factor

*the sensitivity and biological function of target* → tissue weighting factor

## Equivalent dose (H)

Rolf Sievert
1896-1966



„Efficiency" of various forms of radiation is not uniform.

$$H_T = w_R D_T$$

**Radiation weighting factor –** estimation of the relative risk of the given radiation ($w_R$)

Absorbed dose in tissue ($D_T$)

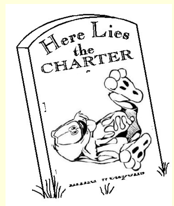
| radiation | $W_R$ |
|---|---|
| photon | 1 |
| electron | 1 |
| neutron | 5-20 |
| proton | 5 |
| α-particle | 20 |

Unit of ***H*** : ***Sievert (Sv)***

## *Why are the fates of the rabbits different?*

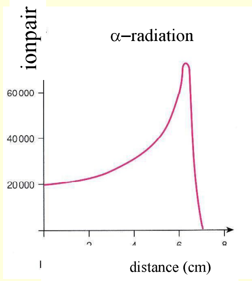
2 Gy absorbed dose – ***X-ray***

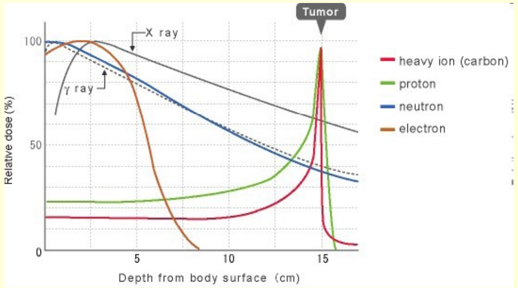
2 Gy absorbed dose – ***α-particles***



# Equivalent dose (H)

„Efficiency” of various forms of radiation is not uniform.



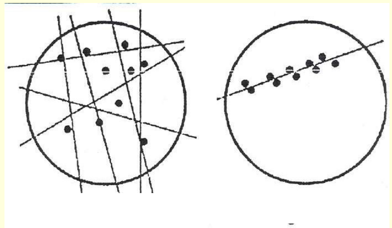




*LET (Linear Energy Transfer* : the energy transferred to the material surrounding the particle track, by means of secondary electrons. $(nE_{ionpair}/l)$

# Equivalent dose (H)

„Efficiency” of various forms of radiation is not uniform.

$$H_T = w_R D_T$$

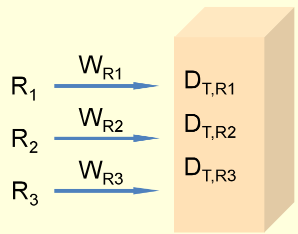


Small LET
e.g. γ, -ray

High LET
e.g.. α, proton

| radiatiom | $W_R$ |
|---|---|
| photon | 1 |
| electron | 1 |
| neutron | 5-20 |
| proton | 5 |
| α-particle | 20 |

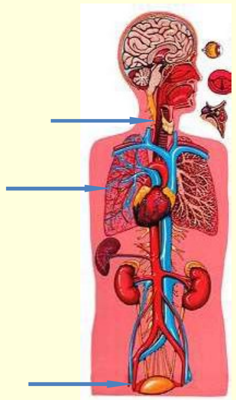
If someone is exposed to more than one type of radiation:




$$H_T = \sum_R w_R D_{T,R}$$

# Effective dose (E)

Various sensitivity of tissues has to be considered



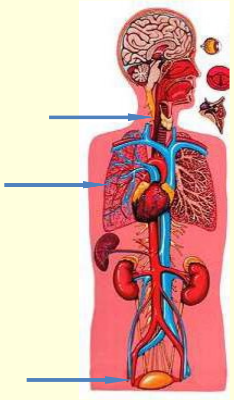
$$E = \sum_T w_T H_T$$

**Tissue weighting factor** – estimation of the relative sensitivity of tissue

**Equivalent dose in the given tissue**

Unit of ***E*** : ***Sievert (Sv)***

$$E = \sum_T w_T H_T$$



| tissue | $W_T$ | tissue | $W_T$ |
|---|---|---|---|
| gonads | 0,2 | breast | 0,05 |
| bone marrow | 0,12 | liver | 0,05 |
| colon | 0,12 | oesophagus | 0,05 |
| lung | 0,12 | thyroid gland | 0,05 |
| stomach | 0,12 | skin | 0,01 |
| bladder | 0,05 | bone surface | 0,01 |

$$\sum_T w_T = 1$$

## Dose rate

Received dose over time.

*Unit:* varies with the type of radiation and the time period (pl. Gy/month, mSv/year etc.)

## Collective dose

Sum of the doses received by a given number of people ($N_i$) in the course of a given time interval.

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Sum of the doses received by a given number of people ($N_i$) in the course of a given time interval.

$$S = \sum_i N_i E_i$$

$E_i$ effective dose in each person

Consider an α-emitting isotope of 5 MBq activity. The energy of the emitted α particles is 6.2 MeV. The total emitted energy is absorbed in 0.1 kg water. Calculate the the absorbed dose in the water after half an hour irradiation. (There is no significant change in the activity of the radioactive sample during the time of the experiment.)

$\Lambda$=5 MBq, azaz $5*10^6$ decay/s

N=$5*10^6 * 1800 = 9*10^9$ decay in half an hour

$E_{abs}=E_\alpha*N$ $\quad$ $E_{abs}=6.2*10^6 eV* 9*10^9$

$E_{abs}=5,58*10^{16}$ eV=$8,92*10^{-3}$ J

$$D = \frac{E_{abs}}{m} = \frac{8.92*10^{-3}}{0.1} = 8.92*10^{-2}[Gy]$$

Consider an α-emitting isotope of 5 MBq activity. The energy of the emitted α particles is 6.2 MeV. The total emitted energy is absorbed in 0.1 kg water. Calculate the temperature change of the water after half an hour irradiation. (There is no significant change in the activity of the radioactive sample during the time of the experiment.)

$\Lambda$=5 MBq, azaz $5*10^6$ decay/s

$N=5*10^6 * 1800 = 9*10^9$ decay in half an hour

$E_{abs}=E_{\alpha}*N$ $\quad E_{abs}=6.2*10^6 eV * 9*10^9$

$E_{abs}=5,58*10^{16}\,eV=8,92*10^{-3}\,J$

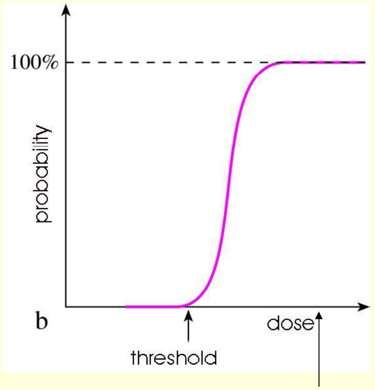
$E_{abs}=c*m*\Delta T$

$$\Delta T = \frac{8.92*10^{-3}}{4.18*10^{3*0.1}} = 2.1*10^{-5}$$

# Types of damages

***Deterministic damages*** ***Stochastic damages***

## Deterministic damages




**Gy**

**Under threshold**: $p=0$

## Deterministic damages

A threshold dose exists.

Above threshold severity depends on the dose.

Appear soon after exposition.

Must not be induced during diagnostic procedures.

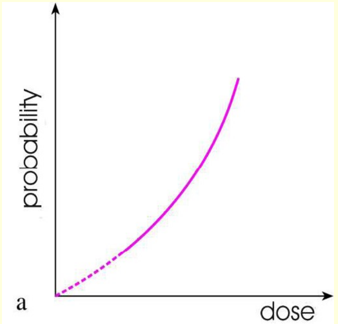
e.g. erythema, epilation, cataract

*1% lethal 60 days after exposition

| Dose (Gy) (whole body) | Biological effect |
|---|---|
| < 0,15-0,2 | No observable effect |
| 0,5 | Slight blood changes – limit of detection by hematological methods. |
| 0,8 | Critical dose – threshold of acute radiation syndrome |
| 2,0 | Minimal lethal dose (LD1/60)* |
| 4,0 | Half lethal dose (LD50/60) |
| 7,0 | Minimal absolute lethal dose (LD99/60) |

Chest X-ray: cc 160 μGy in the skin

## Stochastic damages




NO threshold!

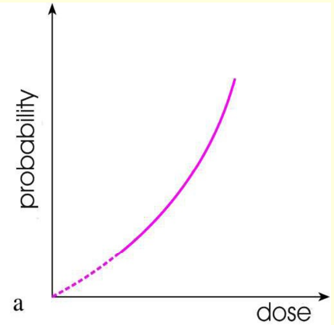
The probability of stochastic damage depends on the dose.

Severity (e.g. cancer) independent of the dose.

Delayed biological effects.

e.g.tumours, heriditary diseases

## Stochastic damages




Sv

$H_T$ (equivalent dose) and E (effective dose) provide a basis for ***estimating the probability of stochastic effects*** for doses below the threshold of deterministic effects.

Dose range is under the threshold of deterministic damages.

## Stochastic damages

Irradiated cell is modified rather than killed

Severity is not effected by the dose

With increasing dose only the probability* increases

*1 gamma photon: the probability to cause cancer is $3 \times 10^{-16}$ (1: 3,000 billion, but this is the Russian roulette!)

*Damjanovich, Fidy, Szöllősi: Medical Biophysics*

II. 4.

4.1
4.2
4.3
4.4
4.5

In the frame: 184. 186.

*Manual :Dosimetry*