Basics of nuclear medicine

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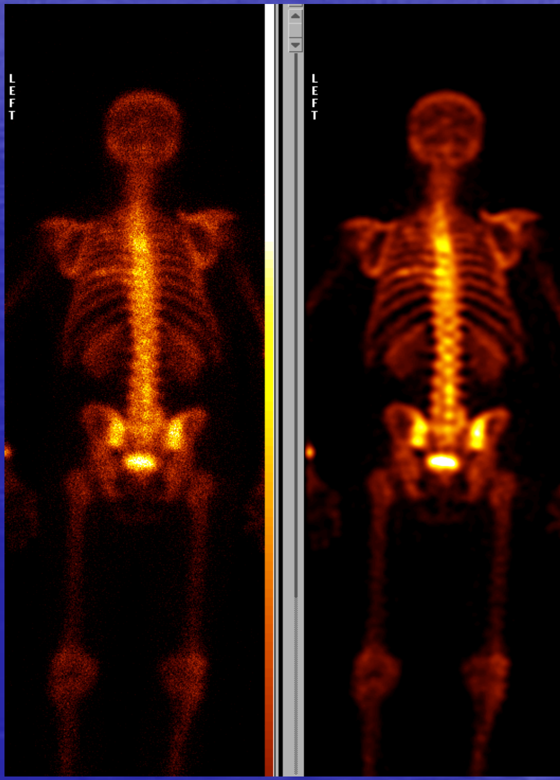


Radioisotopes are used both in diagnostics and in therapy

- **Diagnostics** – gamma emitters are used since gamma rays can penetrate the body and be detected outside

- **Therapy – beta emitters**; short range => local delivery of high doses

Diagnostic activities correspond to sub-physiological masses

- Activities used: 370 KBq-740 MBq (10μCi-20 mCi)
- Corresponding masses <1μg
- => No physiological effects, but enough for registration and diagnostic information

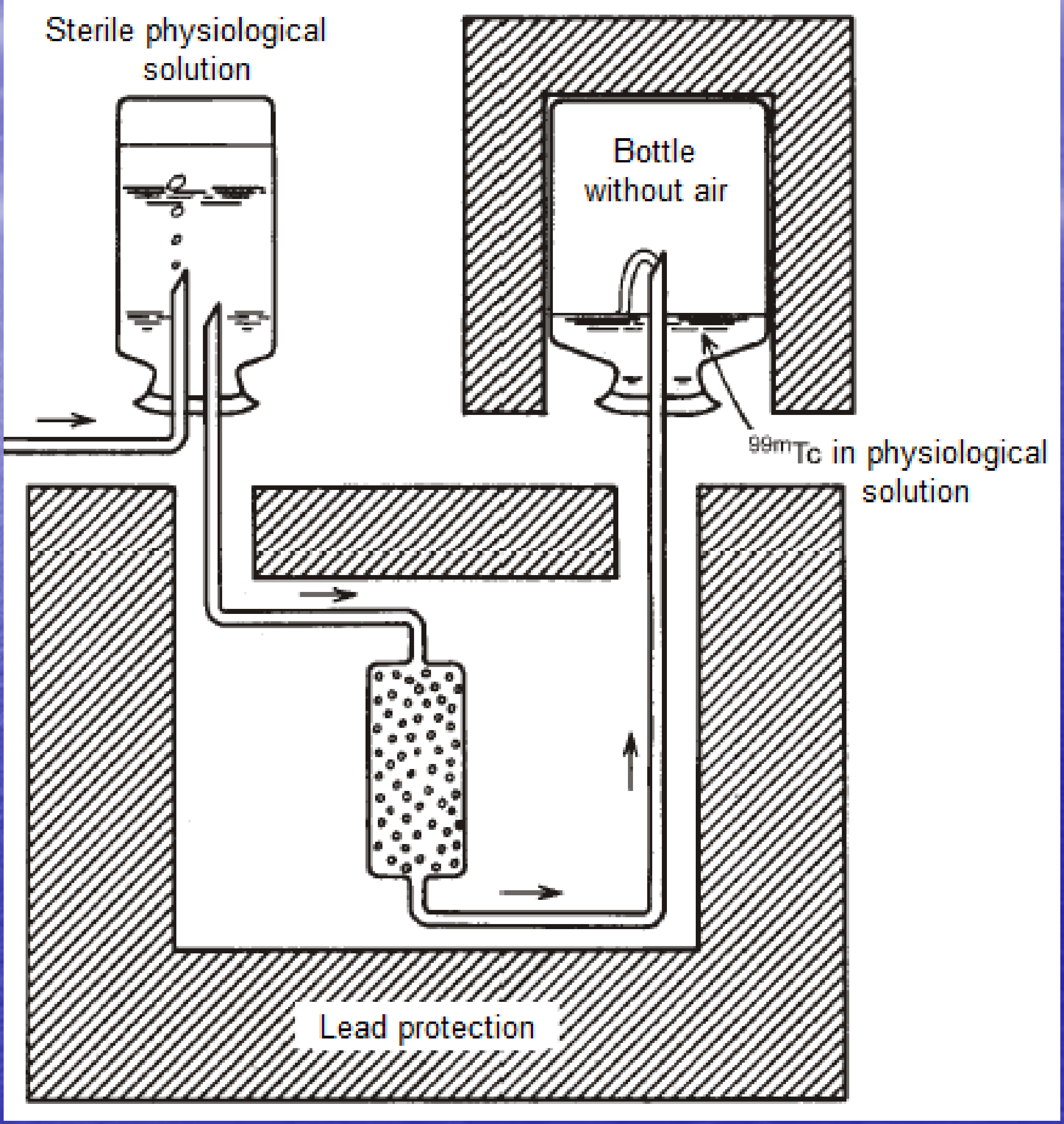
Tc-99m- the most used radioisotope in medicine

- Offspring of a nuclear reactor product Mo-99, which by beta-minus decay becomes Tc-99m, the meta-stable (long living) gamma emitter

- ADVANTAGES:

1. pure gamma emitter- no beta radiation
2. optimal photon energy- sufficient to penetrate body, not too large for efficient detection/protection
3. half life long enough to perform the investigation, with acceptable patient radiation dose
4. great chemical affinity
5. relatively cheap.

Technetium generator



Scintillation detectors: gamma rays are detected after conversion to visible light

- When some materials absorb ionizing radiation the part of absorbed energy is used to excite the atoms to higher energy states, the subsequent de-excitations produce flashes of visible light
- These flashes are called **scintillations**, and the materials **scinillators**
- => SCINTIGRAMS

Sodium iodide chrystal-the commonest gamma ray detector

1. High sensitivity of detection (owing to high density and atomic number of iodine)

2. Relatively high efficiency of conversion of gamma rays to visible light (around 10 %)

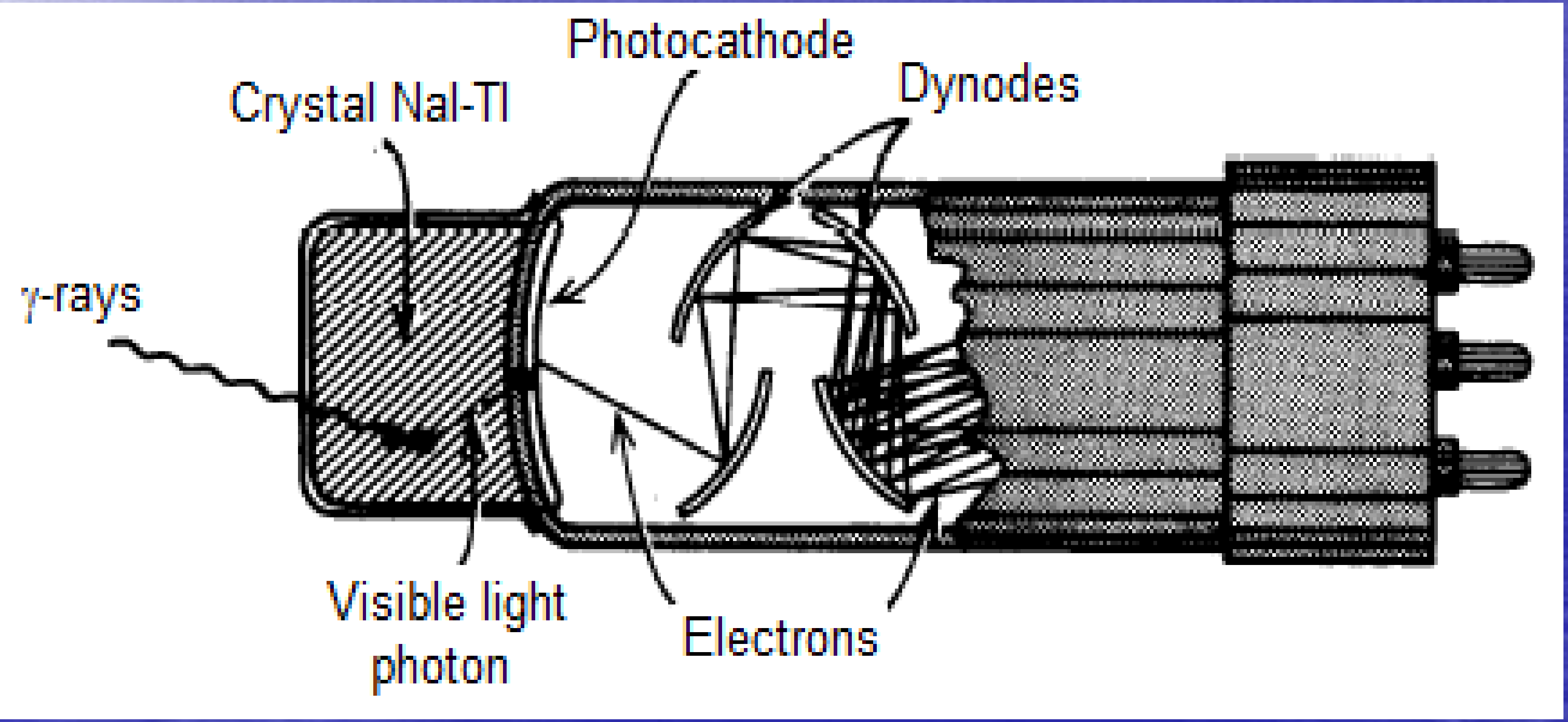
3. Short scintillation time (short dead-time) enables high registration rate (over 10^4 counts/sec)

Scintillation detectors can measure the energy of gamma rays

- The output electrical pulse is proportional to energy of the absorbed radiation, enabling:

1. using the detector as absorbed dose-meter (besides counting)
2. selective counting according to energy of photon (pulse height)- **spectral analysis**

Scintillator and photomultiplier tube comprise the **scintillation counter**



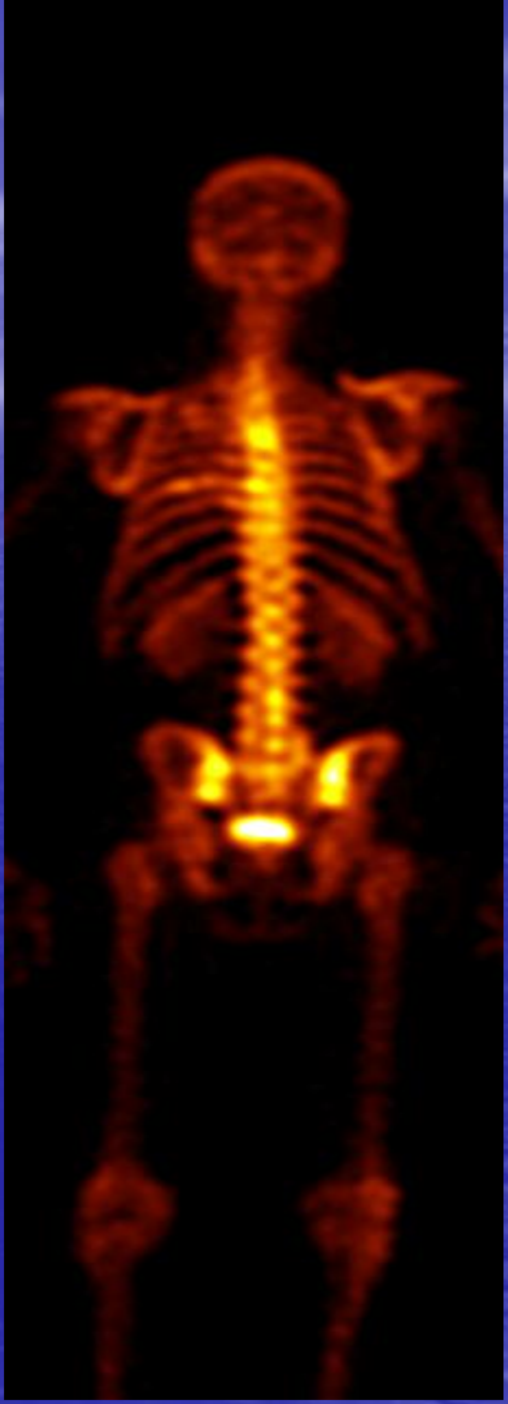
SCINTIGRAM – image of organ function

- Accumulation of radiotracer in part of a body depends only on chemical affinity and physical properties of the tracer to which the radioisotope is bound.

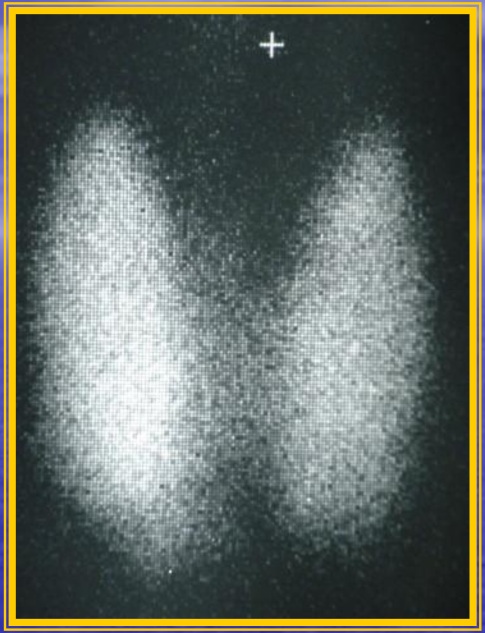
- Nuclear medicine image reflects the physiological function and is created by gamma rays that leave the body.

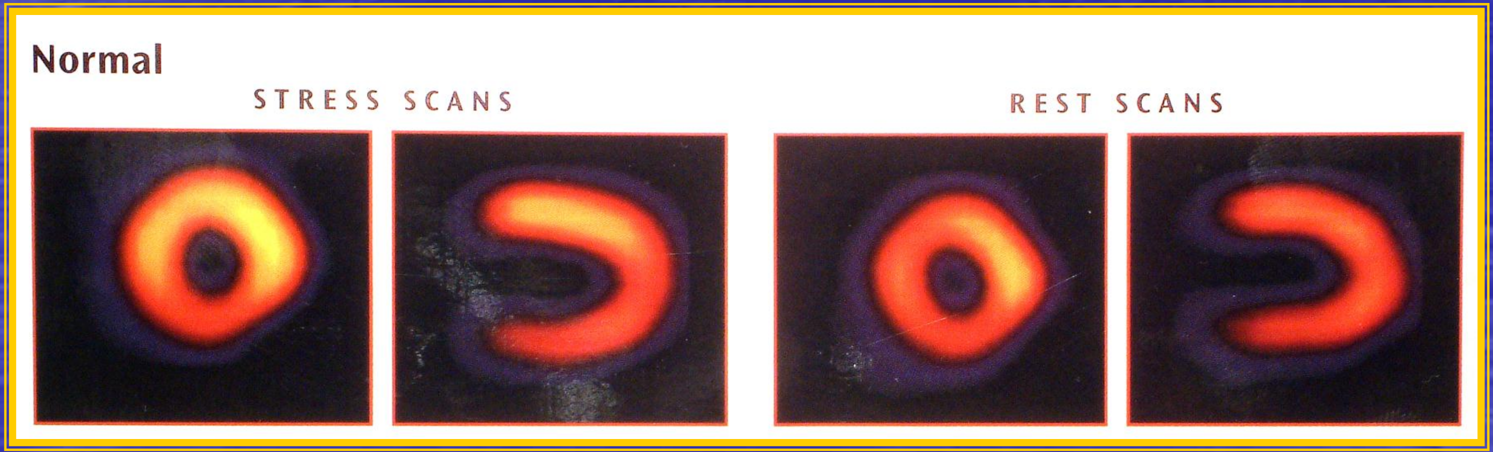
Scintigraphy

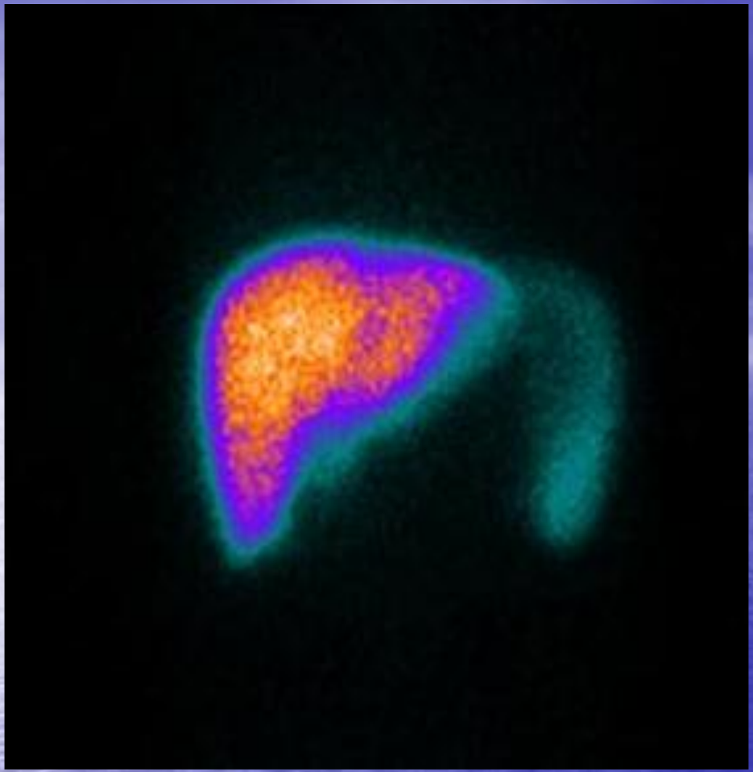
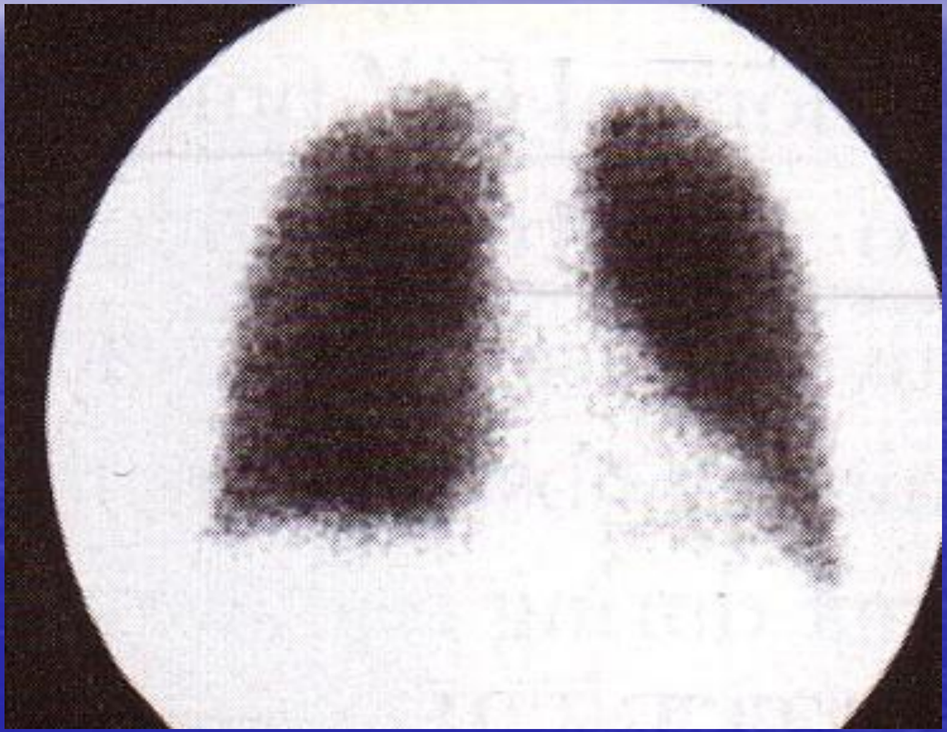
Image of distribution of radioisotope that is attached to a molecule that accumulates in the desired region, tissue or organ, to extent that depends on cellular function



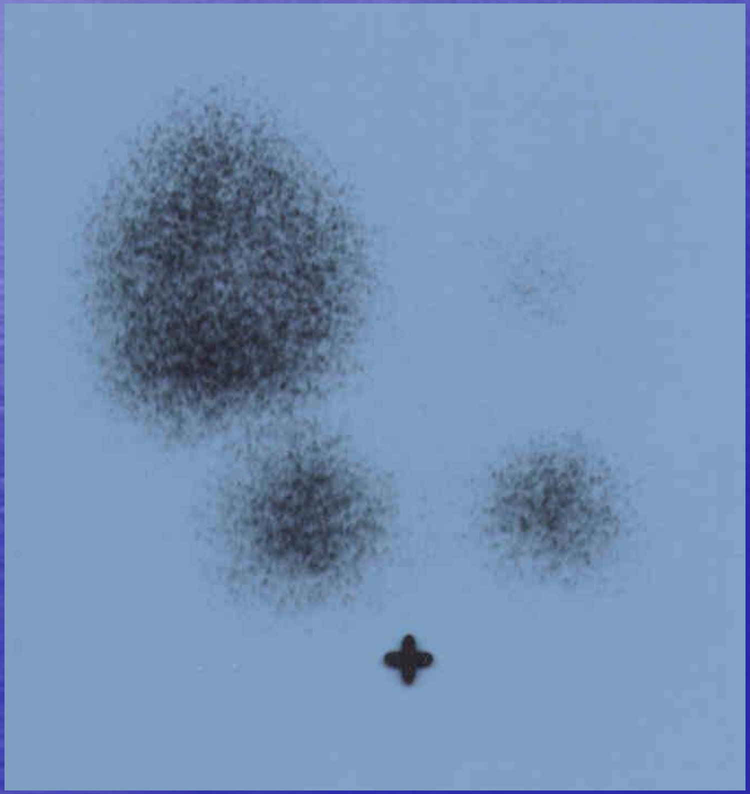
- 99m-Tc-pertechnetate-scintigram of normal thyroid distribution (left)
- 201-Tl-chloride- scintigram of
- normal heart muscle (down)





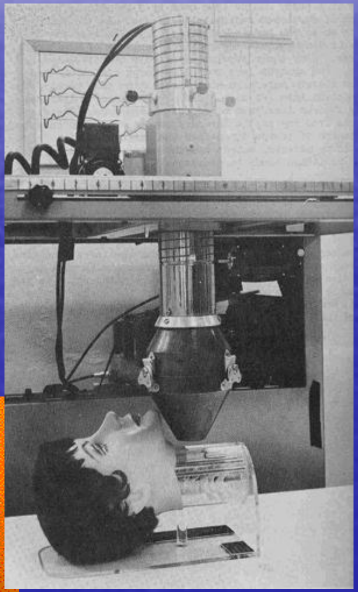



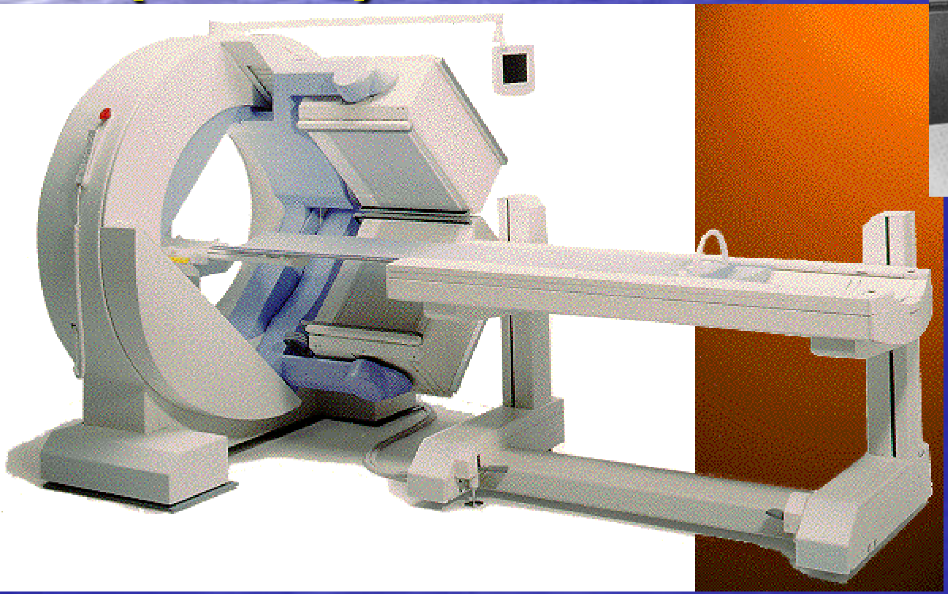

- **I-131 scintigraphy of toxic nodular goitter**



Imaging equipment

- Scanner (middle)
- Gamma camera
- PET scanner (down)





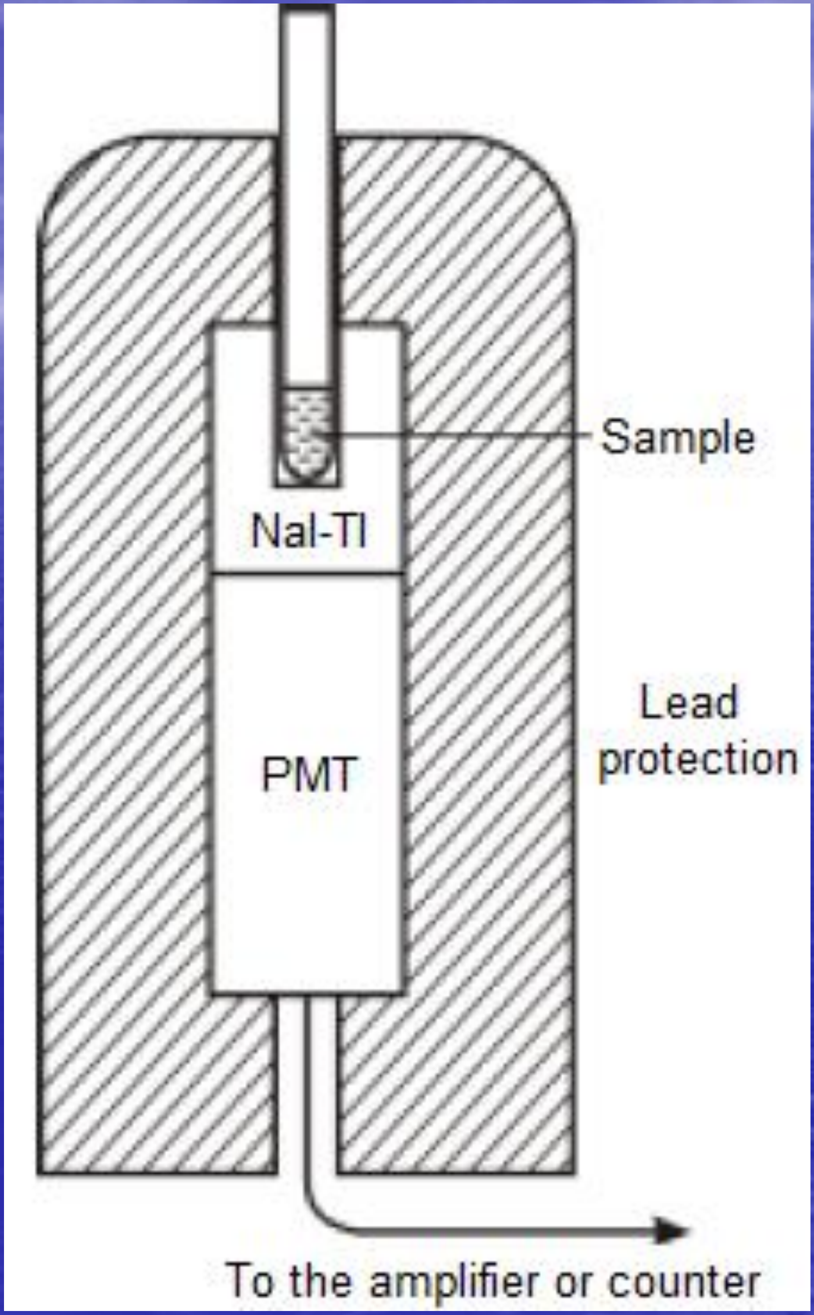
Registration of gamma radiation requires massive detector

- Two purposes of radiactive measurements:
-

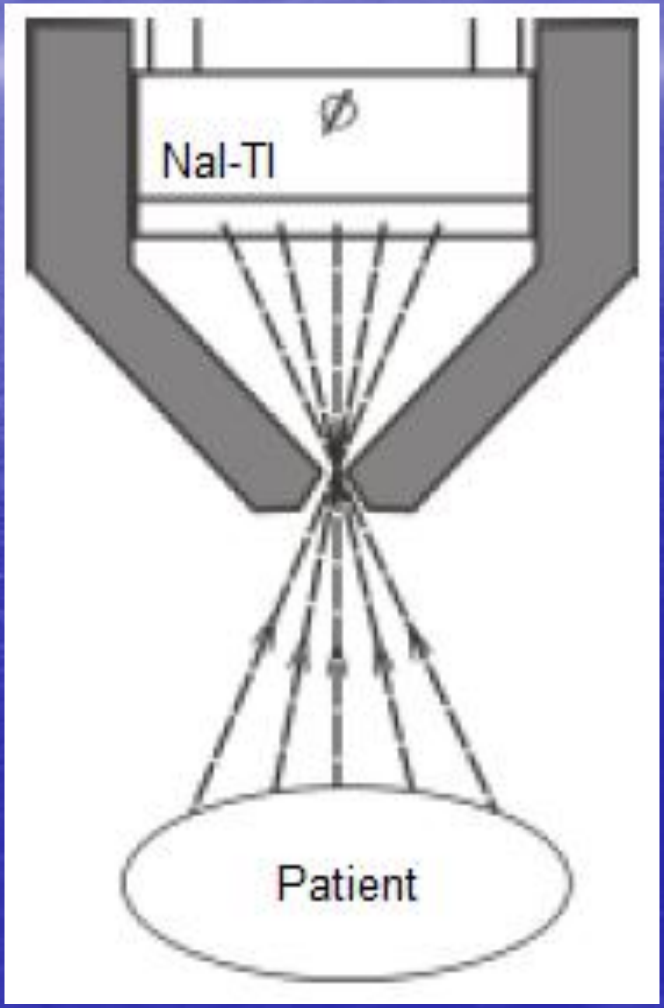
1. measurements of concentration in a sample
2. imaging distribution within the body

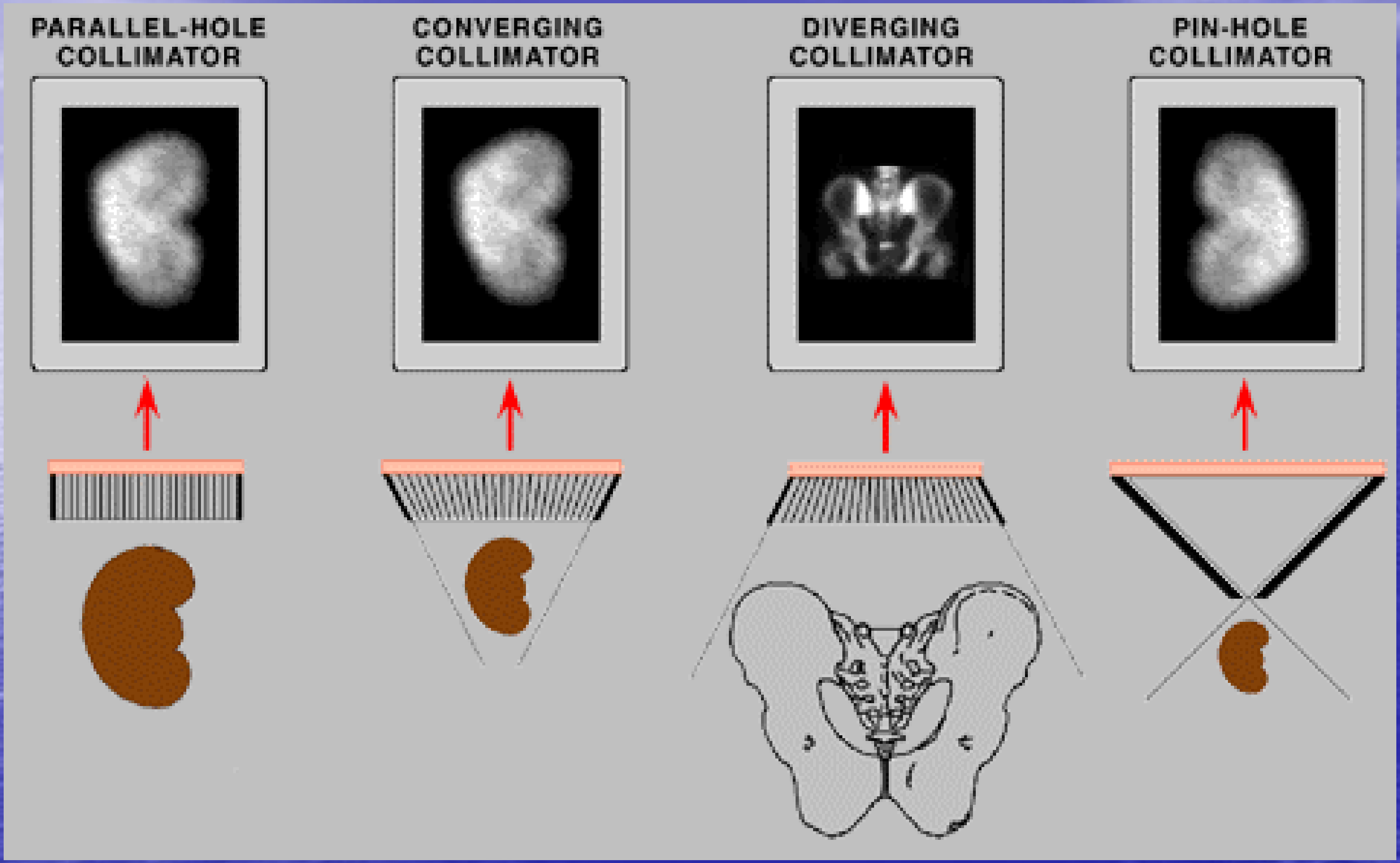
- Due to large energy and consequent penetrability in both cases one needs
- **massive detector** , which limits resolution and sensitivity of registration

Well counter



Pinhole collimator: imaging of small volumes

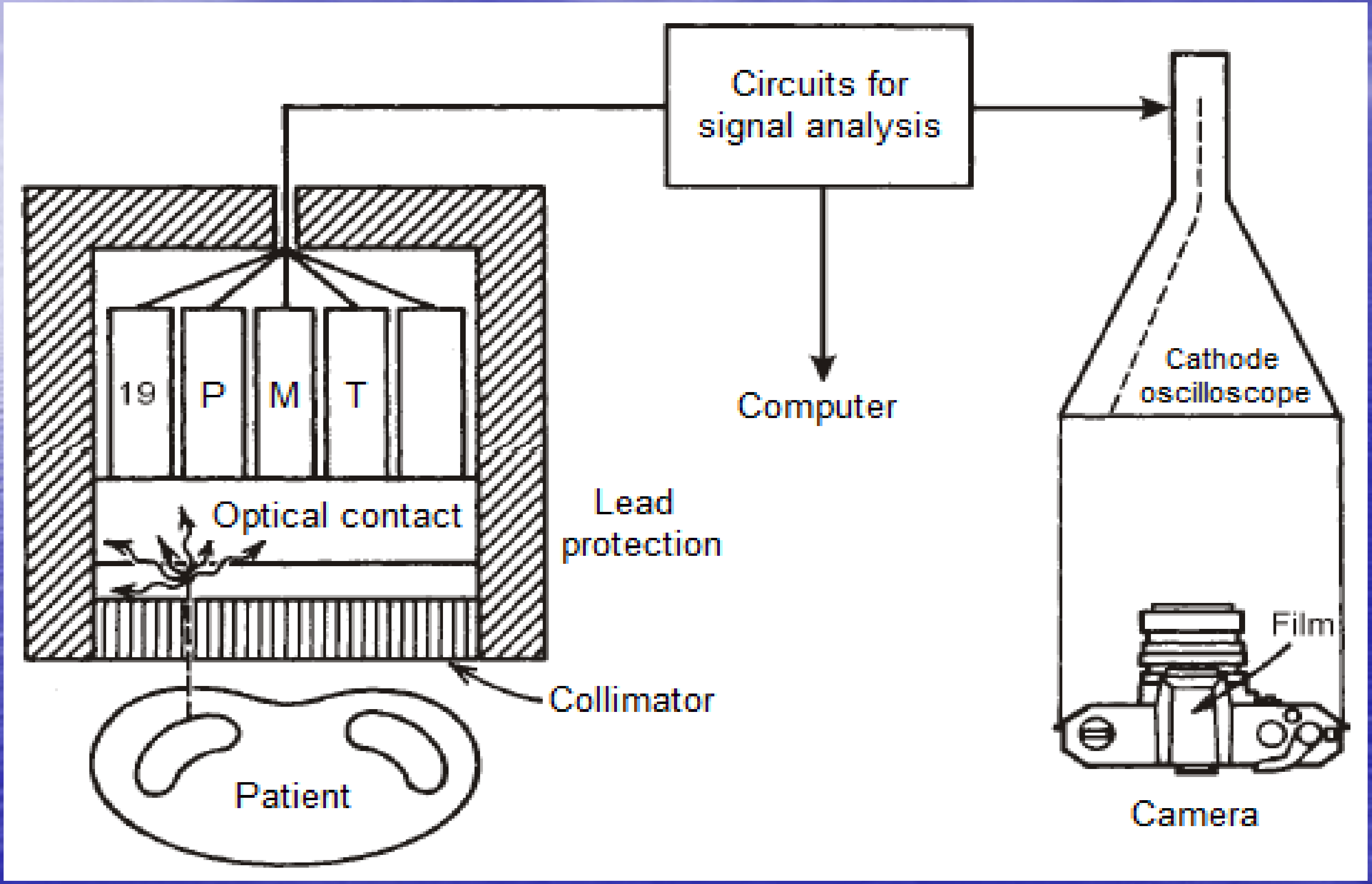


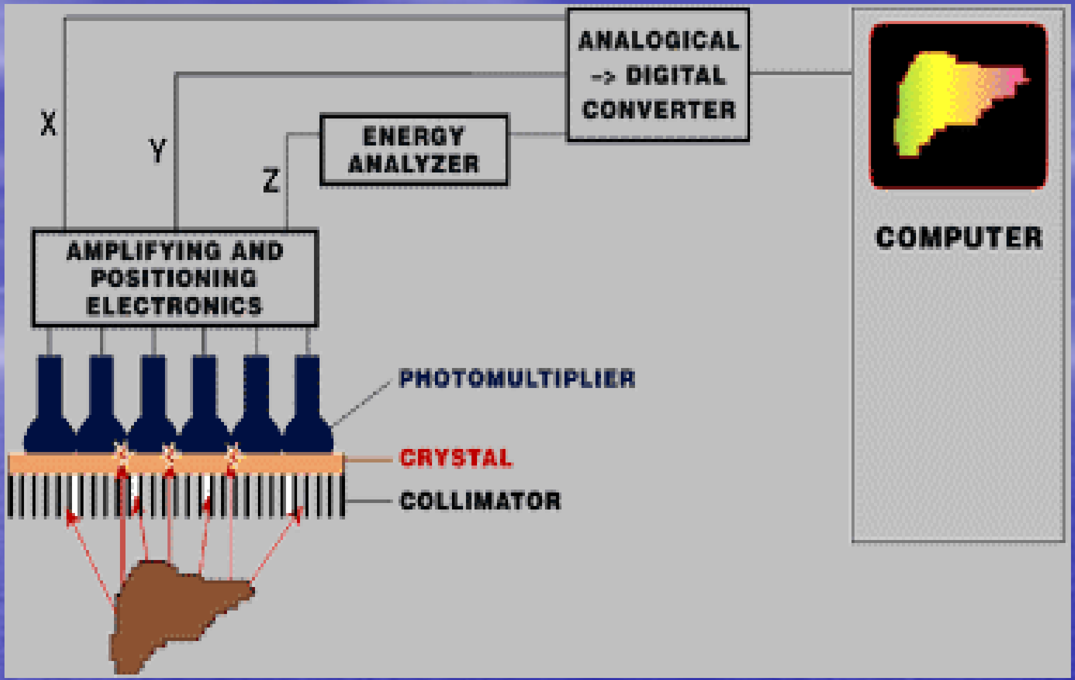

PARALLEL-HOLE COLLIMATOR
CONVERGING COLLIMATOR
DIVERGING COLLIMATOR
PIN-HOLE COLLIMATOR

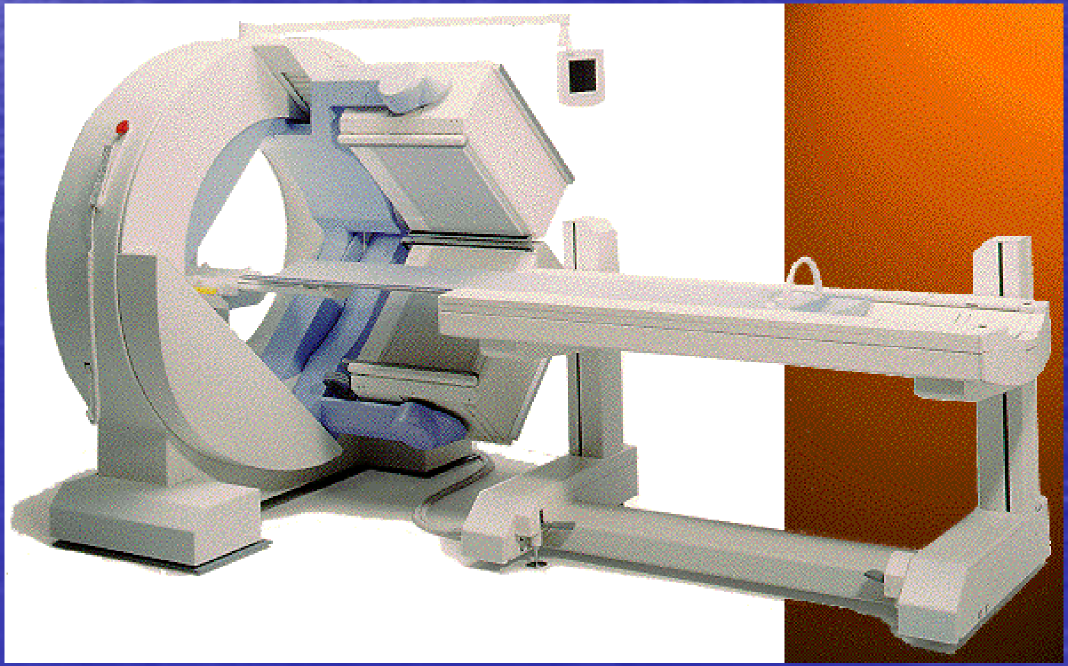
Gamma camera creates live scintigrams

- Parallel collimator – lead plate with many narrow parallel holes (channels) at right angle to plate and crystal bases
- => gamma ray hitting the crystal originates from the area directly bellow the place of absorption
- gamma camera is always sensitive to the toal area beneath the crystal

Gamma camera components




ANALOGICAL -> DIGITAL CONVERTER
ENERGY ANALYZER
X
Y
Z
AMPLIFYING AND POSITIONING ELECTRONICS
COMPUTER
PHOTOMULTIPLIER
CRYSTAL
COLLIMATOR

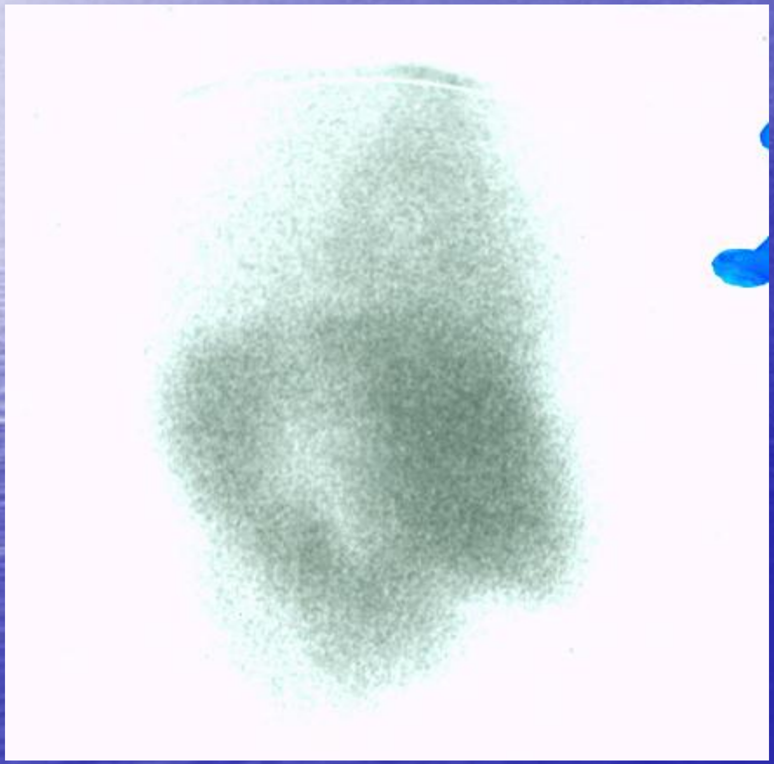


Two ways to present the gamma camera image:

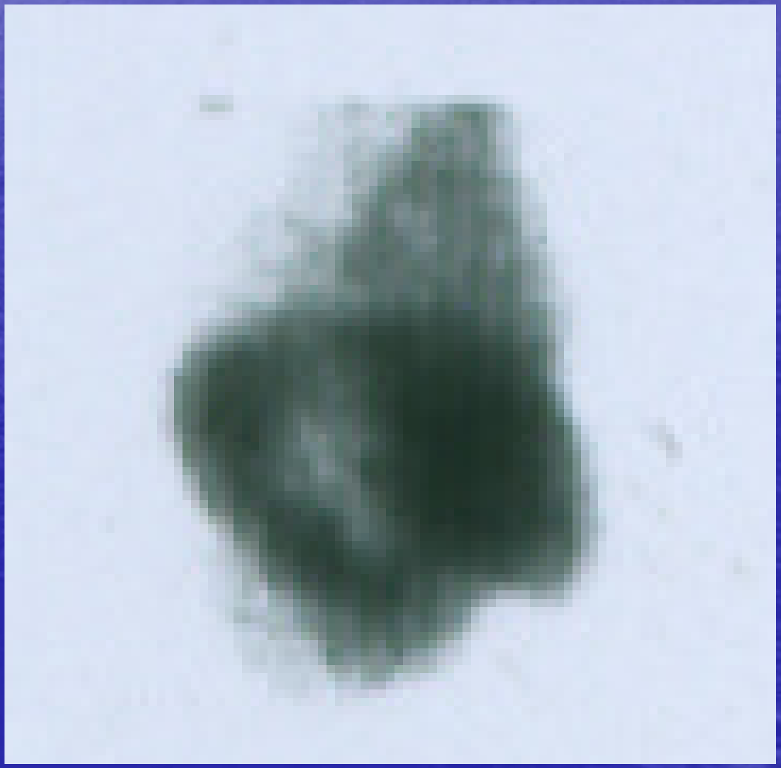
1. **analog image:** the position of scintillation is projected on the screen of an oscilloscope, which illuminates the photograpic film

2. **digital image:** position and rate of scintillations are stored in computer memory as a digital matrix (64x64; 128x128;..)

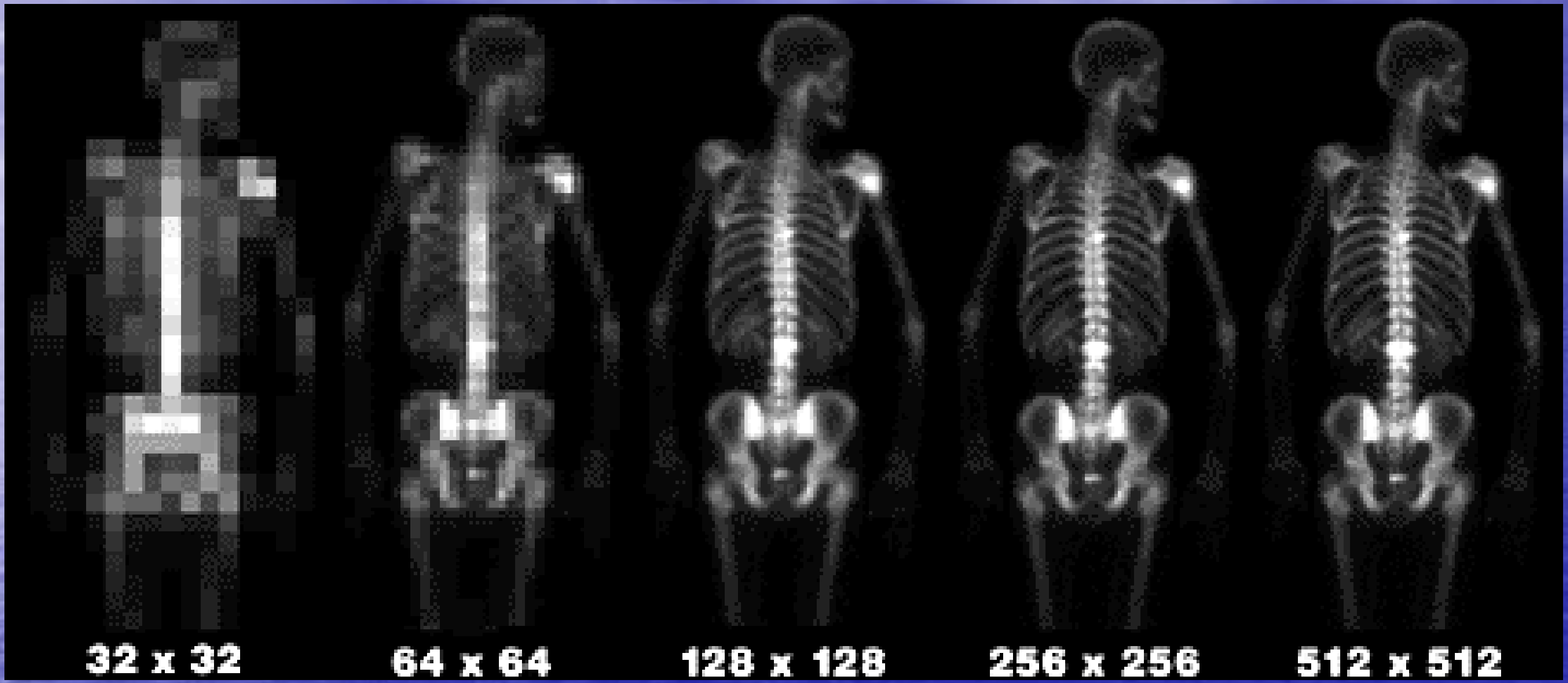
Liver scintigraphy with Tc-99m-colloid in case of trauma causing tissue rupture



analog image



digital image



The effect of matrix size

Distinctive scintigram features: functionality and quantitative aspect

- **functionality:** radiotracer accumulation mirrors the organ(s) function
- **quantitative aspect:** scintigram is basically a table of numbers

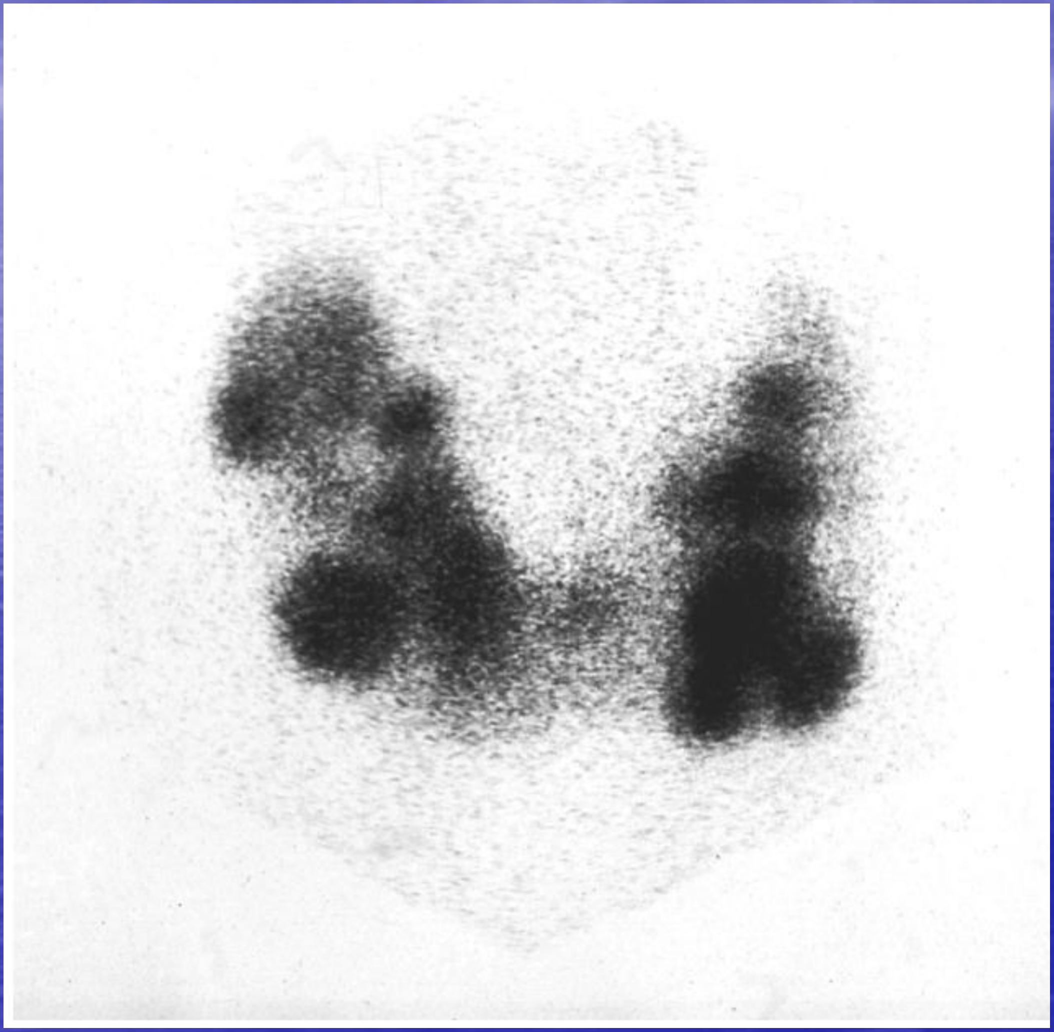
Factors of scintigram (dis)advantages

1. **Large energy of a gamma ray**: requires massive detector, but enables registration of small, deep sources of minute activities
2. **spreadness/wide distribution of gamma ray sources**: requires collimation of radiation, but enables functional organ images

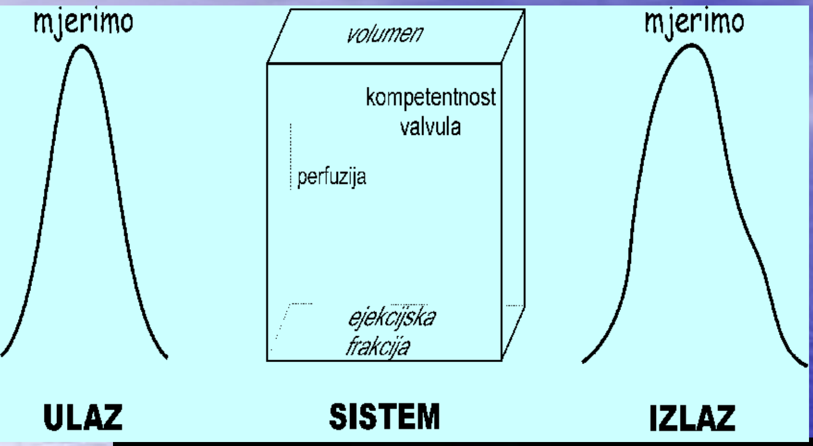
=> Minute amounts of radioindicator, in short time, create diagnostically useful images

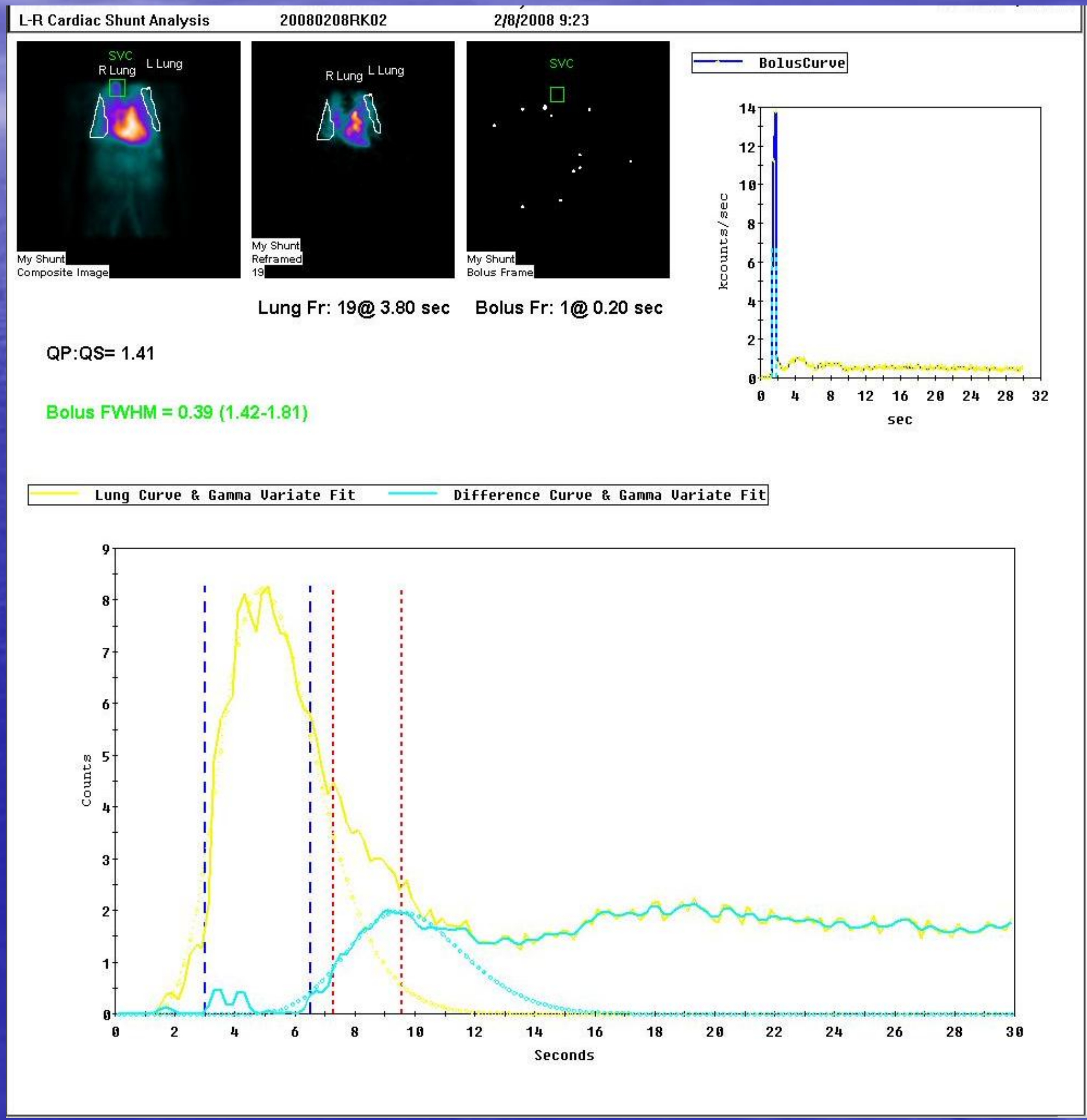
- **Lesion detectability** increases with its **size**, but primarily depends on its **contrast** against the neighboring tissue
- **Resolution**-important for small lesions
- Digital image can manipulated on a computer to enhance visual effects (caution: possibility of artifacts!)

Hot lesions are better seen than cold ones

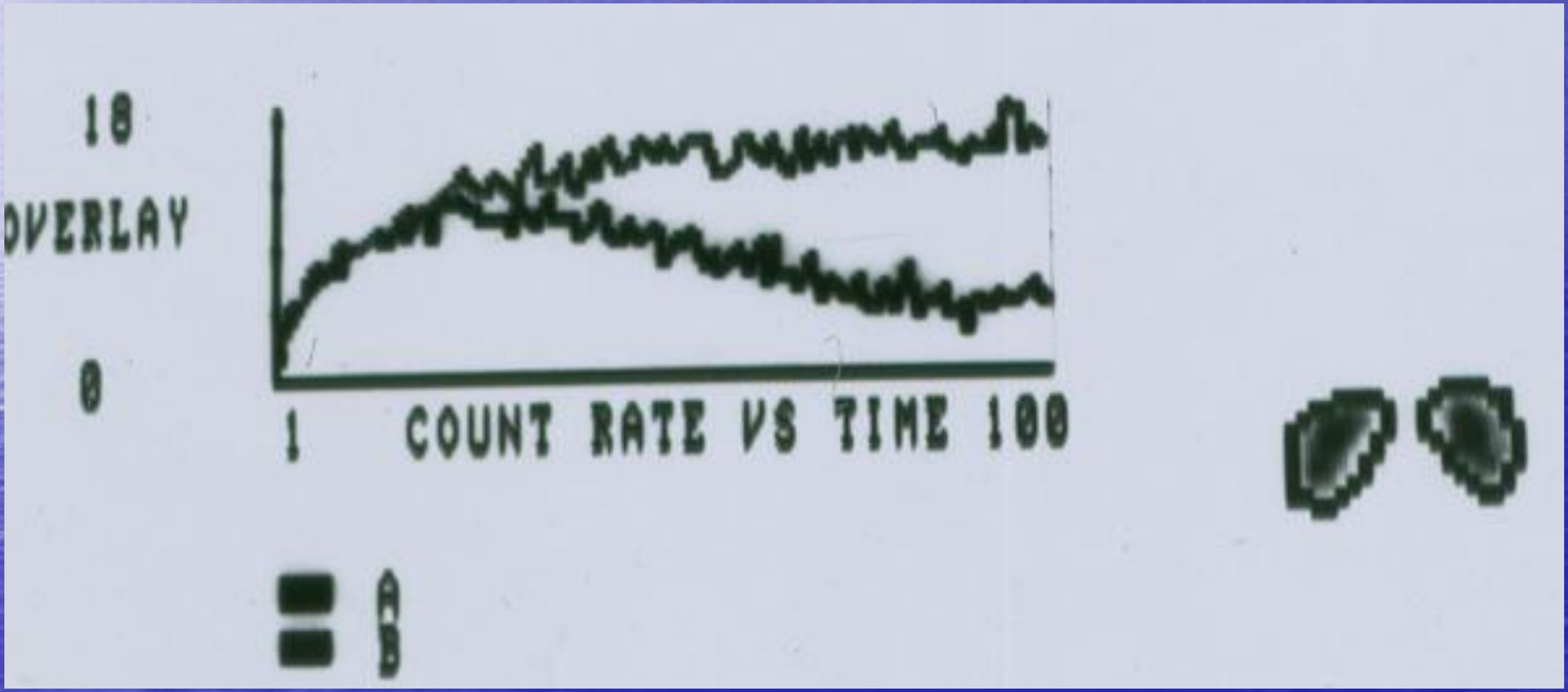


Radiohistogram are analyzed with computer aid to diagnose and quantify various parameters





Radihistogram: time-activity curve



computer programs: algorithm codes to analyze (series of) scintigrams or time-activity curves

Typical mechanisms of ratiotracer localization

Mechanism	Organ	Radiotracer
active transport	thyroid	J-131
active transport	kidney	ortho-I-131-hypurric acid
active transport	myocardiu m	Tl-201
capillary blockade	lungs	Tc-99m-macroaggregate
filtration	kidney	Tc-99m-diethilene-triamine-pentaacetic acid
dilution	blood	Tc-99m-human serum albumin
phagocytosis	liver	Tc-99m-sumphor colloid
sequestration	spleen	Tc-99m- erythrocytes (damaged by heating)

Effective half-life: determinant of absorbed dose due to radioacitivity introduced into the body

- constant of biological elimination (λ_B)
- biological half-life $(T_{1/2})_B = ln(2)/\lambda_B$
- constant of effective elimination:
- $\lambda_{EF} = \lambda_B + \lambda_F$ (constant of radiactive decay)
- effective half-life $(T_{1/2})_{EF} = ln(2)/\lambda_{EF}$

- => The inital radioacitivity in body decreases in time according to:

$$A(t) = A_0 \exp(-\lambda_{EF}\, t)$$

^{99m}Tc

Absorbed doses in common procedures

Procedure	Radiotracer	Activity	Dose in critical organ (Gy)[a]	Dose in gonads (mGy)
Brain scintigraphy	pertechnetate	500 MBq (~ 15 mCi)	Intestines, 0.02	4
Liver scintigraphy	sulphor colloid	150 MBq (~ 4 mCi)	Liver, 0.02	0.85
Lung scintigraphy	macroaggregate	100 MBq (~ 3 mCi)	Lungs, 0.009	0.3
Bone scintigraphy	pyrophosphate	500 MBq (~ 15 mCi)	Bladder, 0.06	4
Renography	hyppuric acid	Bq (~ 200 µCi)	Bladder, 0.02	0.2
Thyroid function	sodium iodide	300 kBq (~ 8 µCi)	Thyroid, 0.08	0.6
Thyroid scintigraphy	pertechnetate	150 MBq (~ 4 mCi)	Intestines, 0.01	0.8

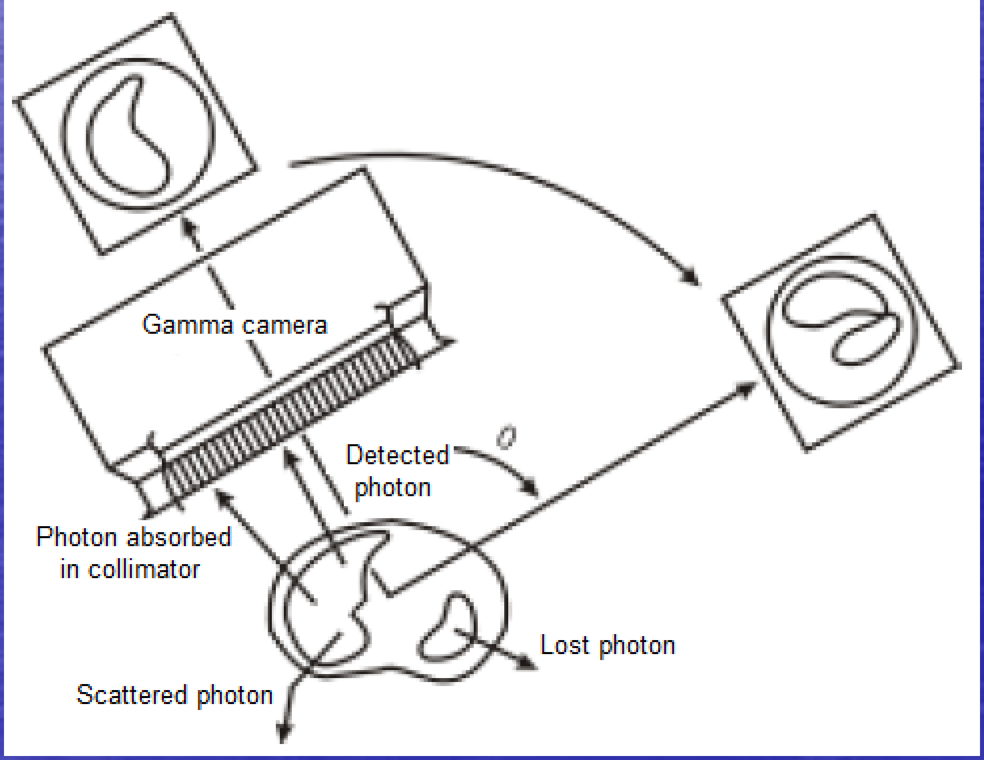
[a] critical organ has the largest absorbed dose

Imaging of body slices= tomography

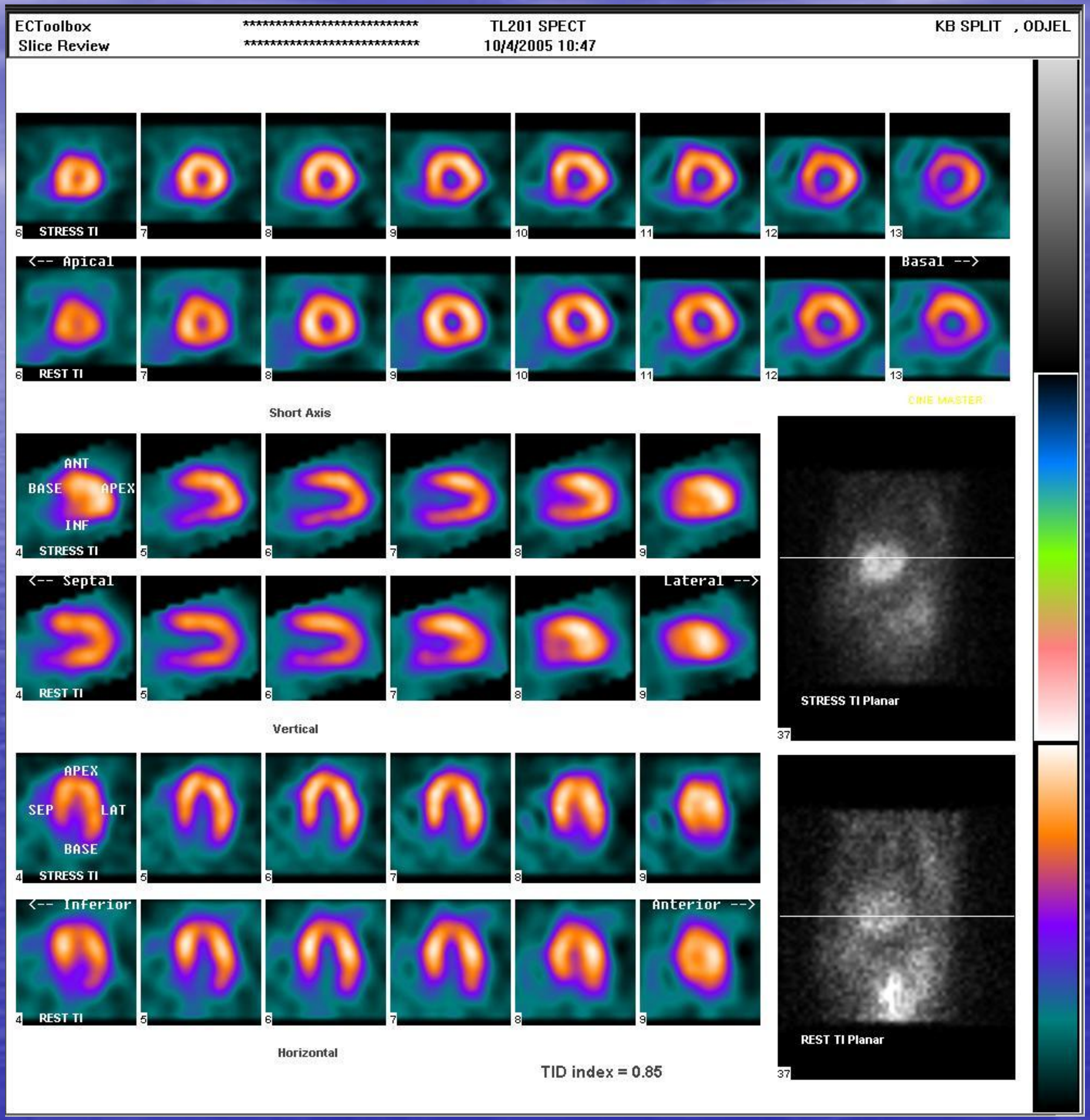
- **SPECT** = single-photon emission computed tomography
- **PET** = positron emission tomography

Imaging from many directions enables slice isolation

- SPECT: gamma camera rotates around body, the series of scintigrams (projections) thus obtained are raw dana from which computer reconstructs slices



SPECT



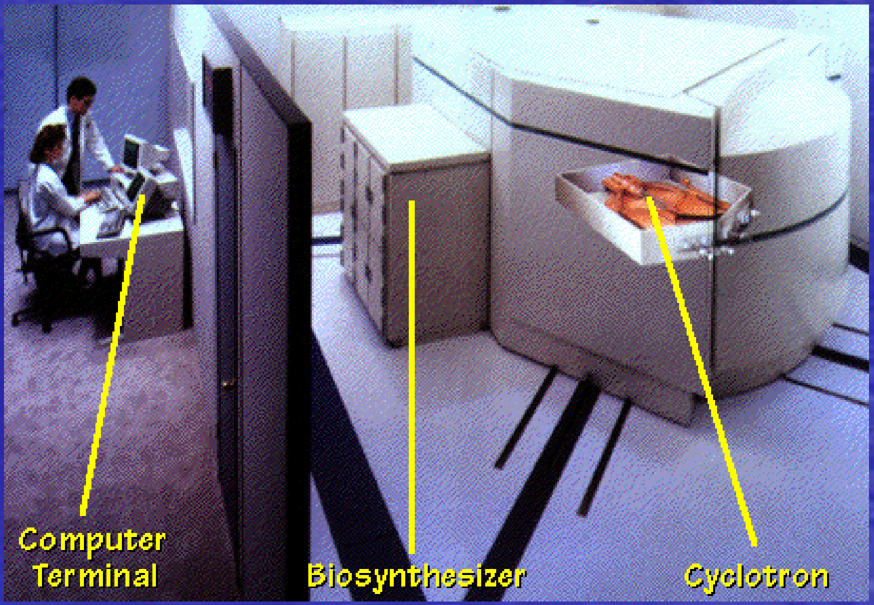
ECToolbox
Slice Review
****
****
TL201 SPECT
10/4/2005 10:47
KB SPLIT , ODJEL
STRESS Tl
<-- Apical
Basal -->
REST Tl
Short Axis
ANT
BASE
APEX
INF
STRESS Tl
<-- Septal
Lateral -->
REST Tl
Vertical
STRESS Tl Planar
APEX
SEP
LAT
BASE
STRESS Tl
<-- Inferior
Anterior -->
REST Tl
Horizontal
REST Tl Planar
TID index = 0.85

Tomograms have inferior resolution compared to planar images

- Tomogram, being derived from series of planar images (projections) by non-perfect algorithm (absorption of radation in the body can be accounted for only approximately) has inferior resolution than the original (raw) images
- Nevertheless, due to increased contrasts, the overall diagnostic information is greater

Positron emissiion tomography-PET

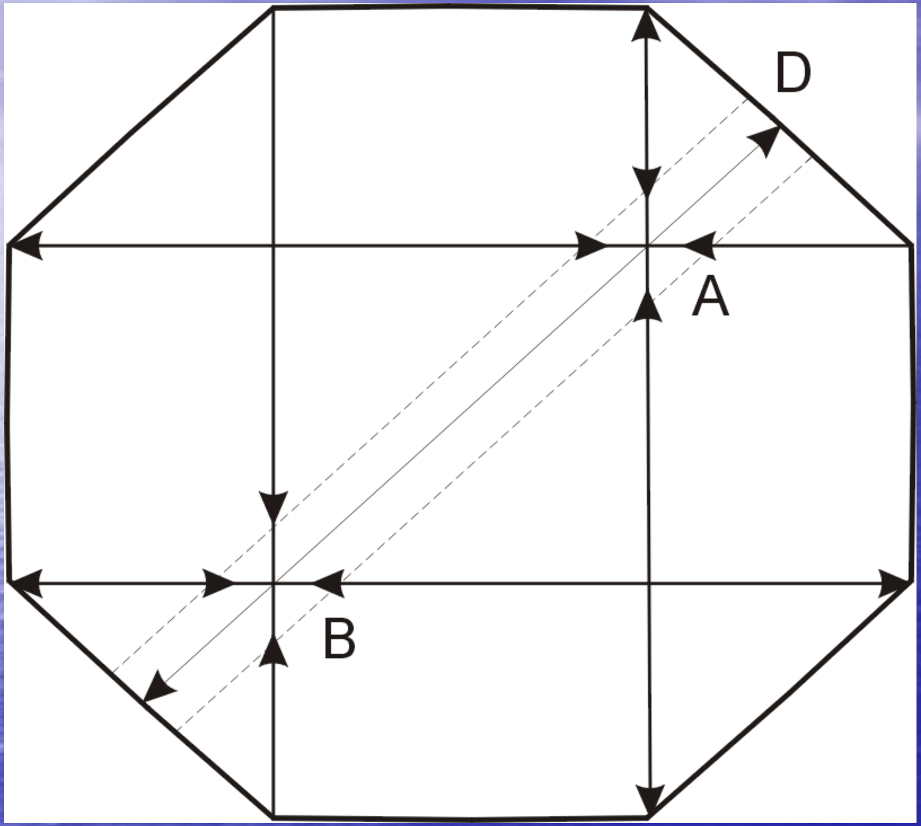
PET is used to detect the (pato)physiological and biochemical processes by virtue of kinetics of positron emitters (F-18, C-11, O-15, N-13), or mollecules attached to them. The images reflect: tissue perfusion, the metabolism of oxygen, carbohydrates, fatty acids, amino acids, as well as neuroreceptors.



Positron emitters display metabolic processes:

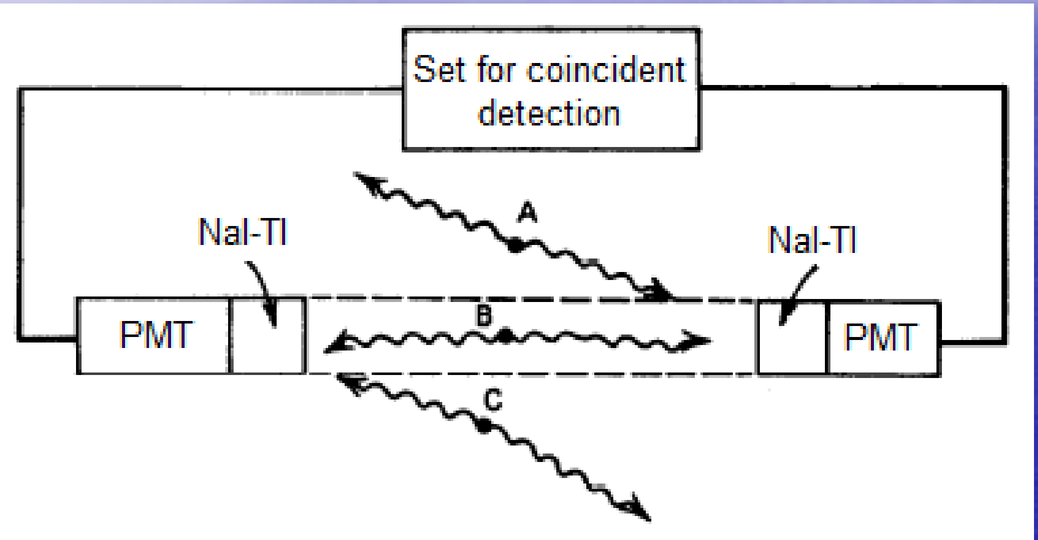
Radionuclide	Half-life (min)	Tracer	Use
Carbon-11	20.5	Nitric acid	Clinical research
Nitrogen-13	10	Cardiology	Cardiology
Oxygen-15	2.1	H_2O, CO, CO_2	Clinical research
Fluorine-18	110	FDG and F-dopamine	Oncology, cardiology, neurology
Rubidium-82	1.3	Potassium analogs	Cardiology

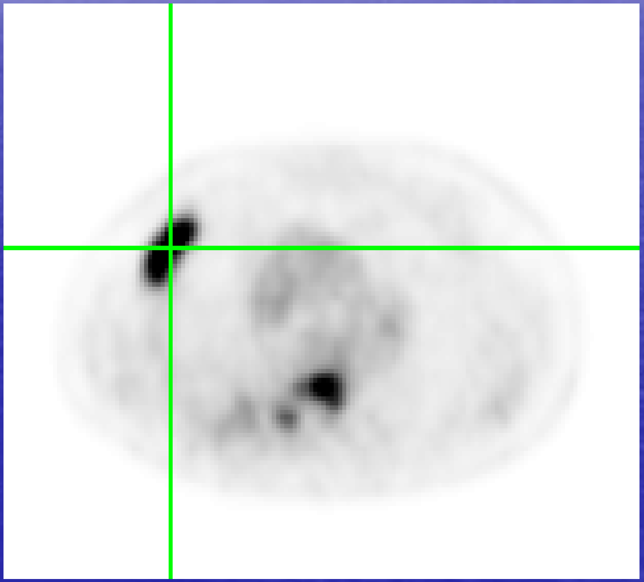
Creation of PET image



The positions of sources (A,B) are reconstructed as sections of straight lines passing through detector pairs

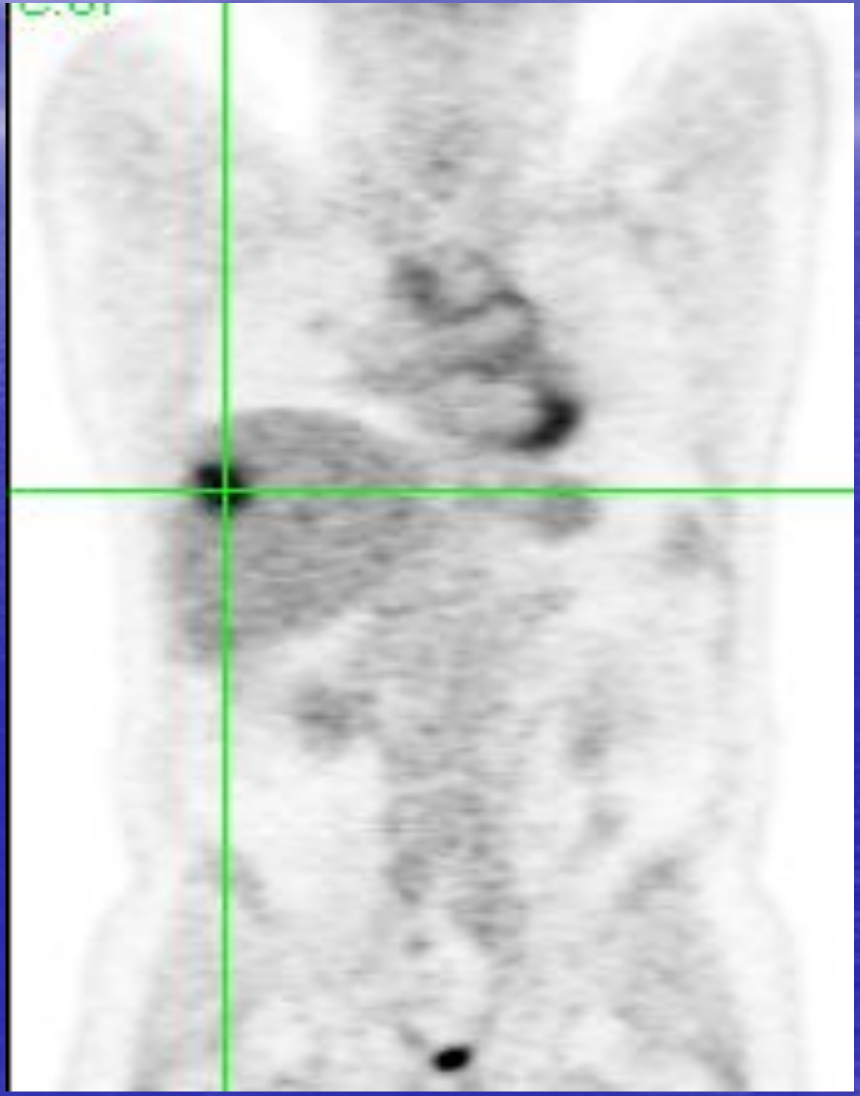
Principle of coincident detection



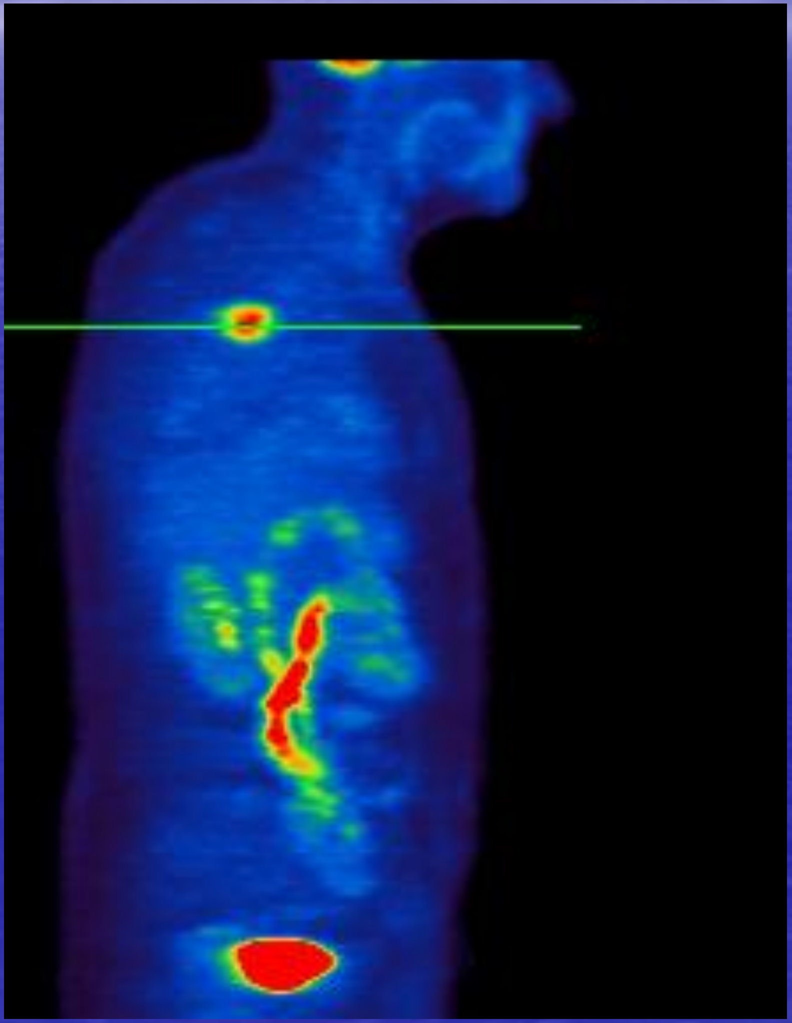


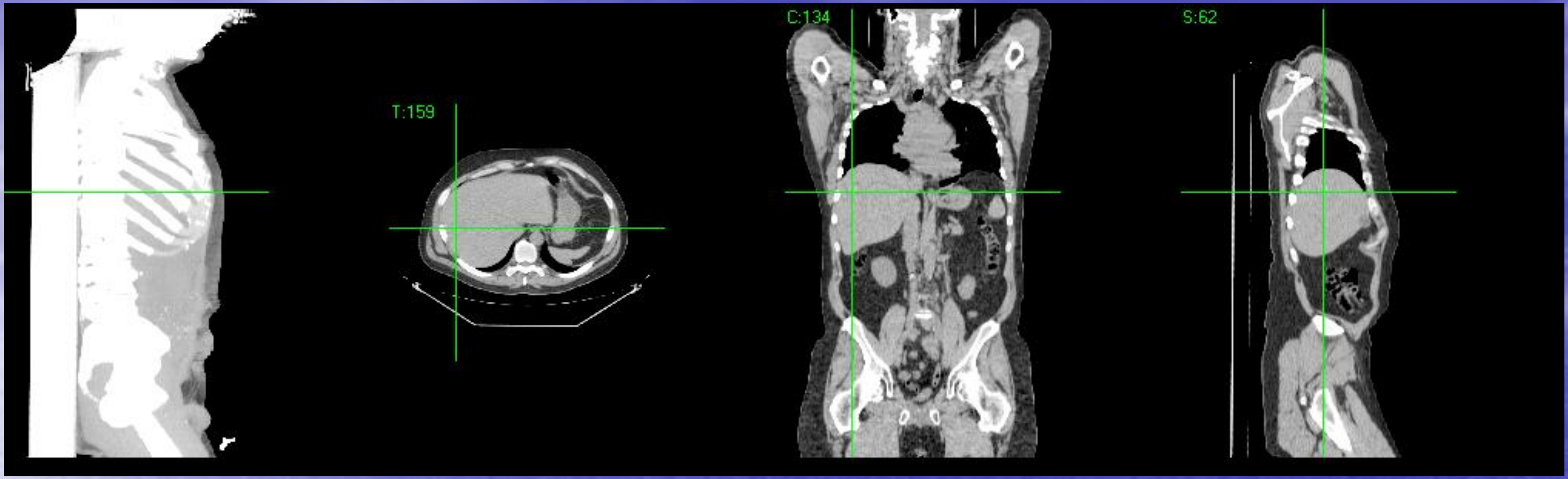
- No collimation needed: ↑ resolution , sensitivity

PET image of a patient with liver metastasis

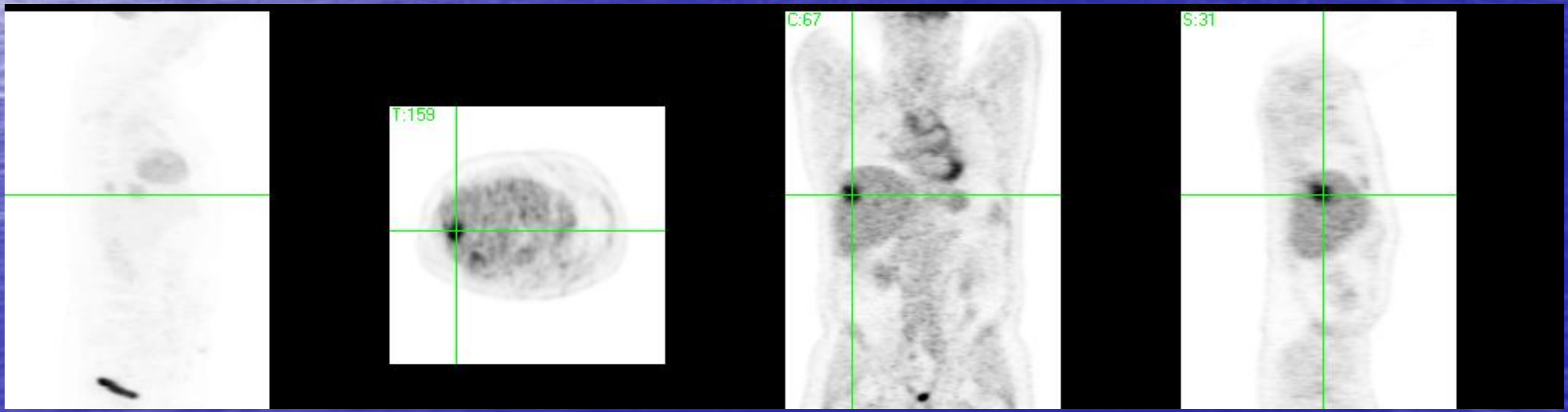


PET: pathologic focus in shoulder region





CT: liver metastasis



PET: liver metastasis

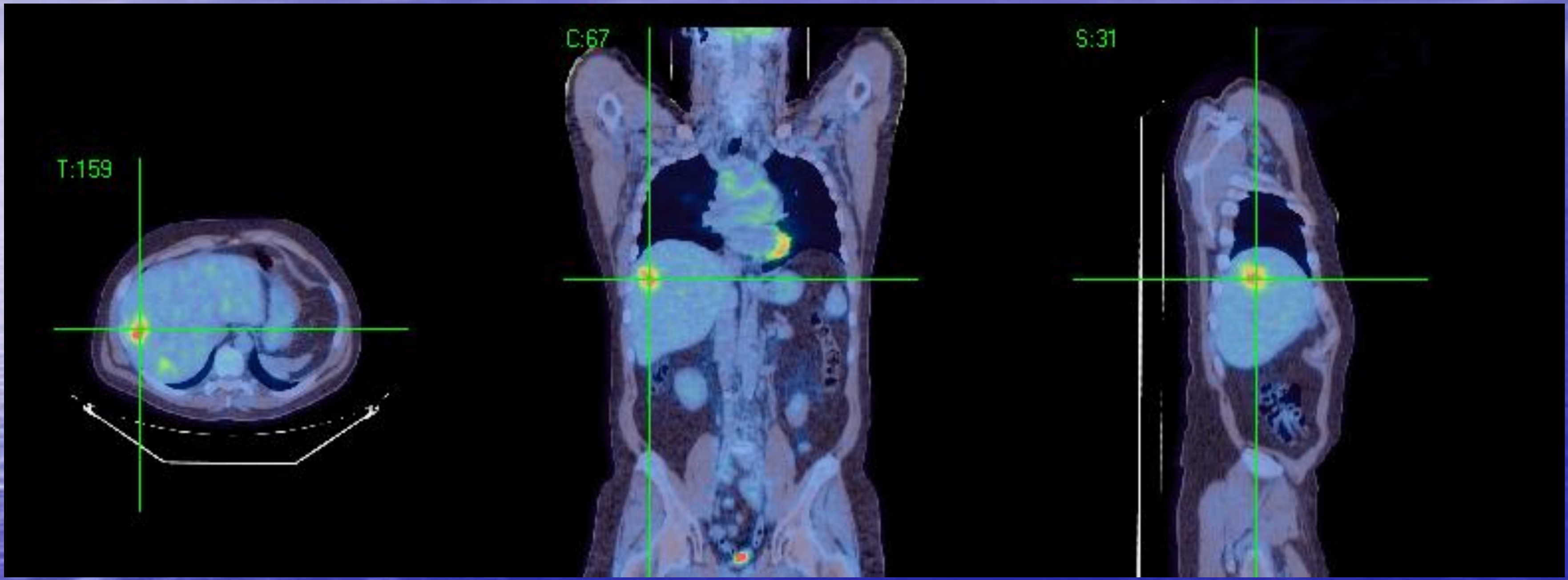
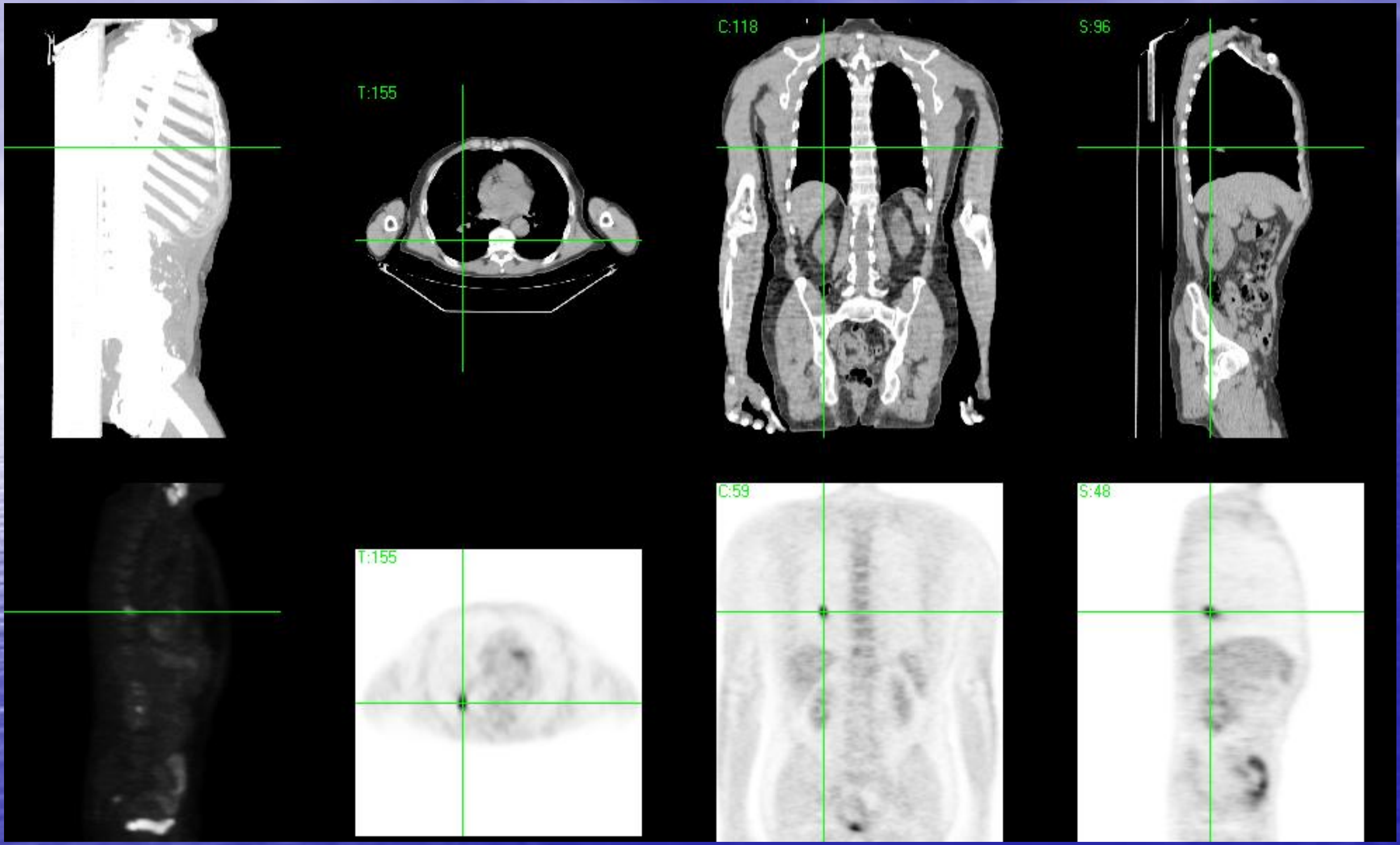


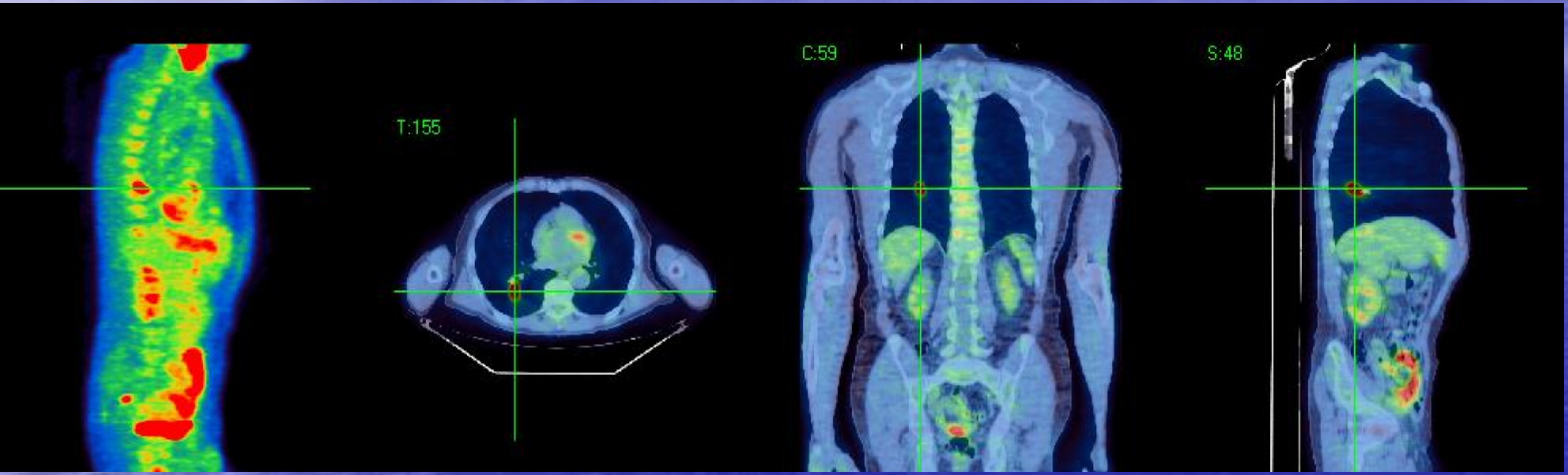
Image fusion: PET-CT



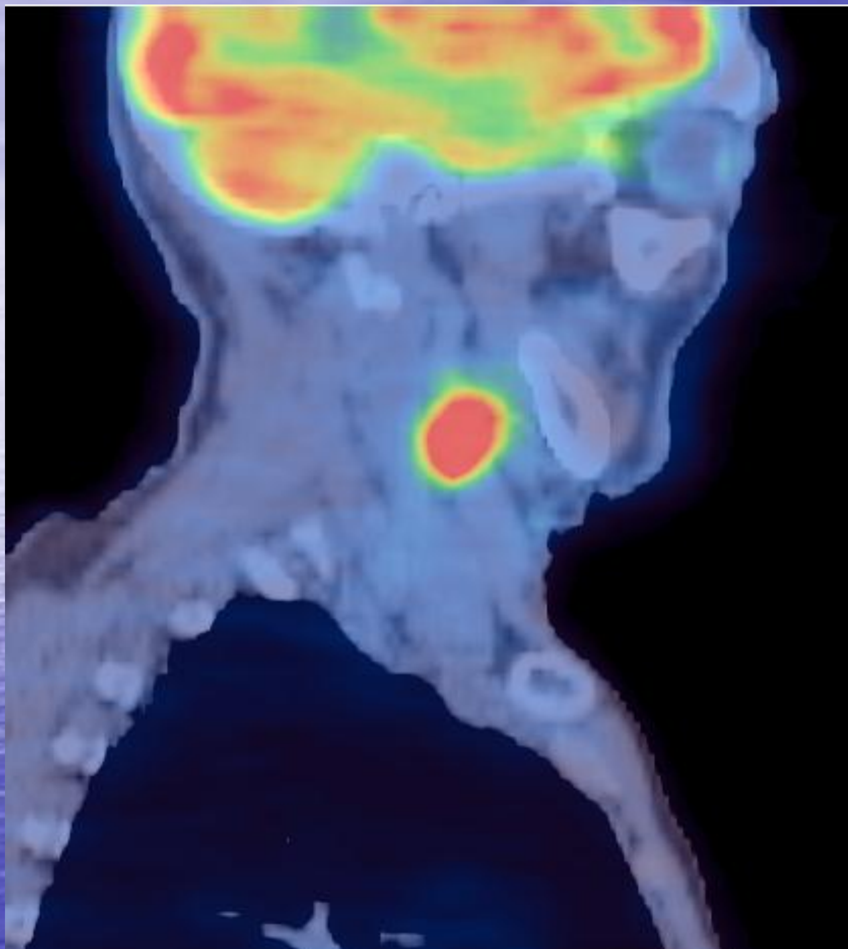
CT

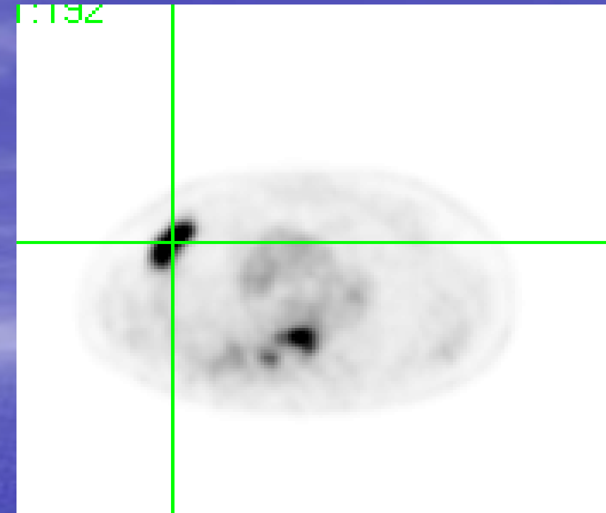
PET

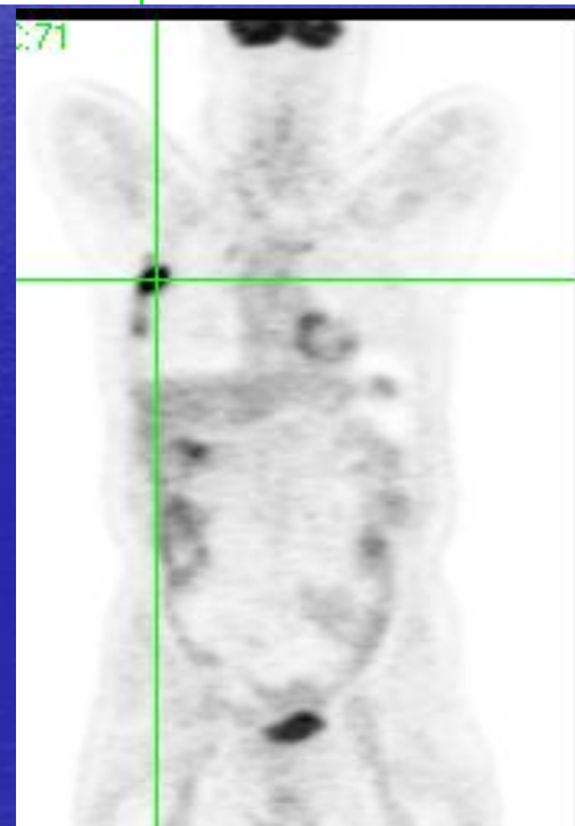
Lung metastasis



PET-CT fusion (lung metastasis)

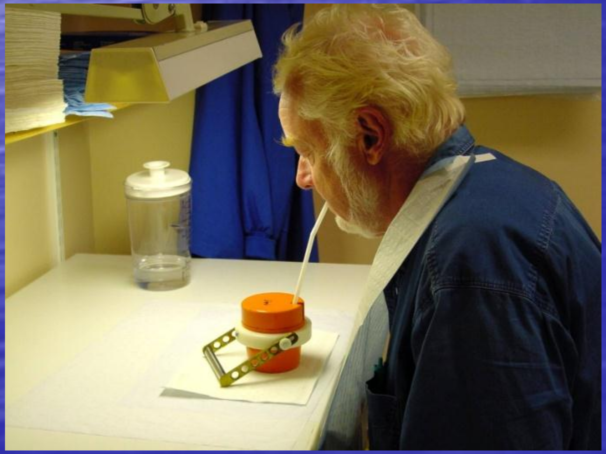






Therapy

Radiotracers containg particle emitters (mostly beta-emitters) can be used for selective tissue destruction, by virtue of their small range and consequent local energy absorption



Nuclear medicine perspective

The future of nuclear medicine depends on development of new radiotracers:
mollecular nuclear medicine

THE END