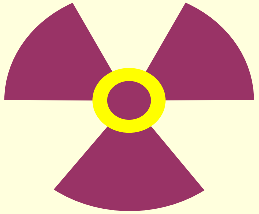
Dosimetry

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

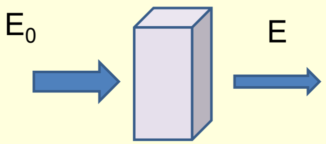
Biological dose concepts:
Equivalent dose,
Effective dose

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

Louis Harold Gray (1905-1965).

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

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?

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

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

$$E_{össz} = N * E$$

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

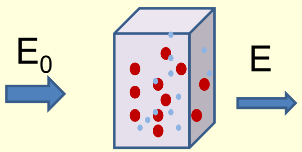
$$E_{össz} = 1,87 * 10^{14} * 2,88 * 10^{-14} = 5,38 [J]$$

$$D = \frac{E_{össz}}{m}$$

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

2. Exposure

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

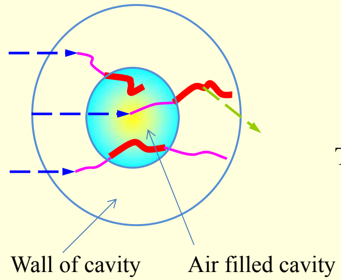


$$X = \frac{\Delta Q}{\Delta m}[C/kg]$$

Validity: in the air, only 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

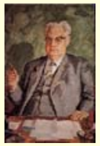
The absorbed energy (absorbed dose) is not sufficient to measure the possible biological consequences.

The biological consequences are influenced by :

the type of radiation.	the sensitivity and biological function of target
↓	↓
radiation weighting factor	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

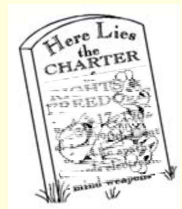
Unit of ***H*** : ***Sievert (Sv)***

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

Why are the fates of the rabbits different?

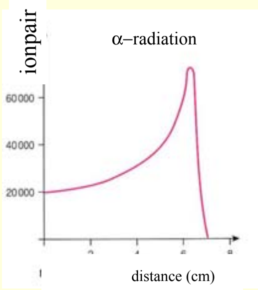
2 Gy absorbed dose – ***X-ray***

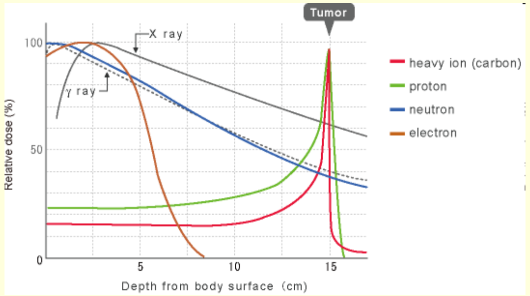
2 Gy absorbed dose – ***α-particles***



Equivalent dose (H)

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

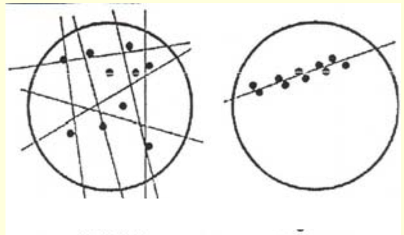




LET (Linear Energy Transfer : the energy transferred to the material surrounding the particle track, by means of secondary electrons. *($nE_{ionpair}/l$)*

Equivalent dose (H)

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



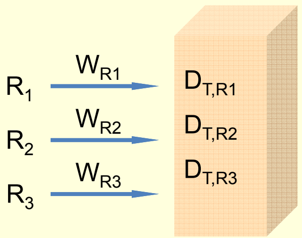
Small LET
e.g. γ, -ray

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

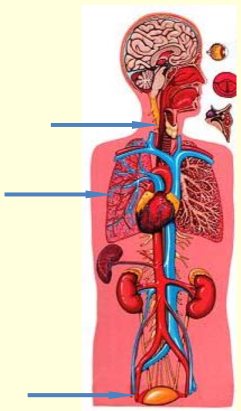
If someone is exposed to more than one type of radiation:



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

Effective dose (E)

Various sensitivity of tissues has to be considered



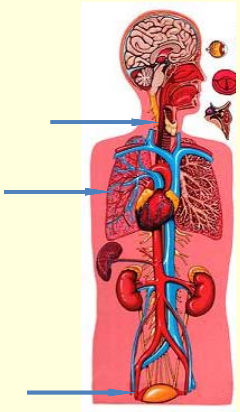
$$E = \sum_T w_T H_T$$

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.

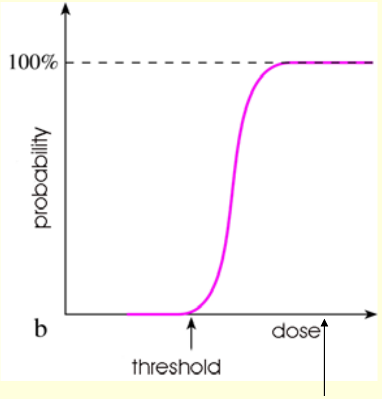
$$S = \sum_i N_i E_i$$

E_i effective dose in each person

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!

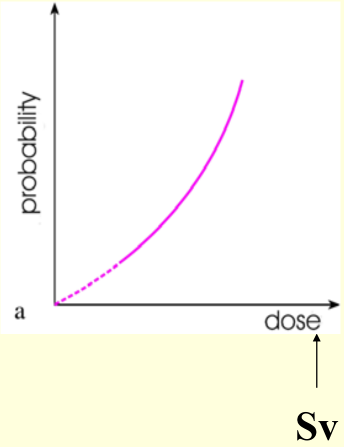
The probability of stochastic damage depends on the dose.

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

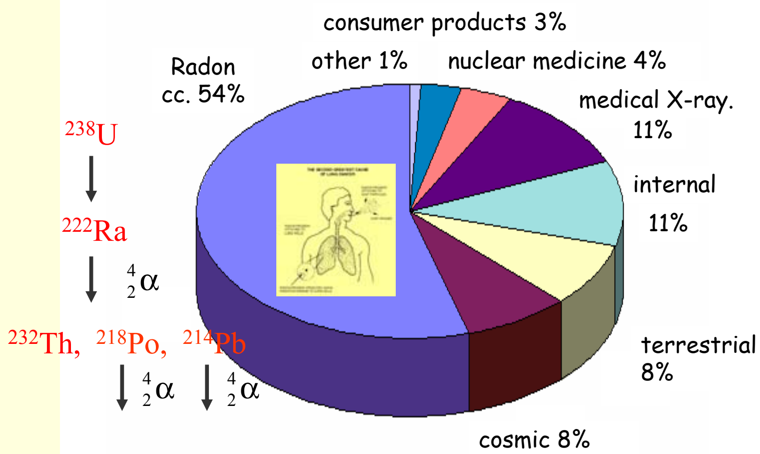
occupation

military

nuclear industry

medical use

Distribution of annual dose among sources

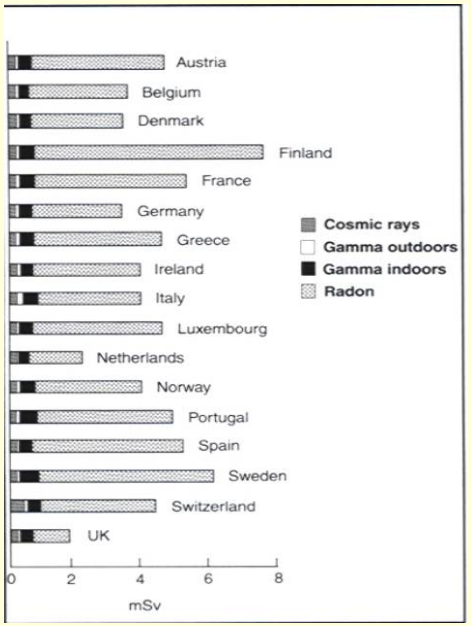


Sources of natural background

cosmic radiatiom
~ 0,4 mSv/year

radon: cc. 1,8 mSv/year

potassium: cc 0,1 mSv/year



Distribution of naturally occuring background levels of radiation in Europe

The highest known level of background radiation is in Kerala and Madras States in India where a population of over 100,000 people receive an annual dose rate which averages 13 millisieverts.

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

Aims of radiation protection:

Prevention from deterministic effects (except in radiotherapy those that are intentionally produced)

Keeping the occupational risk of the users of the sources at the level of occupational risk of other profeesionals.

Keeping the public risk from ionising radiation sources at the level of pudlic risk of other civilisation related harms.

Radiation protection lies on the following ***principles:***

Optimization: All exposures should be kept As Low As Reasonable Achievable (ALARA)

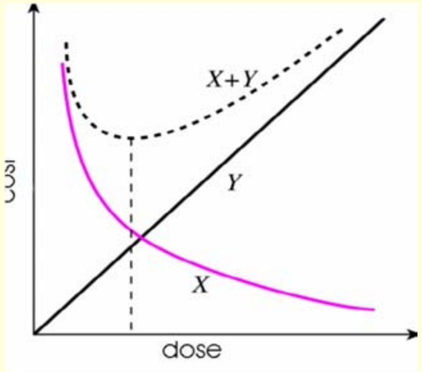
Justification: no practice shall be adopted unless it produces a positive net benefit

Limitation: 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

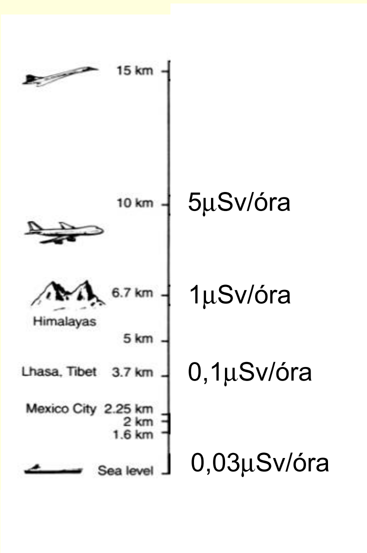
Optimum is the minimum

Dose limits in radiation protection

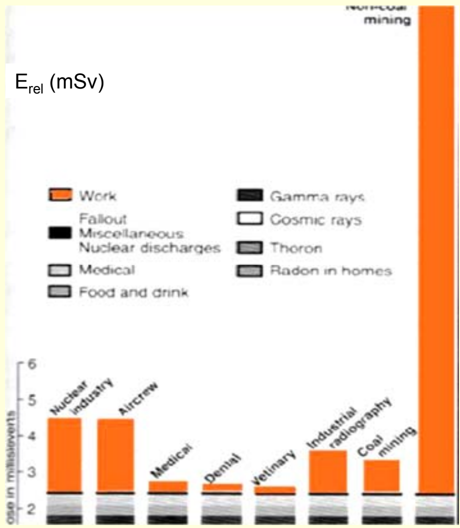
	Occupational (mSv/year)	Population (mSv/year)
Effective dose	20*	1
Dose equivalent (eye lens)	150	15
Dose equivalent (limb/skin)	500	50

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

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

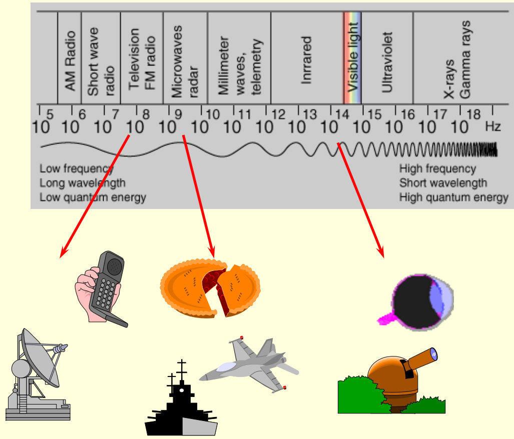


Relative risk of various professions



Detection of radiation – dose measurement

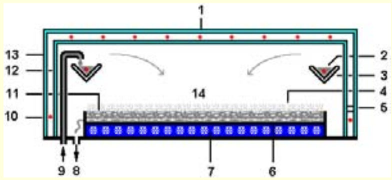
- What? α^{++} p^{+} (n) β γ ν
- How much energy?
- How much intensity?
- How good accuracy?



Measuring devices

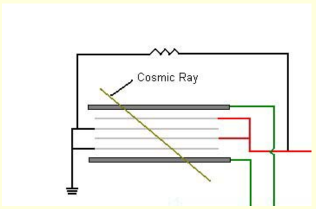
Alteration of a physical parameter ~ absorbed dose

Detection of particles



- **Cloud chamber**
  supersaturated vapor of water or alcohol

- **Spark chamber**
  high voltage wiers



- **Bubble chamber**
  - **superheated transparent liquid (H_2, Ar, Xe)**
  - **entire chamber is subject to a constant magnetic field**

Dose and dose rate measuring devices

*electronic detectors – absorbed energy generats free charges

gas-ionization detectors – prompt and/or delayed evaluation

scintillation detectors

semi-conductor detectors –

* Chemical detectors – based on radiochemical alterations

film – utólagos kiértékelés

* Solid materials – kristályok fizikai tulajdonságait használják ki

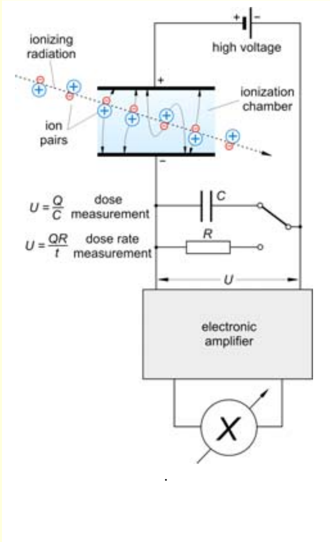
thermoluminescent detector – TLD (LiF, CaF_2, BeO, Al_2O_3)

Electronic Dosimeters

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.

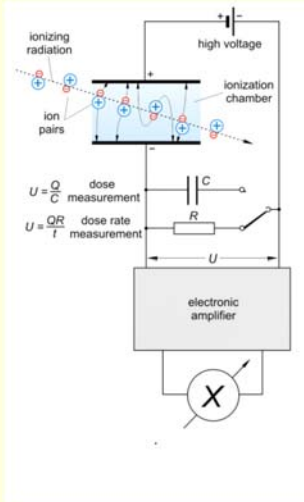
$$U = \frac{Q}{C} \sim X$$



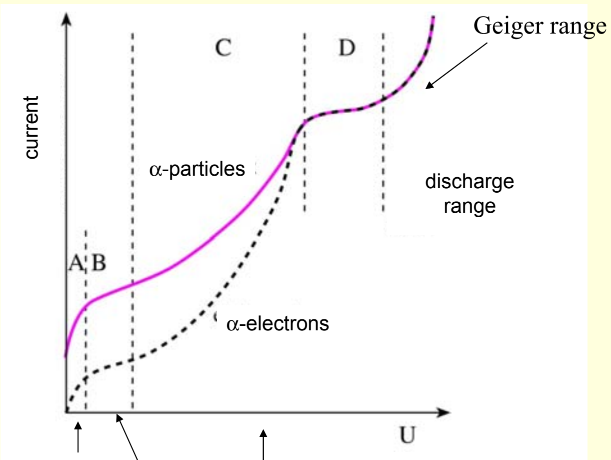
Ionization chambers

***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



Recombination region

Ionization chamber region

Proportional region

The dependence of ionization on voltage

Ionization chambers– Geiger-Müller counter

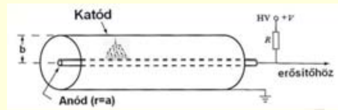
- Inert gas filling
- High accelerating voltage

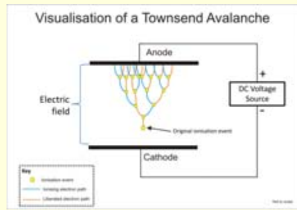
↓

Avalanche effect between electrods

↓

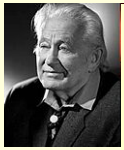
Current pulse





Number of current pulses ~ number of ionising particles

Multiwire chamber



Nobel prize in Physics 2002

Georges Charpak

1924 -2010

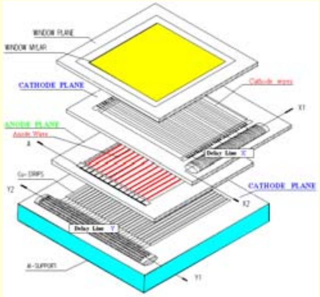


Fig.1 Common view of the 2-D MWPC with delay line readout.

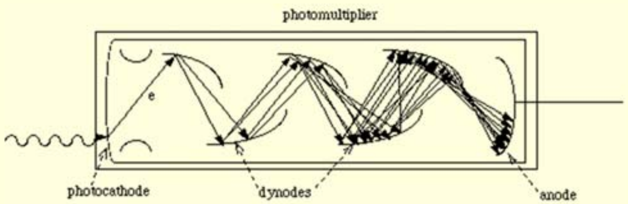
- electric current proportional to the energy of the detected particle
- localised cascade of ionization
- spatial sensitivity!

Scintillation detectors

- folyadékszcintillátorok
  - fénykibocsátó molekulák oldata
  - oldatok többnyire előre kevertek
  - először az oldat, majd a szcintillátor molekulái gerjesztődnek
  - végül fénykibocsájtás
- plasztik szcintillátorok
  - szilárd oldatok
- szervetlen kristályok
  - a kristályrács nyeli el az energiát
  - szennyező atomok → energiaszintek a tiltott sávban

Scintillation detectors

- szcintillátor → sugárzásból látható fény
- fény nem jó → mérhető elektromos jel kell
- megoldás: fotoelektromos effektus, majd elektronok sokszorozása
- anódelektronok = áram „elektronikus trükk”: mérhető feszültségjel



Semiconductor detectors

$$\frac{n}{n_0} = e^{-\frac{\Delta\varepsilon}{kT}}$$

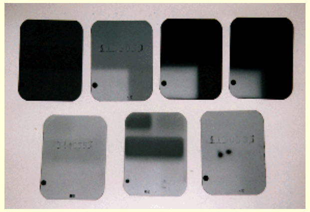
$$\sigma \approx e^{-\frac{\Delta\varepsilon}{2kT}}$$

Conductivity ~ number of excitations

Chemical processes

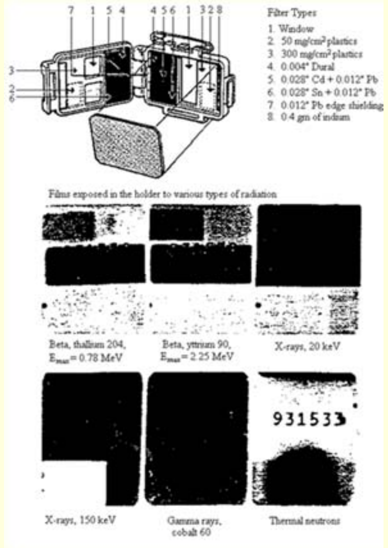
Film badges

It measures darkening of the developed photographic film that was exposed to ionizing radiation.

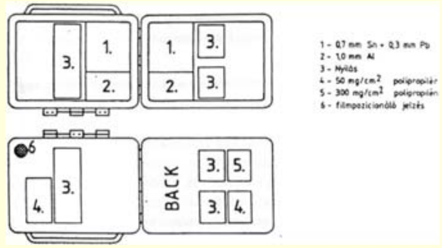


Darkening of the developed photographic film is proportional to the dose rate of the ionizing radiation and to the irradiation time.

Film badges



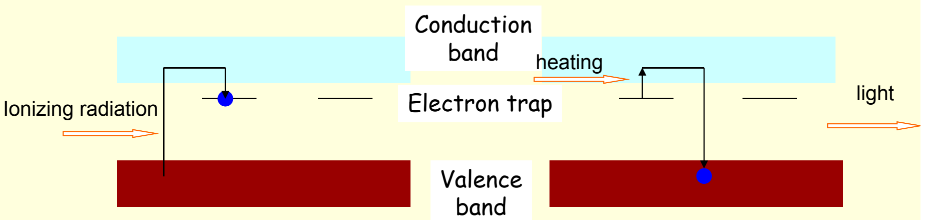
Darkening depends on the type and energy of radiation, and the thickness and material of absorber.



Solid phase detectors

Thermoluminescent dosimeter

Band structure on electronic transitions



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)

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

izotop	γ-energy (MeV)	K_g
^{24}Na	2,754; 1,369	444
$^{52/59}$Fe	0,5; 1,3; 1,1	160
^{60}Co	1,33; 1,17	305
^{131}I	0,364; 0,08; 0,723	54
^{137}Cs	0,661	80

Someone works at 30 cm distance from a ^{24}Na isotope preparation of 75 MBq. Calculate the thickness of the lead shielding that reduces the dose rate to 15 μGyair/h at the working place.

$$\left(\frac{D}{t}\right)_0 = K_\gamma \frac{\Lambda}{r^2} \qquad \left(\frac{D}{t}\right)_0 = 444 \frac{75*10^{-3}}{0{,}3^2} = 370[\mu Gy/h]$$

$$\left(\frac{D}{t}\right) = \left(\frac{D}{t}\right)_0 e^{-\mu_m x_m}$$

x=5,7 cm

Question of the week

Which voltage range(s) of ionization chamber can be used in dose measurements? Why?

Damjanovich, Fidy, Szöllősi: Medical Biophysics

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

In the frame: 184. 186.

Manual :Dosimetry