

Diagnostic and therapeutic applications of nuclear radiations

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Medical, pharmaceutical applications of radioisotopes

Basis of application: radioisotopes have identical behavior in the organism to corresponding stable atoms.

- Organ-specific compounds can be labeled with radioisotopes (radiopharmaceuticals)

George Hevesy 1923 – first biological tracing experiment

- Nobel prize in chemistry 1943.)

Fields of application:

- diagnostics (in vivo, in vitro)
- therapy
- research



If diagnostics + therapy = 100 %, from this 95 % is the diagnostics.

Radiopharmaceuticals

Chemical agents or drugs having radioactivity. Preparations labeled with radioisotopes for diagnostic or therapeutic purposes. During their production the quality and purity requirements of medicines must be fulfilled.

In the pharmacopoeia one can find radiopharmaceuticals in two groups:

- ATC V09 Radiopharmaceuticals used in diagnostics
- ATC V10 Radiopharmaceuticals used in therapy

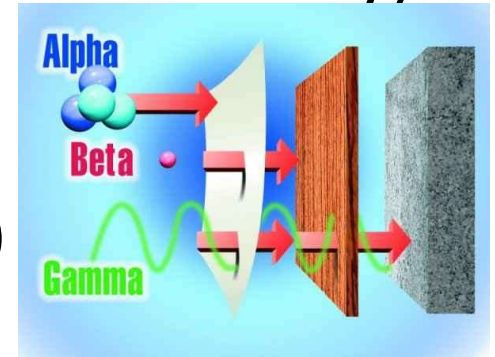


In vivo diagnostics

(the radioisotope is introduced into the patient's body)

Viewpoints for selection of isotopes

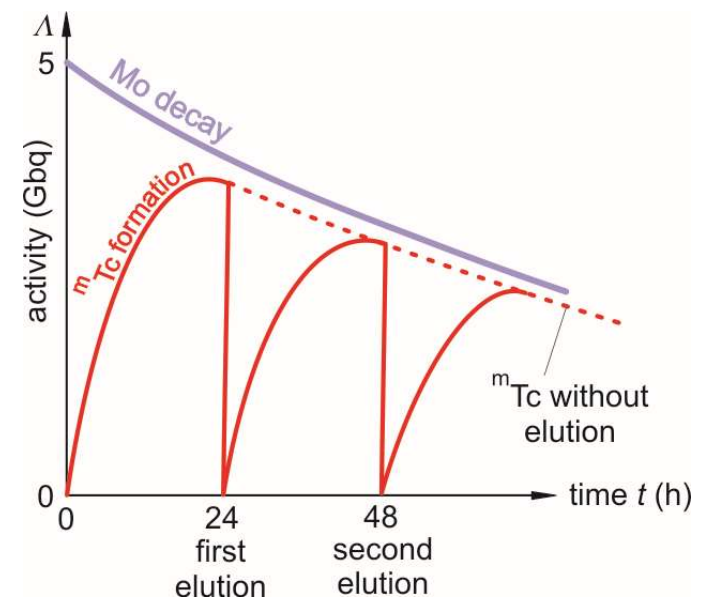
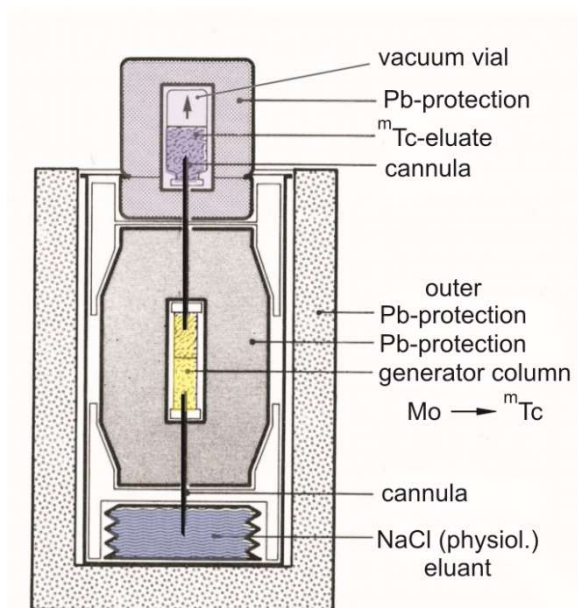
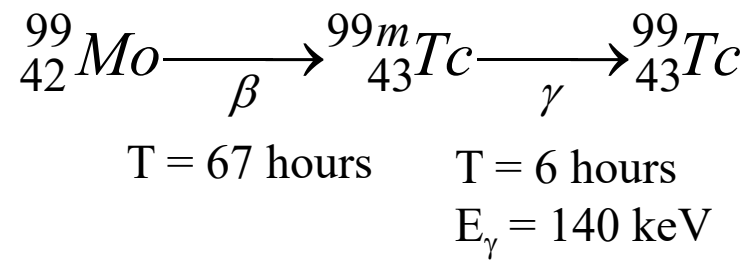
- **gamma-radiating** (the longest effective range)
- **short half-life** (but not shorter, than the examined process)



$\Lambda \sim N/T \rightarrow$ for the necessary activity lower amount is enough

- **photon energy should not be too low, and should not be too high** (higher energy \rightarrow less absorption in the tissues, but the detection efficiency is lower)

\rightarrow ^{99m}Tc is ideal



At least in 75 % of the in vivo diagnostic applications ^{99m}Tc is used to label different organ specific compounds.

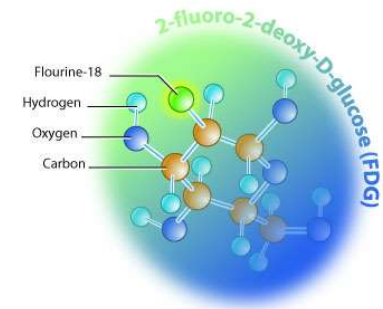
(e.g. pyrophosphate – bones, colloids – liver and RES, albumin – circulation)

Further gamma-radiating isotopes that are frequently used: ^{123}I , ^{125}I , ^{131}I (thyroid gland and kidney), ^{67}Ga (inflammations and tumors), ^{201}Tl (heart muscle), ^{81m}Kr , ^{127}Xe , ^{133}Xe (examination of lungs by inhalation)

The most frequently used positron radiating isotopes (for PET examinations): ^{18}F , ^{11}C , ^{13}N , ^{15}O

They have short half-life. They are produced in cyclotron.

The most frequently used positron radiating radiopharmakon: fluoro-deoxy-glucose (FDG) – brain activation.



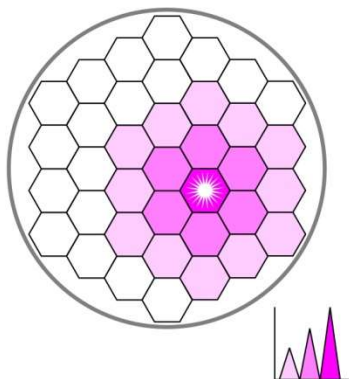
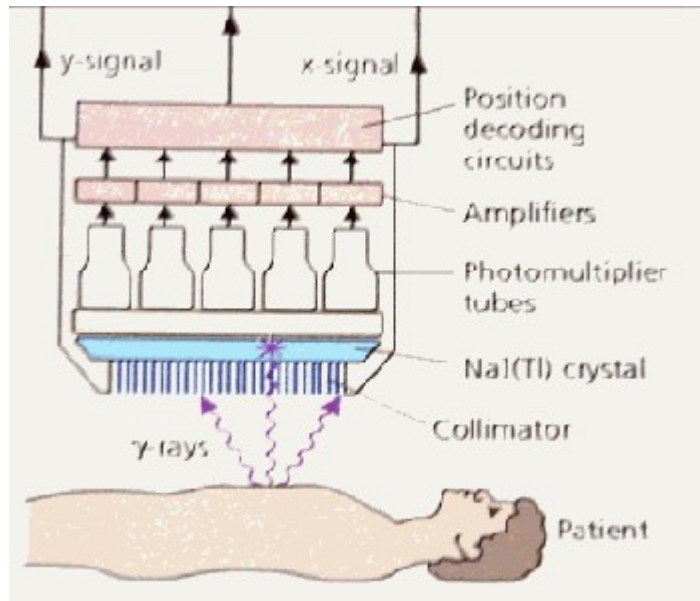
The distribution of isotopes can be detected by diagnostic equipments based on scintillation.

- Scintillation counter (see practice!)
- Gamma camera (Anger camera)
- SPECT (single photon emission computed tomography)
- PET (positron emission tomography)

Gamma camera



Hal Anger
(1920-2005)



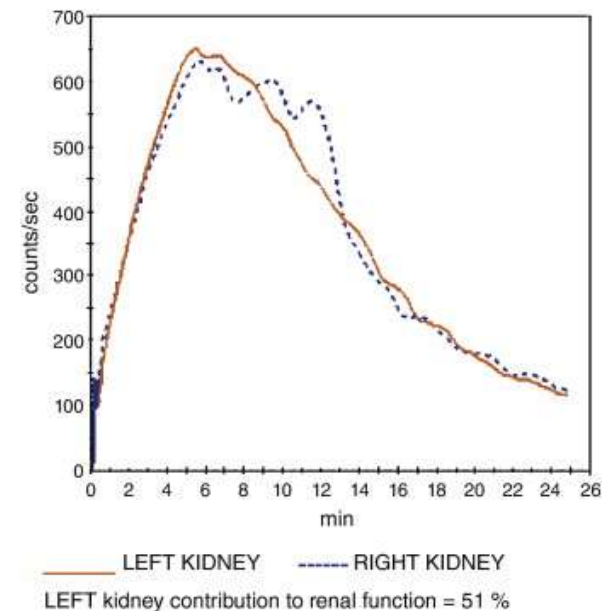
Static examination (scintigram)

- the distribution of isotope in the space can be examined

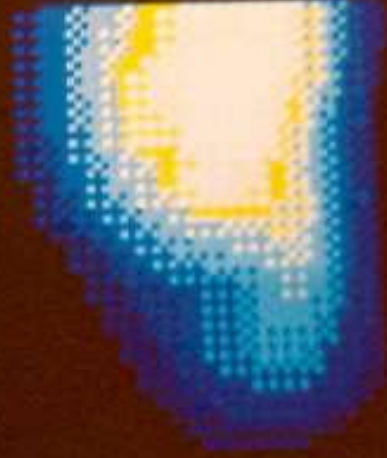


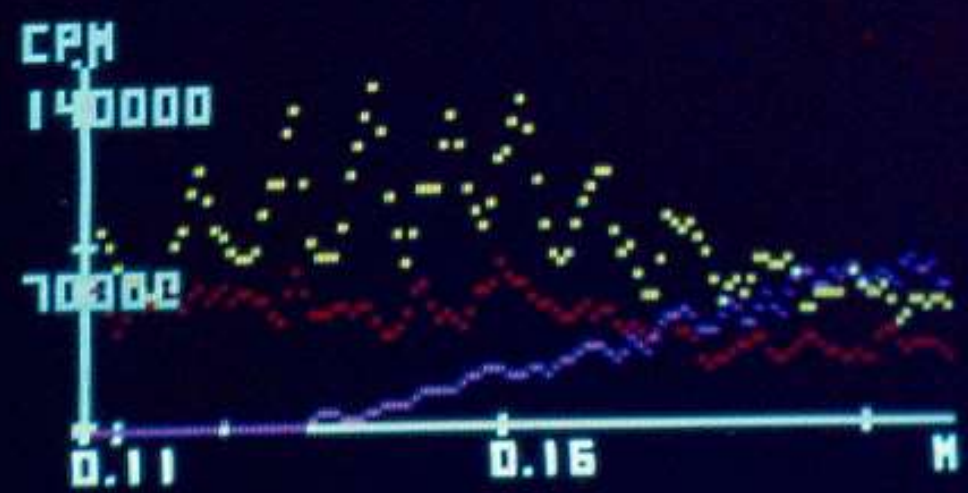
Dynamic examination

- the change of activity in the function of time in a certain region can be examined (ROI – region of interest)

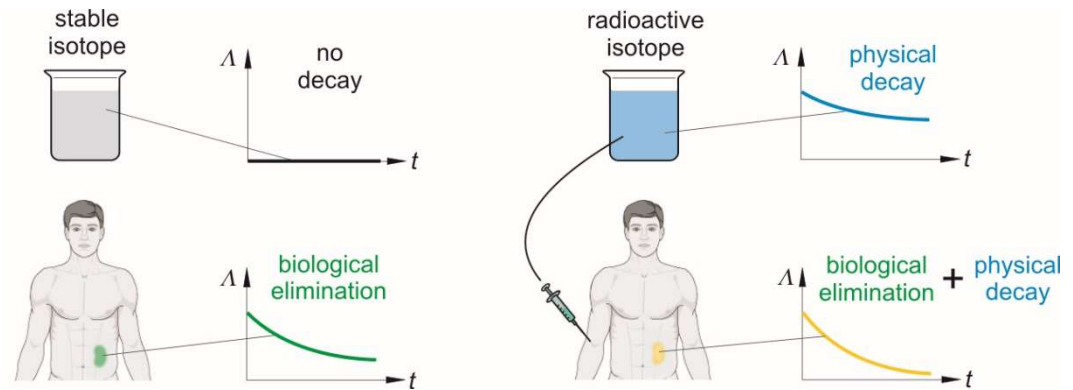
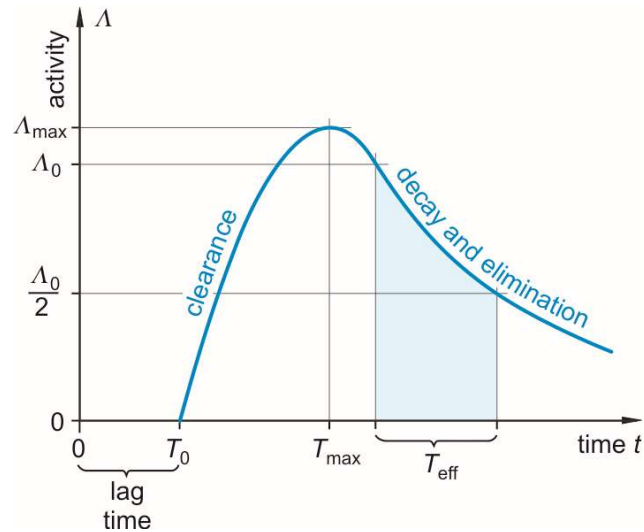


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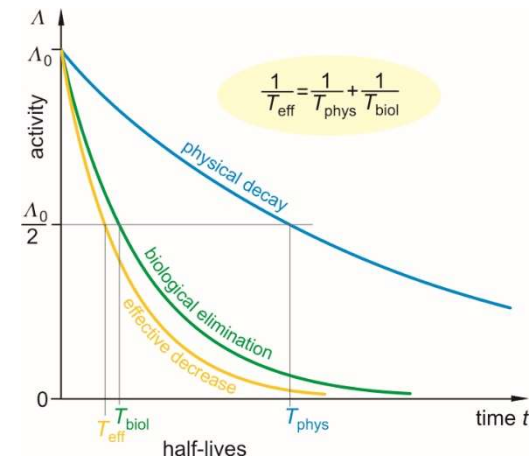


The isotope accumulation curve can be obtained from the measurement of activity in different moments

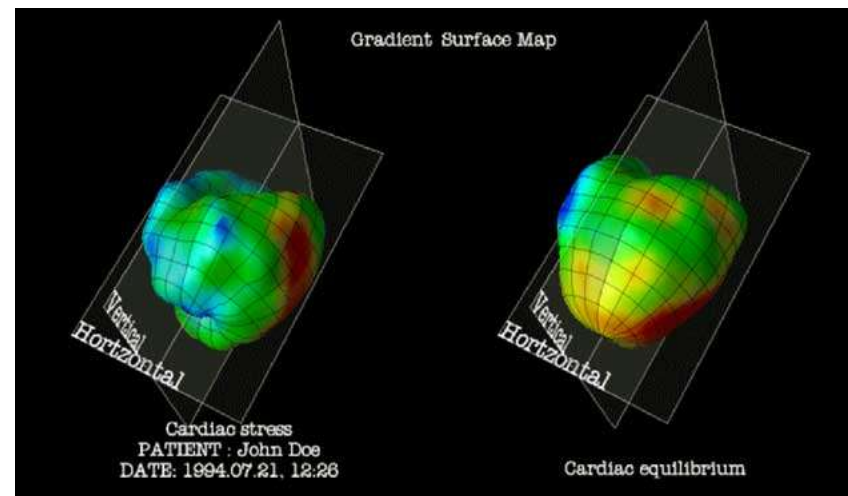


Connection between half-lives:

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

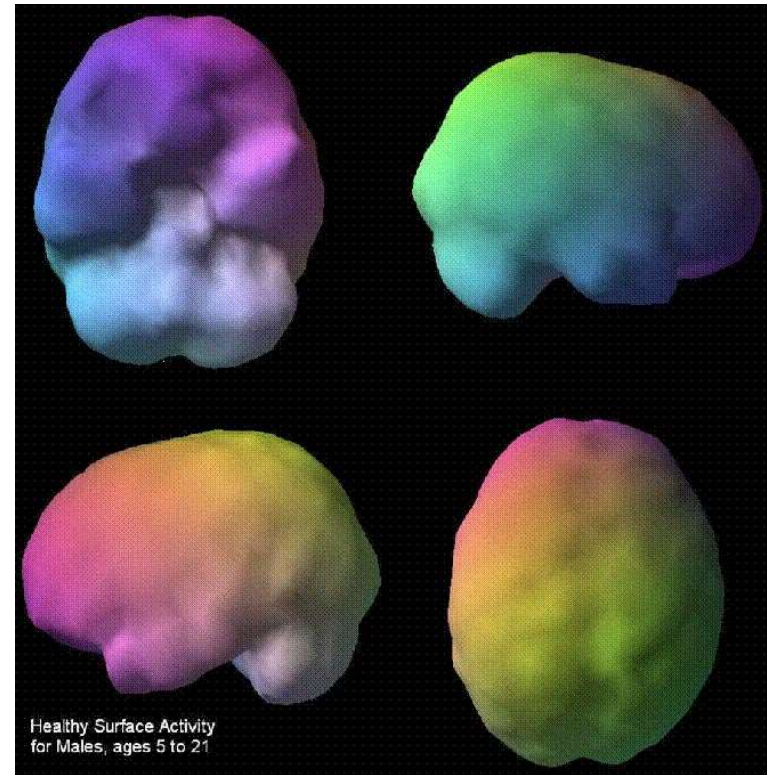
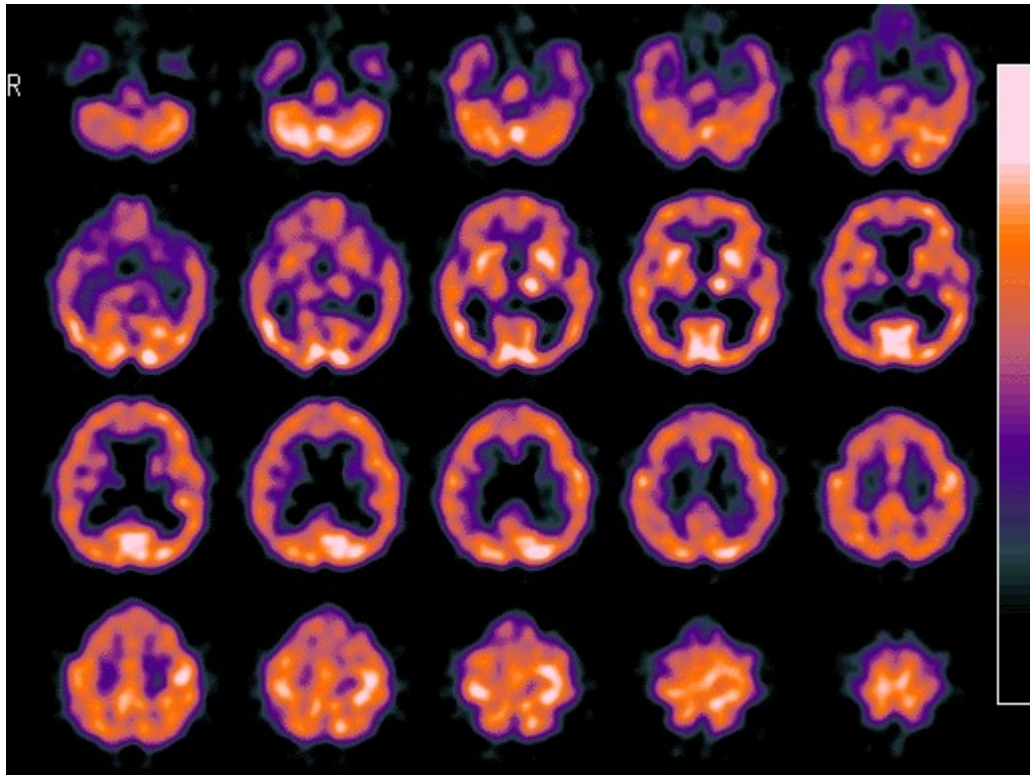


SPECT (the detector of gamma camera is rotated around the body axis → three dimensional image)



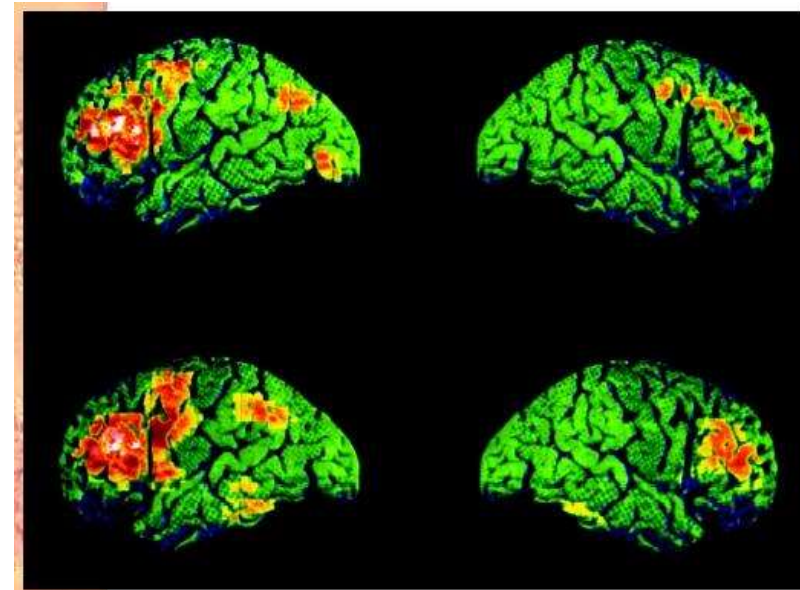
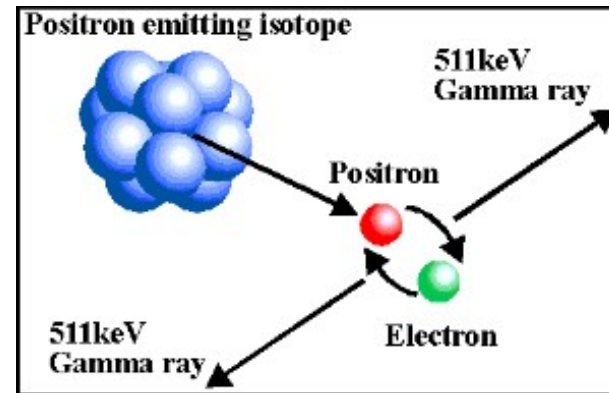
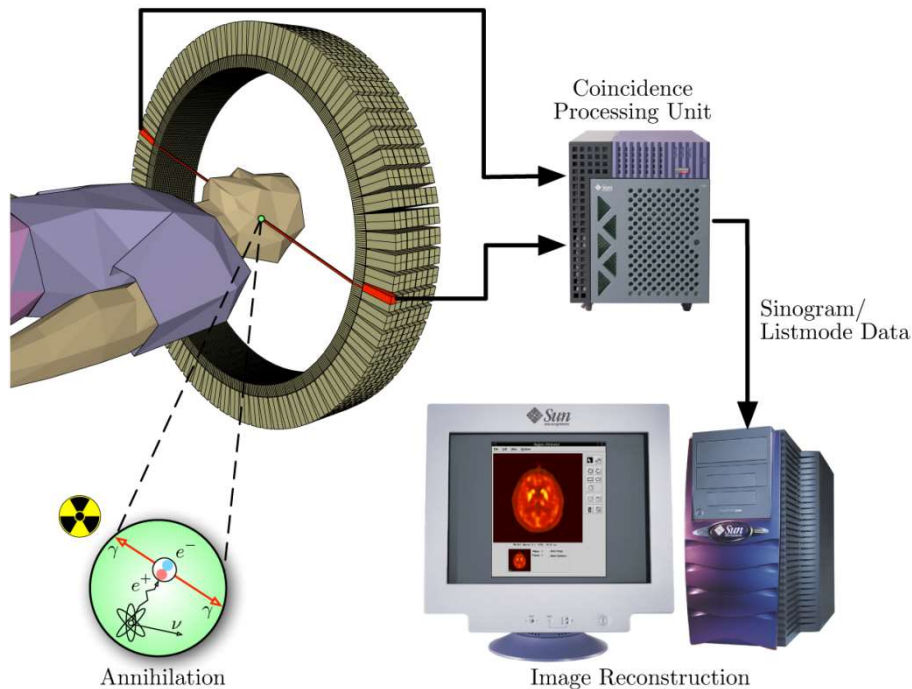
SPECT-images

Similarly to CAT-scan cross-sectional images are produced about the layers above each other. From these sectional image of any direction or three dimensional image can be reconstructed.



PET examination

positron-radiating isotope – positron-electron meeting → annihilation
→ 2 gamma photons (511 keV) - these are detected
coincidence: the gamma photons arrive into the two detectors in the
same time (within a few ns).



PET

The patient is surrounded by circles of scintillation detectors.

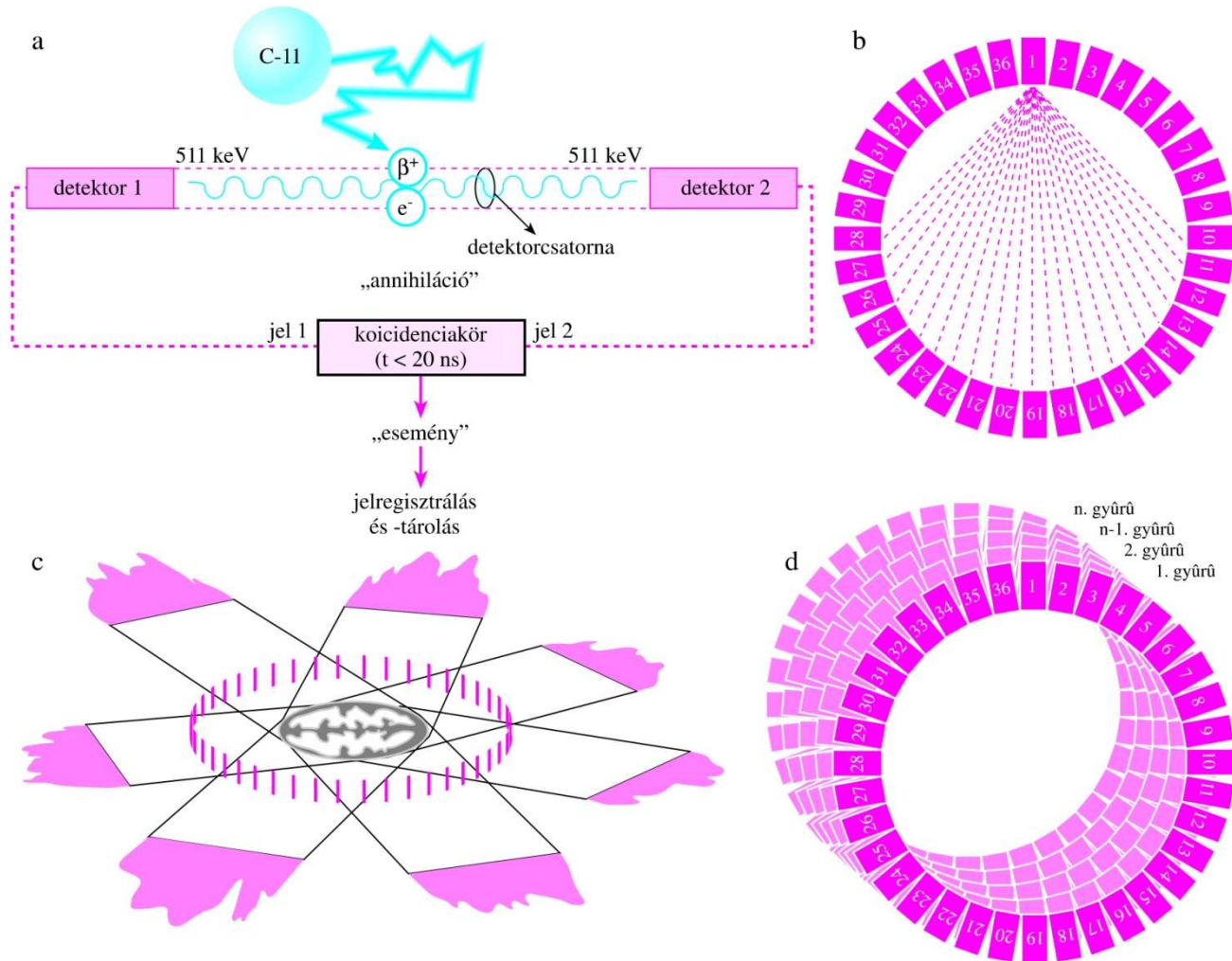
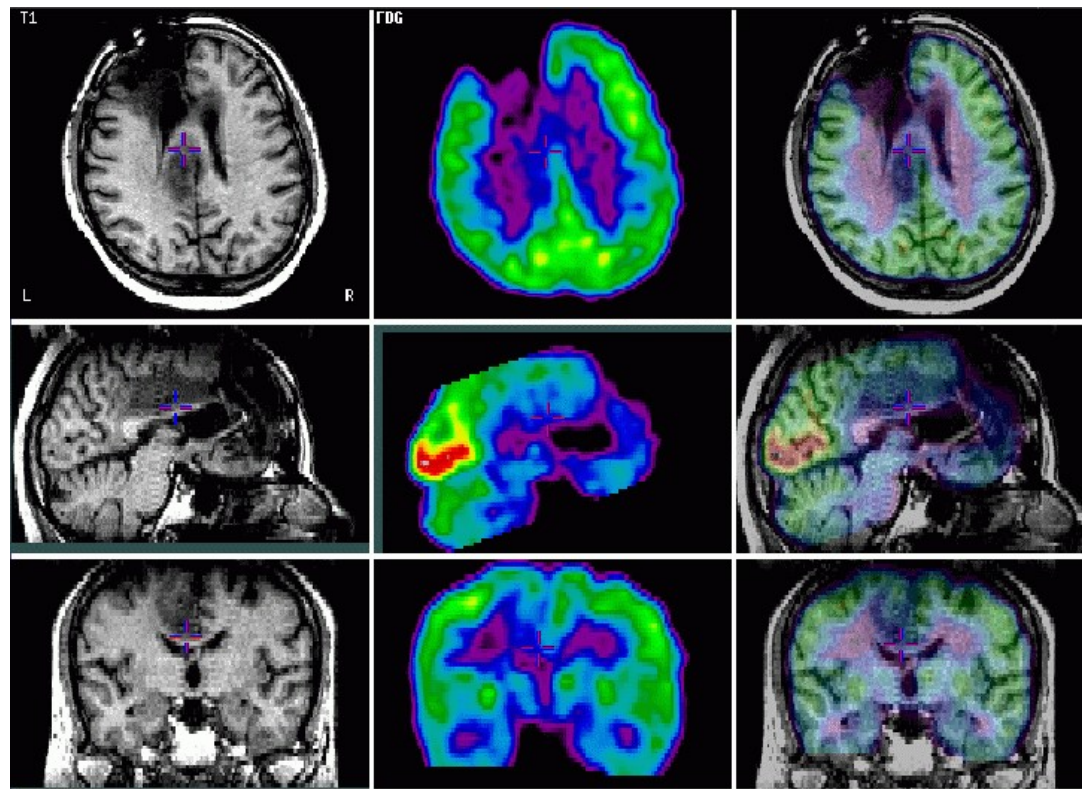


Image fusion

Combination of functional and morphological information

- functional: SPECT and PET
- morphological: CT and MRI



Combined equipments (for both diagnostic and research purposes)



NanoSPECT/CT

NanoPET/MRI



In vitro isotope diagnostics (The patient does not get radioisotope, but some body fluid is taken and labeled with it.)

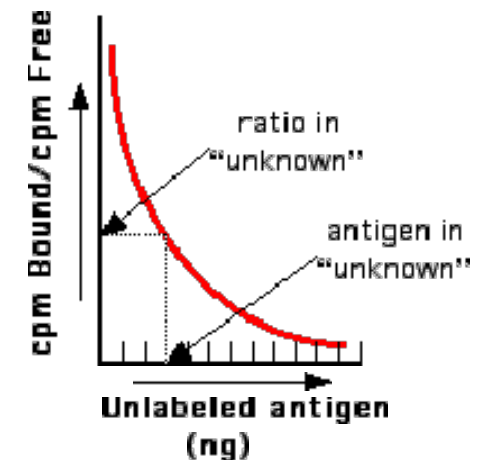
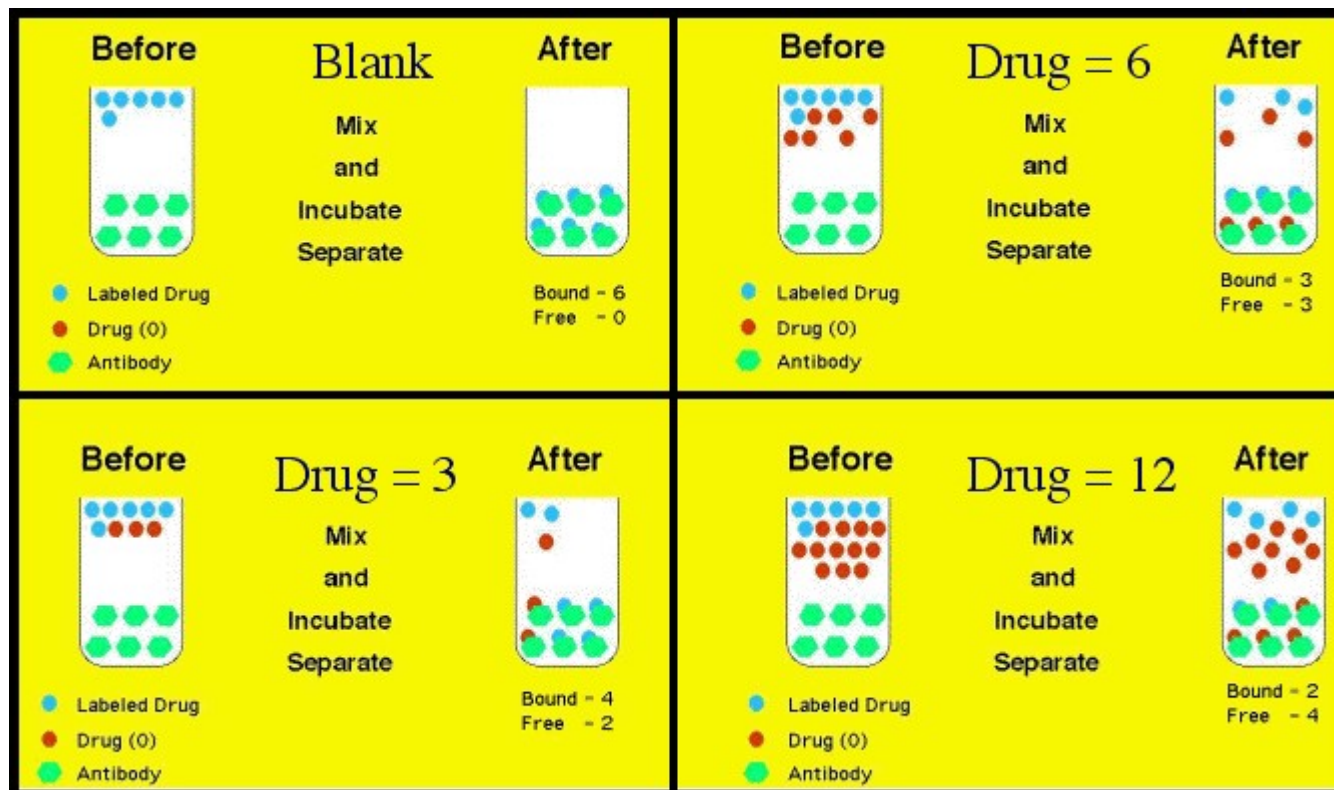
- Usually the concentration of a component (e.g. hormone) in body fluid (blood, urine) sample is determined.
- In the selection of isotopes the measurement technological viewpoints are important. Negative beta-, or soft gamma radiating isotopes are used, e.g. ^3H , ^{14}C , ^{125}I . Half-life can be also longer.
- Working with these preparations plexi plates are used for radiation protection.



Radioimmunoassay (RIA)

- known amount of antibody and radioactive antigen + „cold” antigen in different amounts → calibration curve is made from where the unknown concentration can be read.

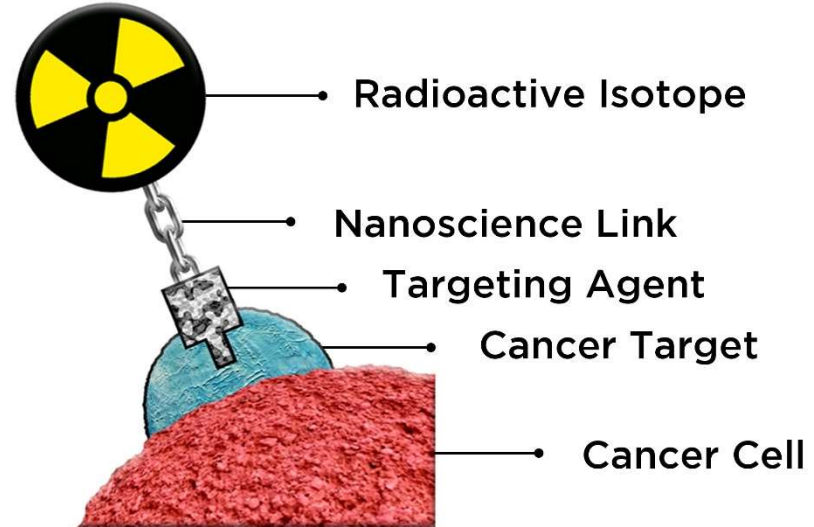
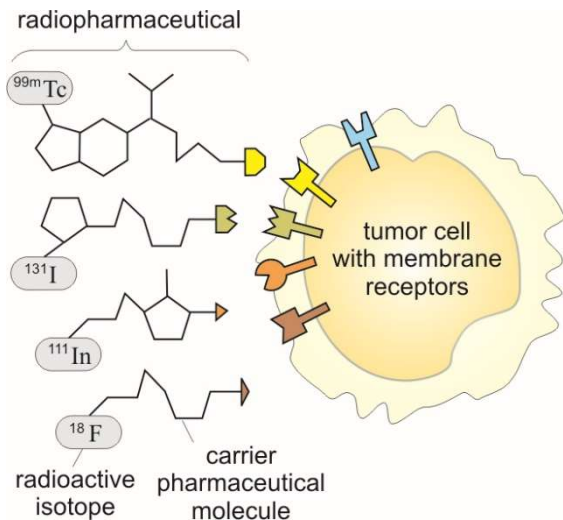
(Very sensitive method. Concentration of hormones and drugs in the blood serum can be determined.)



Isotope therapy

The cell killing effect of ionizing radiation is used for the treatment of e.g. hyperthyreosis (^{131}I) or tumors (^{90}Y , ^{153}Sm , ^{186}Re bound to monoclonal antibody)

Alpha-, or beta-radiating isotopes are given to have local effect. The same object labeled with different isotopes can be used for diagnostic and therapeutic purposes (theranostics)



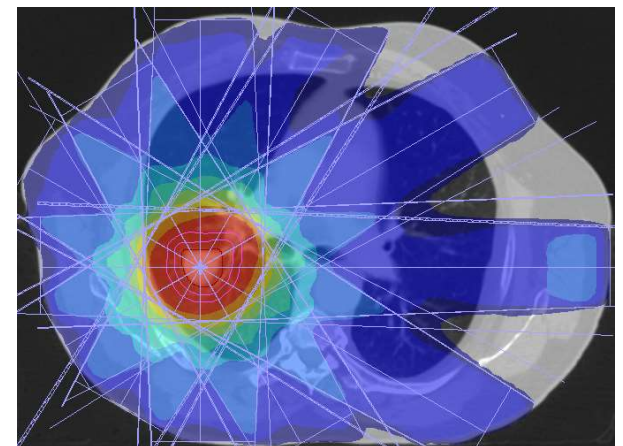
Therapy with radiation sources outside the body

Gamma-radiating isotopes are used
(high penetration depth)
Mainly for killing of tumors
(^{137}Cs , ^{60}Co)

Radiation sources of very high activity
are applied, because high dose is necessary to kill the tumor cells.

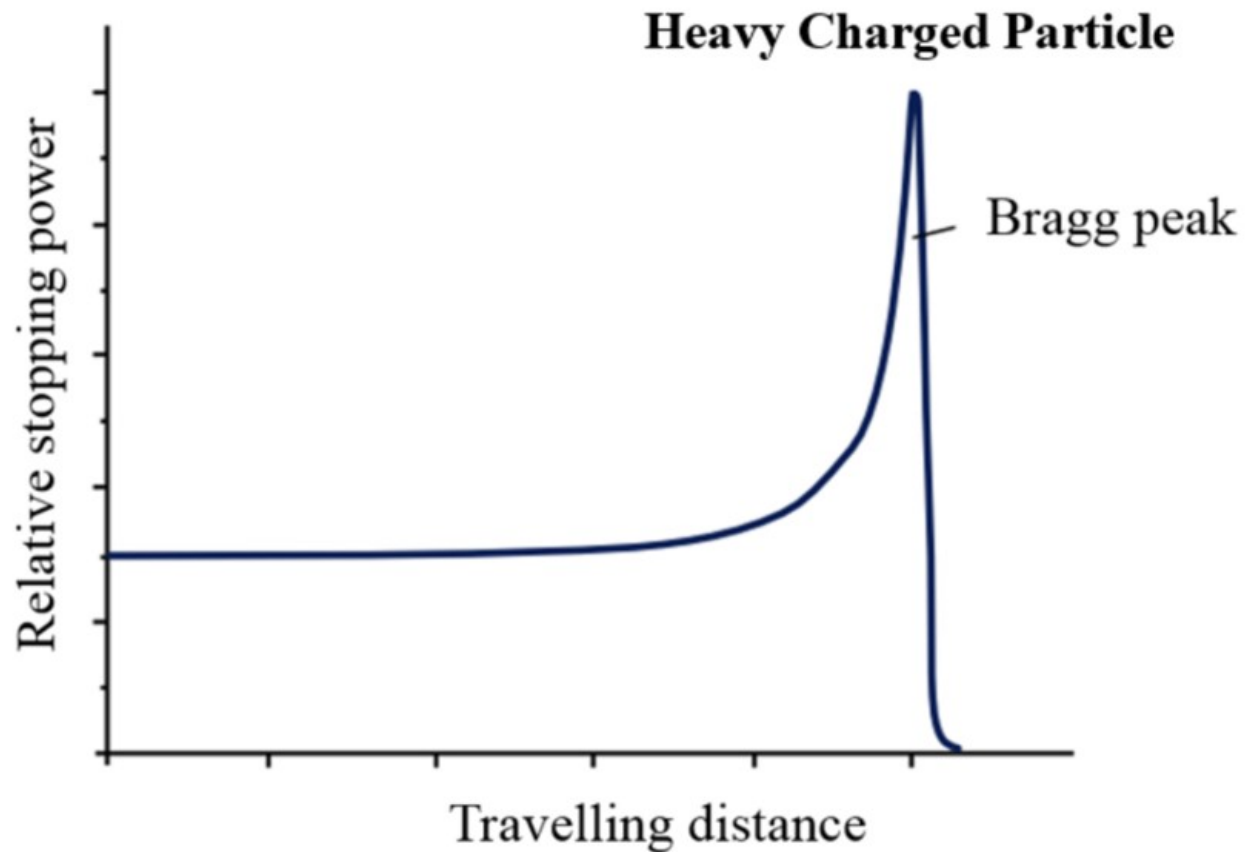
Isotopes of long half-life are useful to keep the activity for a long time.

The necessary amount of radiation is given
in smaller parts from many direction in order
to avoid the injury of the surrounding healthy
tissues. The exact distribution in space and time
is planned by computer.



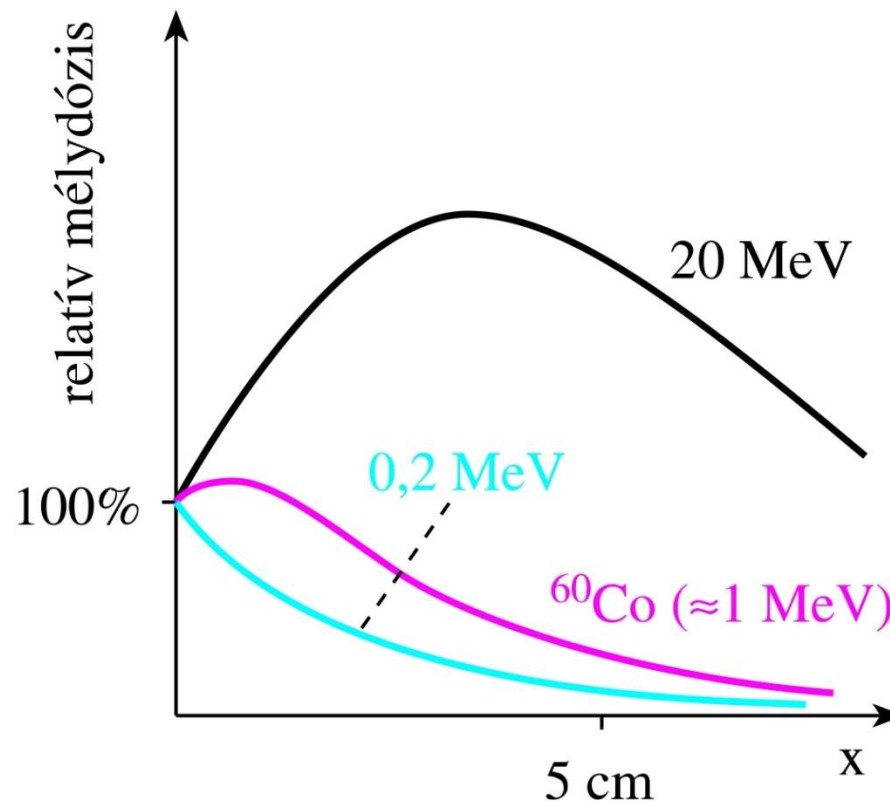
Optimization of penetration depth on the basis of energy

- Penetration depth of higher energy radiation is higher (Bragg-peak)



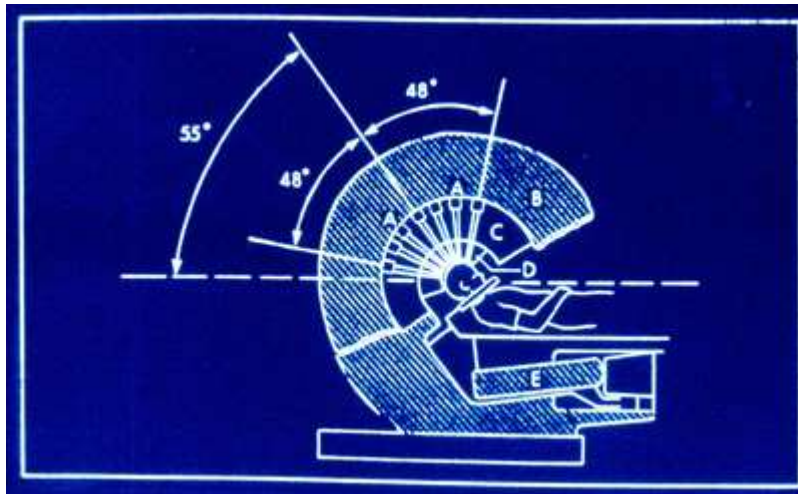
Relative depth dose

The dose at a certain depth related to the dose on the skin surface. Higher energy radiation and higher distance of radiation source from the body surface results in higher relative depth dose.



Gamma-knife

Used for the treatment of intracranial tumors. Many (approx. 200) ^{60}Co isotopes are put in different directions around the skull. Their radiation is focused to a small volume.



Radiation protectional viewpoints during work with ionizing radiation

1. **Justification** – the application of ionizing radiation must be useful: the risk of application should be lower than the risk of not applying the radiation – this must be considered from the viewpoint of the patient.
2. **Optimization** – the dose caused by the application should be **As Low As Reasonably Achievable** (ALARA-principle). This must be considered both from the viewpoint of the patient and the personnel.
3. **Dose limits** – the probable doses should not exceed the individual dose limits that are safe. This must be considered from the viewpoint of the personnel.

The risk depends on the type of radiation

If the source is **outside the body**, gamma- or X-radiation is the most dangerous. (because of high effective range)

If the isotope is **incorporated** (by inhalation or by swallowing), alpha-Radiating isotopes are the most dangerous. (All the radiation is absorbed in the body tissues.)



Possibilities to decrease the exposure from radiation source outside the body

- Increase the distance
- Decrease the exposition time
- Application of shielding

