Radioisotopes in action

Diagnostic application of radioisotopes

Optimal activity for diagnostic procedure

Maximize the information

Minimize the risk

$$\Lambda \sim 100 \text{ MBq}$$

Types of images

Static picture – spatial distribution of isotope / activity at a certain time

Dynamic picture – variation of the amount of isotope / activity in time

Static and dynamic picture – series of static recordings

Emission CT

SPECT (Single Photon Emission Computed Tomography)

PET (Positron Emission Tomography)

Types of images

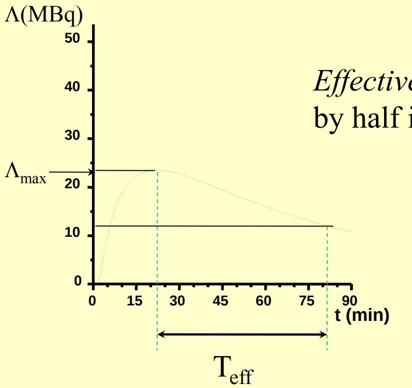
Static picture – spatial distribution of isotope / activity at a certain time

Isotope accumulation in

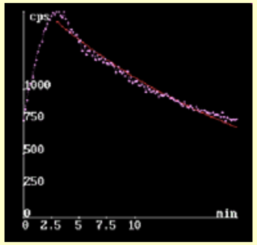
thyroid glands kidneys

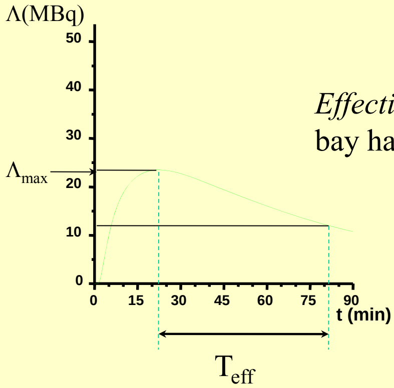
Types of images

Dynamic picture – variation of the amount of isotope / activity in time



Effective half -life – activity decreases by half in the target organ





Effective half-life – activity decreases bay half in the target organ

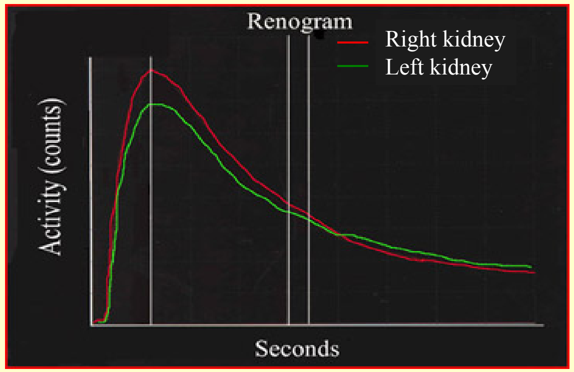
$$\Lambda = \Lambda_0 e^{-(\lambda_{phys} + \lambda_{biol})t}$$

$$\lambda_{effective} = \lambda_{phys} + \lambda_{biol}$$

$$\frac{1}{T_{eff}} = \frac{1}{T_{phys}} + \frac{1}{T_{biol}}$$

The final fate of the radiotracer depends on how the addressed organ deals with the molecule, whether it is absorbed, broken down by intracellular chemical processes or whether it exits from the cells and is removed by kidney or liver processes. These processes determine the **biological half-life** $\boldsymbol{T_{biol}}$ of the radiopharmaceutical.

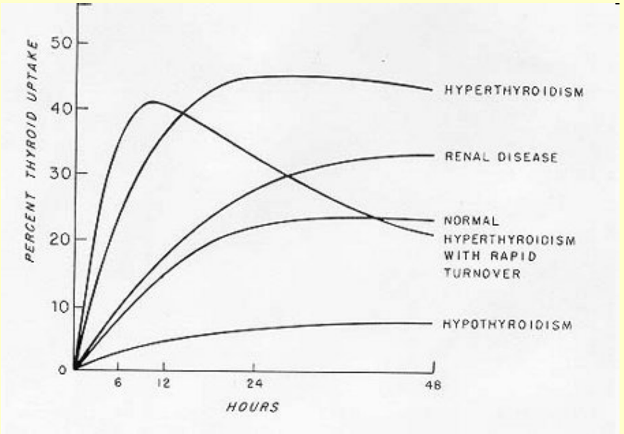
example



kidney

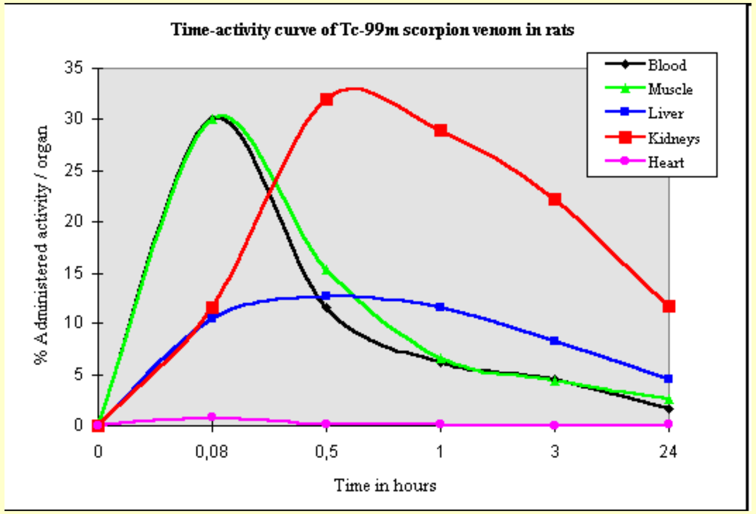
Isotope accumulation

example



Thyroid glands

Isotope accumulation



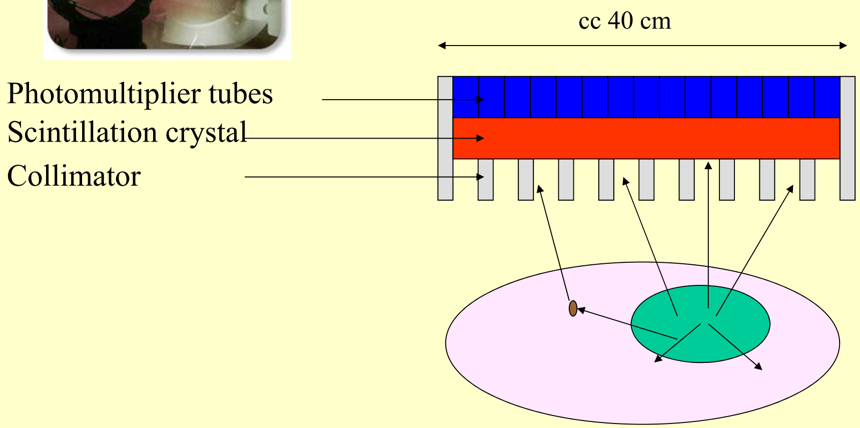
Hal Anger

1920-2005

Hal Anger and coworkers

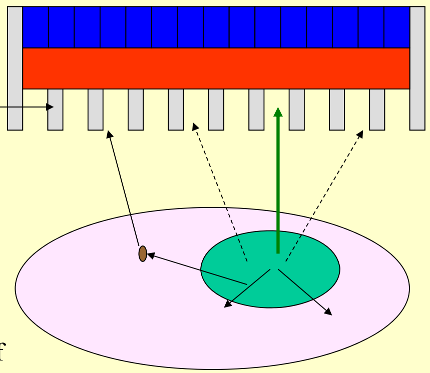
1952

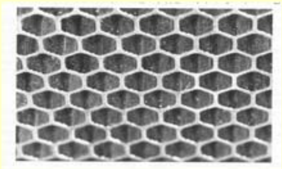
Gamma camera



A radioactive source emits gamma ray photons in all directions.

collimator



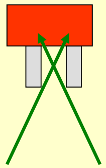


Collimators are composed of thousands of precisely aligned channels made of lead.

The collimator conveys only those photons traveling directly along the long axis of each hole.

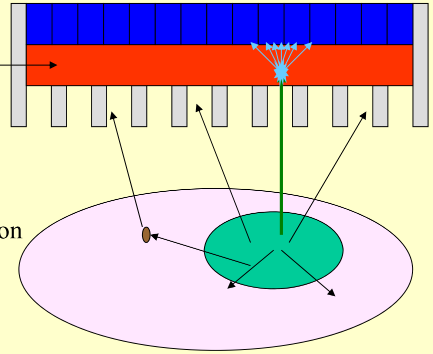
Photons emitted in other directions are absorbed by the septa between the holes.

Size and geometry of holes are essential for the resolution.



Scintillation crystal

NaI(Tl)



Sufficient detection efficiency

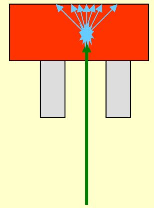
photons of 150 keV μ ~2.2 1/cm

10 mm thickness ~ 90% attenuation

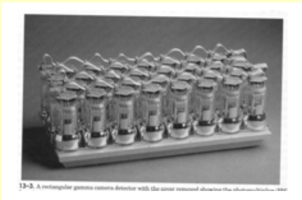
Proper wavelength – 415 nm – for PM photocathode

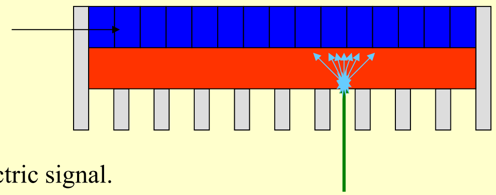
Problems:

- fragile
- temperature sensitive
- hygroscopic



Photomultiplier tubes



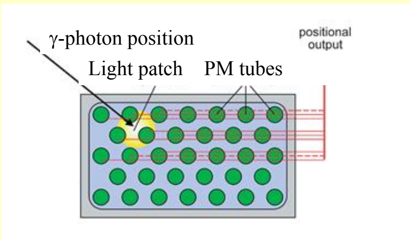


Transformation of light pulses to electric signal.

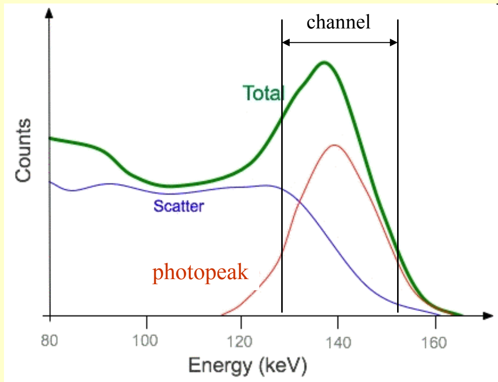
Typically 37-91 tubes, 5.1-7.6 cm diameter each

Amplitude of electric pulses varies in a wide range, because

- absorption of one γ-photon induces electric signals in more then one tubes.
- attenuation mechanism can be photoeffect and Compton-scatter.



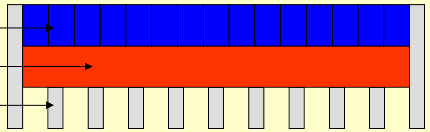
Pulse amplitude spectrum – Amplitude of an electric pulse generated by a γ-photon absorption in photoeffect is proportion to the photon energy.



These electric pulses can be distinguished by discrimination (DD).

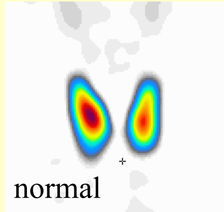
Gamma camera

Photomultiplier tubes
Scintillation crystal
Collimátor

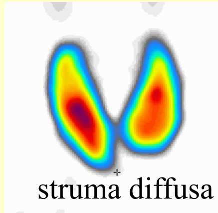


Identification of source position is facilitated by
- the collimator
- the PM tubes
- the discrimination.

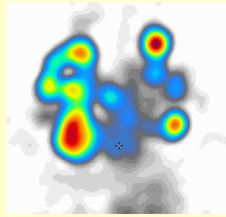
Pertechnetate (intravenous 80 MBq) distribution in thyroid glands



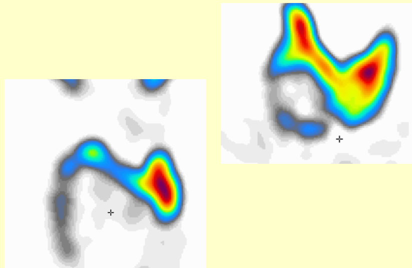
normal



struma diffusa

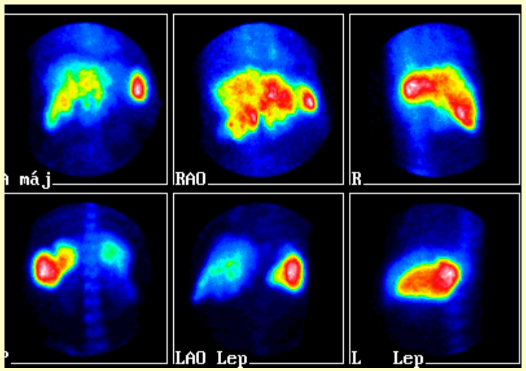


struma multinodularis



Cold nodules

Liver lesion nodules

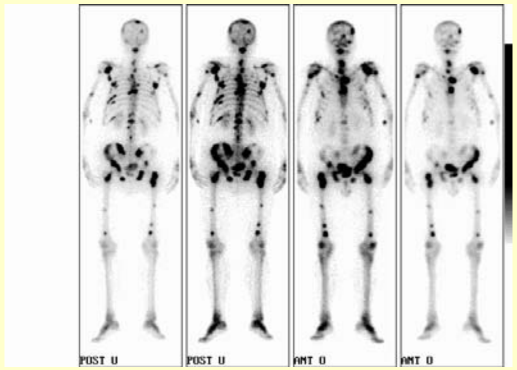


^{99m}Tc- fyton

Bone scintigraphy

^{99m}Tc-MDP: 600 MBq

normal



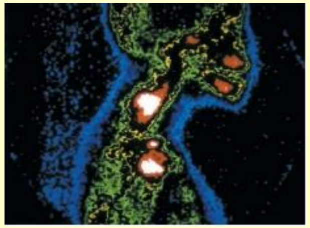
imaging in bone metastases

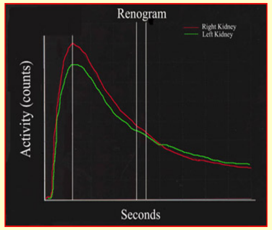
Gamma camera – space and time distribution can be recorded

static and dynamic pictures can be reconstructed

Camera parameters:
- spatial resolution
- energy resolution
- efficiency of detection

Gamma camera image:
summation image

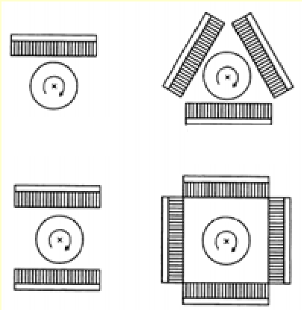




For depth resolution: tomographic device is necessary

SPECT

Single Photon Emission Computed Tomography



Variouos camera arrangements

SPECT

Tomographic application of γ-cameras – data collection in 360°.

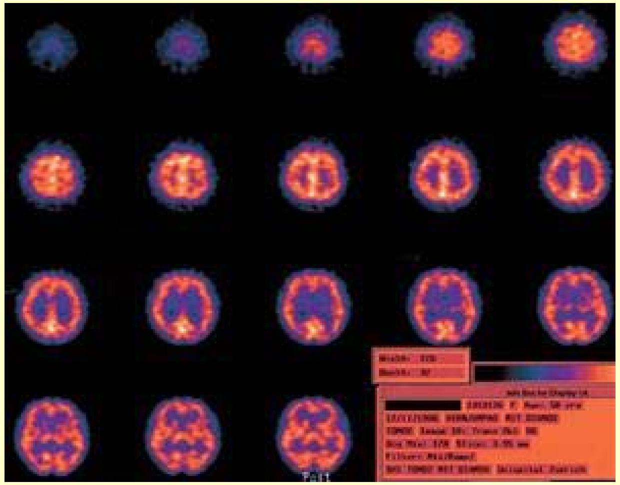
Cross-sectional image can be reconstructed.

Measurement from a series of projections.

Computer directs the movement of the detector, stores the data, reconstruct the cross-sectional image

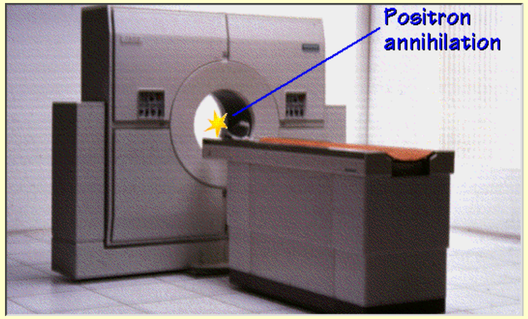
SPECT – images of scalp

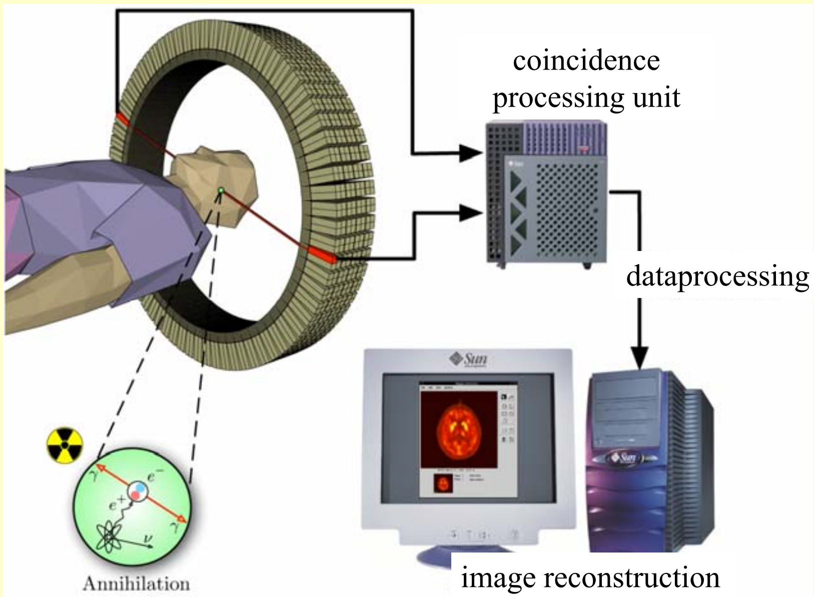
^{99m}Tc- HMPAO



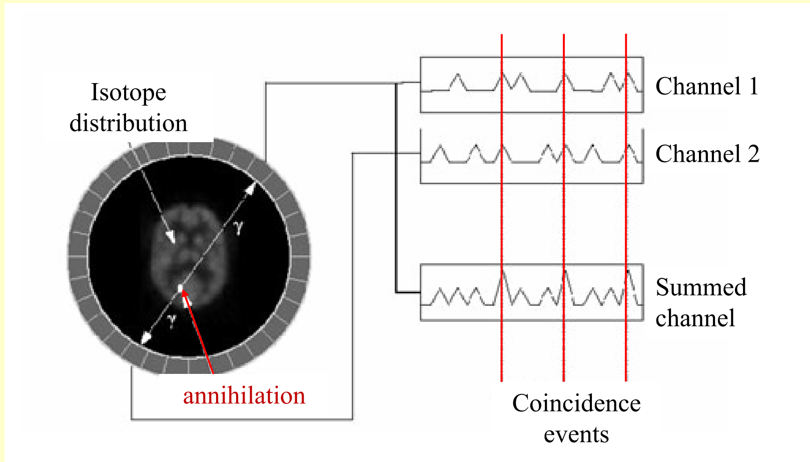
PET

Positron Emission Tomography





coincidence processing



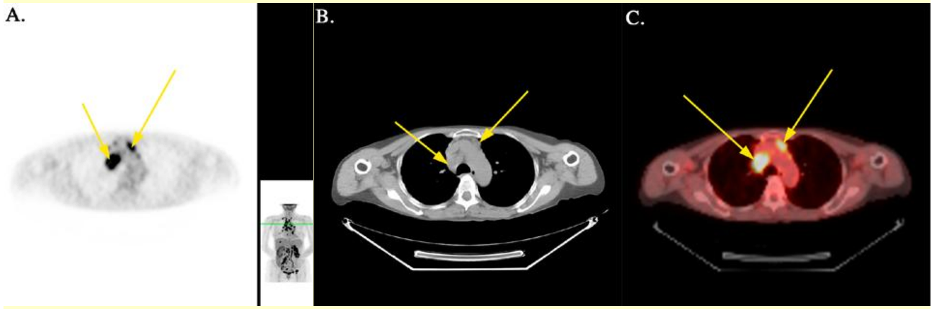
The most frequently used radionuclides in PET are radioisotopes of structural elements of natural organic molecules.

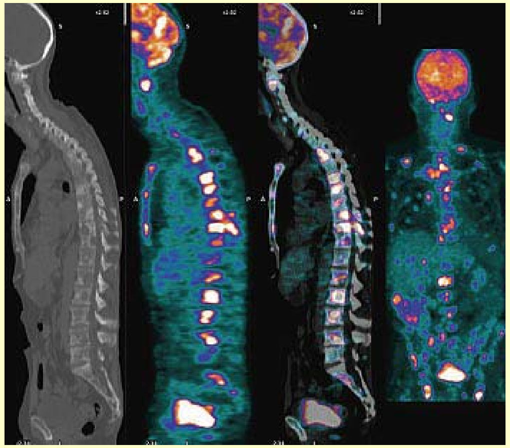
Isotope	β^+ energy (MeV)	β^+ range (mm)	1/2-life	Applications
^{11}C	0.96	1.1	20.3 min	receptor studies
^{15}O	1.70	1.5	2.03 min	stroke/activation
^{18}F	0.64	1.0	109.8 min	oncology/neurology
^{124}I	2.1350/1.5323	1.7/1.4	4.5 days	oncology

Isotope manufacturing nearby the site of application (see half-lives).

PET/CT

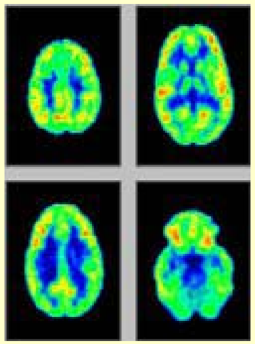
Combination of structural and functional imaging



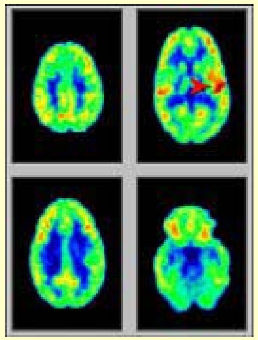


CT PET PET/CT PET

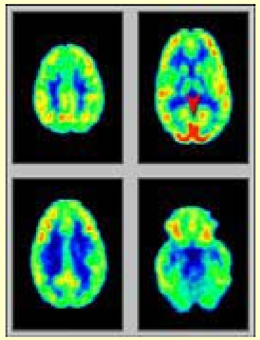
Activity of brain areas



In rest

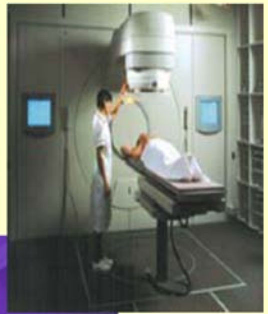


hearing



vision

Radiation therapy

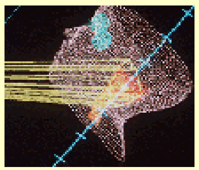


Radiotherapy : ionizing radiation induces damages at molecular and cellular level. This can be beneficial against tumour tissues

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




α

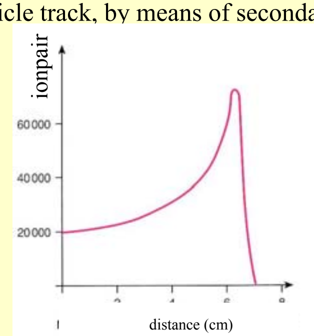
Internally deposited radioactivity

β^-, e-, γ, Rtg, p, n

Linear ion density: the amount of ion pairs in a line generated in a unit distance *(n/l)*

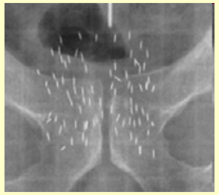
LET (Linear Energy Transfer : the energy transferred to the material surrounding the particle track, by means of secondary electrons. $(nE_{ionpair}/l)$

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



α

β⁻: Particle energy is not optimal
continuous energy spectrum
typical energy: few MeV



Internally seeded radioactivity

e⁻: accelerated electron - 10-20 MeV

γ,

production: linear accelerator

Rtg,

Efficient distance! ≈1cm/3MeV

p

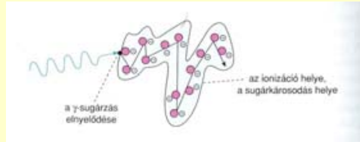
In the practice 6-21 Mev => 2-7 cm
treatment of superficial tumours

n

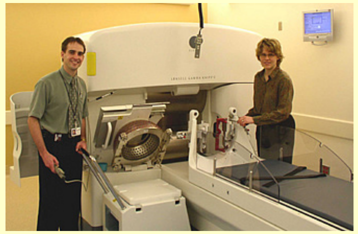
γ : external radiation source

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

Penetration distance
is energy dependent



γ-knife: focused dose of radiation

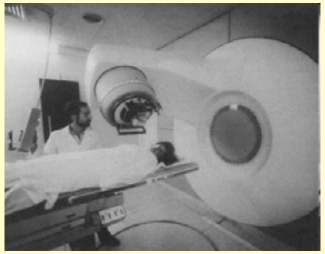


about 200 portals in a specifically designed helmet

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

Treat tumours and lesions in the brain

X/ray:



The X-rays are generated by a linear accelerator .

Few MeV photon energy.

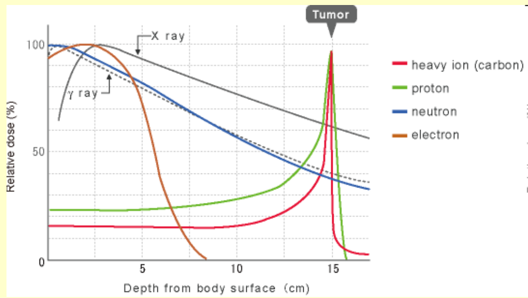
Would be ideal, but very expensive!

γ,

Rtg,

p :

n

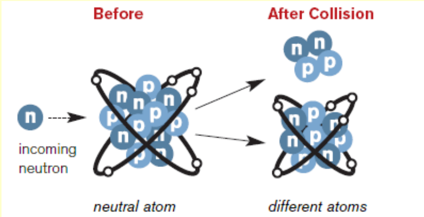


Neutron radiation:collision of high energy protons (66 MeV) into berillium target (p(66) +Be)

α

β-

Neutrons induce nuclear reactions.



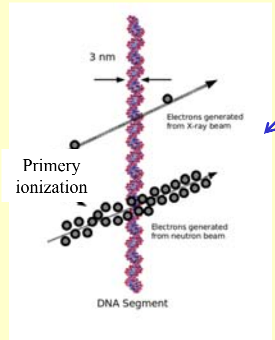
γ,

Rtg,

P,

High LET

n :



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	

Damjanovich, Fidy, Szöllősi: Medical biophysics

II. 3.2.3
3.2.4
3.2.5

VIII. 3.2
VIII. 4.4

IX.3