Dosimetry of ionizing radiations-2: dosimeters, radiation protection

03-25-2021

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Radiotherapy

Which radiation is the best?

What is the optimal dose of radiation?

What is the best technique for generating radiation?

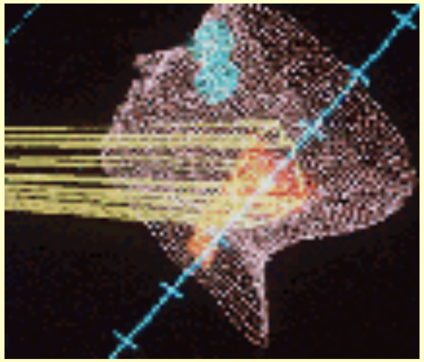
Irradiation selectivity – protection of healthy structures?

Approaches

- **Palliative radiotherapy** to reduce pain and address acute symptoms – e.g. bone metastasis, spinal cord compression etc.,

- **Radical radiotherapy** as primary modality for cure – e.g. head and neck tumours

- **Adjuvant treatment** in conjunction with surgery – e.g. breast cancer



Ionizing radiation in radiotherapy

Electromagnetic

- X-ray – Bremsstrahlung and characteristic
- gamma
  - ^{60}Co (1,25MeV) – tele-therapy
  - ^{192}Ir, ^{125}I (35 keV), ^{137}Cs, ^{60}Co - brachytherapy

Electron/β⁻ – energy range 6 – 21 MeV

Alpha - ^{225}Ac 6 MeV, ^{226}Ra 4,78 MeV

Proton – increasing use

Heavy ions – limited use

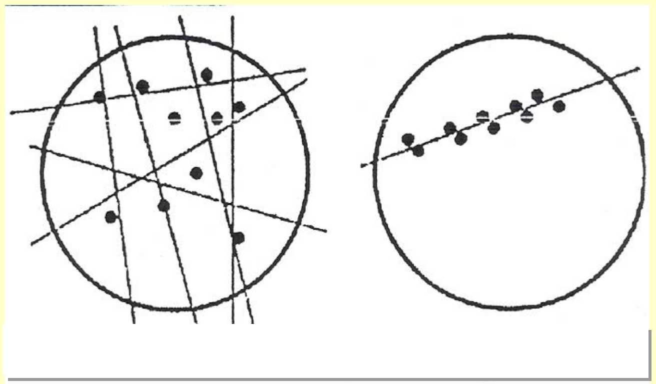
Neutron – limited use

„Efficacy” of various modalities are different

Linear ion density:

the amount of ion pairs in a line generated in a unit istance *(n/l)*

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



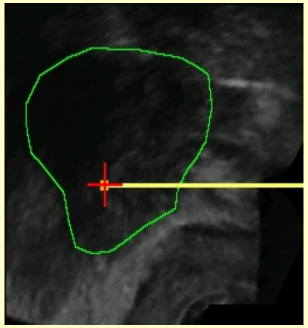
Low LET
e.g.,. γ, rtg

High LET
e.g., α, proton

Typical LET values

LET	Radiation	Energy(MeV):	LET(keV/µm):
high	α – particles	5.0	90
	fast neutron s	6.2	21
	protons	2.0	17
low	X-rays	0.2	2.5
	60-Co γ–radiation	1.25	0.3
	β – particles	2.0	0.3
	accelerated electrons	10.0	

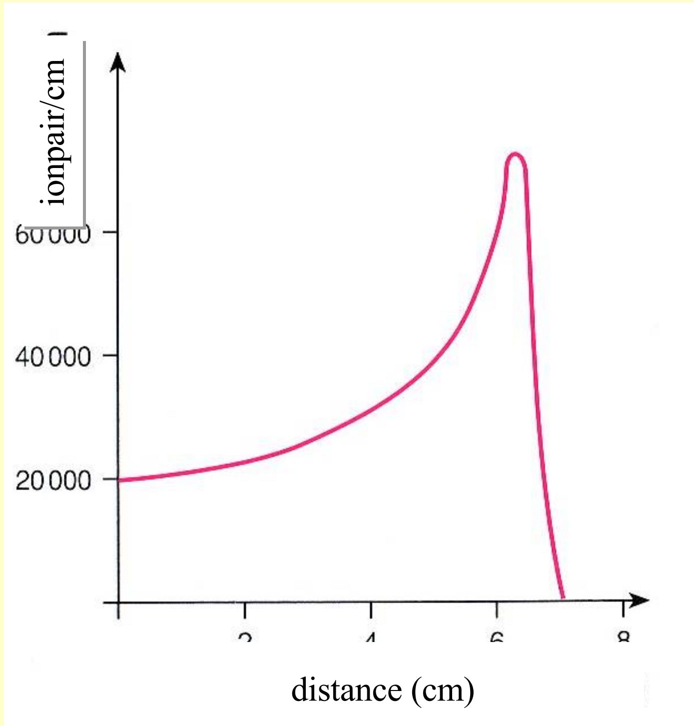
α



Internally deposited radioactivity

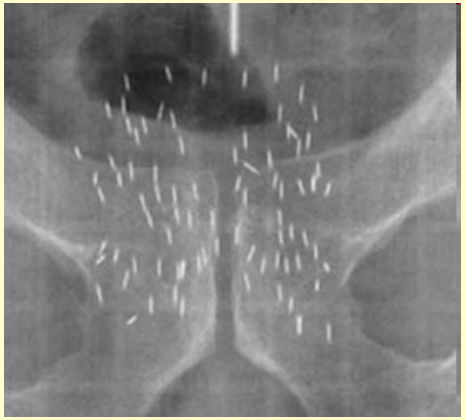
Brachytherapy

In the air: $E_{ionpair} = 34\ eV$



β^-:

Internally seeded radioactivity



Particle energy is not optimal

continuous energy spectrum

typical energy: few MeV

e^-:

accelerated electron - 10-20 MeV

production: linear accelerator

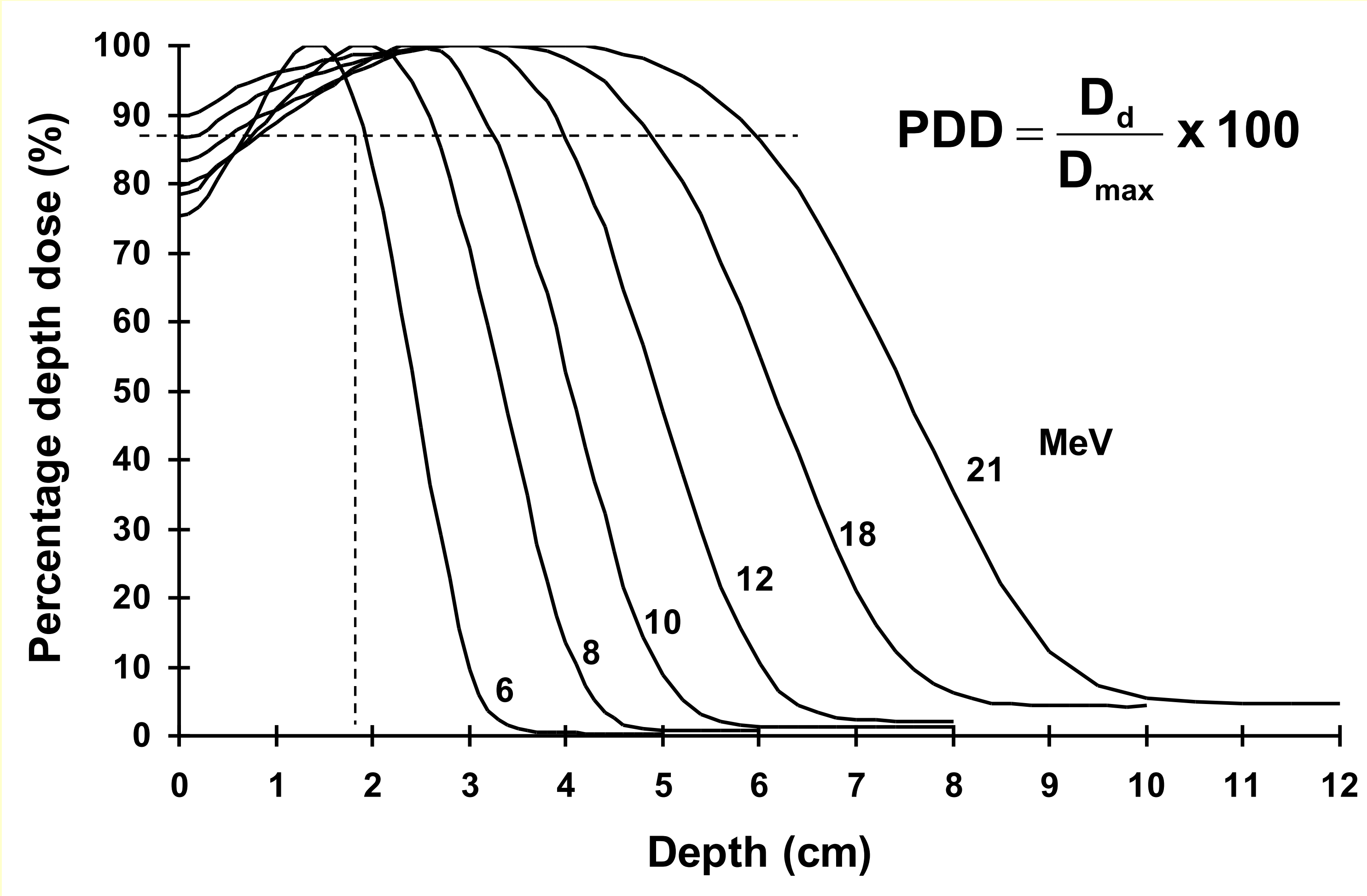
Efficient distance! ≈1cm/3MeV

In the practice 6-21 MeV => 2-7 cm

treatment of superficial tumours

Electron PDD (percentage depth dose) curves with different energies

Reduced skin-sparing effect

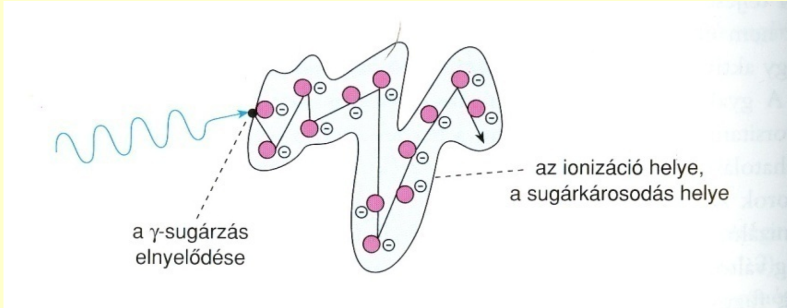


Conclusion: only superficial tumors can be treated with electron beams

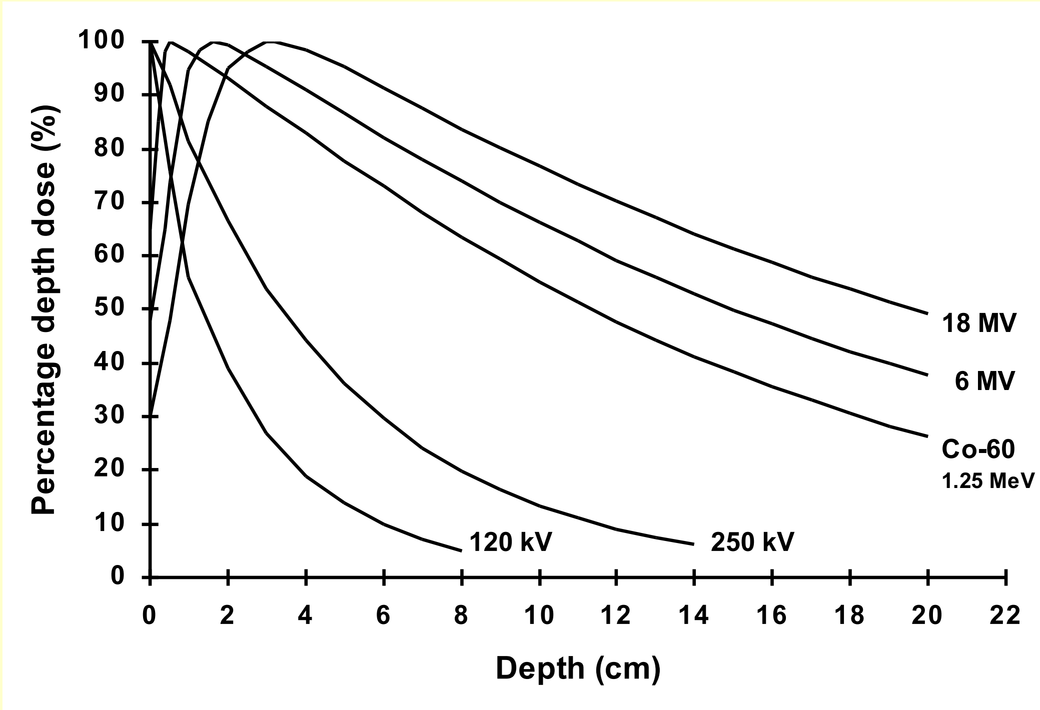
γ :

Site of absorption≠ sites of ionization = site of radiation damages

Penetration distance
is energy dependent



PDD curves at voltages
(see X-ray) and various
photon energies



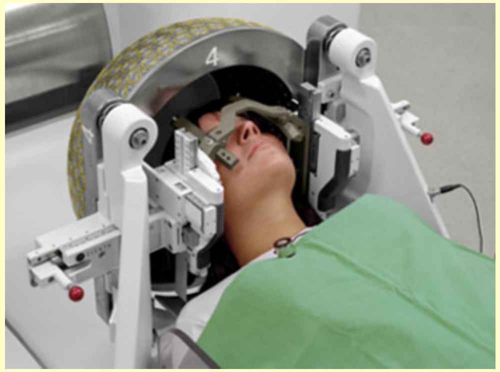
γ :

γ-knife: focused dose of radiation

about 200 portals in a specifically designed helmet

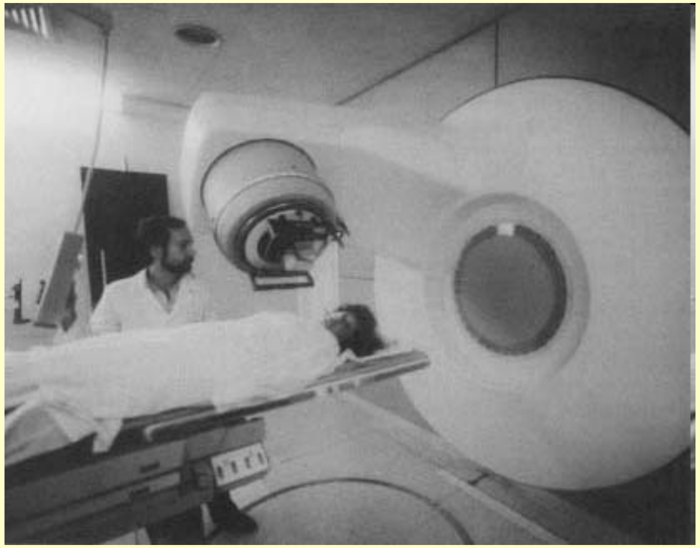
e.g., ^{60}Co $E\gamma \approx$ MeV , about TBq activity

The radiation isocenter is the point in space where radiation beams intersect



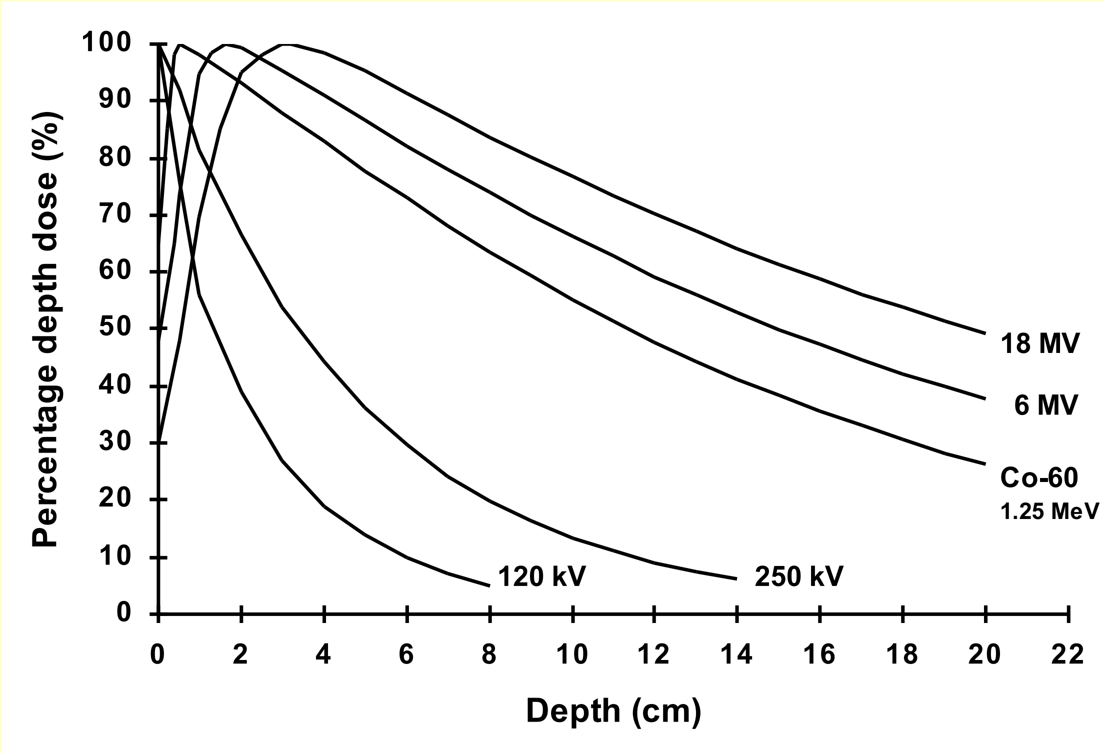
Treat tumours and lesions in the brain

X-ray:



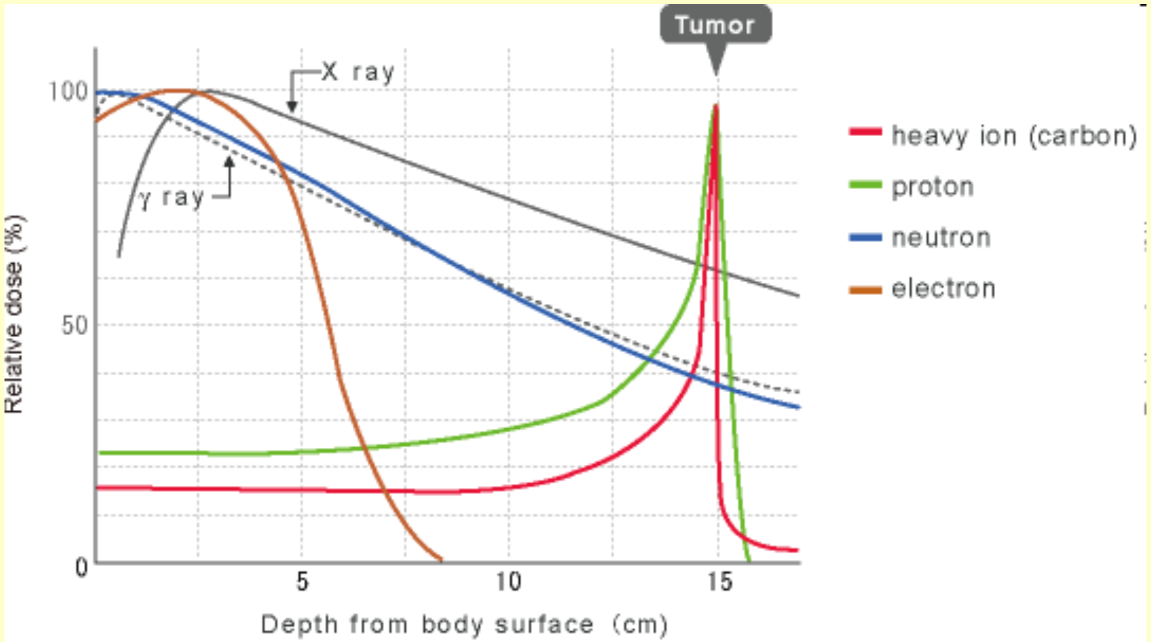
The X-rays are generated by a linear accelerator.

Few MeV photon energy.

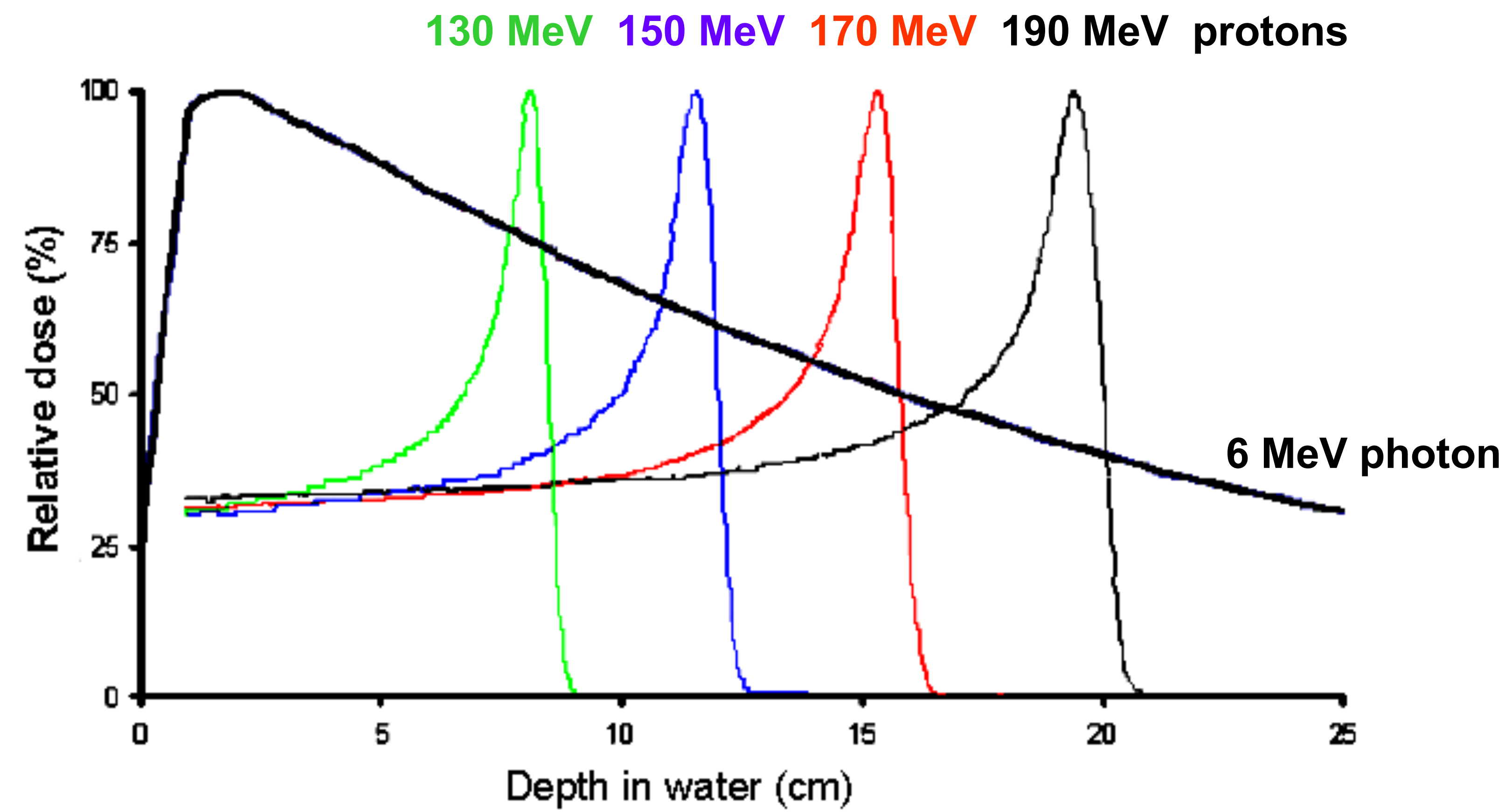


Would be ideal, but very expensive!

proton:



Comparison of photon and proton depth doses

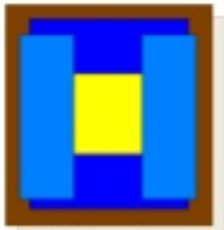


The Evolution of Radiation Therapy

1ST Telecobalt machine in August 1951 in Sasaktoon Cancer Clinic, Canada

1960's

The First Clinac



Standard Collimator

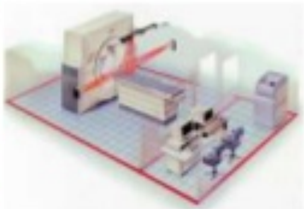
The linac reduced complications compared to Co60

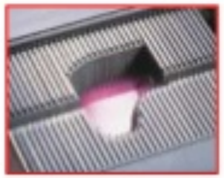
1970's

Cerrobend Blocking
Electron Blocking

Blocks were used to reduce the dose to normal tissues

1980's

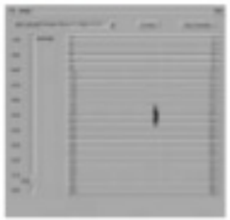




Multileaf Collimator

MLC leads to 3D conformal therapy which allows the first dose escalation trials.

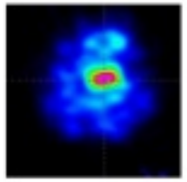
Computerized 3D CT Treatment Planning **1990's**



Dynamic MLC and IMRT

Computerized IMRT introduced which allowed escalation of dose and reduced compilations

2000's



Functional Imaging

High resolution IMRT

IMRT Evolution evolves to smaller and smaller subfields and high resolution IMRT along with the introduction of new imaging technologies

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***.

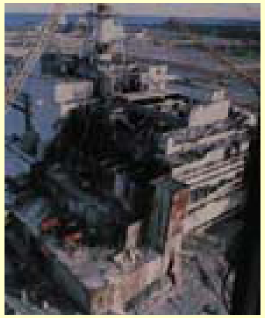
Estimated average of annual dose from natural background and man-made sources is 3.6 mSv.

environmental

occupation

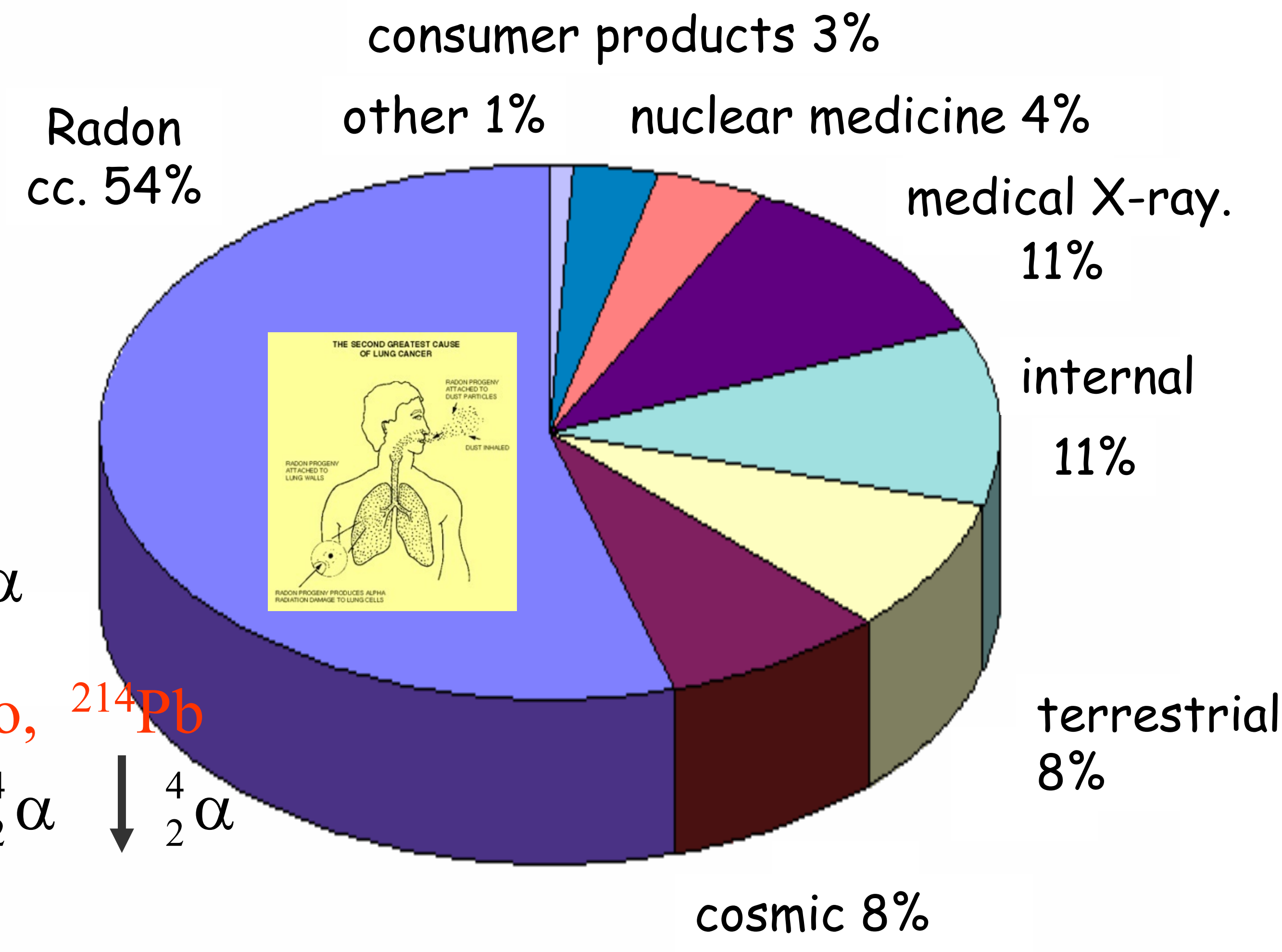
military

nuclear industry



medical use

Distribution of annual dose among sources



^{238}U

$\downarrow$

^{222}Rn

$\downarrow \; ^{4}_{2}\alpha$

^{232}Th, ^{218}Po, ^{214}Pb

$\downarrow \; ^{4}_{2}\alpha \quad \downarrow \; ^{4}_{2}\alpha$

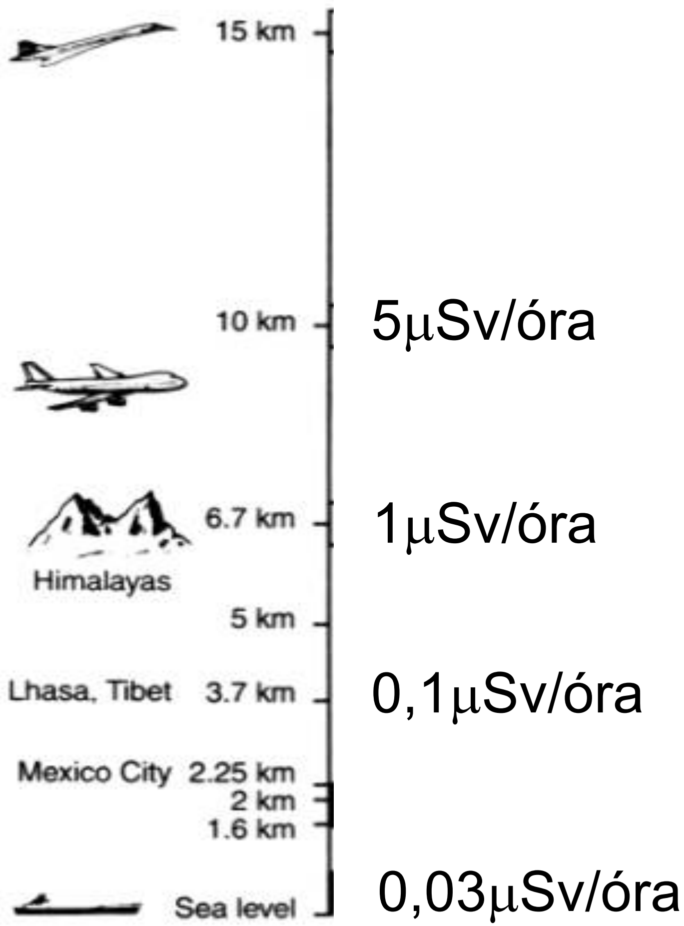
Sources of natural background

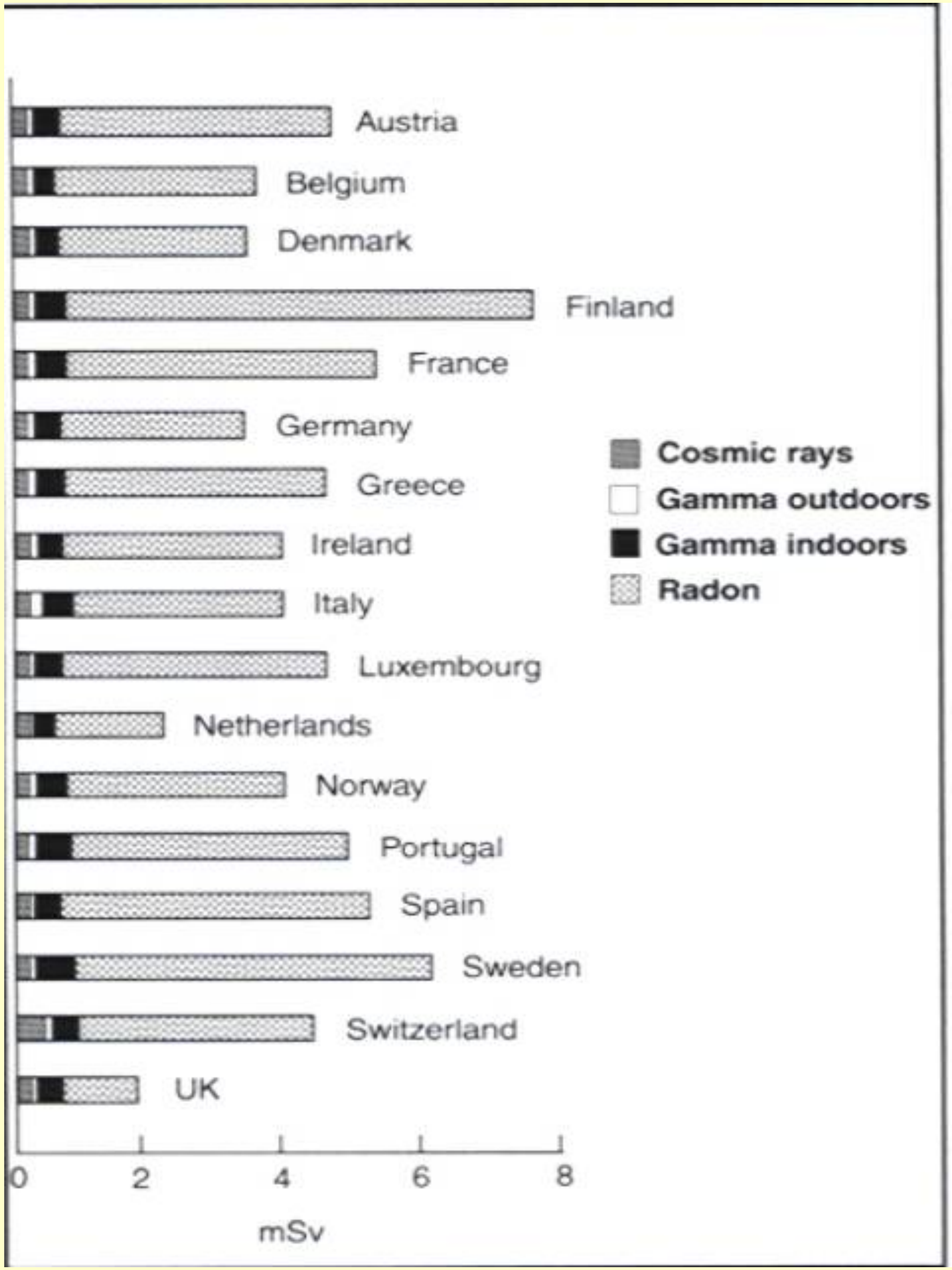
cosmic radiatiom
~ 0,4 mSv/year

radon: cc. 1,8 mSv/year

potassium: cc 0,1 mSv/year

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





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

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)

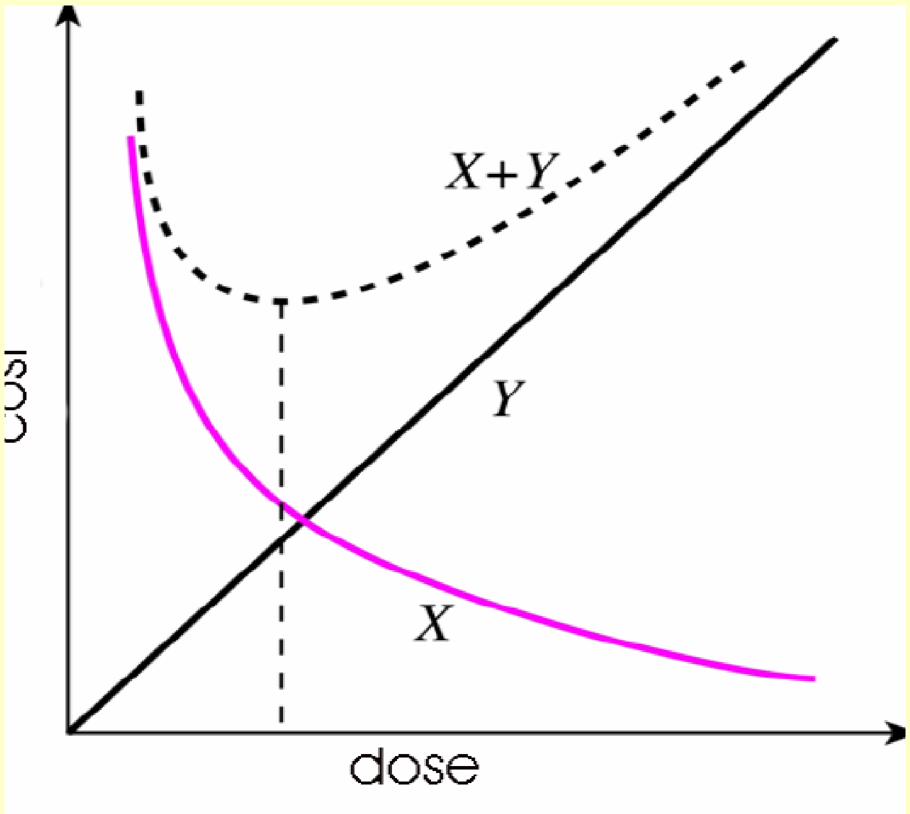
Justification: no practice shall be adopted unless it produces a positive net benefit

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



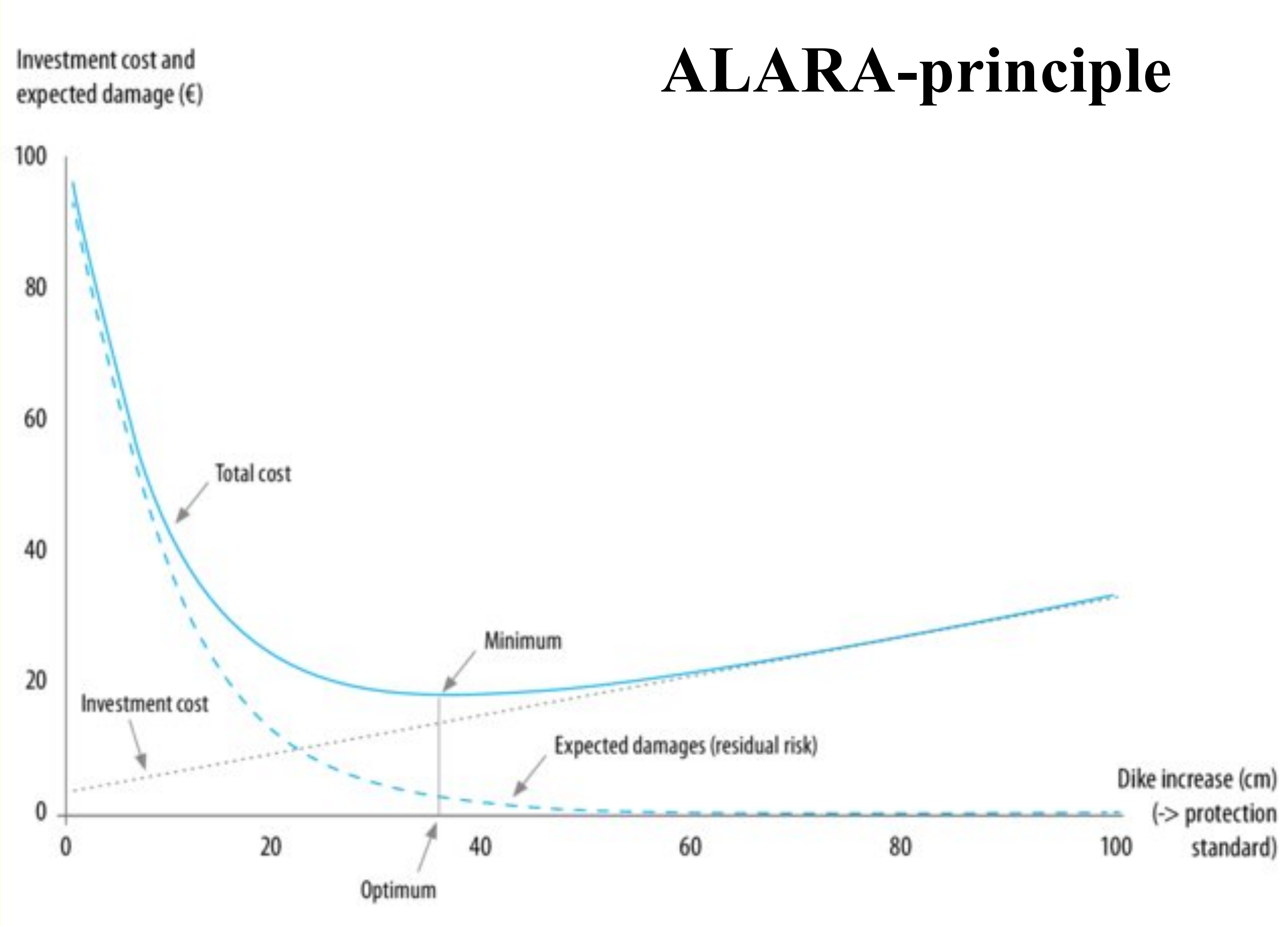
X : cost of radiation protection

Y : cost of treatment

X+Y: total cost

Optimum is the minimum

Optimization of radiation protection

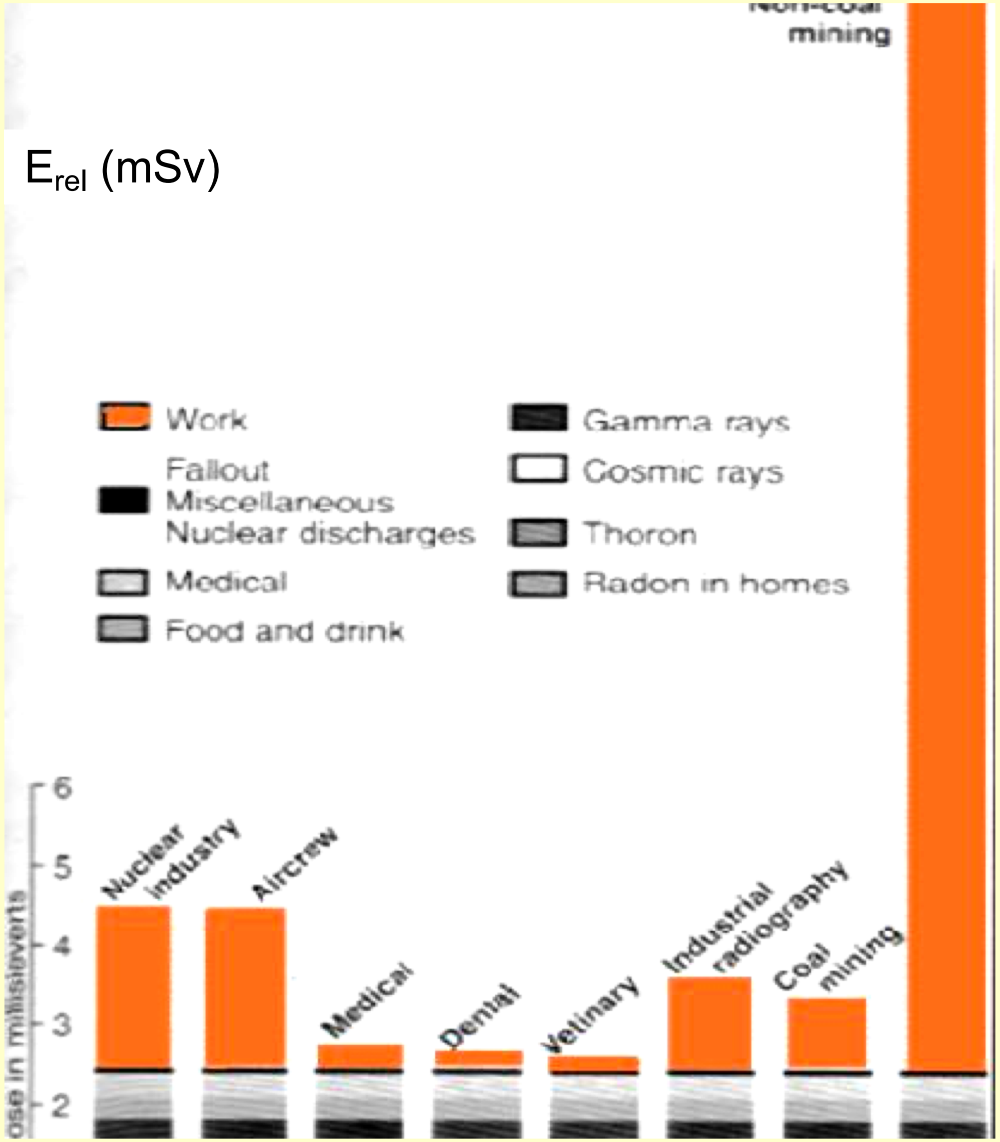


Dose limits in radiation protection

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

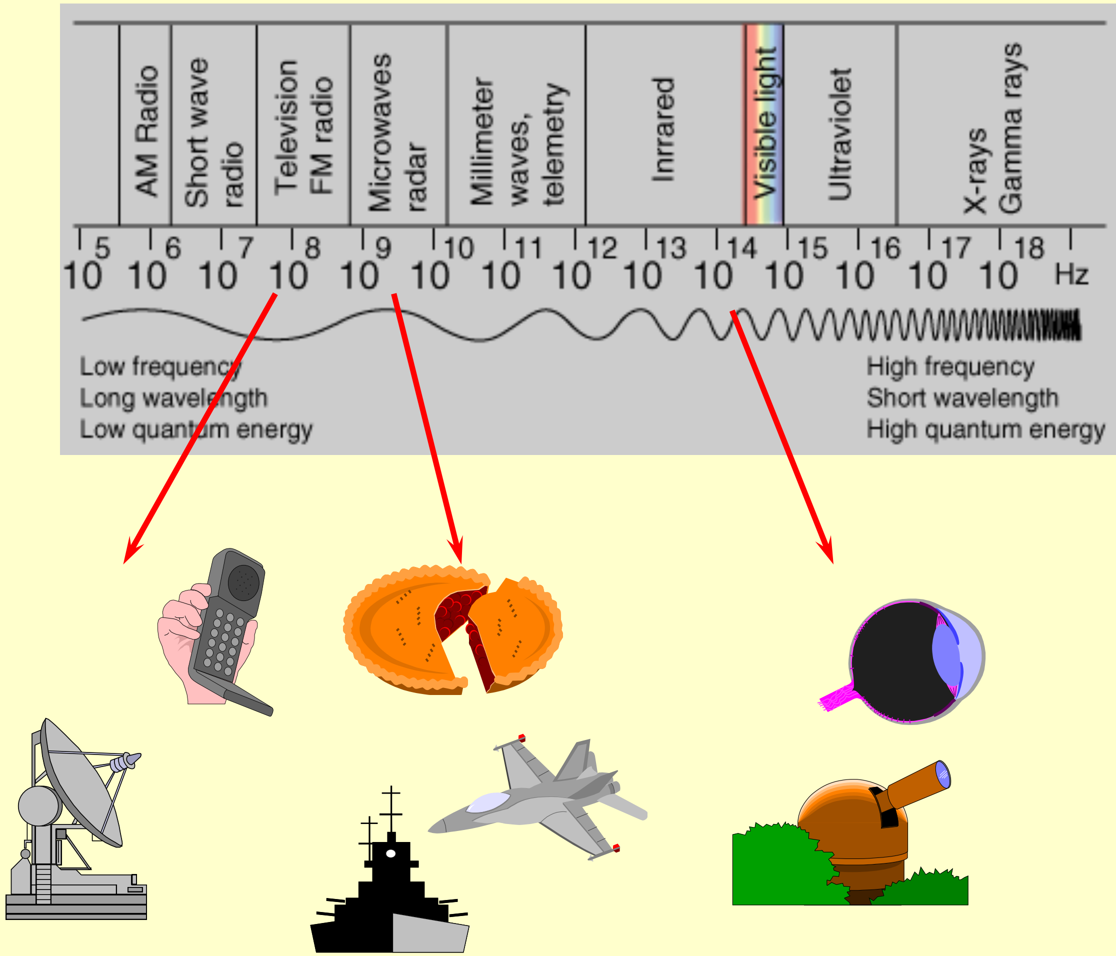
* Over the average of 5 years but maximum 50 mSv/year

Relative risk of various professions

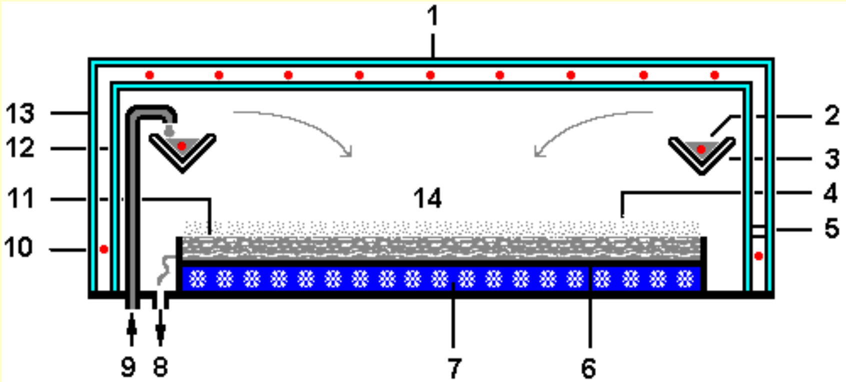


Detection of radiation - dose measurement

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



Detection of particles

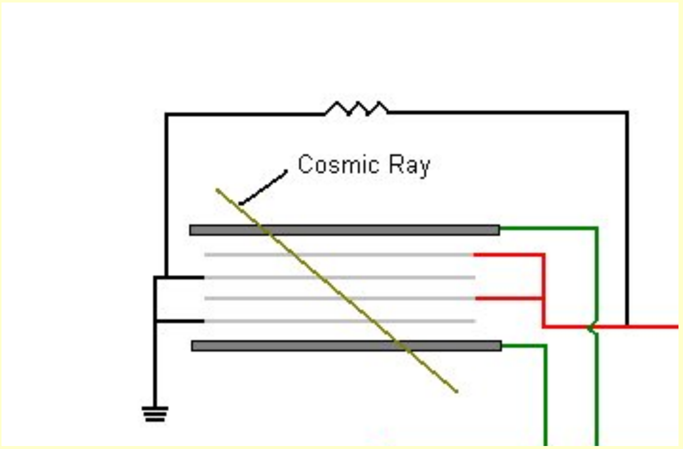


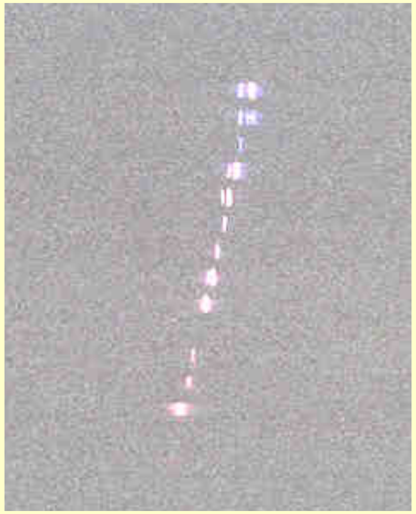
- **Cloud chamber**

  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 – follow-up evaluation

* Solid materials – based on physical parameters of solid materials

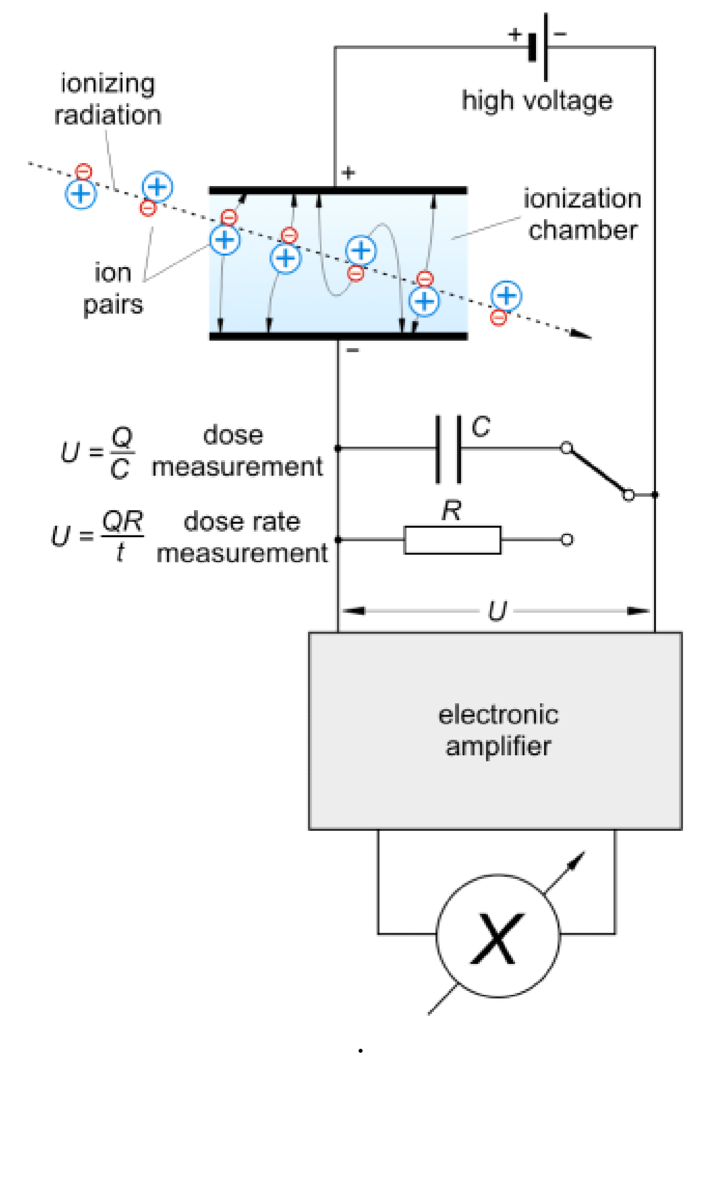
thermoluminescent detector – TLD (LiF, CaF_2, BeO, Al_2O_3)

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.

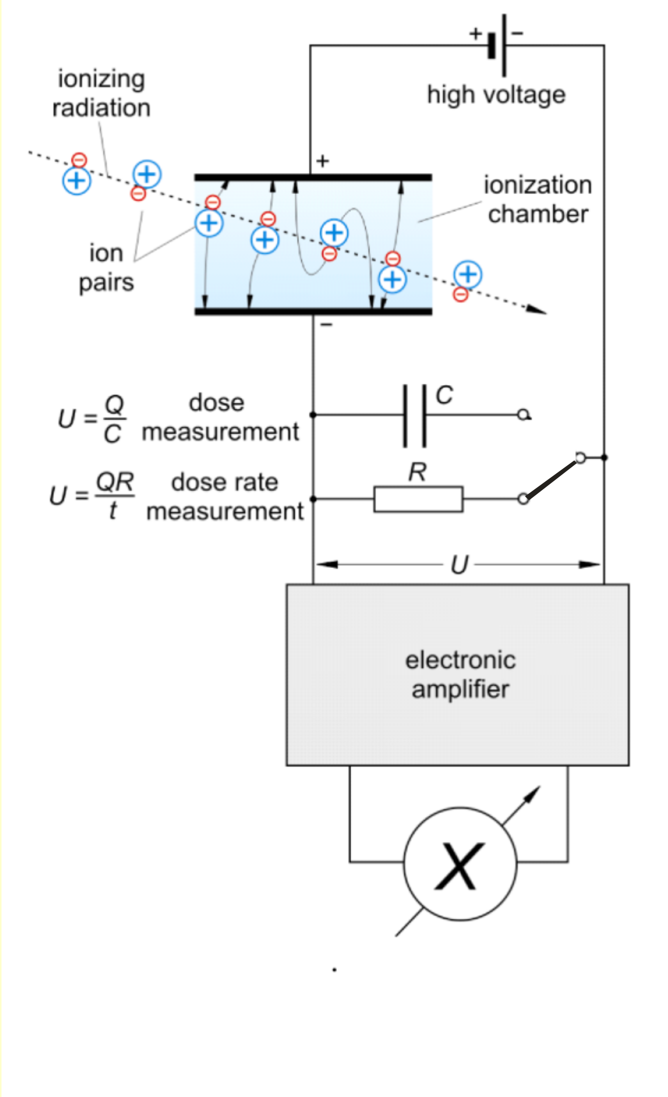
$$U = \frac{Q}{C} \sim X$$

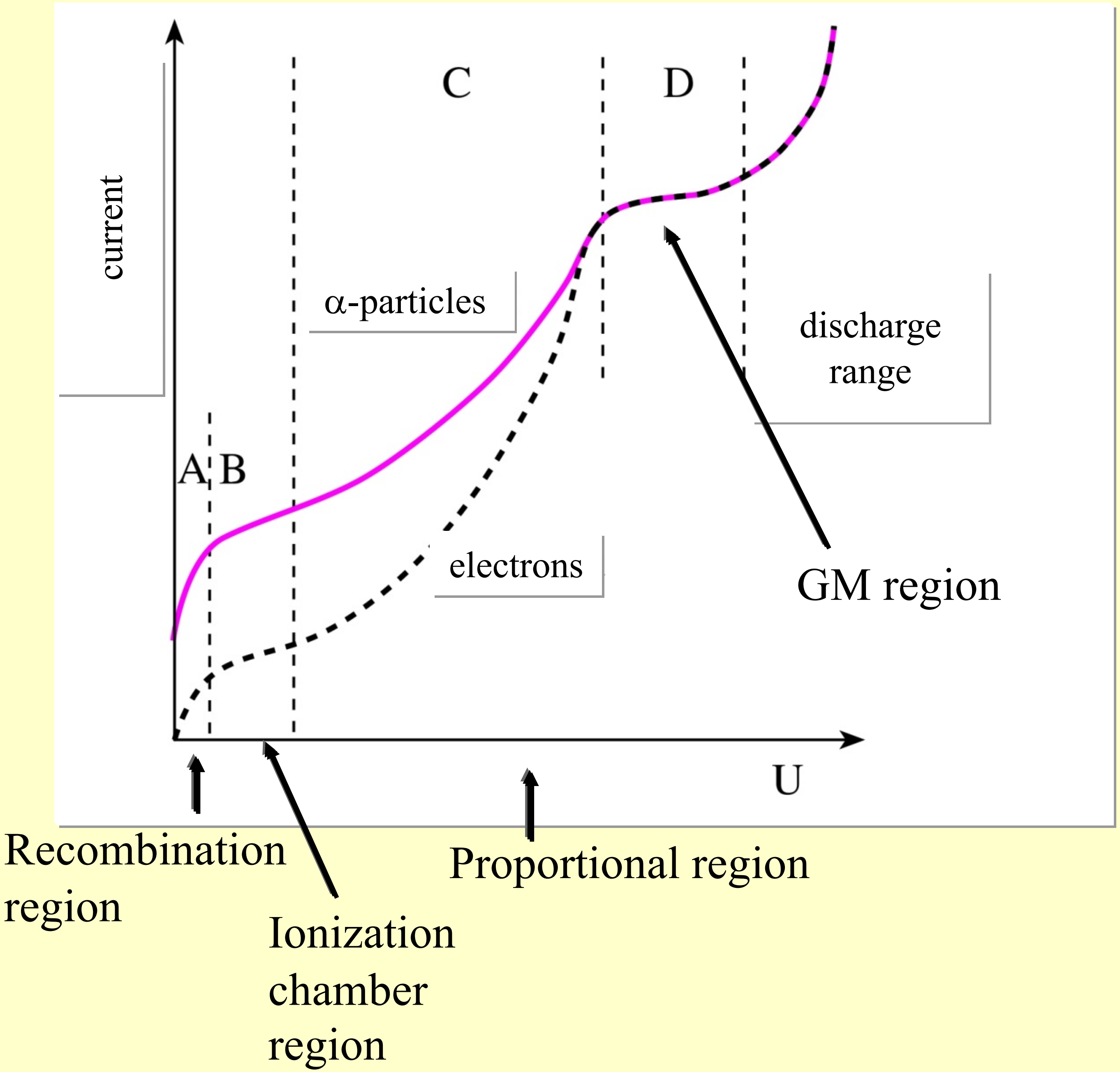


Ionization chambers

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.

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





The dependence of ionization on voltage

Ionization chambers– Geiger-Müller counter

- Inert gas filling
- High accelerating voltage

↓

Avalanche effect between electrods

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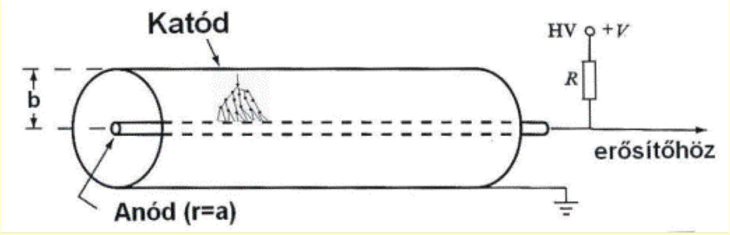
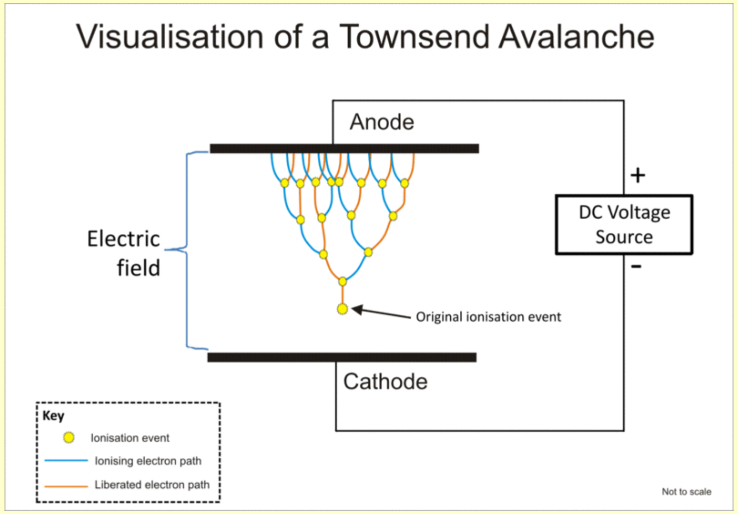
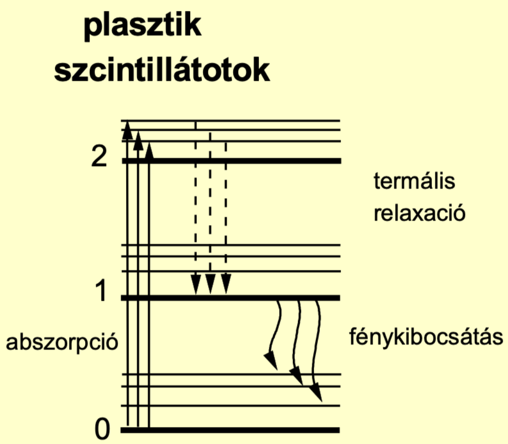
Current pulse

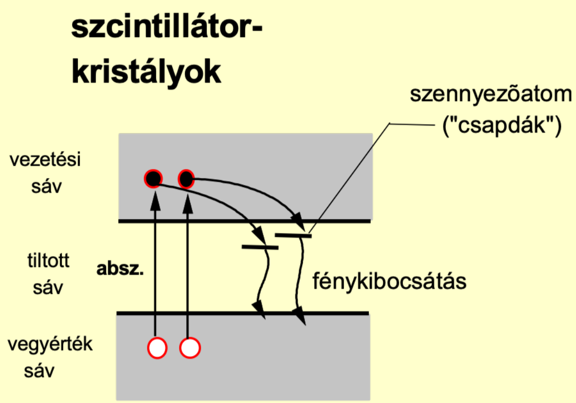




Number of current pulses ~ number of ionising particles

Scintillation detectors



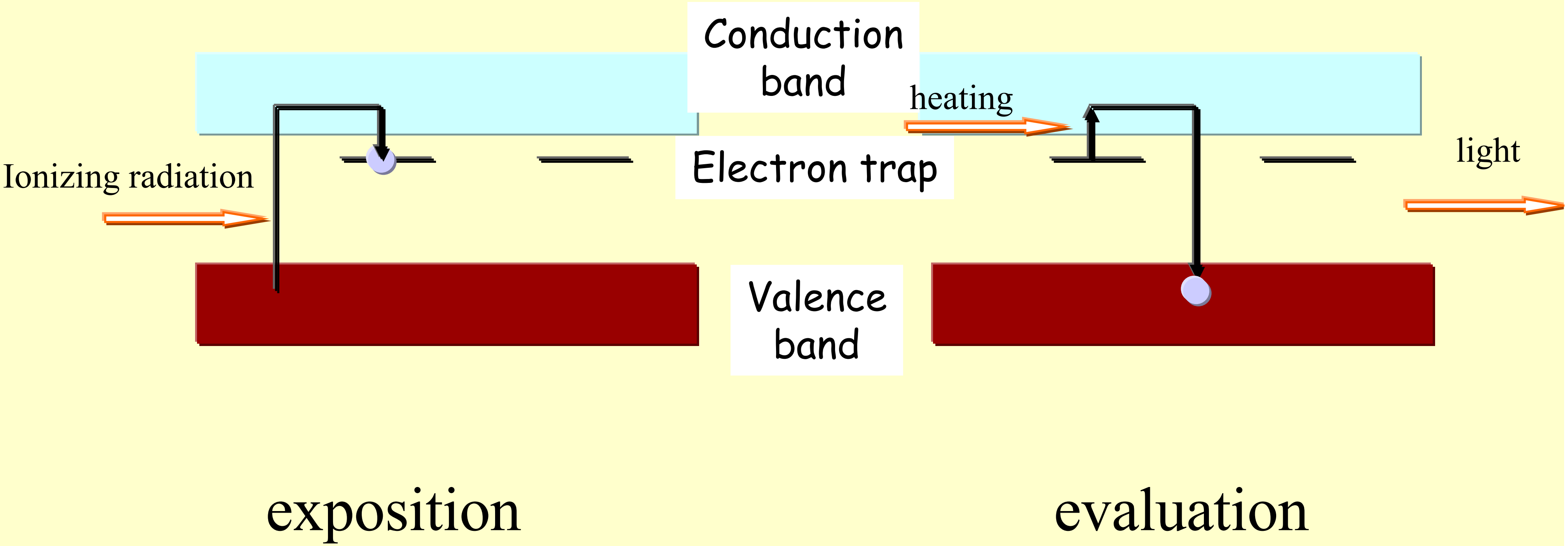


- Liquid scintillator
  - Solution of fluorescent compounds
  - Primary excitation of solvent and follow-up excitation of diluted compound
  - Light emission
- Plastic scintillator
  - Solid materials
- Inorganic crystals
  - Primary excitation of crystal, follow-up excitation of luminescent atoms

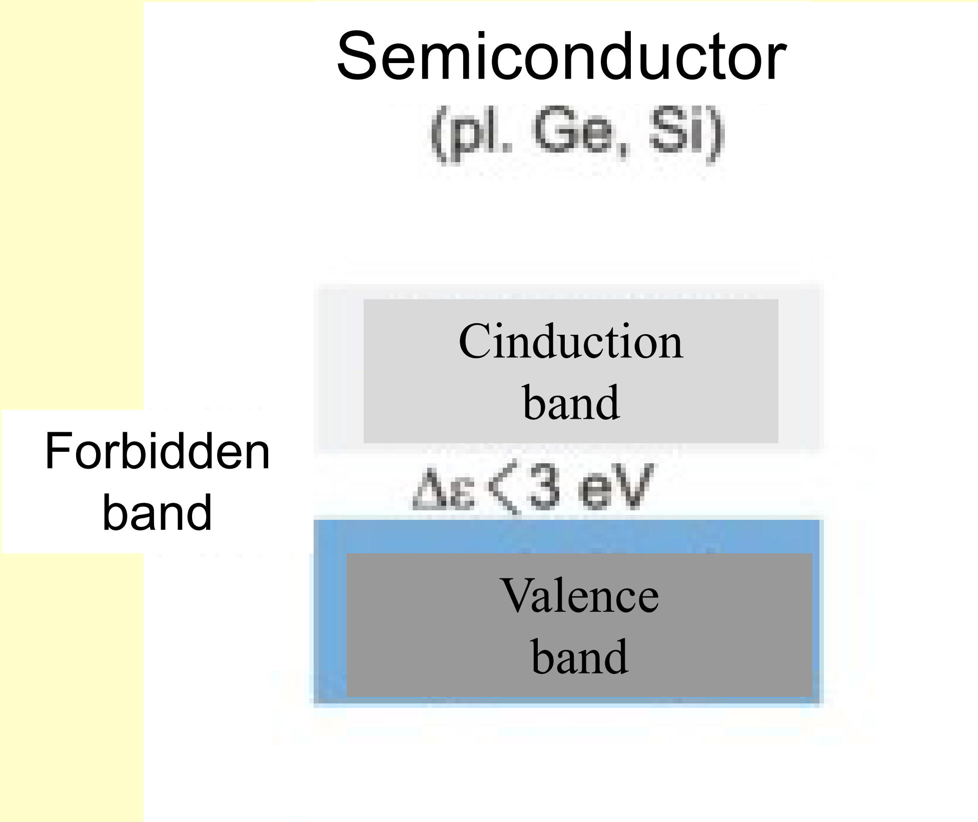
Solid phase detectors

Thermoluminescent dosimeter

Band structure on electronic transitions



Semiconductor detectors



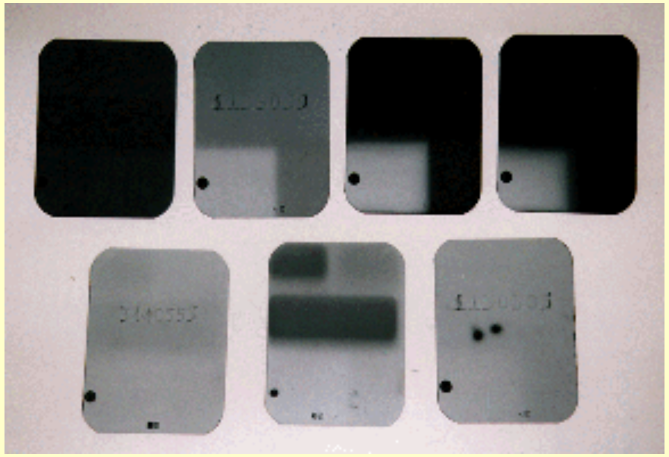
$$\frac{n}{n_0} = e^{-\frac{\Delta\varepsilon}{kT}}$$

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

Conductivity ~ number of excitations

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.

Damjanovich, Fidy, Szöllősi „Medical Biophysics”:

II. 4.

4.1
4.2
4.3
4.4
4.5

IX.3.

Kellermayer „Medical Biophysics Practices”: Dosimetry

http://report.semmelweis.hu/linkreport.php?qr=7XPEOKK02O1TDMAI