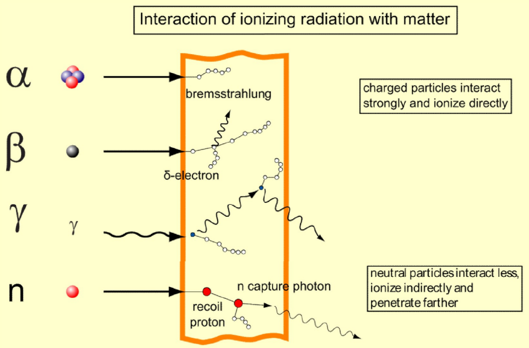
Radiation therapy

Radiation therapy is a clinical modality dealing with the use of ionizing radiations in the treatment of patients with malignant neoplasias (and occasionally benign diseases).

The **aim of radiation therapy** is to deliver a **curative** dose of irradiation to a defined tumor volume with as minimal damage as possible to surrounding healthy tissue.

Consequences of the absorption of ionizing radiation.

1. Physical events — Direct or indirect ionization



The amount of secondary ionization depends on the material; it can be up to 10 times the amount of primary ionization.

The gamma photon emitted by the nucleus of the cesium isotope with 137 mass number is absorbed with photoeffect. The absorbing medium is air, assume the work function to be 34 eV. What will be the kinetic energy of the photoelectron in eV?

$E_{^{137}Cs} = 0{,}661 MeV$

$$hf = A + 1/2mv^2$$

$$1/2mv^2 \approx 661\ 000\ eV$$

What is the maximum number of ion pairs that the ejected photoelectron is able to produce during the secondary ionization process?

$$n_{max} = 661\ 000\ eV/34eV$$

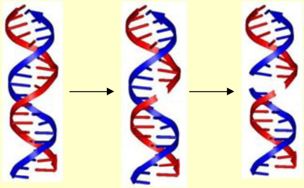
$$n_{max} = 19440$$

2. Chemical reactions

Direct effect

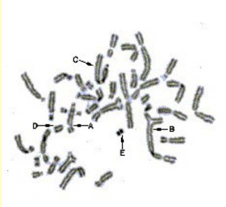
Direct ionization of the macromolecules.

DNA damage is the most important!



single double

strand breaks



chromosome aberrations

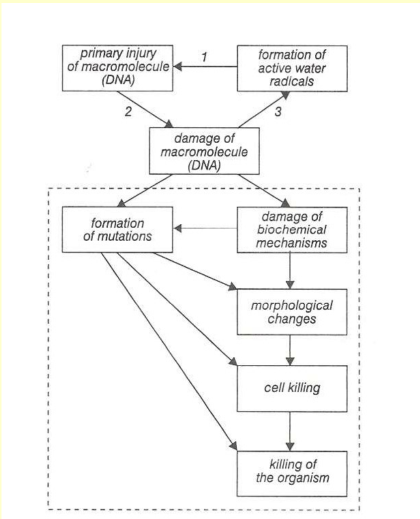
Indirect effect

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)

↓

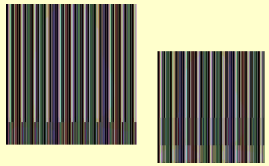
Reactive species induce damages in macromolecules and membrane structures.

3. Biological consequences



Grades of biological consequences

Cells are undamaged.



Cells are damaged, repair damages and operate normally.

Cells are damaged,
repair damage and operate abnormally.

Cells die as a result of damage.

Timescale of events

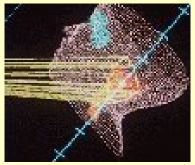
Physical	$10^{-20} – 10^{-8}$ s	Ionization, excitation
Chemical	$10^{-18} – 10^{-9}$ s	Direct/indirect chemical reactions
	10^{-3} – few hours	Repair of damages
Early biological	hours – weeks	Cell death, death of living system
Delayed biological	years	Carcinogenesis, genetic transformation

Radiotherapy : ionizing radiation induces damages at molecular and cellular level. This can be beneficial against malignant tissues

1. Which radiation is the best?
2. What is the optimal dose of radiation?
3. What is the best technique for generation radiation?
4. 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

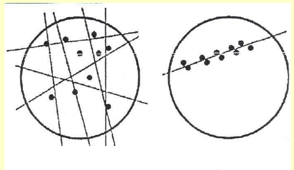
Heavy ions – limited use

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. $(nE_{ionpair}/l)$



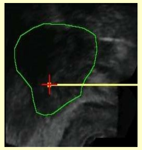
Low LET e.g.,. γ, rtg

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	

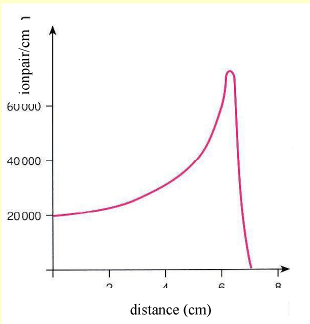
α



Internally deposited radioactivity

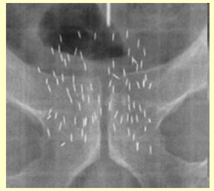
Brachytharapy

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

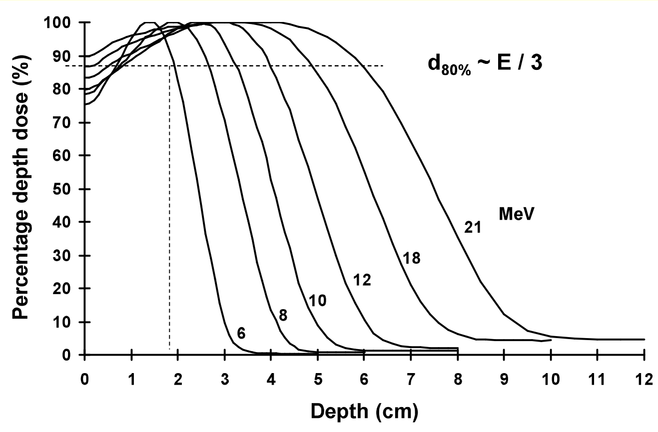
production: linear accelerator

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

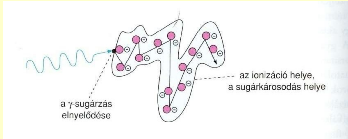


Conclusion: only superficial tumors can be treated with electron beams

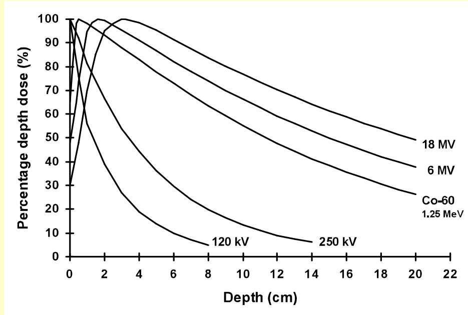
γ :

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



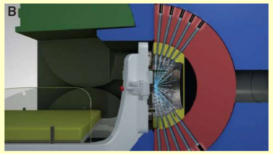
γ :

γ-knife: focused dose of radiation

about 200 portals in a specifically designed helmet

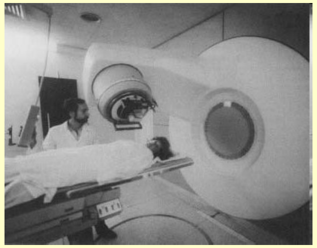
e.g., ^{60}Co Eγ≈MeV , about TBq activity

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



Treat tumours and lesions in the brain

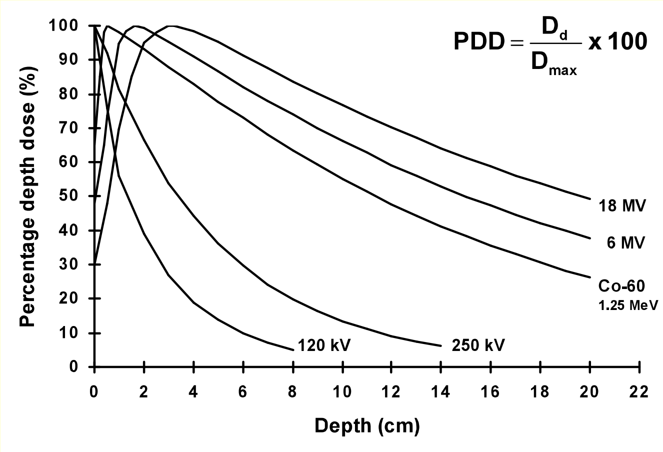
X-ray:



The X-rays are generated by a linear accelerator .

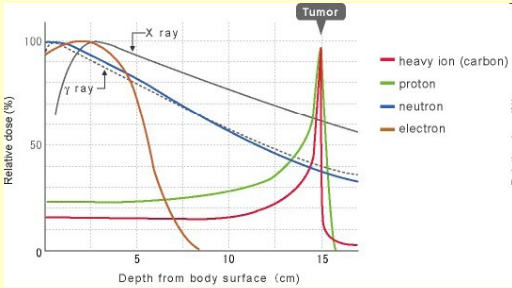
Few MeV photon energy.

Photon PDD (percentage depth dose) curves with different energies

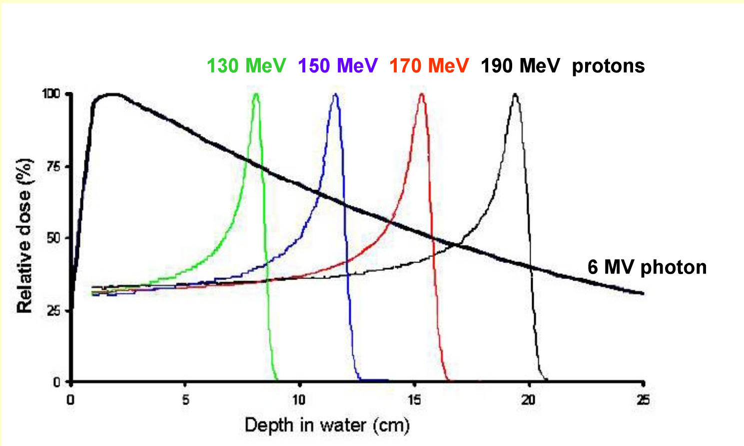


Would be ideal, but very expensive!

p :

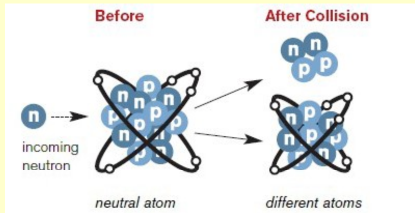


Comparison of photon and proton depth doses



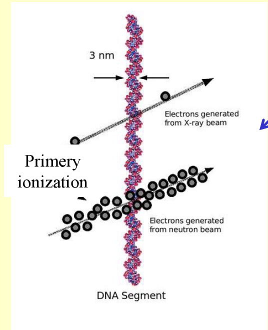
Neutron radiation: collision of high energy protons (66 MeV) into berillium target (p(66) +Be)

Neutrons induce nuclear reactions.



n :

High LET



Question of the week

Compare the PDD (percentage depth dose) of 130 MeV protons and gamma radiation of Co-60 at 12 cm depth.

Damjanovich, Fidy, Szöllősi: Medical biophysics

IX.3