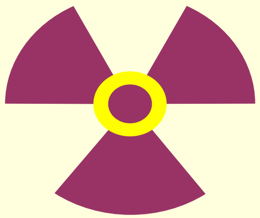
Dosimetry of ionizing radiation



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

Dose concepts

Physical dose concepts:
Absorbed dose,
Exposure

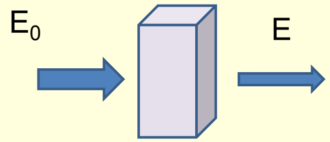
Biological dose concepts:
Equivalent dose,
Effective dose

Derived dose concepts:
Collective dose,
Dose rate

1. Absorbed dose

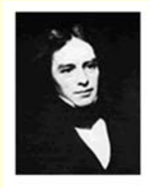
measures the absorbed energy in a unit mass

$\Delta E = E_0 - E$



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

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



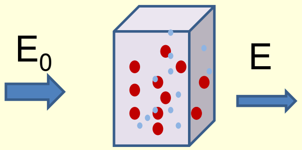
Louis Harold Gray
(1905-1965).

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

How to be measured ????

2. Exposure

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



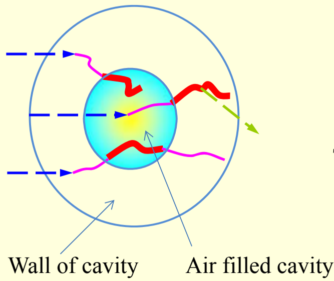
$$X = \frac{\Delta Q}{\Delta m}[C/kg]$$

Validity: in the air, only γ and X –rays, measured in electron equilibrium*

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

ΔQ – 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.

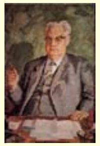
The biological consequences are influenced by :

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

Absorbed dose in tissue

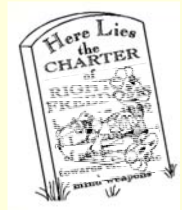
radiation	W_R
photon	1
electron	1
neutron	5-20
proton	5
α-particle	20

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)

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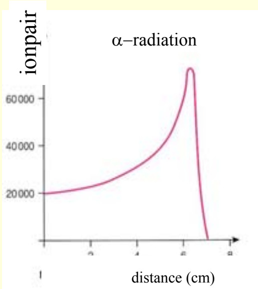
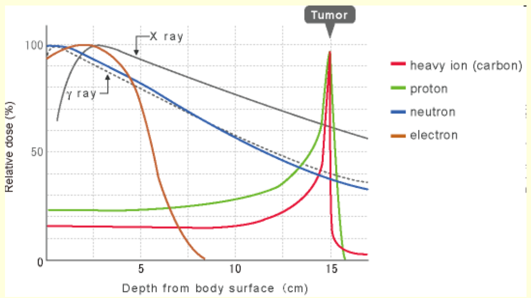


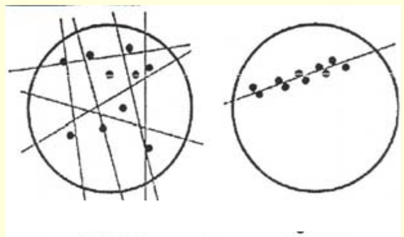


LET (Linear Energy Transfer : the energy transferred to the material surrounding the particle track, by means of secondary electrons. *($nE_{ionpair}/l$)*

Equivalent dose (H)

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

$$H_T = w_R D_T$$

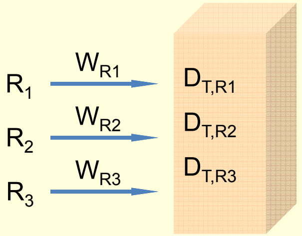


Small LET
e.g. γ, -ray

High LET
e.g.. α, proton

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

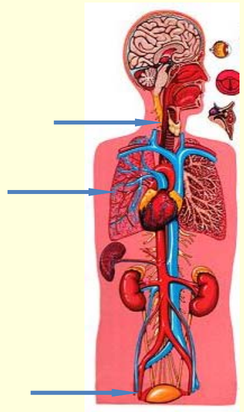
If someone is exposed to more than one type of radiation:



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

Effective dose (E)

Various sensitivity of tissues has to be considered



$$E = \sum_T w_T H_T$$

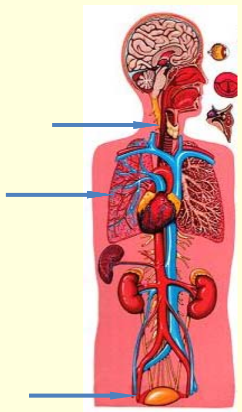
Tissue weighting factor – estimation of the relative sensitivity of tissue

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.

Collective dose

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

Consequences of the absorption of ionizing radiation.

1. Physical events

   Direct or indirect ionization

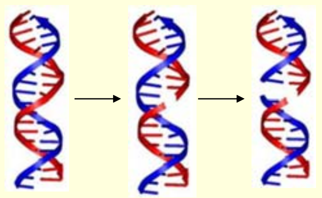
2. Chemical reactions

   Direct or indirect reactions

Direct effect

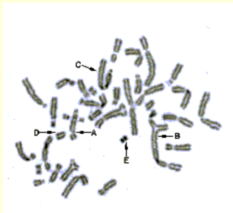
Direct ionization of the macromolecules.

DNA damage is the most important!



single double

strand breaks



chromosome aberrations

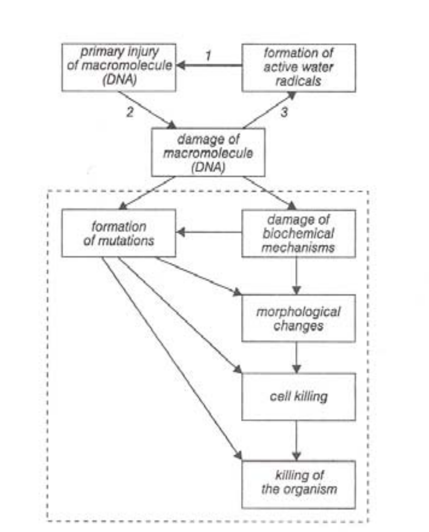
Indirect effect

Reactive ions (e.g. OH^-) and/or radicals (e.g. *OH) are generated manly from water molecules.
(65-70% of the human body is water)

↓

Reactive species induce damages in macromolecules and membrane structures.

3. Biological consequences



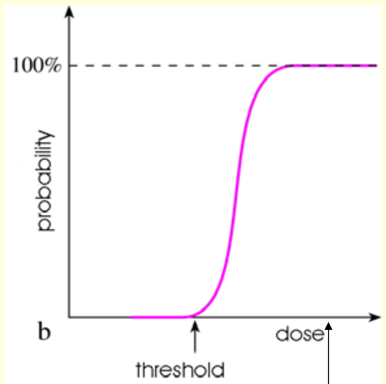
Timescale of events

Physical	10^{-20} – 10^{-8} s	Ionization, excitation
Chemical	10^{-18}– 10^{-9} s	Direct/indirect chemical reactions
	10^{-3} – few hours	Repair of damages
Early biological	hours – weeks	Cell death, death of living system
Delayed biological	years	Carcinogenesis, genetic transformation

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.

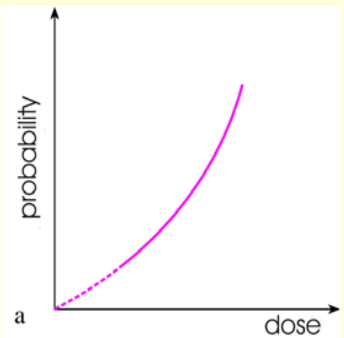
e.g. erythema, epilation, cataract

*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!

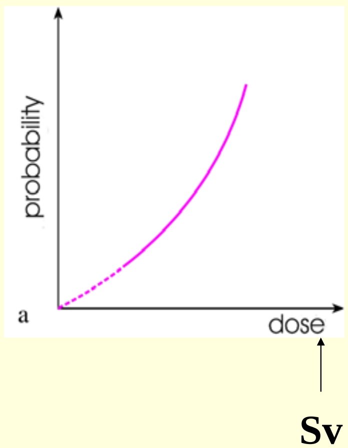
The probability of stochastic damage depends on the dose.

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

Delayed biological effects.

e.g.tumours, heriditary diseases

Stochastic damages



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 3×10^{-16} (1: 3,000 billion, but this is the Russian roulette!)

examination	Approximate effective doses mSv
Chest X-ray	0,04
Chest CT	7,8
Cranial CT	1,8
Abdominal X-ray	1,2
Abdominal CT	7,6
X-ray of the dorsal vertebrae	1,0
X-ray of the lumbar vertebrae	2,1
Barium enema with fluoroscopy	8,7

Radiotherapy

Irradiation results ***deterministic effects*** (tumour cell kill) - in this context some deterministic effects and stochastic effects must be tolerated (side effects)

Radiation protection

The aim is to ***exclude deterministic effects***
and
minimize the risk of ***stochastic effects***.

Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 4.
4.1
4.2
4.3
4.4
4.5
In the frame: 184. 186.

Manual :Dosimetry