Diagnostic and therapeutic applications of nuclear radiations

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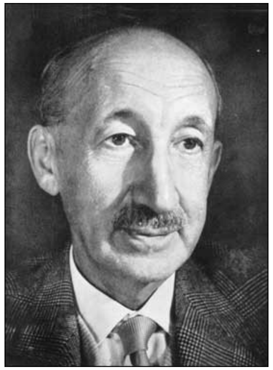
Medical, pharmaceutical applications of radioisotopes

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.)

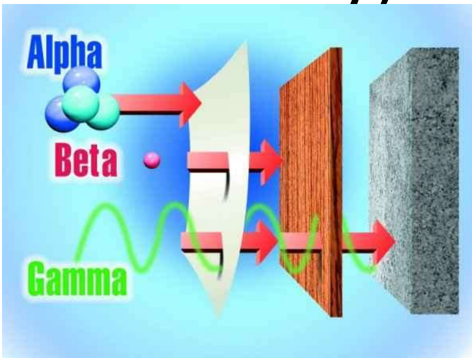


Fields of application:
- diagnostics (in vivo, in vitro)
- therapy
- research

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

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)

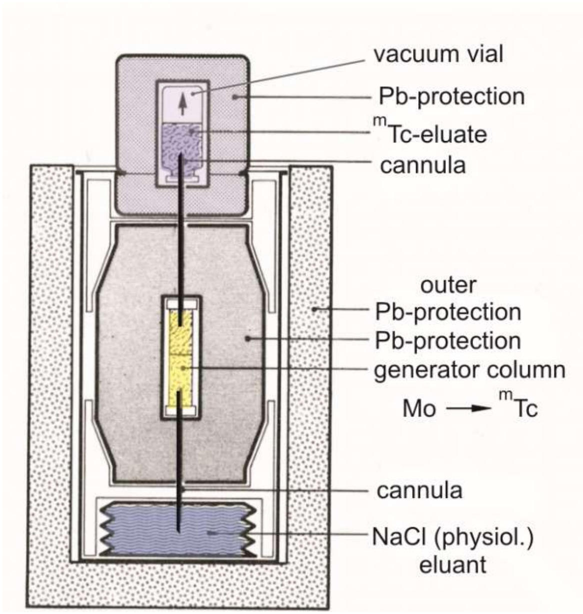
$\rightarrow$ ^{99m}Tc is ideal

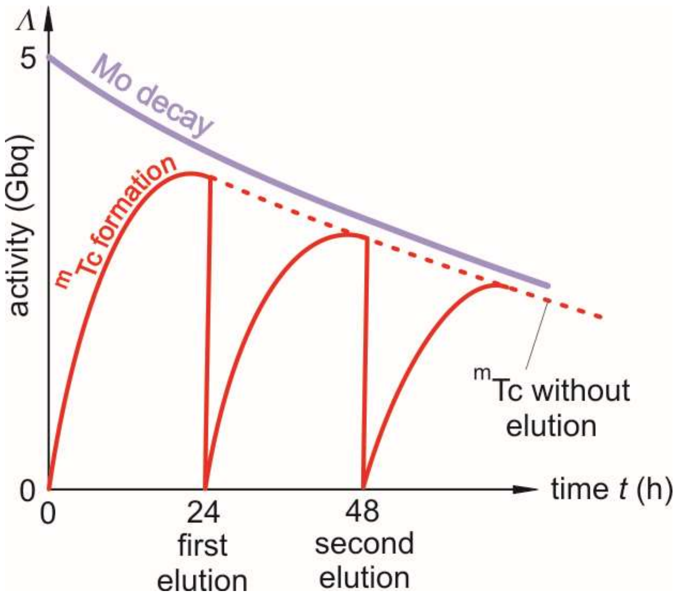
$$ {}^{99}_{42}Mo \xrightarrow[\beta]{} {}^{99m}_{43}Tc \xrightarrow[\gamma]{} {}^{99}_{43}Tc $$

T = 67 hours

T = 6 hours

E_γ = 140 keV

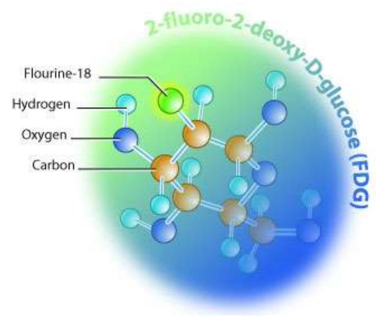




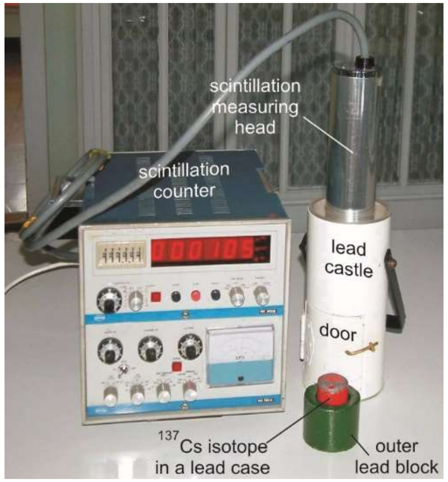
At least in 75 % of the in vivo diagnostic applications ^{99m}Tc is used to label different organ specific compounds.
(e.g. pyrophosphate – bones, colloids – liver and RES, albumin – circulation)

Further gamma-radiating isotopes that are frequently used: ^{123}I, ^{125}I (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 radiopharmacon: fluoro-deoxy-glucose (FDG) – brain activation.



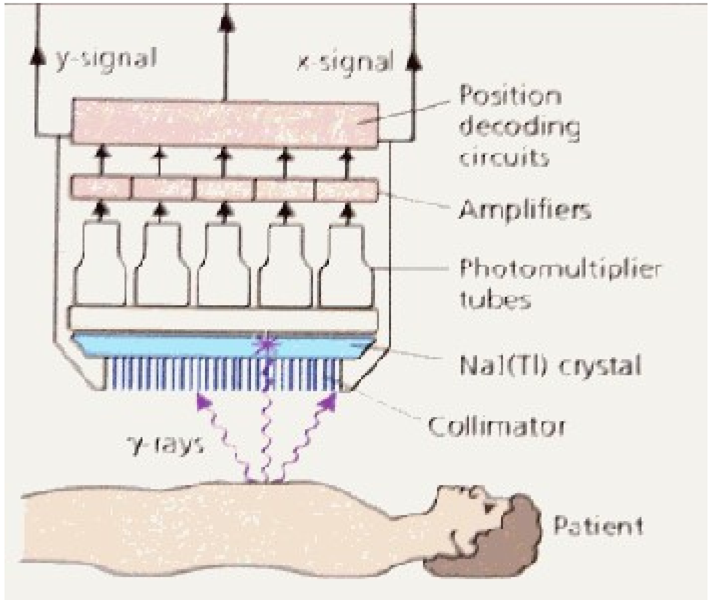
The distribution of isotopes can be detected by diagnostic equipments based on scintillation.

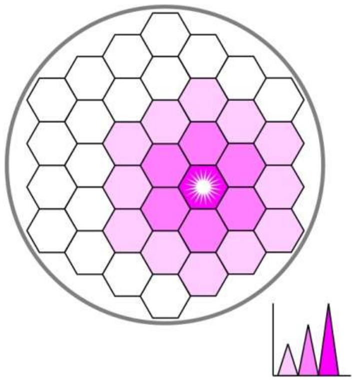


- Scintillation counter (see practice!)
- Gamma camera (Anger camera)
- SPECT (single photon emission computed tomography)
- PET (positron emission tomography)

Gamma camera

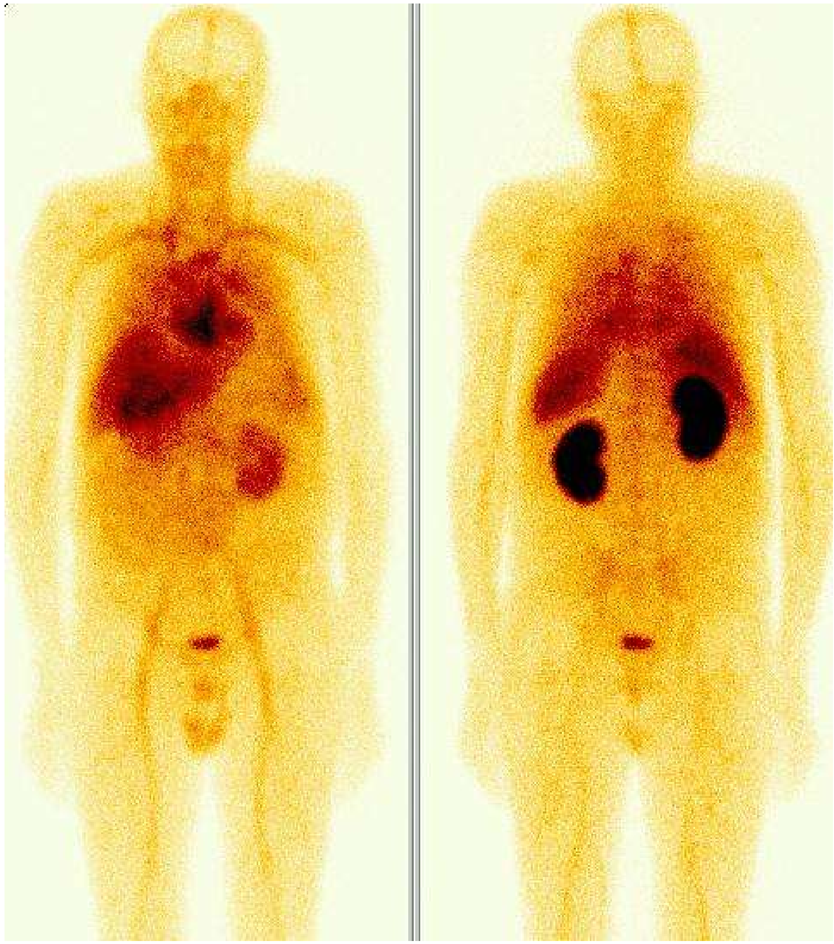
Hal Anger
(1920-2005)





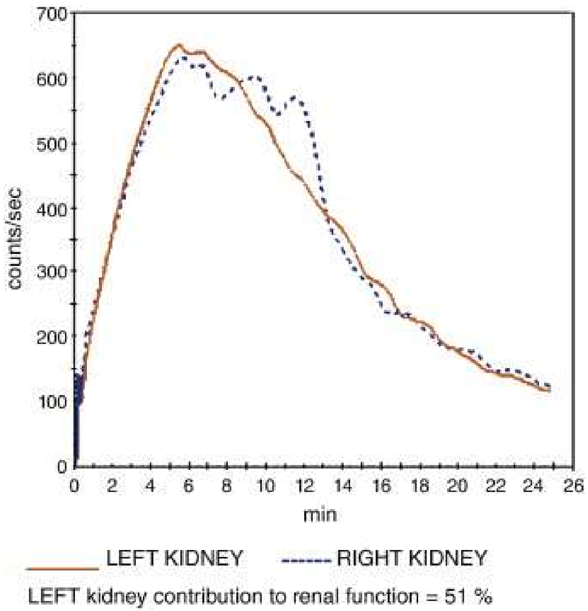
Static examination (scintigram)

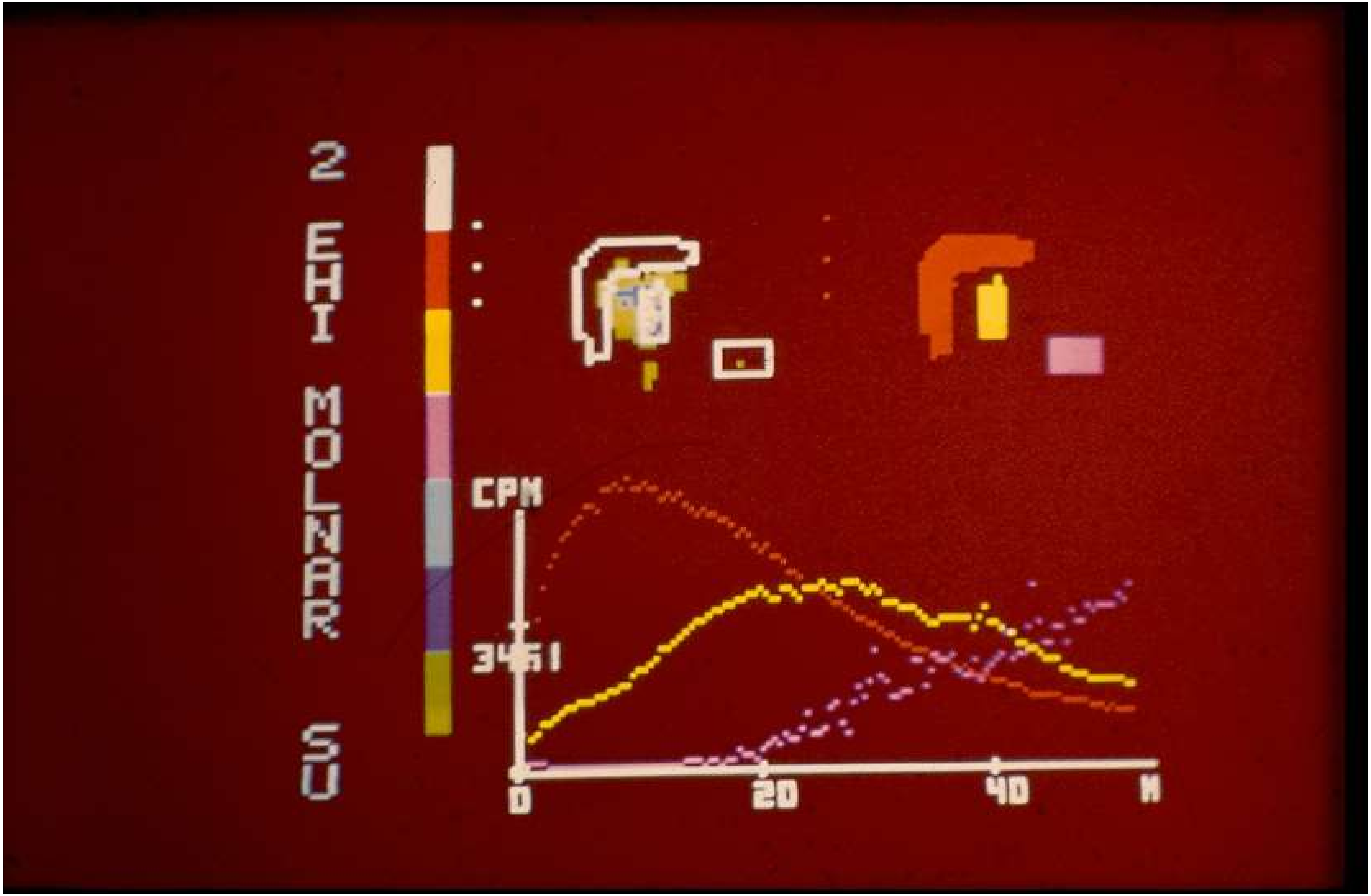
- the distribution of isotope in the space can be examined



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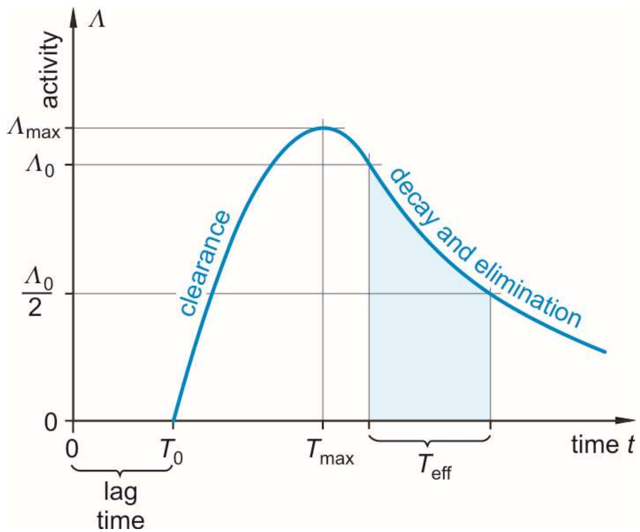
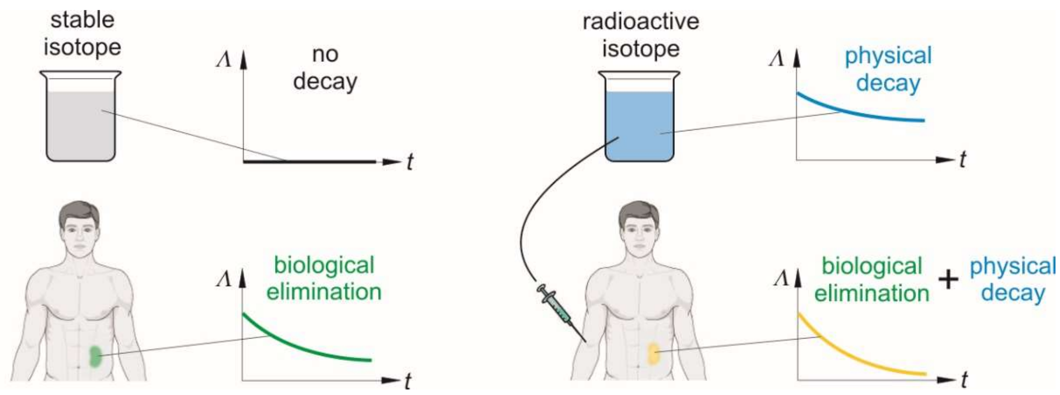
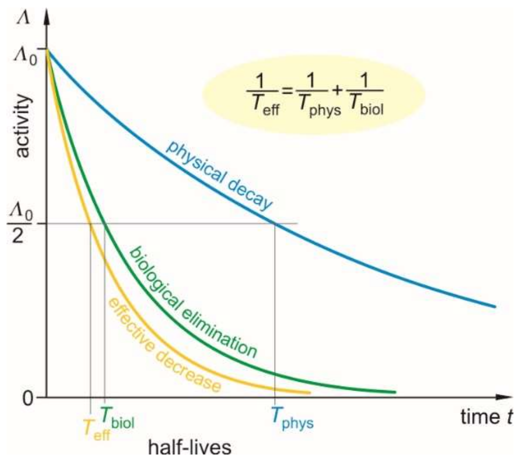
The isotope accumulation curve can be obtained from the measurement of activity in different moments



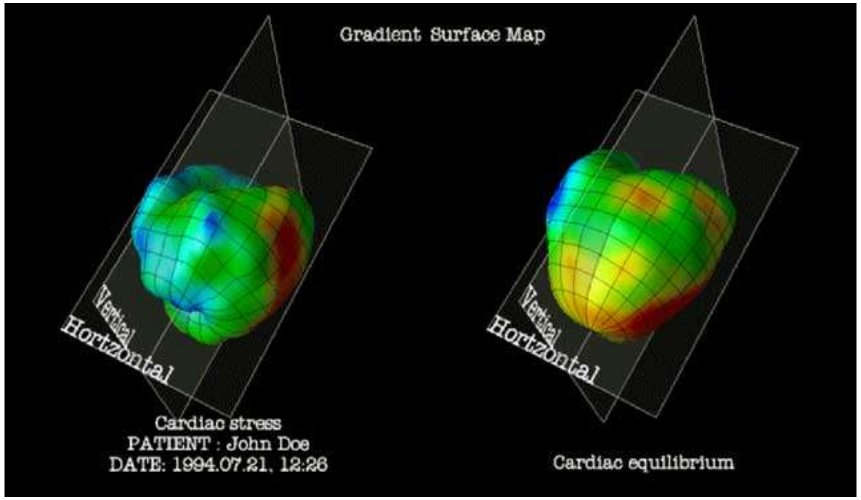


Connection between half-lives:

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



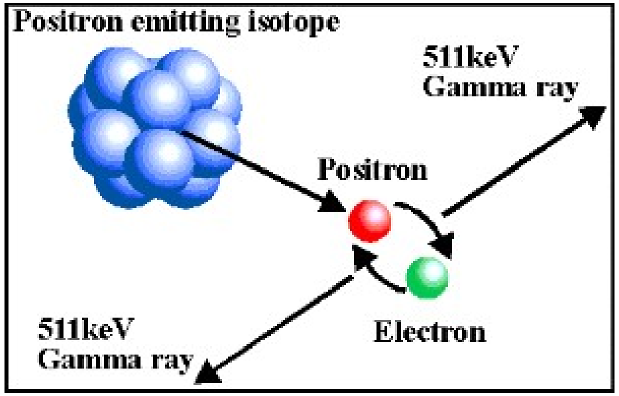
SPECT (the detector of gamma camera is rotated around the body axis $\rightarrow$ 3D image)

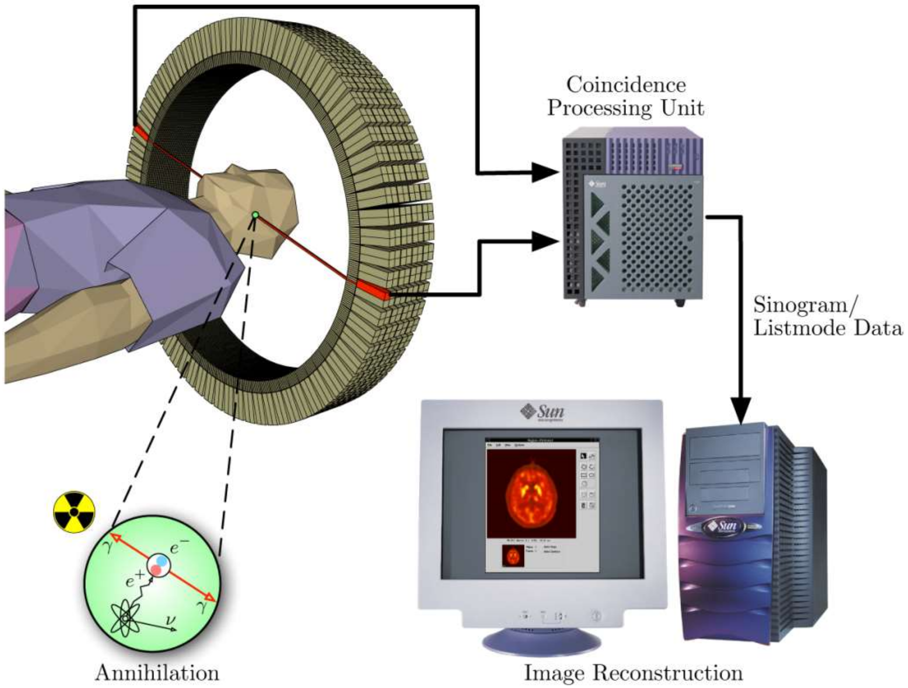


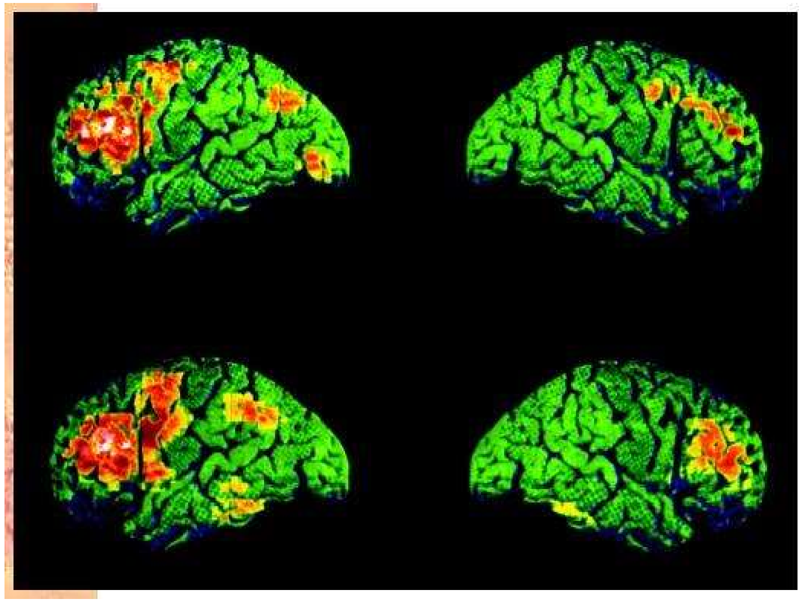
PET examination

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.

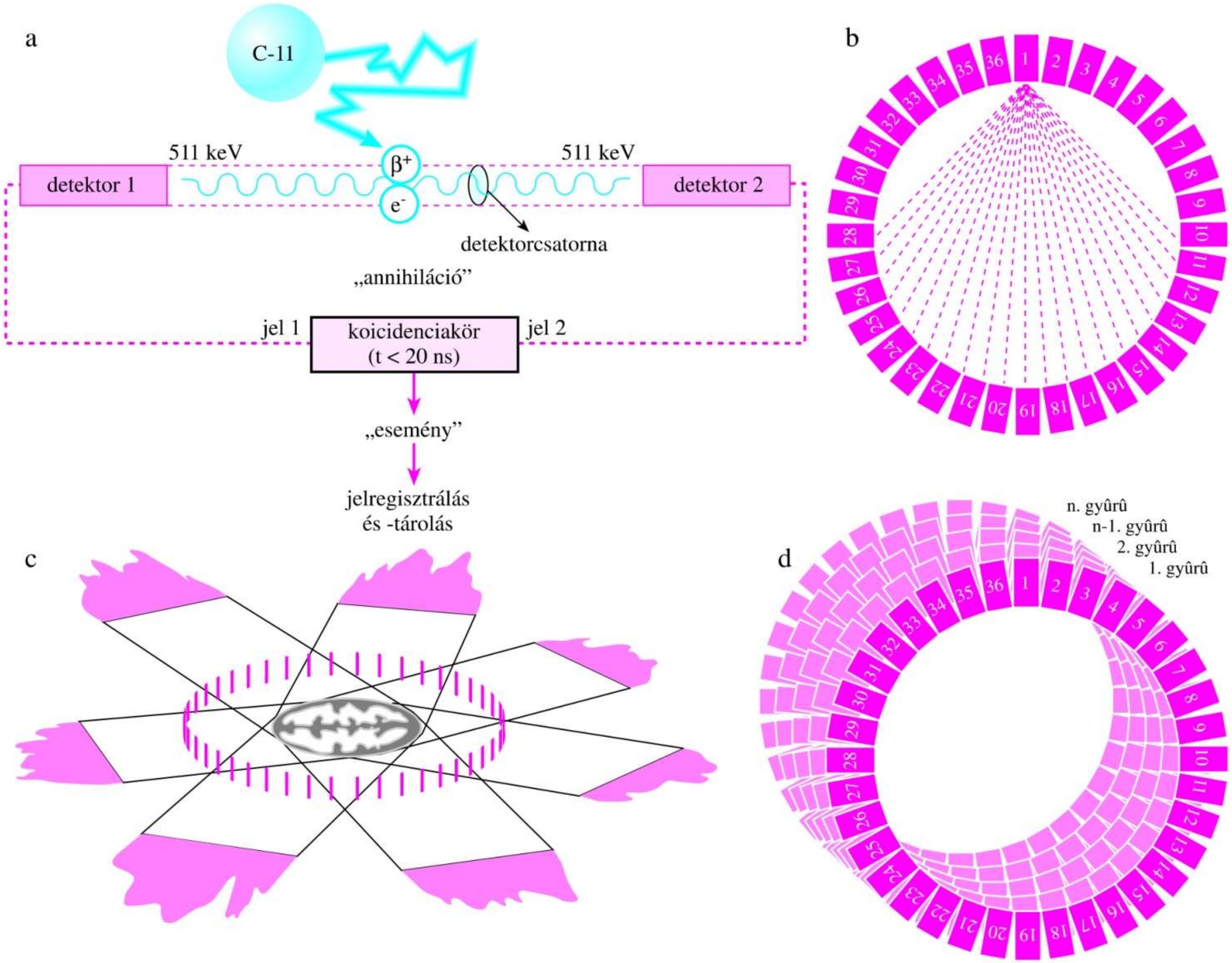
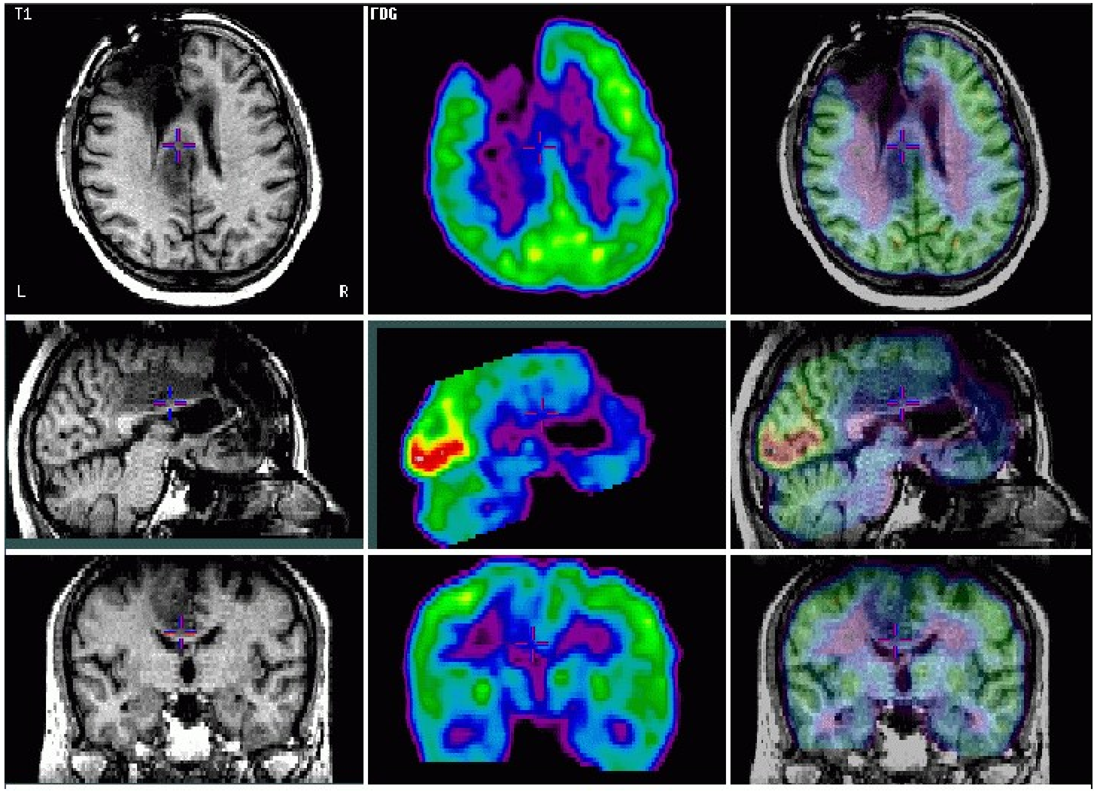


Image fusion

Combination of functional and morphological information

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



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. ^{3}H, ^{14}C, ^{125}I. Half-life can be also longer.

- Working with these preparations plexi plates are used for radiation protection.

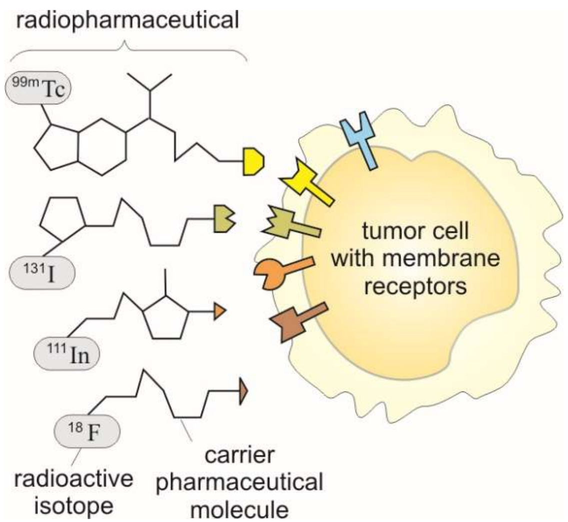
Isotope therapy

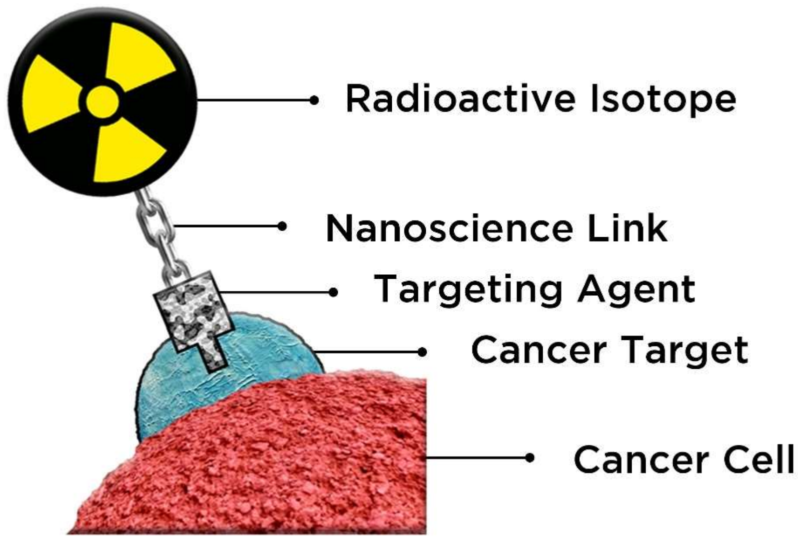
Internal radiation therapy (brachytherapy)

The cell killing effect of ionizing radiation is used for the treatment of e.g. hyperthyroidism (^{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)





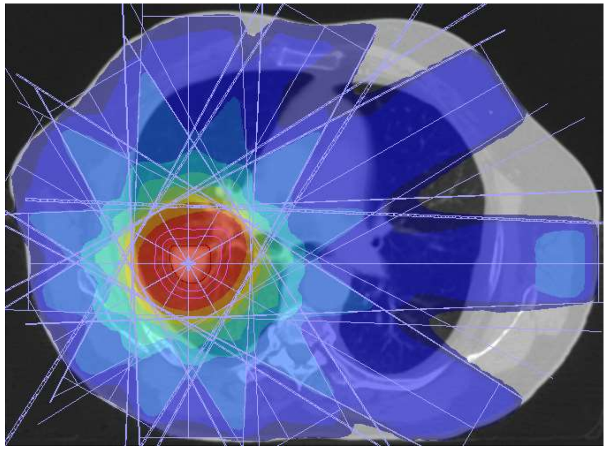
Therapy with radiation sources outside the body (teletherapy)

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.



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.