

## Radioisotopes in action



## Diagnostic application of radioisotopes

## Steps of diagnostic procedure

- 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

<b>Structure</b>	X-ray	<i>differences according to the different physical parameters / properties of tissues</i>
	Ultrasound	
MRI		
<b>Function</b>	Isotope diagnostics	<i>dynamic physiological / metabolic processes of different body organs can be followed</i>
	MRI	



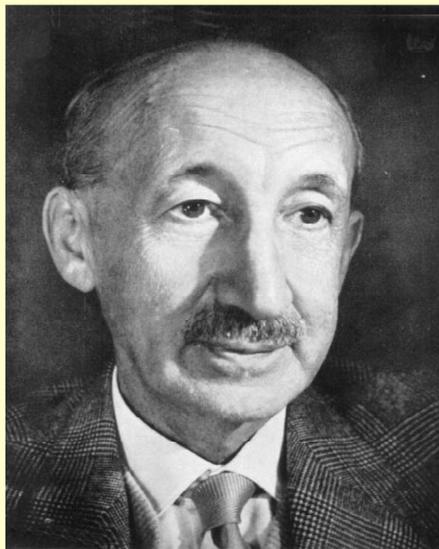
X-ray

*Shows the structure*



Isotope diagnostics

*Report the metabolic activity*



*Georg Charles de Hevesy*

*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**

### George Hevesy and his landlady



In any event, he became convinced that his landlady had a nasty habit of recycling food. Hevesy secretly spiked the leftovers on his plate with radioactive material. A few days later, the electroscope he smuggled into the dining room revealed the presence of the tracer

### The choice of the appropriate radioisotope for nuclear imaging

Maximize the information

Minimize the risk.

For that find the optimal

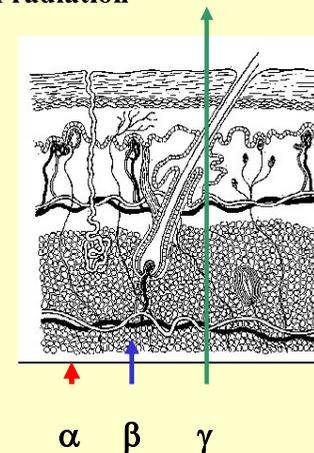
type of radiation

photon energy

half-life

radiopharmakon

### Type of radiation

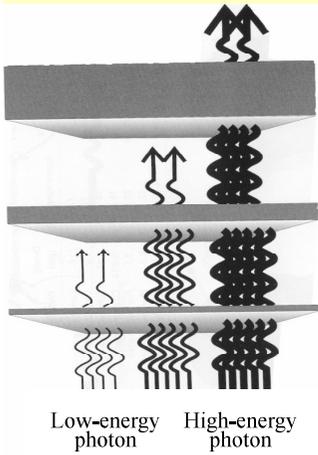


decay via photon emission  
to minimize absorption  
effects in body tissue  
Only **γ-radiation** has  
sufficient penetration  
distance.

*purely gamma-emitting isotope would be preferable*

photon energy

$$hf > 50 \text{ keV}$$



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)

**a suitable physical half-life**

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

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

smaller is better  
dosimetric considerations for patients

**shorter is better**  
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* : *non-target* ratio

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

A number of factors is responsible for the ultimate distribution of the radioisotope:

- blood flow (percent cardiac input/output of a specific organ)
- availability of compound to tissue, or the proportion of the tracer that is bound to proteins in the blood
- basic shape, size, and solubility of molecule which controls its diffusion capabilities through body membranes

examples

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

## 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

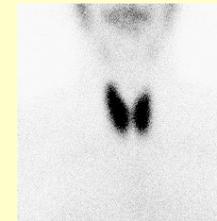
Emission CT

SPECT (Single Photon Emission Computed Tomography)

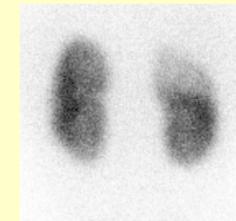
PET (Positron Emission Tomography)

## Types of images

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



thyroid glands

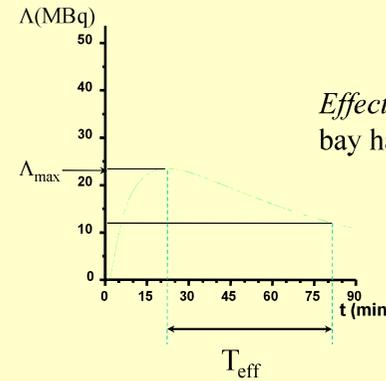
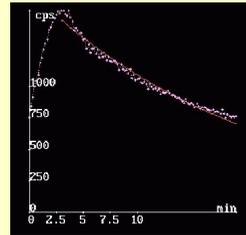
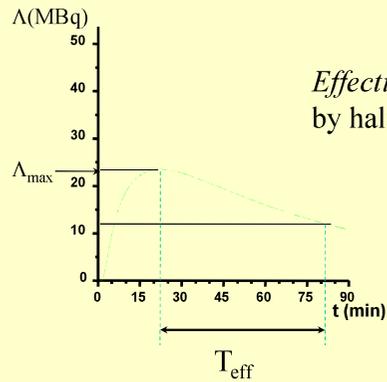


kidneys

Isotope accumulation in

## 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

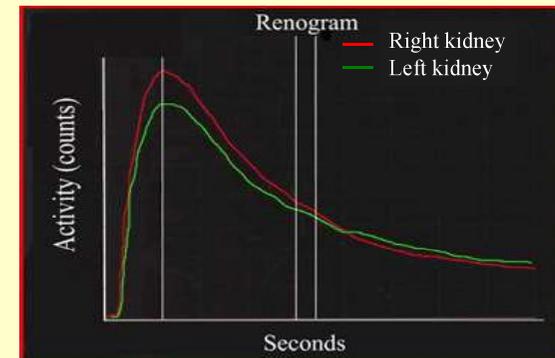
$$\Lambda = \Lambda_0 e^{-(\lambda_{\text{phys}} + \lambda_{\text{biol}})t}$$

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

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

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**  $T_{\text{biol}}$  of the radiopharmaceutical.

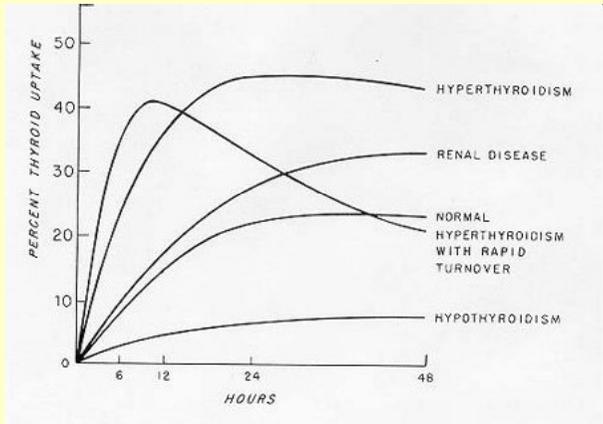
example



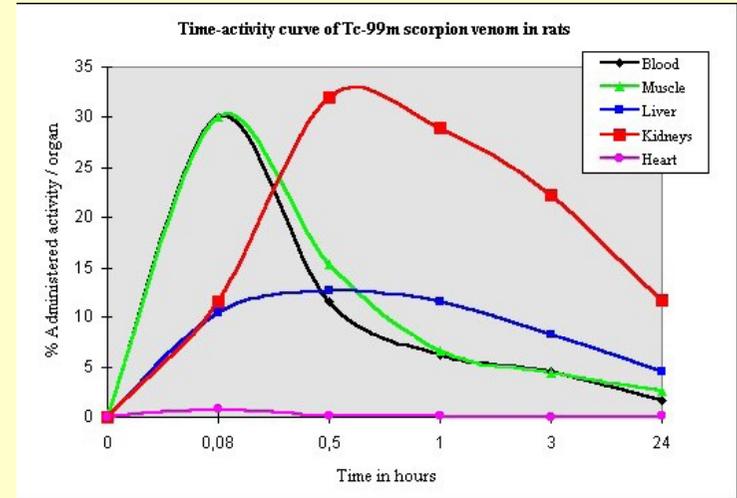
kidney

Isotope accumulation

example



Thyroid glands  
Isotope accumulation



Hal Anger  
1920-2005

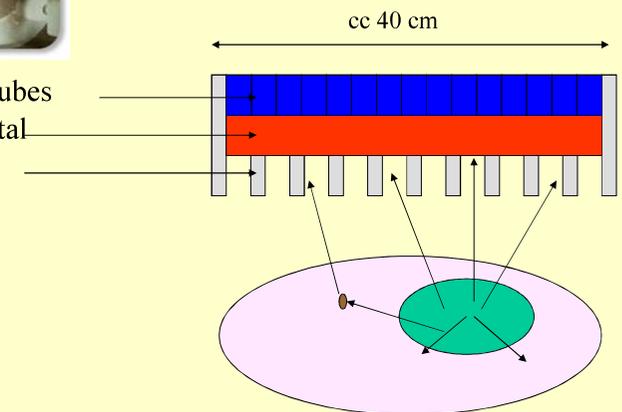


Hal Anger and coworkers  
1952



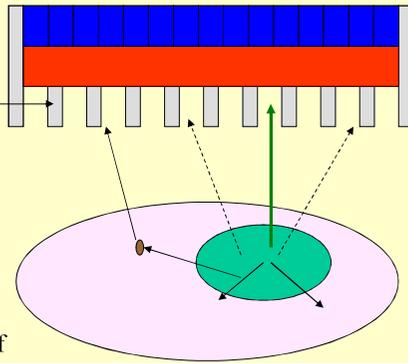
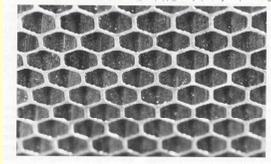
Gamma camera

Photomultiplier tubes  
Scintillation crystal  
Collimator



A radioactive source emits gamma ray photons in all directions.

collimator

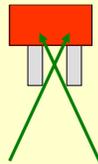


Collimators are composed of thousands of precisely aligned channels made of lead.

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.



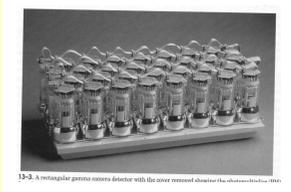
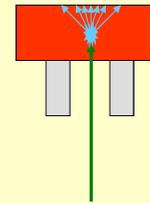
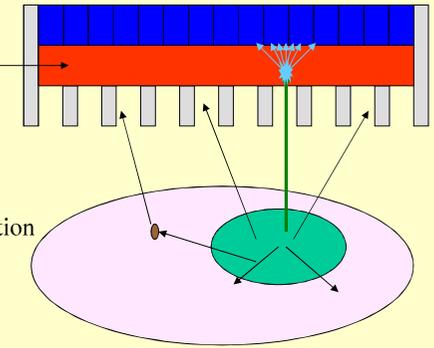
## Scintillation crystal

NaI(Tl)

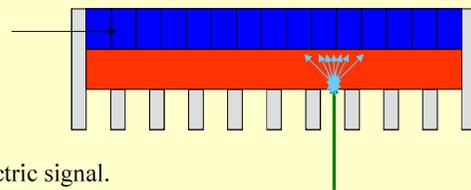
Sufficient detection efficiency  
 photons of 150 keV  $\mu \sim 2.2 \text{ 1/cm}$   
 10 mm thickness  $\sim 90\%$  attenuation  
 Proper wavelength – 415 nm – for PM photocathode

Problems:

fragile  
 temperature sensitive  
 hygroscopic



## Photomultiplier tubes

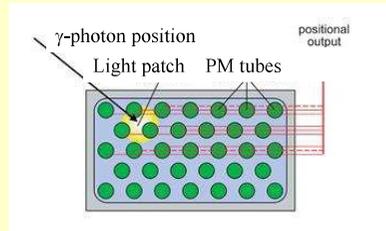


Transformation of light pulses to electric signal.

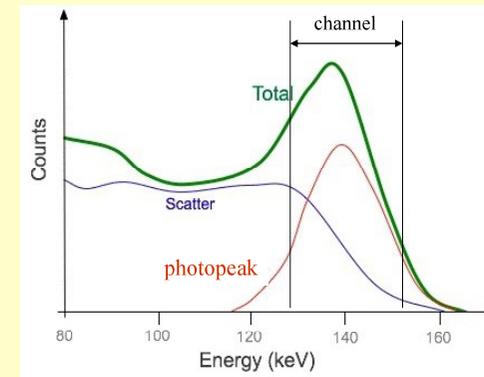
Typically 37-91 tubes, 5.1-7.6 cm diameter each

Amplitude of electric pulses varies in a wide range, because

- absorption of one  $\gamma$ -photon induces electric signals in more than one tubes.
- attenuation mechanism can be photoeffect and Compton-scatter.

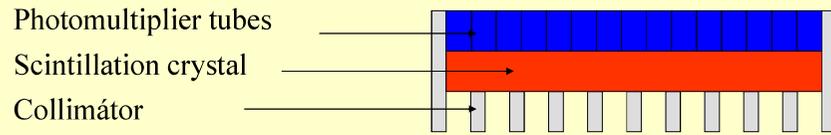


Pulse amplitude spectrum – Amplitude of an electric pulse generated by a  $\gamma$ -photon absorption in photoeffect is proportion to the photon energy.



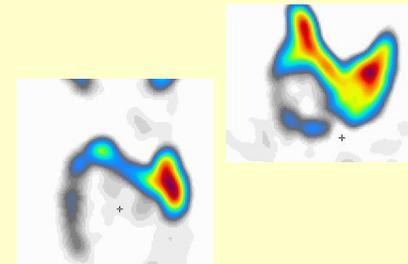
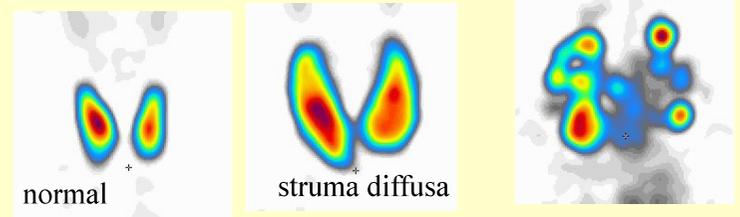
These electric pulses can be distinguished by discrimination (DD).

# Gamma camera

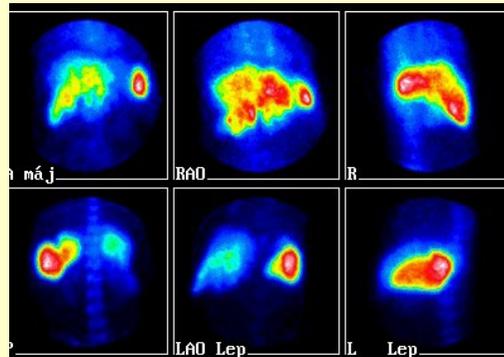


Identification of source position is facilitated by the collimator  
the PM tubes  
the discrimination.

# Pertechnetate (intravenous 80 MBq) distribution in thyroid glands



# Liver lesion nodules



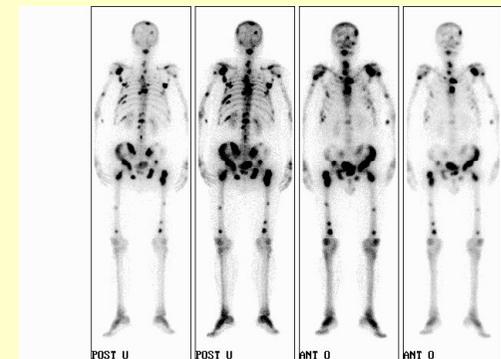
<sup>99m</sup>Tc- fyton

# Bone scintigraphy

<sup>99m</sup>Tc-MDP: 600 MBq



normal

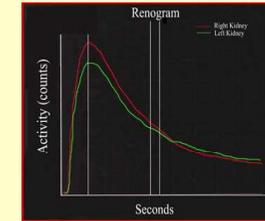
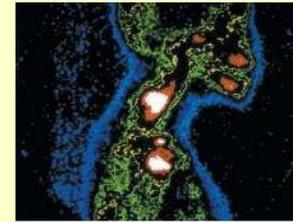


imaging in bone metastases

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

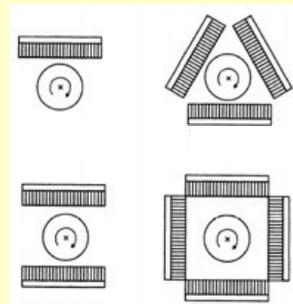
## Gamma camera image: summation image



For depth resolution: tomographic device is necessary

## SPECT

Single Photon Emission Computed  
Tomography



Various camera arrangements

## SPECT

Tomographic application of  $\gamma$ -cameras – data collection in  $360^\circ$ .

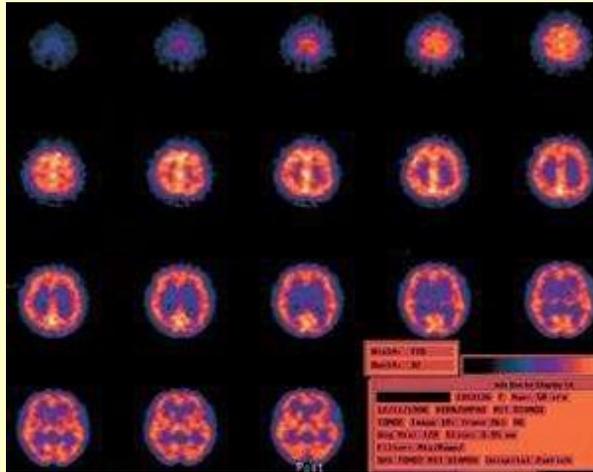
Cross-sectional image can be reconstructed.

Measurement from a series of projections.

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

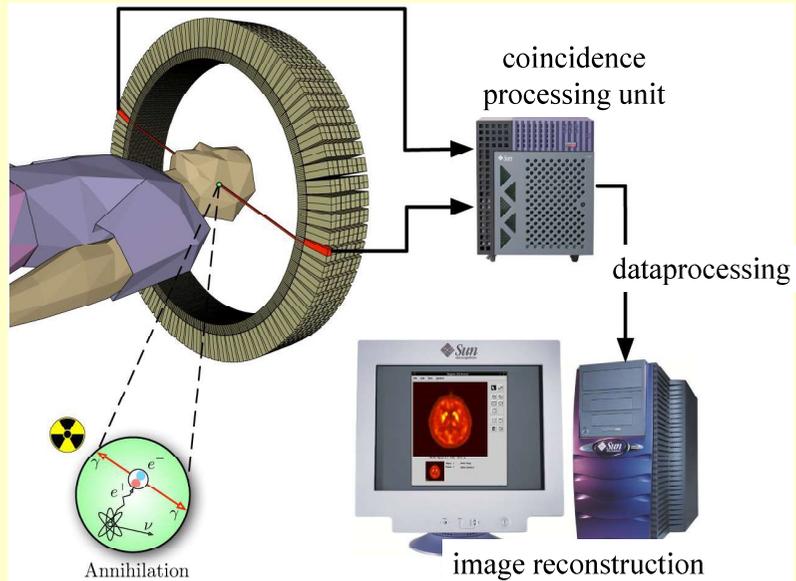
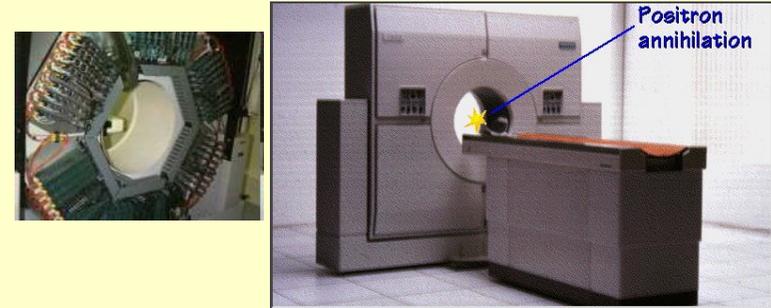
# SPECT – images of scalp

$^{99m}\text{Tc}$ - HMPAO

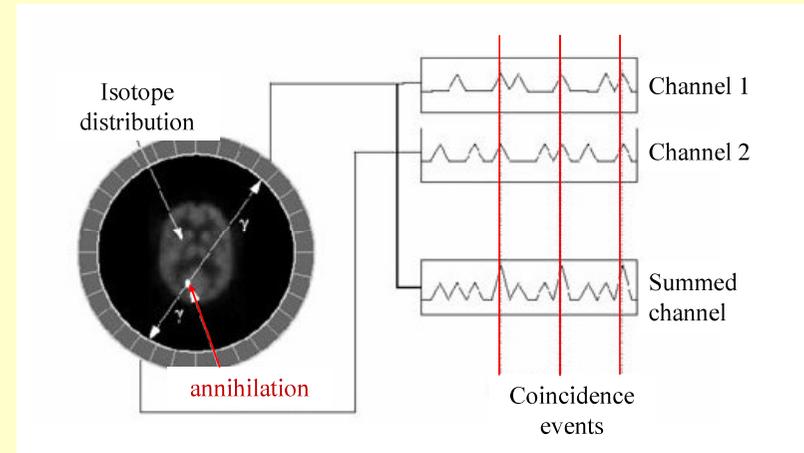


# PET

Positron Emission Tomography



# coincidence processing



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

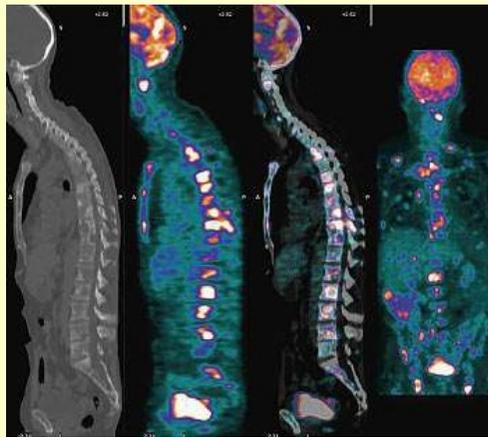
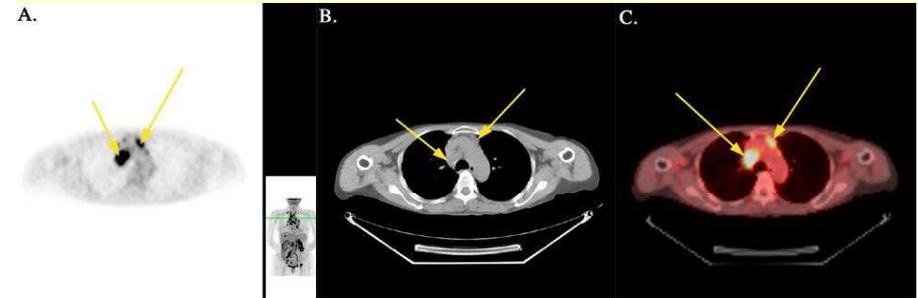
Isotope	$\beta^+$ energy (MeV)	$\beta^+$ range (mm)	1/2-life	Applications
$^{11}\text{C}$	0.96	1.1	20.3 min	receptor studies
$^{15}\text{O}$	1.70	1.5	2.03 min	stroke/activation
$^{18}\text{F}$	0.64	1.0	109.8 min	oncology/neurology
$^{124}\text{I}$	2.1350/1.5323	1.7/1.4	4.5 days	oncology

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



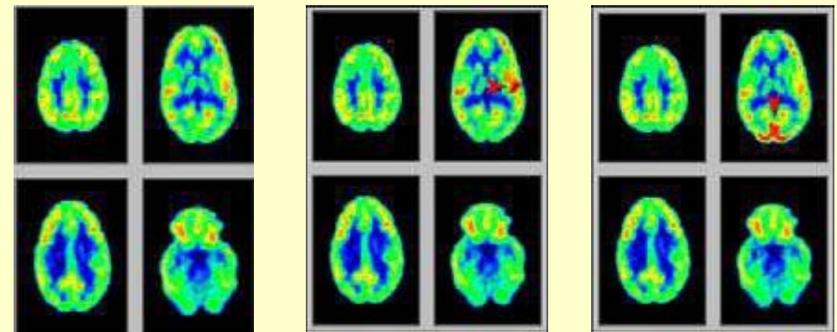
# PET/CT

Combination of structural and functional imaging



CT      PET      PET/CT      PET

## Activity of brain areas



In rest

hearing

vision

*Damjanovich, Fidy, Szöllősi: Medical biophysics*

II. 3.2.3

3.2.4

3.2.5

VIII. 3.2

VIII. 4.4

IX.3