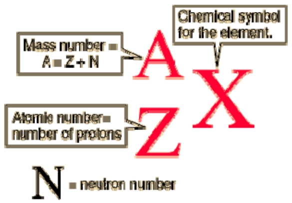
Radioactivity in Medicine

Some medical applications of nuclear radiation

László Smeller Dept Biophysik and Radiation Biology

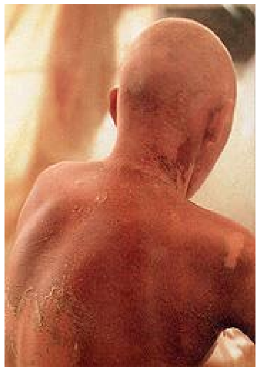
Reminder: basic definitions



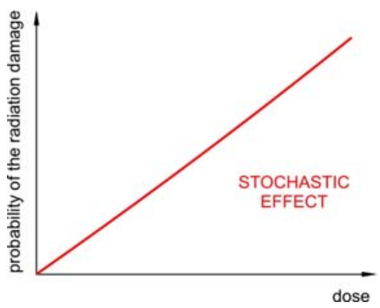
mass number (A)
atomic number (Z)
A = Z + N

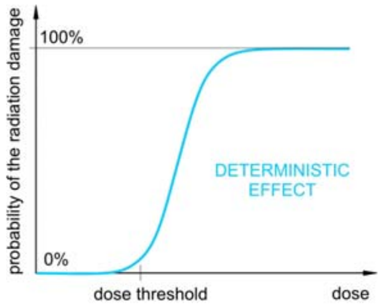
- Nuclides with equal proton number (Z), but different neutron numbers (N) are called **isotopes** of an element.
- Unstable isotopes (=**radioactive isotopes**) decay:
- **Decay types**: α, β^-, β^+, electron-capture, isomeric transiton
- **Nuclear radiations**: α (He^{2+}), β^-(e^-), β^+ (e^+), γ(electromagn.)

Biological effects of ionizing radiation



Stochastic and deterministic damages





Deterministic effects

- Large number of cells killed – physiological effect, e.g.
  - **Erythema, epilation, cataracts, "radiation sickness**"
- No risk below threshold doses, e.g.
  - Opacities = 500 mGy
  - Transient erythema = 2 Gy

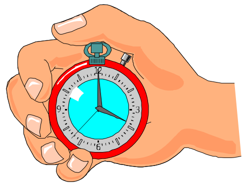
Stochastic damage

- can be caused by a single photon
- the severity is not effected by the dose
- with increasing dose only the probability increases (somatic cells: cancer, reproductive cells: hereditary effects)

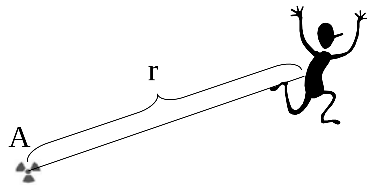
1 gamma photon: the probability to cause cancer is 3 x 10^{-16} (1: 3,000 billion, but this is the Russian roulette!)

Basic radiation protection strategies

- spend as **little time**, as necessary in the radiation field.

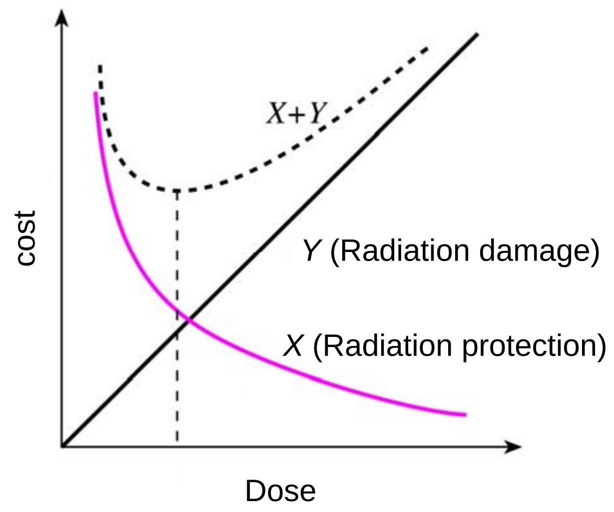


- **keep the distance** between radiation source and yourself as **large** as possible. Dose~$1/r^2$



- use **shielding**.

ALARA principle (as low as reasonably achievable)



Imaging using radioactive nuclides

Basic steps of the isotope diagnostics

Radioactive material introduced into the patient

Distribution and alteration of activity is detected

Monitoring of physiological pathways and/or identification and localization of pathological changes

Information from various medical imaging techniques

Structure

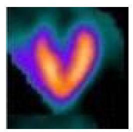
X-ray

Ultrasound

MRI

differences according to the different physical parameters / properties of tissues

Function



Isotope diagnostics

MRI

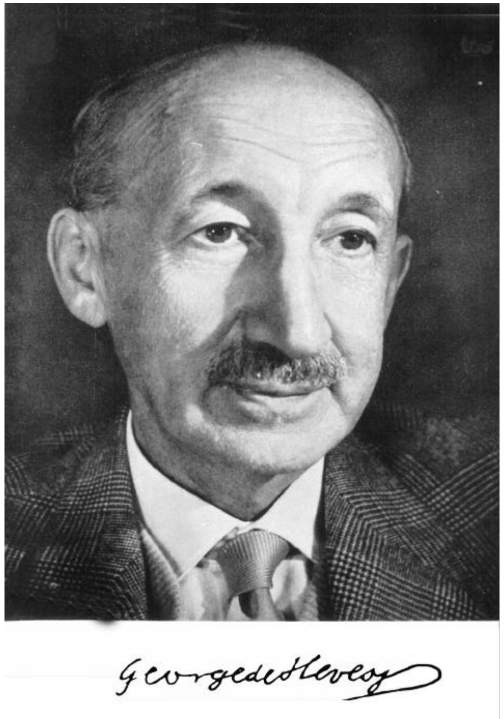
dynamic physiological / metabolic processes of different body organs can be followed

X-ray

Shows the structure

Isotope diagnostics

Reports the metabolic activity



Father of Nuclear Medicine

Georg Charles de Hevesy
(1885 - 1966)

Nobel Prize in Chemistry
1943

for his work on the use of isotopes as tracers in the study of chemical processes

The choice of the appropriate radioisotope for nuclear imaging

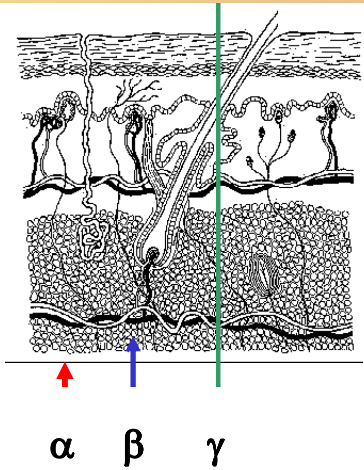
Maximise the information

Minimise the risk.

For that find the optimal

- type of radiation
- photon energy
- half life
- radiopharmacon

Type of radiation

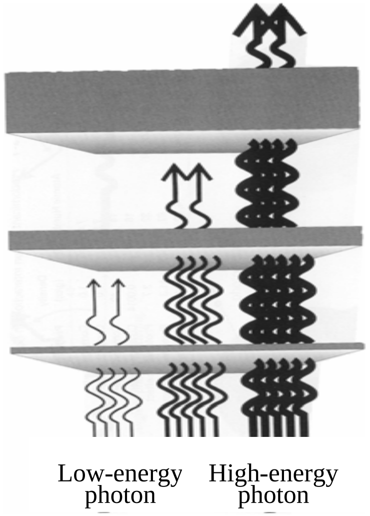


Only **γ-radiation** has sufficient penetration distance .

Decay via photon emission is needed to minimize absorption (radiation damage) in body tissue

purely gamma-emitting isotope would be preferable

Photon energy



Photon must have sufficient energy to penetrate body tissue with minimal attenuation

BUT!

Photon must have sufficiently low energy to be registered efficiently in detector and to allow the efficient use of lead collimator systems (must be absorbed in lead)

Suitable physical half-life

$$\Lambda = \lambda N = \frac{0,693}{T} N$$

smaller is better (Λ)
but
the value is limited from below e.g., by the sensitivity of the detector

smaller is better (N)

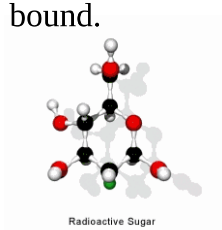
dosimetric considerations for patients

shorter is better (T)

but

it has to be long enough for monitoring the physiological organ functions to be studied

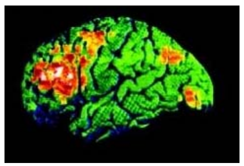
radiopharmaceutical – is substance that contain one or more ***radioactive atoms*** and are used for ***diagnosis*** or ***treatment*** of disease.
It is typically made of two components, the ***radionuclide*** and the ***chemical compound*** to which it is bound.



Basic requirements:

specific localizing properties;
high *target : nontarget* ratio

have no pharmacological or toxicological effects which may interfere with the organ function under study.



Optimal activity for diagnostic procedure

Maximize the information

Minimize the risk

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

Isomeric transition

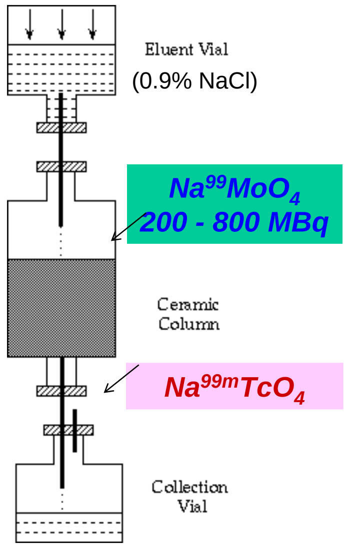
$$ {}^{99}_{42}Mo \rightarrow {}^{99m}_{43}Tc + \beta^{-} \rightarrow {}^{99}_{43}Tc + \gamma $$

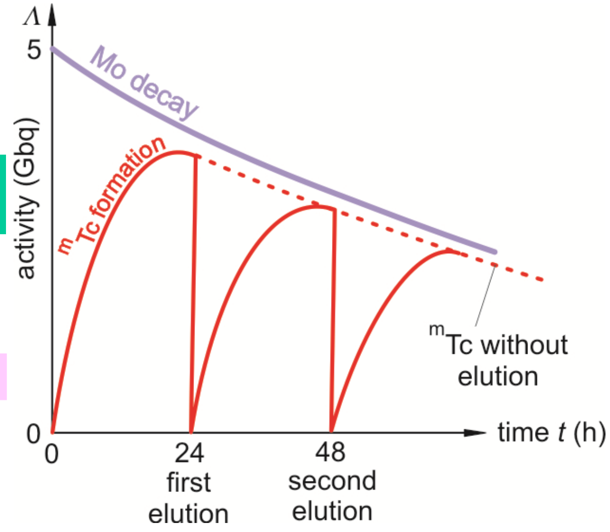
$T_{1/2}$=67 hours $T_{1/2}$=6 hours

hf=140 keV

One of the features that makes **Tc-99m** such an ideal radioisotope for diagnostic imaging is its ability to **readily bind to a wide variety of compounds** under physiological conditions.

Technetium-99m generator





Examples

pharmaceutical	radioisoptope	activity (MBq)	target organ
Pertechnetate	^{99m}Tc	550 - 1200	brain
Pirophosphate	^{99m}Tc	400 - 600	heart
Diethylene Triamine Penta Acetic Acid (DTPA)	^{99m}Tc	20 - 40	lung
Mercaptoacetyltriglycine (MAG3)	^{99m}Tc	50 - 400	kidney
Methylene Diphosphonate (MDP)	^{99m}Tc	350 - 750	bones

Types of images

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

Dynamic picture
variation of the amount of isotope/activity as a function of time

Static and dynamic picture – series of static recordings

Types of images

Summation image

Tomographic image
Emission CT

γ -camera

- SPECT (Single Photon Emission Computed Tomography)
- PET (Positron Emission Tomography)

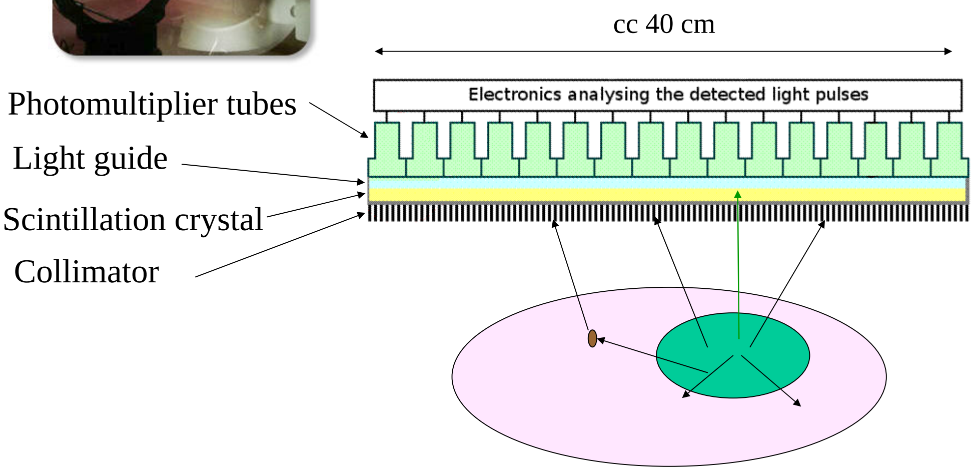
Hal Anger

1920-2005

Hal Anger and coworkers

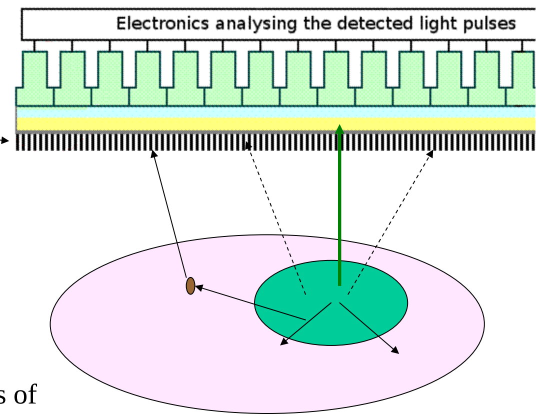
1952

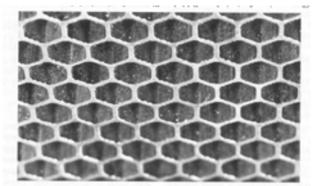
Gamma camera



A radioactive source emits gamma ray photons in all directions.

collimator



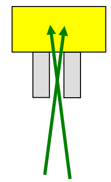


Collimators are composed of thousands of precisely aligned ***channels*** made of lead.

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

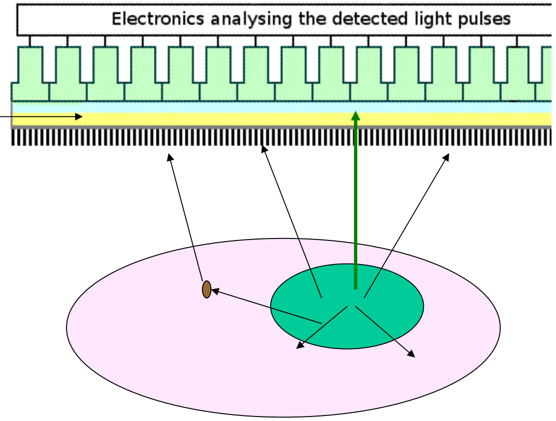
Photons emitted in other directions are absorbed by the septa between the holes.

Size and geometry of holes are essential for the **resolution**.



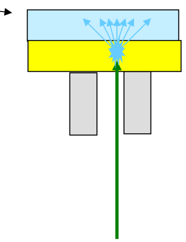
Scintillation crystal

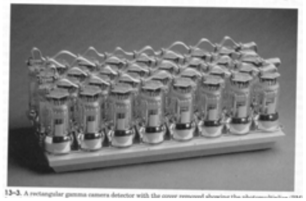
Na(Tl)



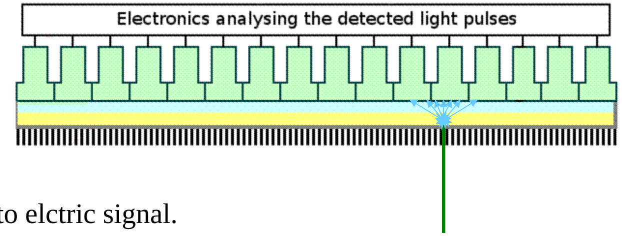
Light guide

Distribution of the ligth
for the prhotmultipliers



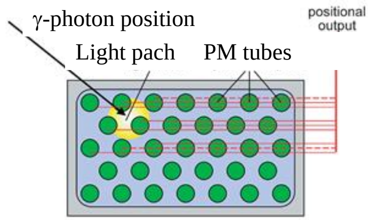


Photomultiplier tubes

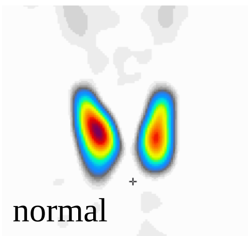


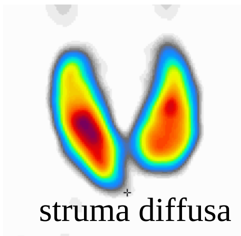
Transformation of light pulses to elctric signal.

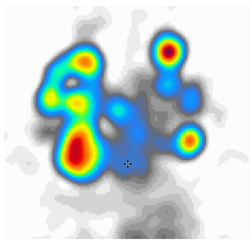
Typically 37-91 tubes,
5-7 cm diameter each

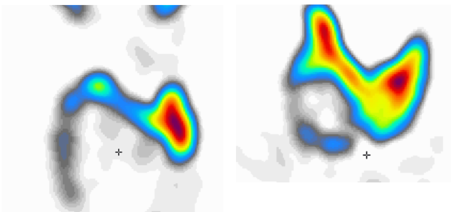


Pertechnetate (intravenous 80 MBq) distribution in thyroid glands

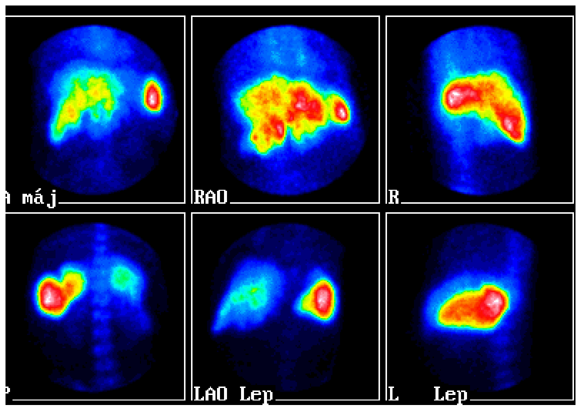

normal


struma diffusa


struma multinodularis


Cold nodules

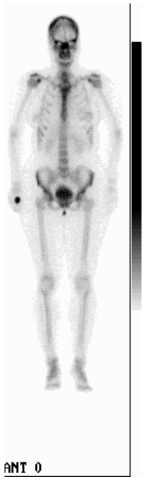
Liver lesion nodules



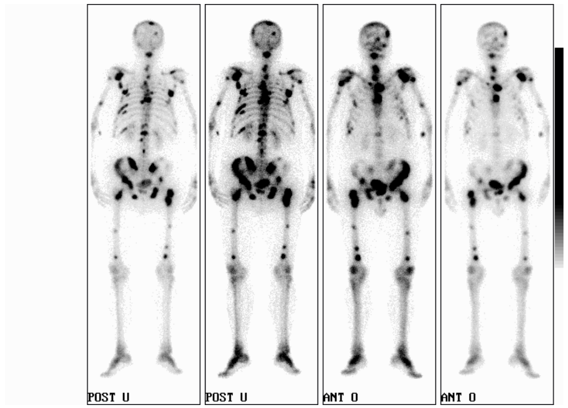
^{99m}Tc- fyton

Bone scintigraphy

^{99m}Tc-MDP: 600 MBq



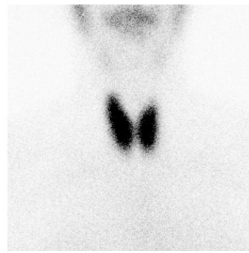
normal



imaging in bone metastases

Static picture

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



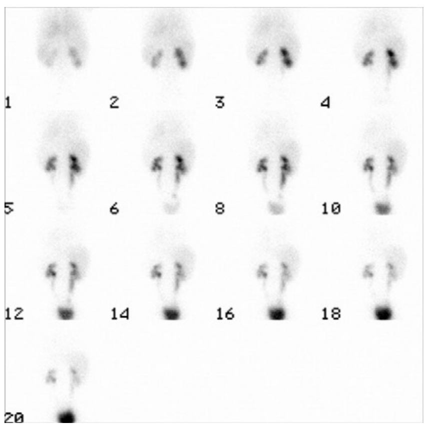
Isotope accumulation in

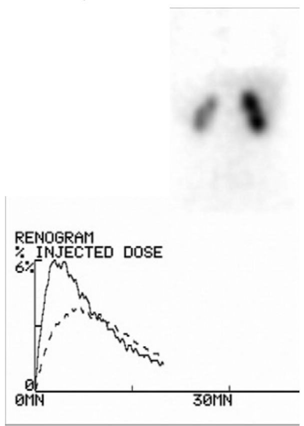
thyroid glands

kidneys

Static and dynamic picture

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

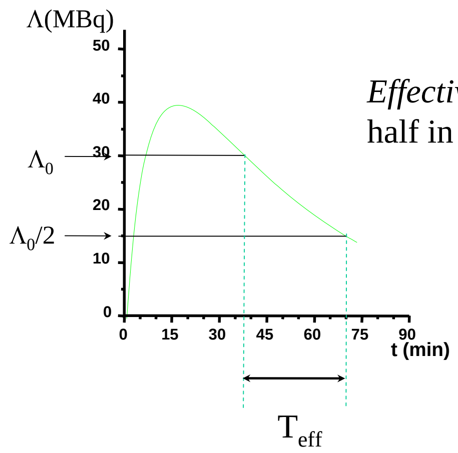




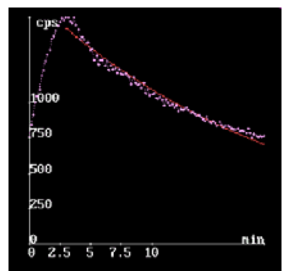
Images from: Biassoni © Chippington: Imaging in Urinary Tract Infections: Current Strategies and New Trends Seminars in Nuclear Medicine Volume 38, Issue 1, January 2008, Pages 56–66

Static and dynamic picture

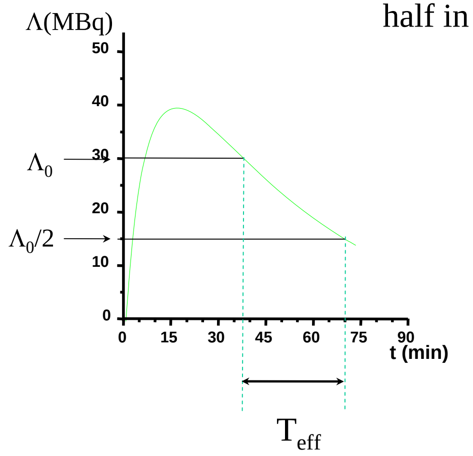
Dynamic picture – variation of the amount of isotope / activity in time



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



Effective half life



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

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

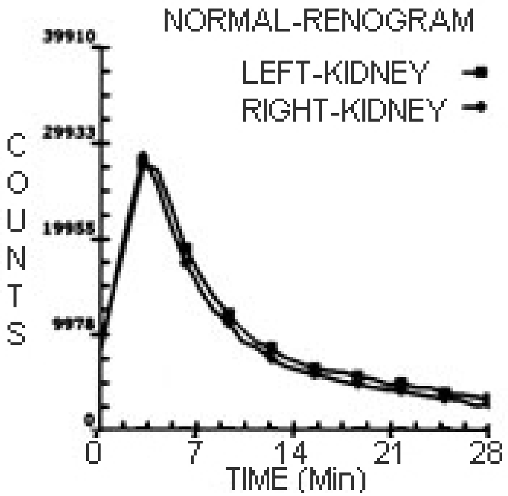
$$\lambda_{effective} = \lambda_{phys} + \lambda_{biol}$$

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

Biological half life

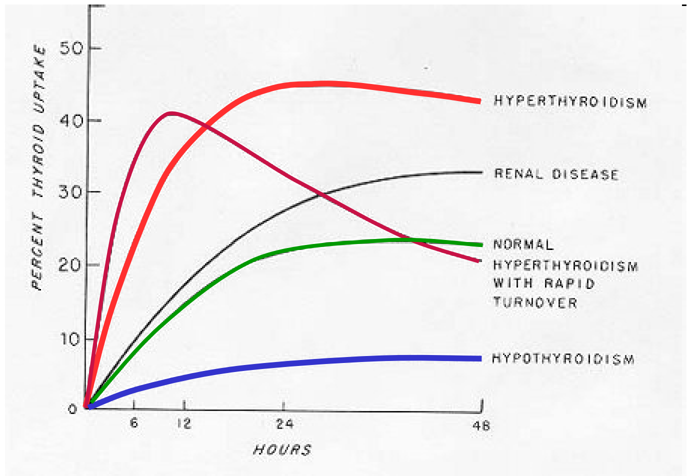
The final fate of the radiotracer depends on how the addressed organ deals with the molecule, whether it is absorbed, broken down by intracellular chemical processes or whether it exits from the cells and is removed by kidney or liver processes. These processes determine the **biological half-life**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

example



Isotope accumulation in kidney

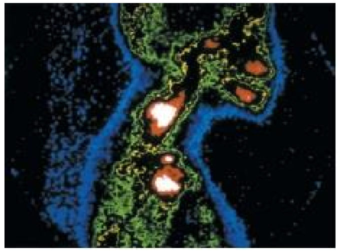
example

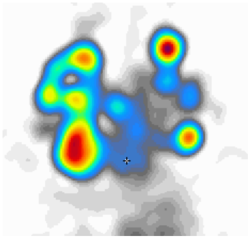


Thyroid glands

Isotope accumulation

Gamma camera image:
summation image

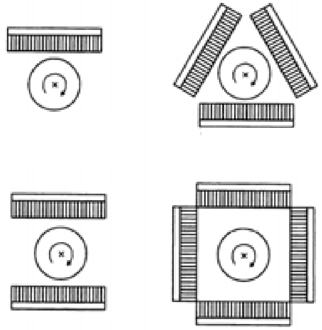




For depth resolution: tomographic device is necessary

SPECT

Single Photon Emission Computed Tomography



Variouos camera arrangements

SPECT

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

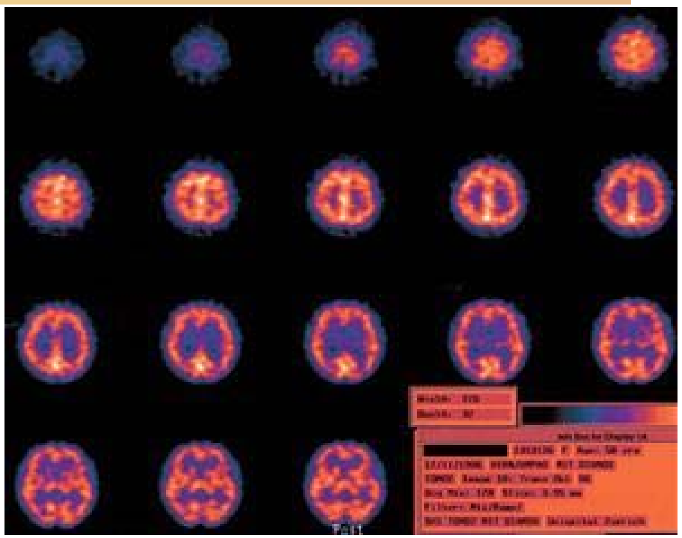
Cross-sectional image can be reconstructed.

Measurement from a series of projections.

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

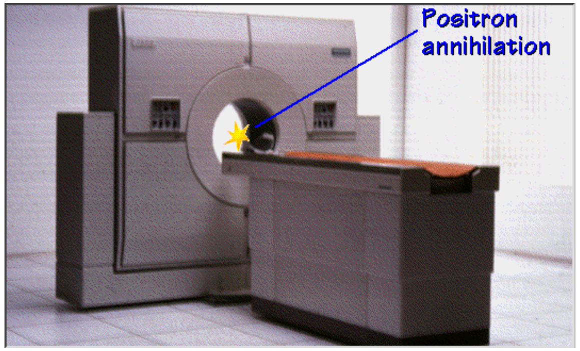
SPECT – images of scalp

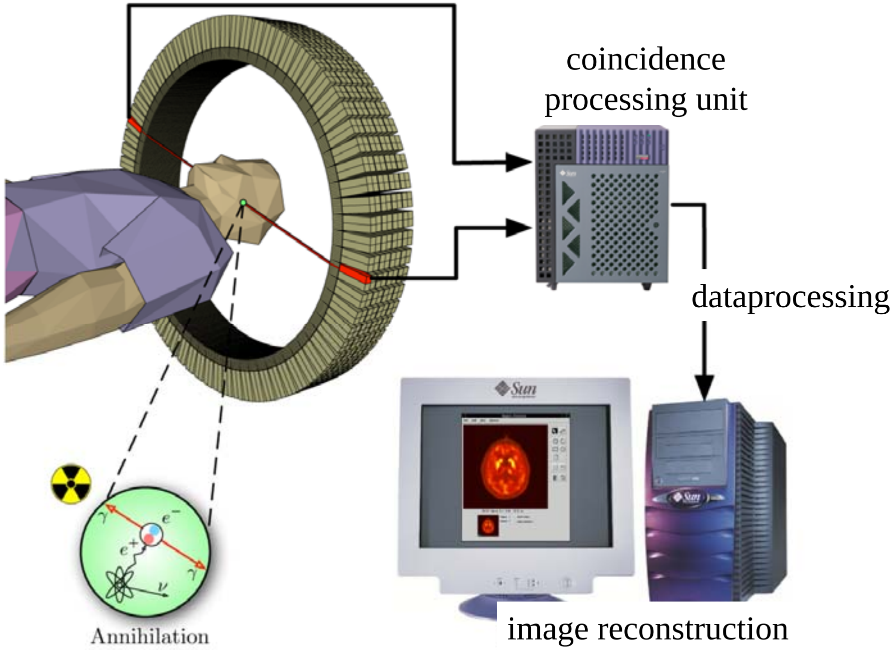
^{99m}Tc- HMPAO



PET

Positron Emission Tomography





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