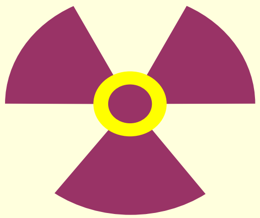
Dosimetry of ionizing radiation



Ionizing radiation

Classification according to the primary effect

↙ ↘

Direct ionization	*Indirect ionization*
Incoming particles already held charges. E.g. α- and β-particles.	Primary electrons ejected by the photons and secondary electrons present charges. e.g. γ-radiation, X.ray.

Ionizing radiation

☺

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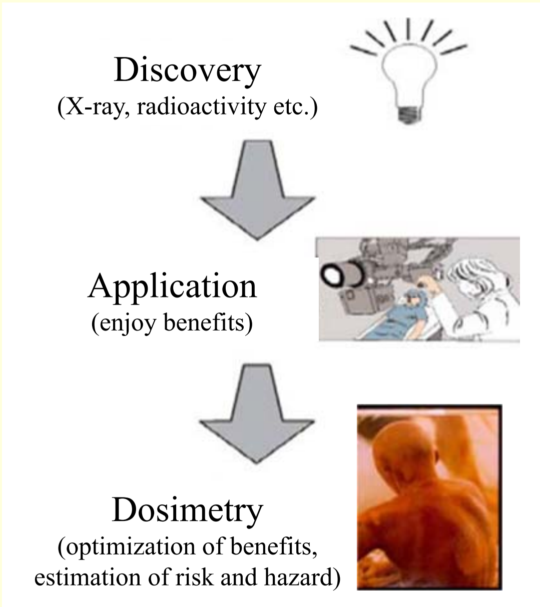


Task for dosimetry

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. Quantities, i.e. dose concepts

They should be

- proprtional to the severity and probable consequence of damage!
- additive!
- 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

Physical dose concepts

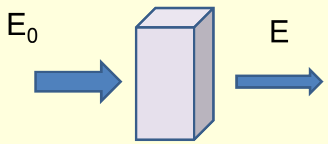
Absorbed dose

Exposure

1. Absorbed dose

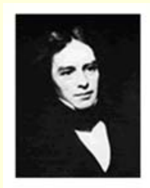
measures the absorbed energy in a unit mass

$\Delta E = E_0 - E$



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

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



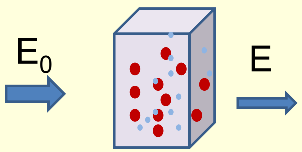
Louis Harold Gray
(1905-1965).

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.



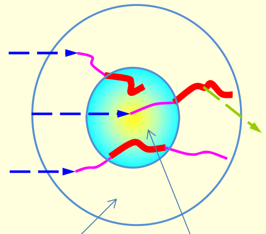
$$X = \frac{\Delta Q}{\Delta m}[C/kg]$$

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

Absorbed dose in tissue

E> 0.6 MeV

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

Electron energy (MeV)	$s_{m,carbon}/s_{m,air.}$
1.0	0.985
3.0	0.946

s_m: mass stopping power (LET)

Biological dose concepts

Equivalent dose

Effective dose

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

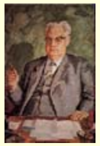
The biological consequences are influenced by :

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)

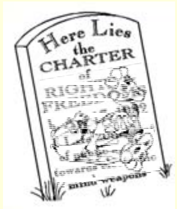
Unit of ***H*** : ***Sievert (Sv)***

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

Why are the fates of the rabbits different?

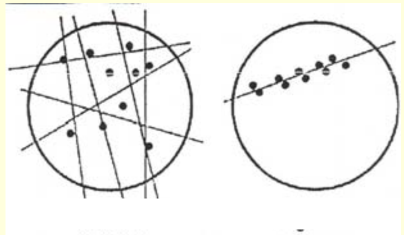
2 Gy absorbed dose – ***X-ray***

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



Equivalent dose (H)

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



Small LET
e.g. γ, -ray

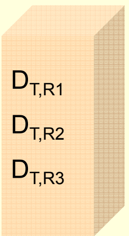
High LET
e.g.. α, proton

$$H_T = w_R D_T$$

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:

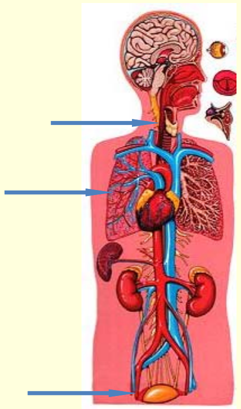
R_1 W_{R1} →
R_2 W_{R2} →
R_3 W_{R3} →



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

Effective dose (E)

Various sensitivity of tissues has to be considered



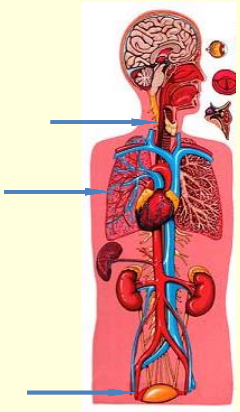
$$E = \sum_T w_T H_T$$

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

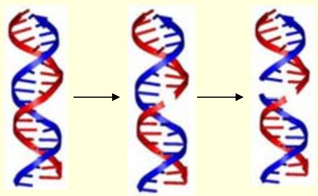
2. Chemical reactions

Direct or indirect reactions

Direct effect

Direct ionization of the macromolecules.

DNA damage is the most important!



single double

strand breaks

chromosome aberrations

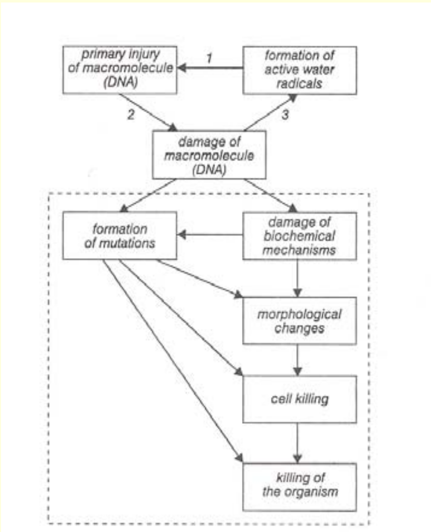
Indirect effect

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



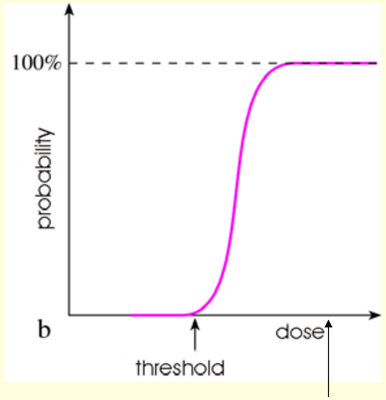
Timescale of events

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.

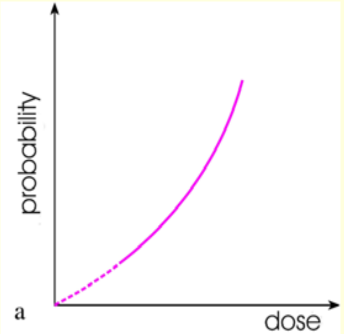
e.g. erythema, epilation, cataract

*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



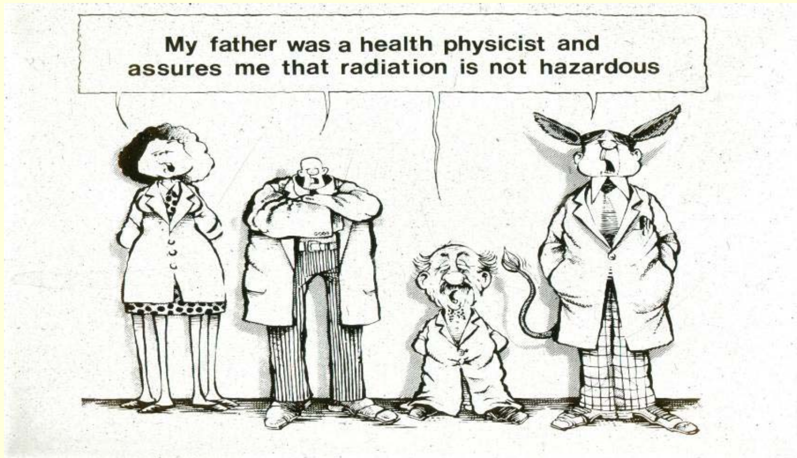
NO threshold!

The probability of stochastic damage depends on the dose.

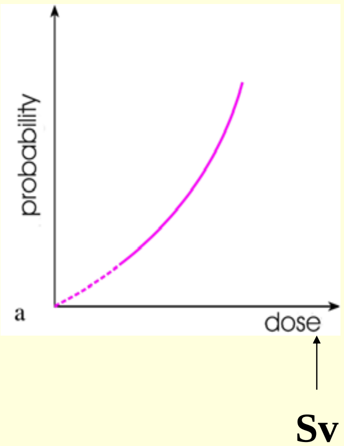
Severity (e.g. cancer) independent of the dose.

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***.

Estimated average of annual dose from natural background and man-made sources is 3.6 mSv.

environmental

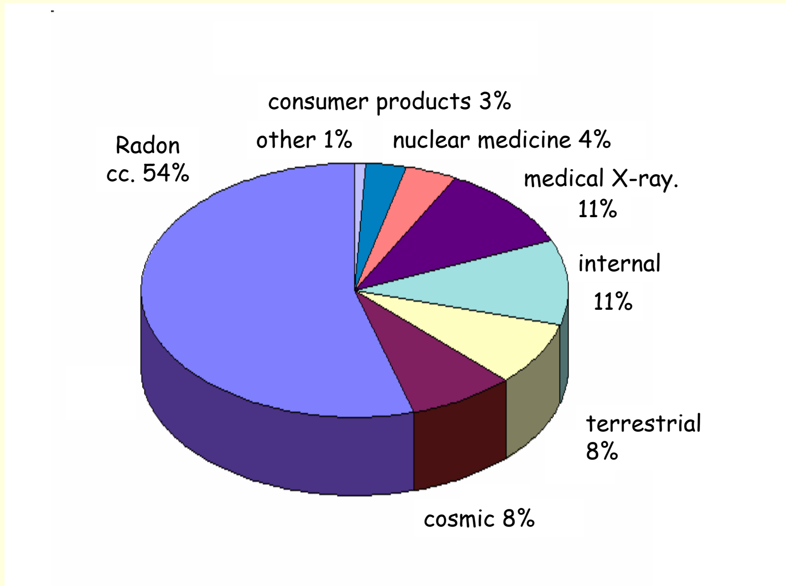
occupation

military

nuclear industry

medical use

Distribution of annual dose among sources



Sources of natural background

cosmic radiatiom
~ 0,4 mSv/year

radon: cc. 1,8 mSv/year

potassium: cc 0,1 mSv/year

Risk – loss of life expectancy

Days of average life expectancy lost

Being unmarried male	3500
Smoking (pack/day)	2250
Being unmarried female	1600
Being a coal miner	1100
25% overweight	777
Alcohol abuse	365
Being a construction worker	227
Driving motorcycle	207
1 mSv/year effective dose for 70 years	10
Coffee	6

Relative risk of dying: 1 in a million odds

Smoking 1.4 cigarettes (lung cancer)

Eating 40 tablespoons of peanut butter

Eating 100 charcoal broiled steaks

2 days in New York City (air pollution)

Driving 40 miles in a car (accident)

Flying 2500 miles in a jet (accident)

Canoeing for 6 miles

Receiving 0.10 mSv radiation dose (cancer)

Radiation protection lies on the following principles:

<u>Optimization:</u> All exposures should be kept As Low As Reasonable Achievable (ALARA)

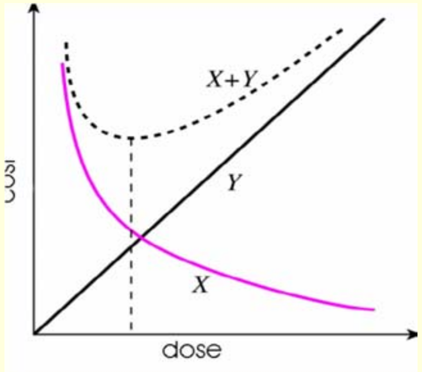
<u>Justification:</u> no practice shall be adopted unless it produces a positive net benefit

<u>Limitation:</u> the effective dose (E) to individuals shall not exceed the limits recommended by the ICRP (maximum permitted doses)

Optimization of radiation protection

ALARA-principle

As **L**ow **A**s **R**easonably **A**chievable



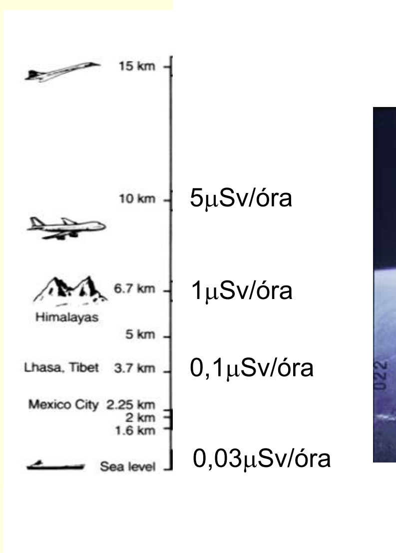
X : cost of radiation protection

Y : cost of treatment

X+Y: total cost

Optimum is the minimum

Cosmic ray contributions to dose rate as the function of the altitude

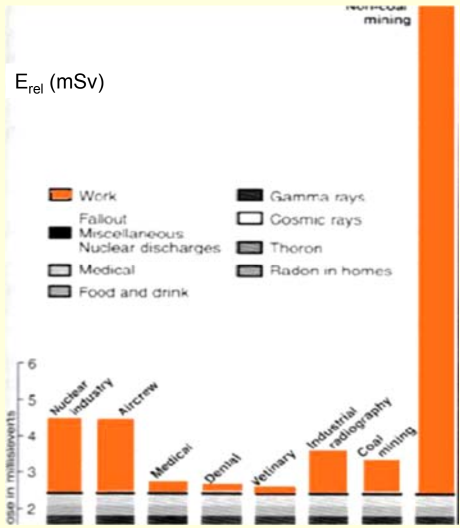


Dose limits in radiation protection

	Occupational (mSv/year)	Population (mSv/year)
Effective dose	20*	1
Dose equivalent (eye lens)	150	15
Dose equivalent (limb/skin)	500	50

* Over the average of 5 years but maximum 50 mSv/year

Relative risk of various professions



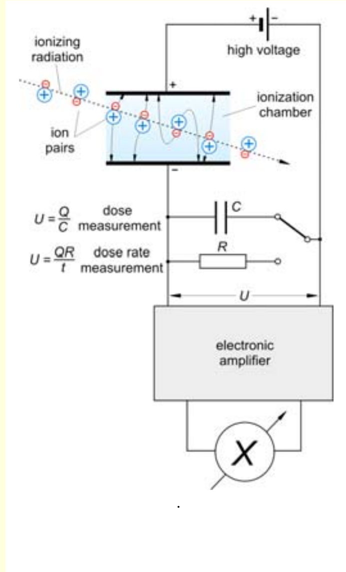
Measuring devices

Alteration of a physical parameter ~ absorbed dose

Ionization chambers

***Dose measurement**:* the voltage U that is produced by collected charge Q on the capacitor C is proportional to the total amount of the separated charges.

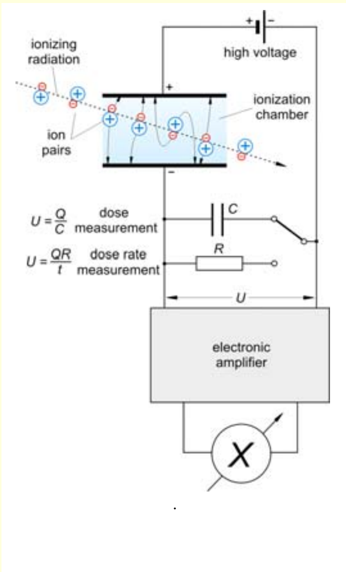
$$U = \frac{Q}{C} \sim X$$



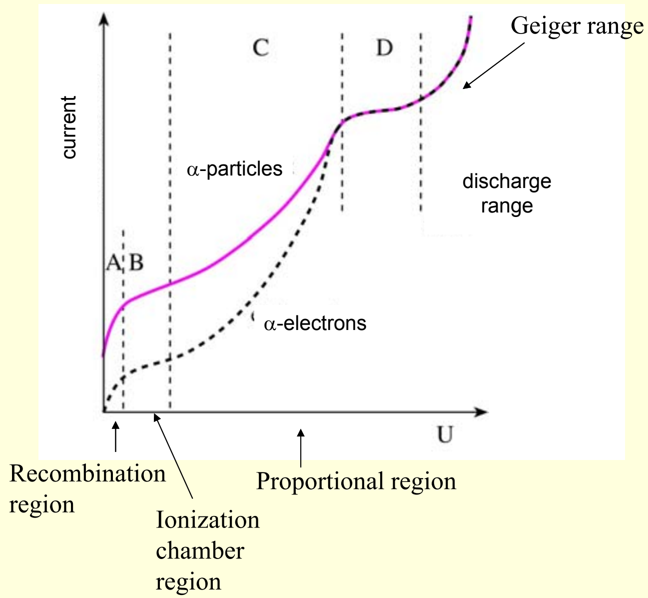
Ionization chambers

***Dose rate measurement**:* the potential drop is measured on a large resistance R , that is proportional to the charge Q that flows through at unit time.

$$U = \frac{QR}{t} \sim \frac{X}{t}$$



Ionization chambers



The dependence of ionization on voltage

Personal dosimeters

Film dosimeter

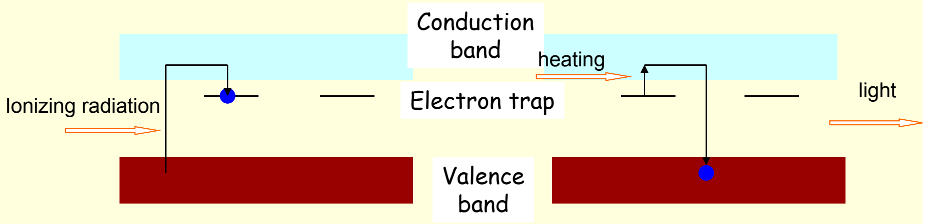
It measures darkening of the developed photographic film that was exposed to ionizing radiation. Darkening depends on the type and energy of radiation, and the thickness and material of absorber.

Darkening of the developed photographic film is proportional to the dose rate of the ionizing radiation and to the irradiation time.

Personal dosimeters

Thermoluminescent dosimeter

Band structure on electronic transitions



exposition evaluation

Calculation of the dose in case of γ - radiation

The absorbed dose in air (D_{air}) for any γ - radiating isotope

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

Λ: activity of the isotope preparation

t: time of exposition

r: distance from the source

K_γ: dose constant (specific γ - ray constant)

$$[K_\gamma] = \frac{\mu Gy \cdot m^2}{h \cdot GBq}$$

Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 4.
- 4.1
- 4.2
- 4.3
- 4.4
- 4.5

In the frame: 184. 186.

Manual :Dosimetry