Nuclear medicine

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1. Basic Principles
2. Detection of radiation
3. SPECT, PET

Nuclear Medicine

- In Vitro methods
- In Vivo methods
- Therapy

The Structure of Atoms

- Nucleus: (nucleons)- protons (p), neutrons (n)
- Shell: electrons (e)

Atom description:

- Atomic number – Z (p)
- Neutron number- N (n)
- Mass number (nucleons) – A (p+n)
- Izotop (Z), izobar (A), izomer (same Z+A; different energy)

${}^{1}_{1}H$, ${}^{2}_{1}H$ a ${}^{3}_{1}H$.

${}^{40}Ar$, ${}^{40}K$, ${}^{40}Ca$

Radioactivity and radionuclides

- Radioactivity is effect, when atom´s nuclei of definite element spontaneously change to nuclei of other element, during which time is emitted high energy radiation.

- Nuclei with this property are radionuclides
- Substances with radionuclides are radioactive emitter

$$-\frac{dN}{dt} = \lambda \cdot N.$$

$$N(t) = N_0 \cdot \exp - \lambda \cdot t,$$

Radioactivity as quantity is number of nuclei´s disintegrations in given quantum of substance per time

- International units is Becquerel – Bq (Curie: $1Ci=3,7.10^{10}$ Bq)
  - Mass activity: Bq/mg
  - Specific activity: Bq/ml

Physical half-life is defined as the time required for the number of radioactive atoms in a sample to decrease by exactly one half

- physical, biological, effective

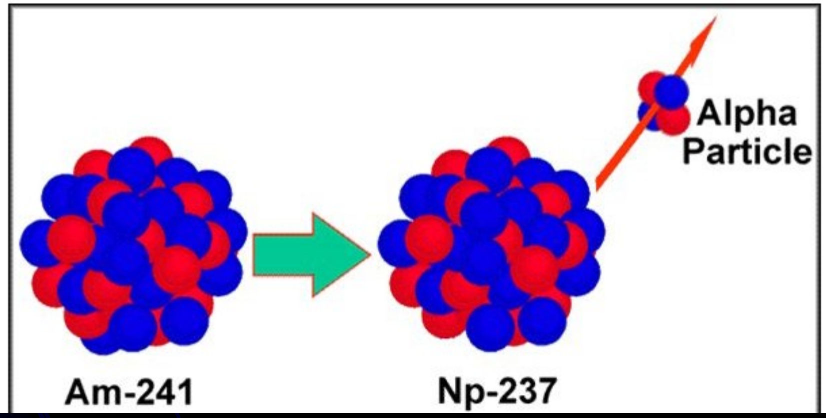
- $\mathbf{A(t) = A_o \,.\, e^{-\lambda .\, t} = A_o \,.\, 2{,}7183^{-(0{,}693/T_{1/2}) \,.\, t}}$
- E is Euler´s Number

Radionuclides and Radiations 1

Alfa emission

- emission of Alfa particles (He nuclei) is common in elements with the higher atomic number – 82.
- High radiation, but short radius (cca 0,03 mm)
- Only for therapy - ^{226}Ra

Alpha emission is when a radioactive nucleus emits a helium nucleus, and looses 2 protons and 2 neutrons.



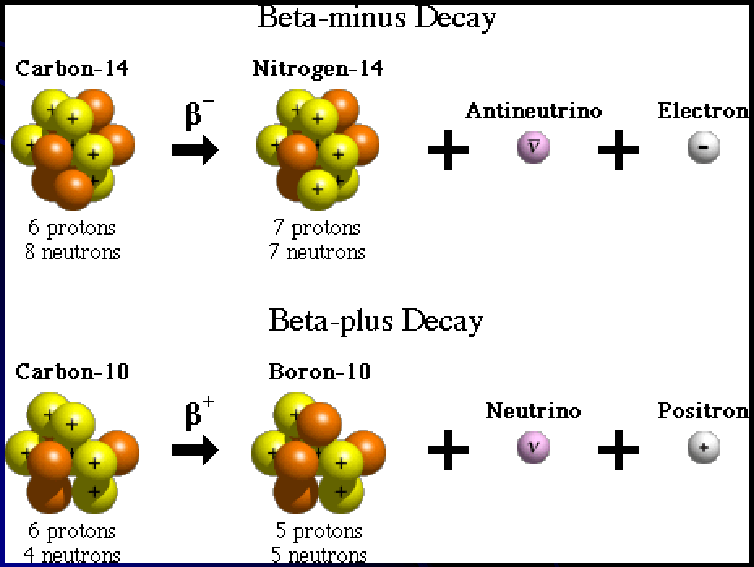
Radionuclides and Radiations 2

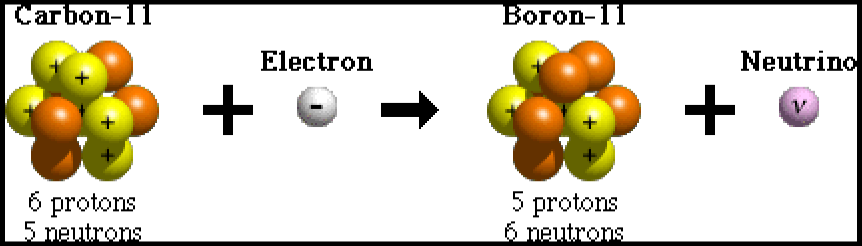
Beta emission:

Beta$^-$ - electron + antineutrino

Beta$^+$ - positron + neutrino

Electron Capture – neutrino + photon X



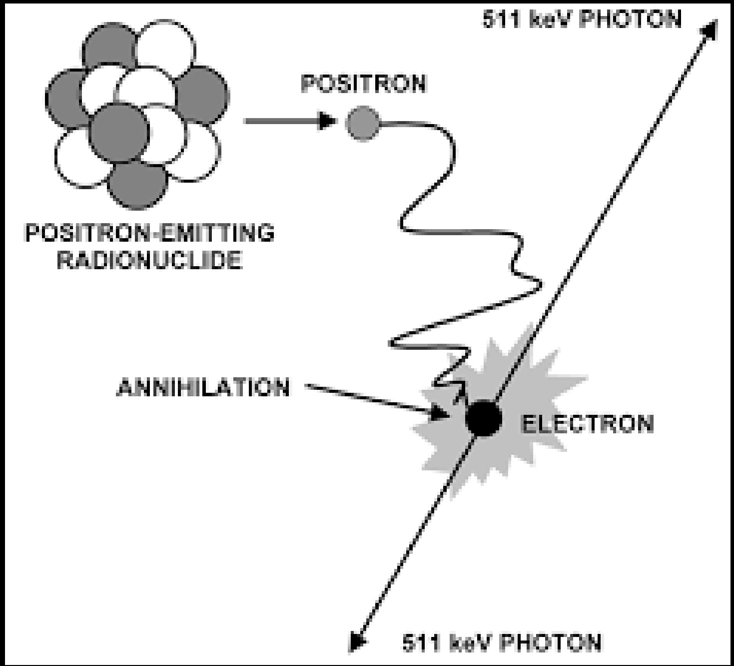


Beta emission – continuous spectrum – particles with different energy, low ionizing effect – higher radius

Beta$^-$ - ^{131}I – radius 2,4mm. ^{32}P, ^{99}Mo

Beta$^+$ - reaction positron with electron – positron annihilation 511 keV – PET - ^{11}C

Electron Capture – ^{67}Ga



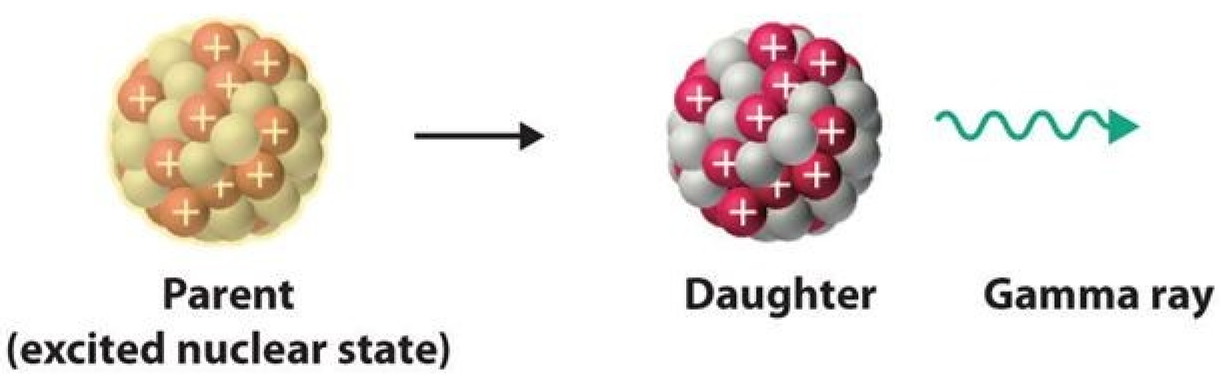
Gamma Emission

- gamma emission usually occurs in concert with other forms of decay that produce nuclei in 'nuclear excited states'

$$\,^{238}_{92}\mathrm{U} \rightarrow \underset{\substack{\text{excited}\\ \text{nuclear}\\ \text{state}}}{\,^{234}_{90}\mathrm{Th}^*} +^{4}_{2}\alpha \xrightarrow{\text{relaxation}} \,^{234}_{90}\mathrm{Th} +^{0}_{0}\gamma$$

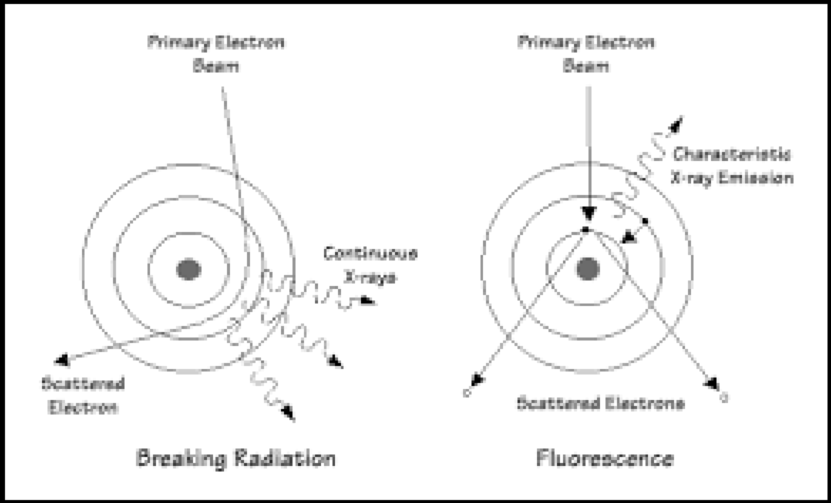
ignoring the alpha decay event, gamma emission looks like this:

$$\,^{234}_{88}\mathrm{Th}^* \rightarrow \,^{234}_{88}\mathrm{Th} +^{0}_{0}\gamma$$



X-RAYS (RTG) EMISSION

- braking radiation
  - Spring from braking free-flying electrons in heavy metals
  - continuous spectrum

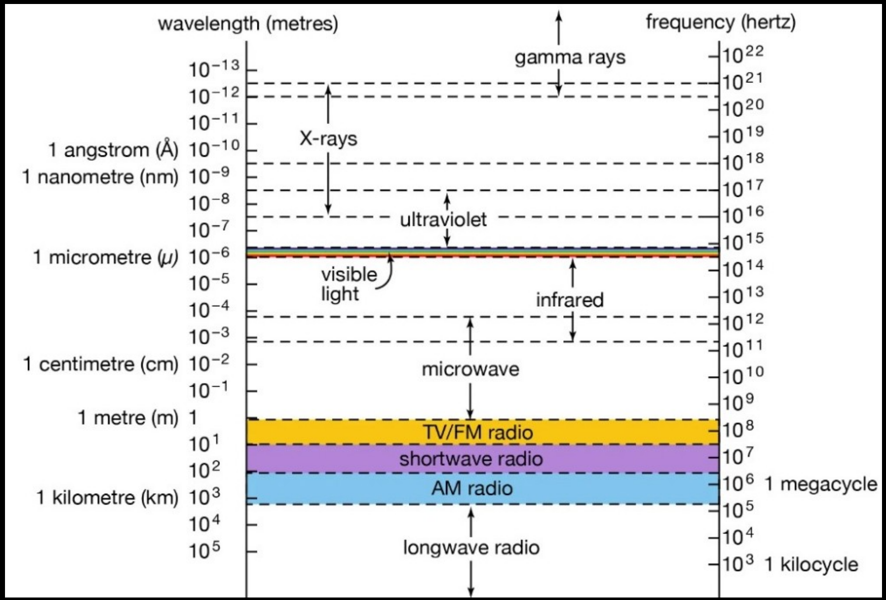


- characteristic X-Rays
  - Spring from cascading electrons between atom´s shells
  - line spectrum
  - ^{201}Tl, ^{125}I

X-ray x gamma emission

- Source
  - X-ray: atomic shell
  - Gamma emission: atomic nucleus

- Spectrum
  - X-ray: continuous
  - Gamma emission: line



Interactions with matter

Directly ionizing emission – kinetic energy of particles inductive ionization or/and excitation in matter

- Alfa particles – strong ionization
- Beta particles
  - $beta^-$ - braking radiation, dependence on atomic number
  - $beta^+$ - positron annihilation

Indirectly ionizing emission– uncharged particles induce emission other particles, which inductive ionization or/and excitation in matter

- Electromagnetic radiation
  - Gamma, X-rays emission
- Uncharged particles
  - neutrons

Photoelectric effect, Compton scattering, pair production, nucleus fotoeffect

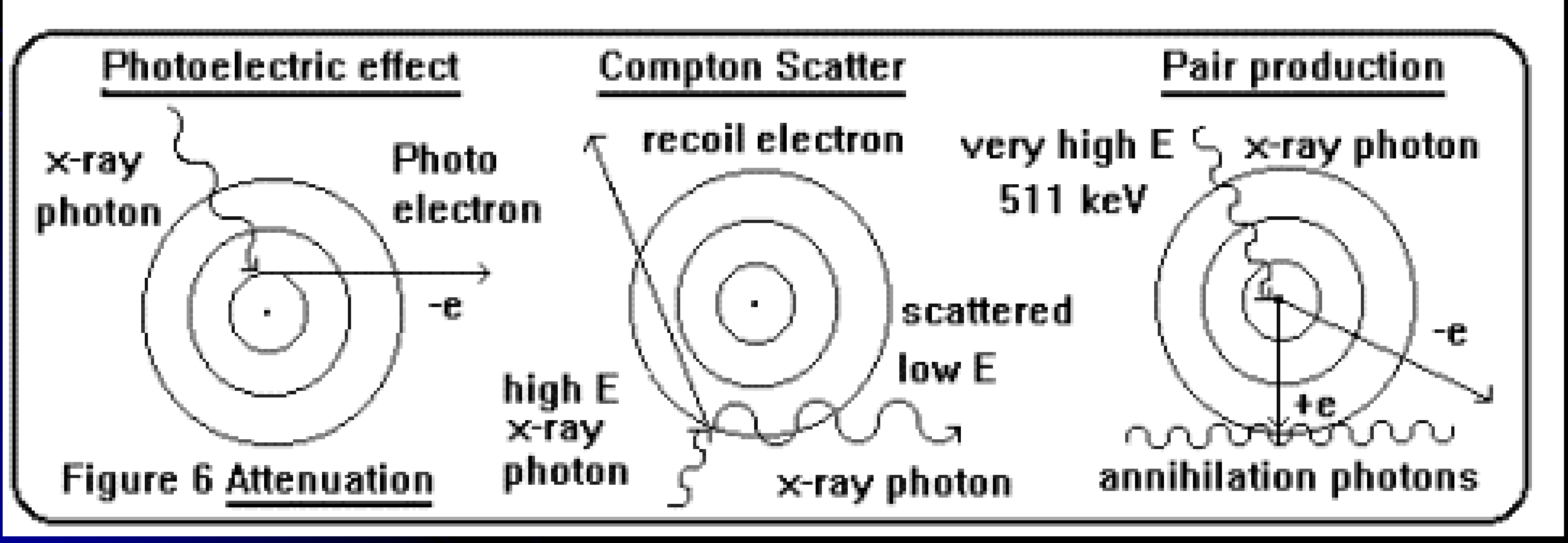


Figure 6 Attenuation

Radionuclides

Production methods

Characteristic	Production method: Cyclotron	Nuclear reactor (fission)	Nuclear reactor (neutron activation)	Radionuclide generator
Bombarding particle	Proton, deuteron, triton, alpha	Neutron	Neutron	Production by decay of parent
Product	Neutron poor	Neutron excess	Neutron excess	Neutron poor or excess
Typical decay pathway	Positron emission, electron capture	Beta-minus	Beta-minus	Several modes
Typically carrier free	Yes	Yes	No	Yes
High specific activity	Yes	Yes	No	Yes
Relative cost	High	Low	Low	Low (^{99m}Tc) High (^{81m}Kr)
Radionuclides for nuclear medicine applications	^{201}Tl, ^{123}I, ^{67}Ga, ^{111}In, ^{18}F, ^{15}O, ^{57}Co	^{99}Mo, ^{131}I, ^{133}Xe	^{32}P, ^{51}Cr, ^{125}I, ^{89}Sr, ^{153}Sm	^{99m}Tc, ^{81m}Kr, ^{68}Ga, ^{82}Rb

Radionuclides II

Characteristic:

- Physical half-life – ^{99m}Tc - 6,03 h
- Character of decay – ^{99m}Tc – isomeric transition
- Character of emission – ^{99m}Tc – gamma emission
- Energy of emission – ^{99m}Tc - 140 keV

Detection of radiation

Detector

- Radiation shield, collimator
- Detector
- Evaluation device

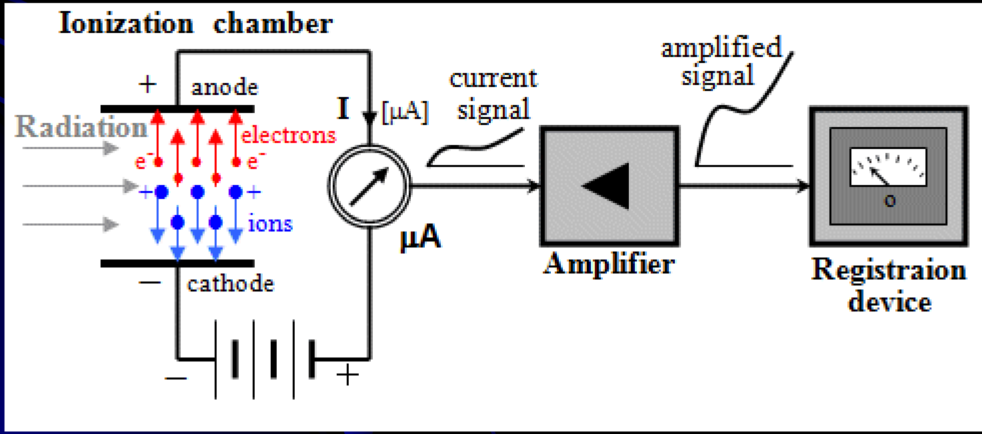
Type of detectors:

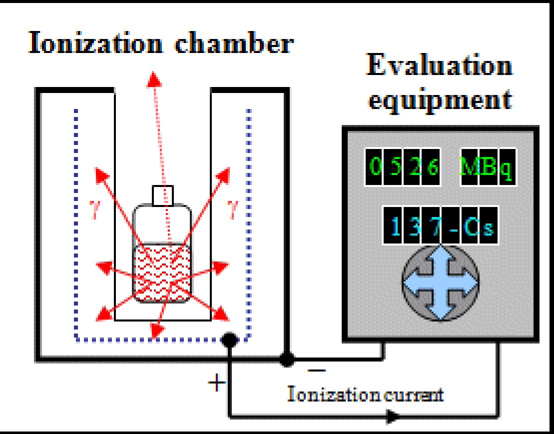
- Gas-filled – ionization chambers, Geiger Müller counters, proporcional counters
- Scintillation – organic (in vitro), anorganic
- Solid-state – research

Ionization chambers

Gas-filled chamber with positive and negative electrodes. Radiation evokes in gass ionization and excitation, ions are high voltage oriented on electrode. Linear dependence between radiance and current.

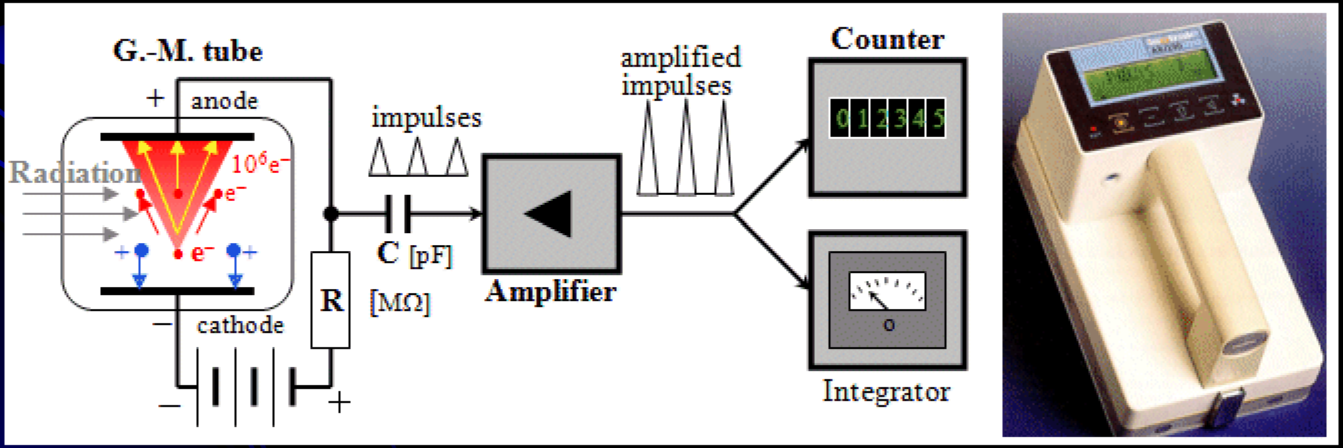
Has low detection sensitivity





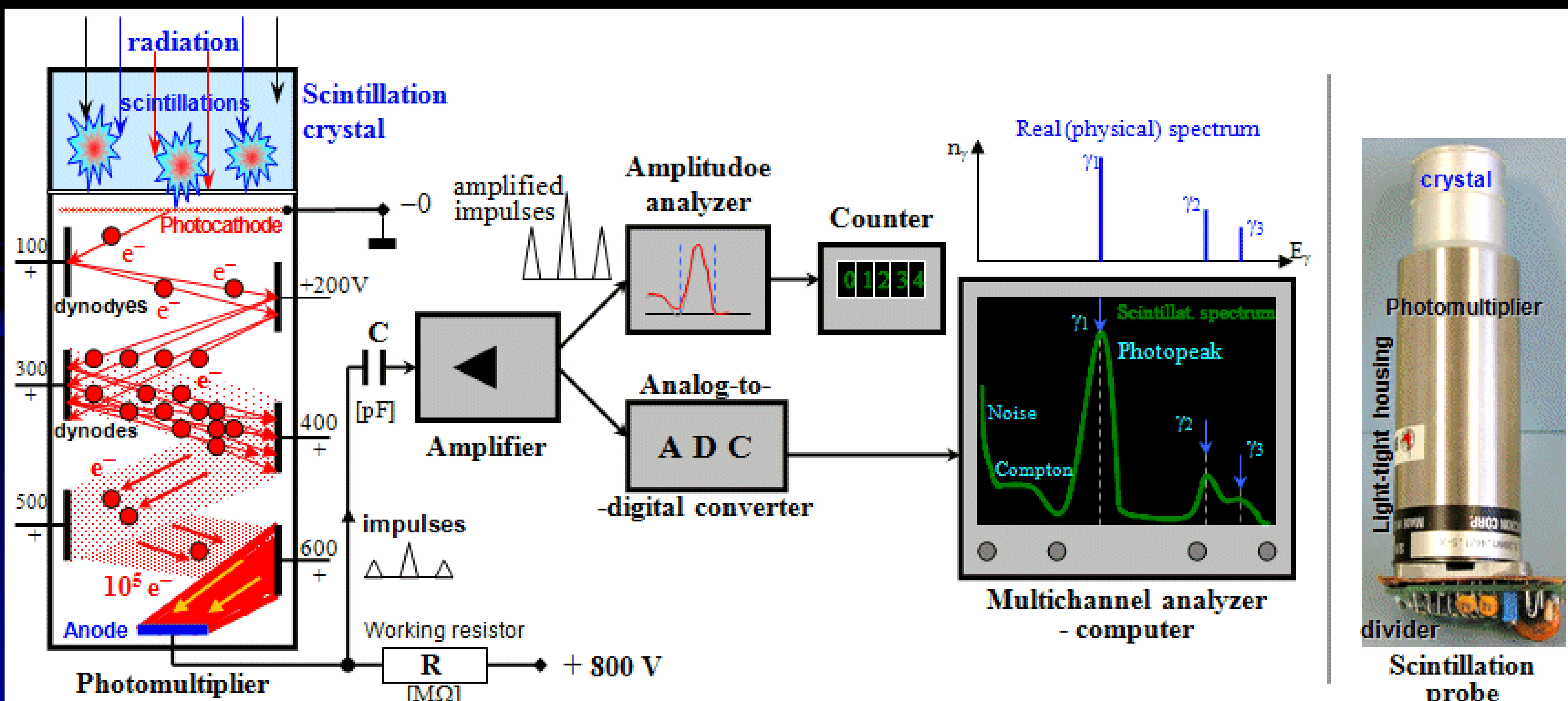
Geiger – Müller Counters

- Gas detector with high voltage, that the speeds electrons, avalanche ionisation rise – strong discharge.
  - Interrupt discharge – voltage drop and quenching gas
- For monitoring workplace



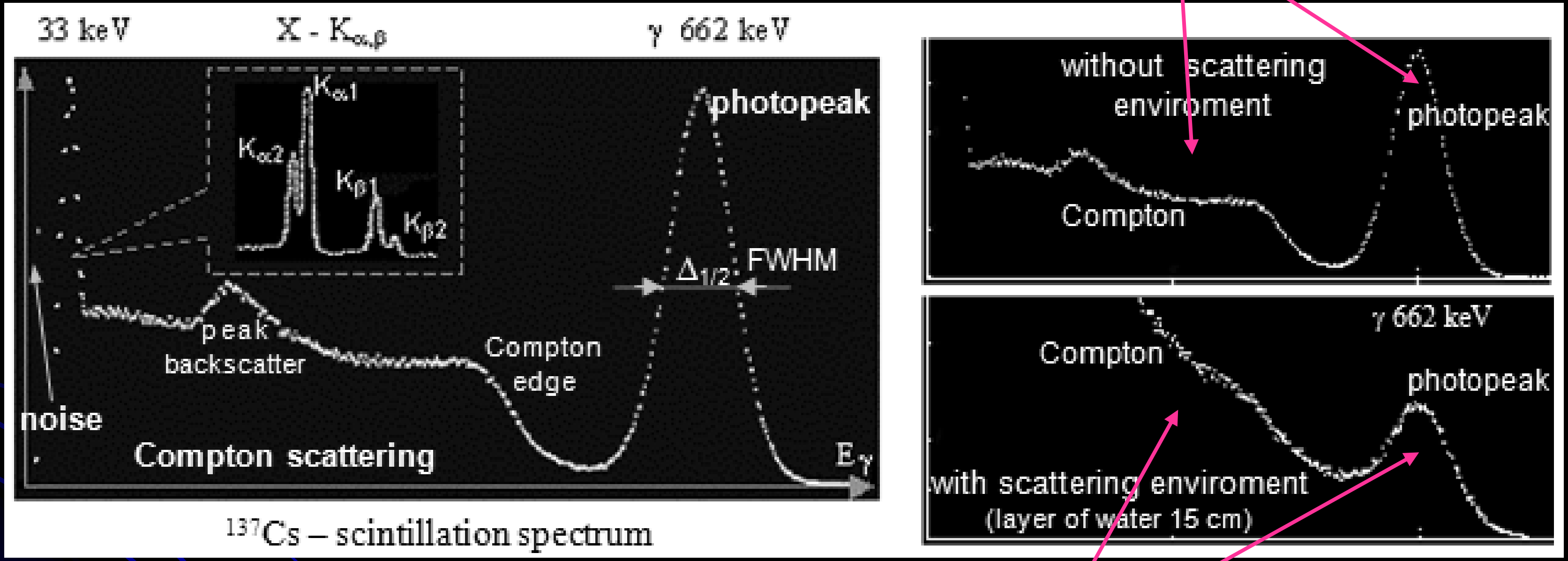
Scintillation Detectors

- Radiation evokes in material scintillation – flashing lights
- Thalium Activated Sodium Iodide and LSO



Scintillation spectrum

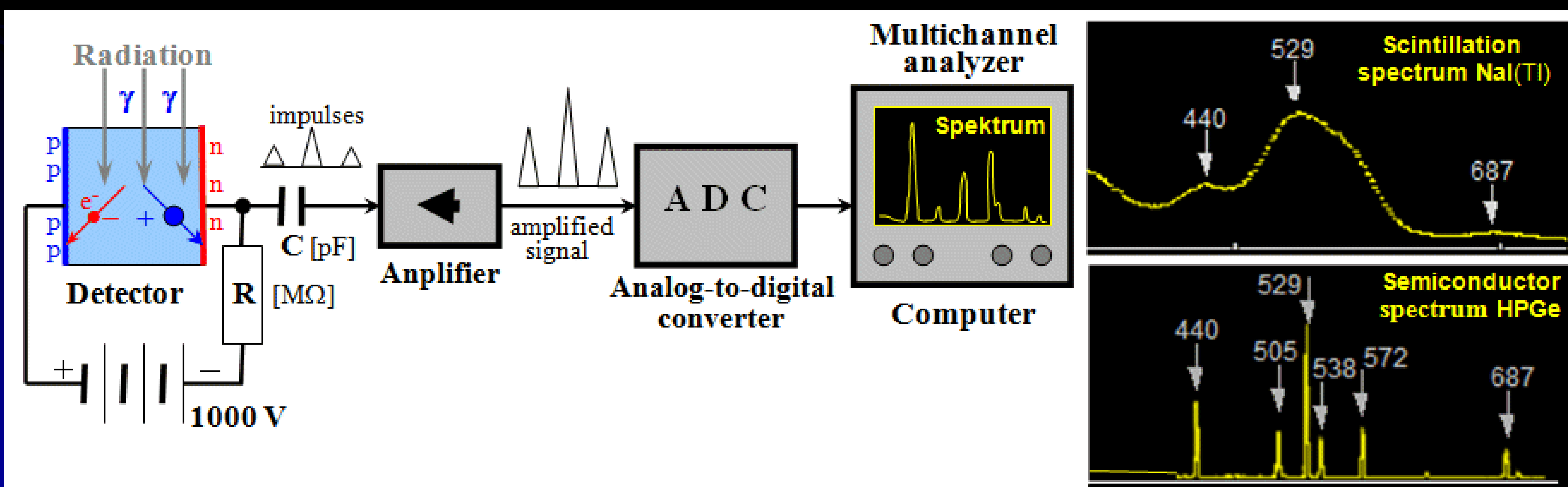
Without scattering environment



With scattering environment

Solid-state detectors

- For Nuclear Medicine - In Research
- Very good energy resolution, but long „dead time“ and low sensitivity
- Germanium as solid-state detector



Interference qualities detection

- Detection sensitivity
- Time resolution – „dead“ time
- Spatial resolution
- Energy resolution
- Volume dependence – in vitro
- Geometry metering – in vitro
- Metering errors (systematic, random)
- Radioactivity in background
- Better from picture-
  - „ hot" lesion than „ cold„
  - surface placing lesion than at a depth

Principle dosimeters

- Filming dosemeter

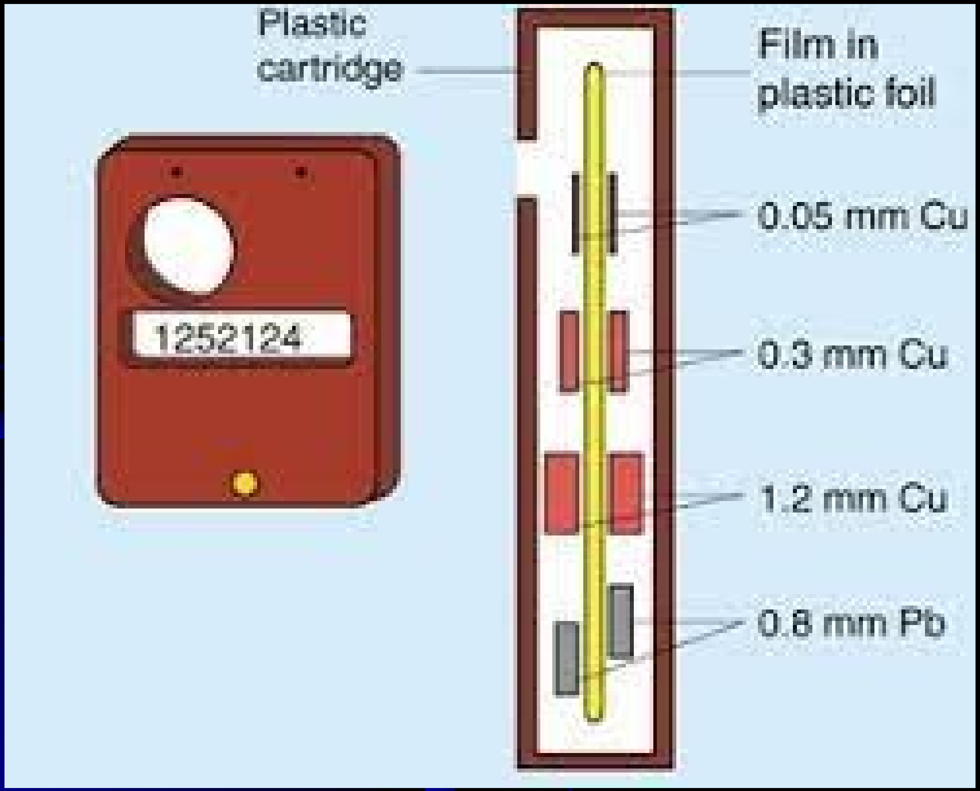
  Photographic detection ionizing radiation – blackening film density is proportional to density ionizing – quantity of absorbed energy

- Thermoluminescence dosemeter

  Radiation in material will excite electrons to the higher energy level; after warm up will electrons return back and gained energy release in flashlight

Dosimeters II

Filming Dosimeter



Shielding material:

- Plastic
- Metals: Copper, Lead
- Free space

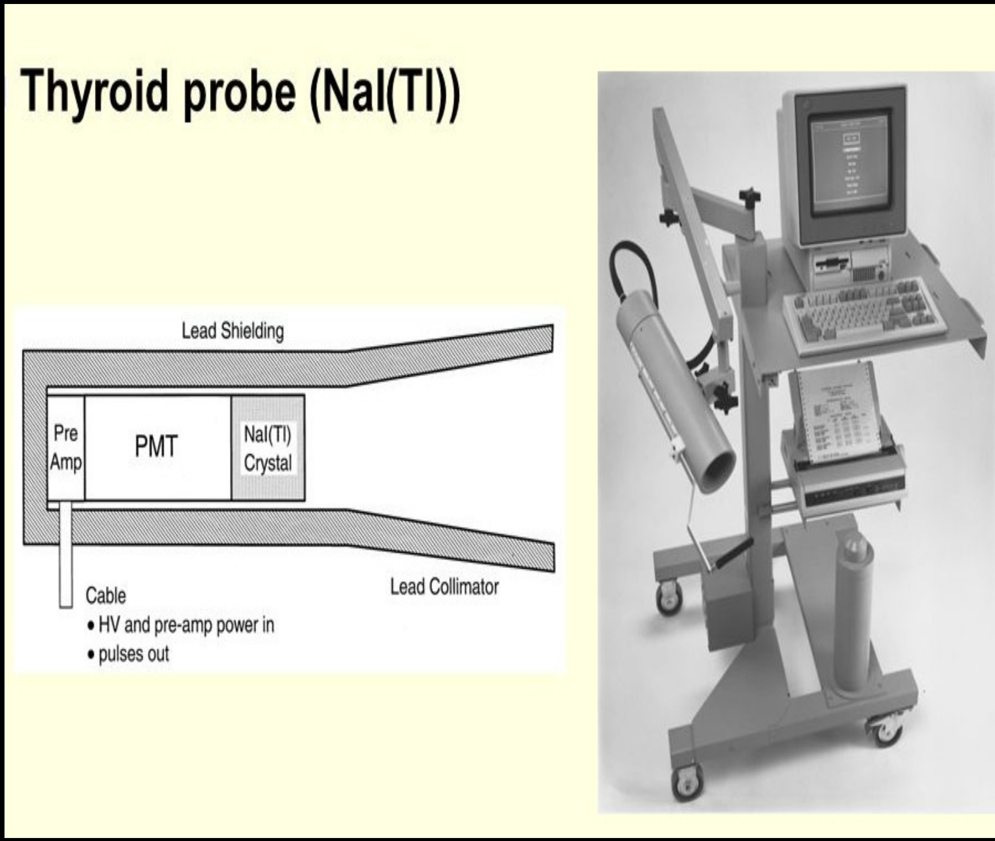
Instrumentation

Instrumentation for in vivo detection

- Scintillation probe
- Gammagraf
- Gamma Scintillation Camera, PET Camera
- Hybrid systems – SPECT-CT, PET-CT

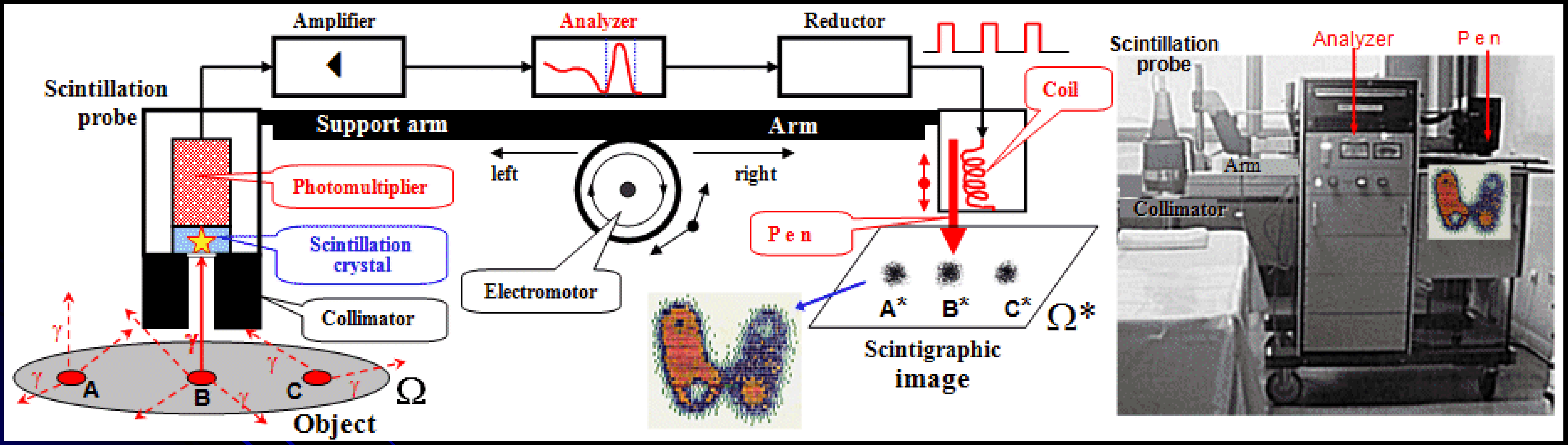
Scintillation probe

- without visual information
- Time histograms activities above examinate region
- To examination kidney – renography; metering activities above thyroid gland – ^{131}I



Gammagraph

- Historical system

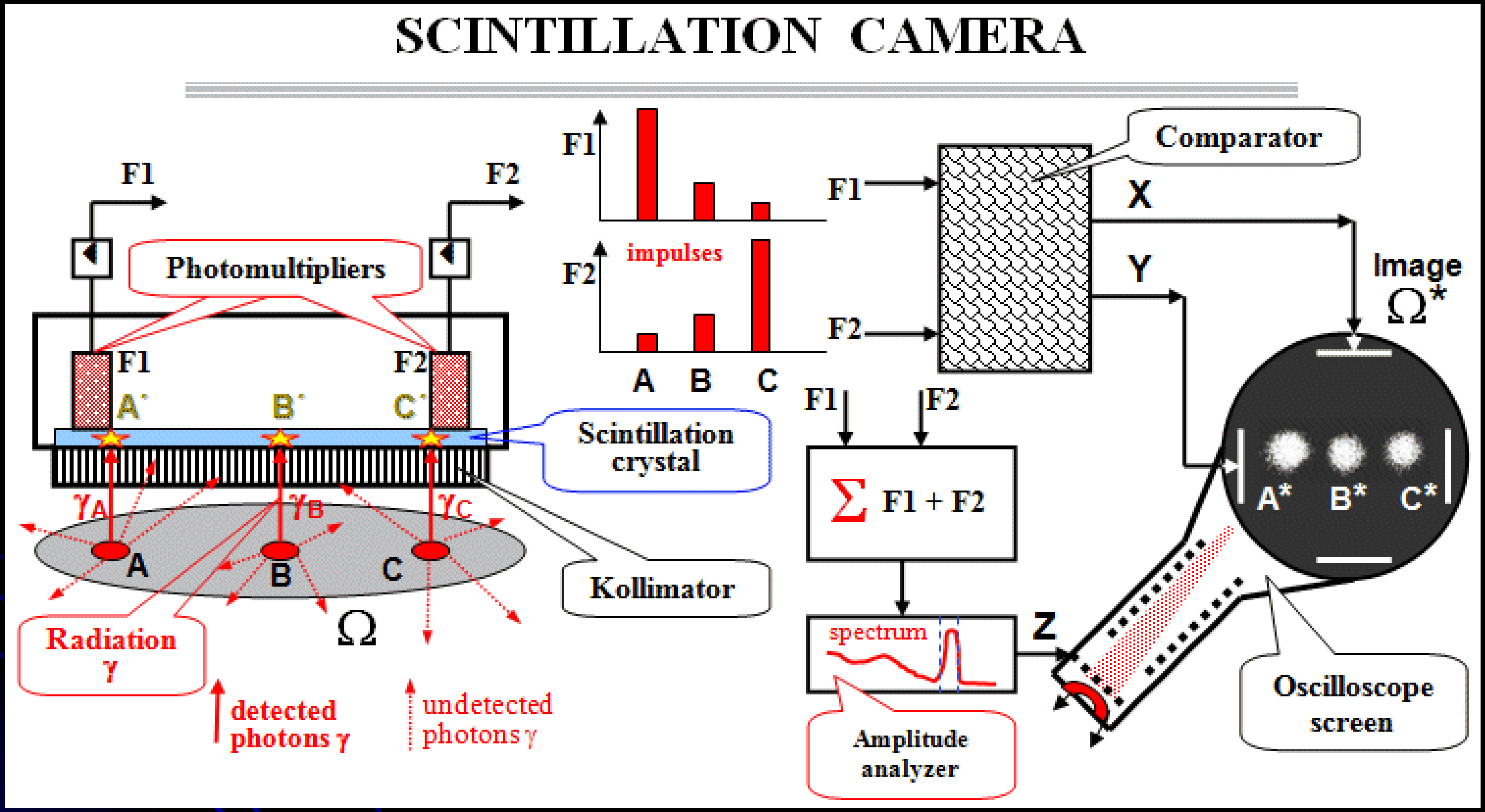


Source- detection- supporting strut- register

Scintillation camera

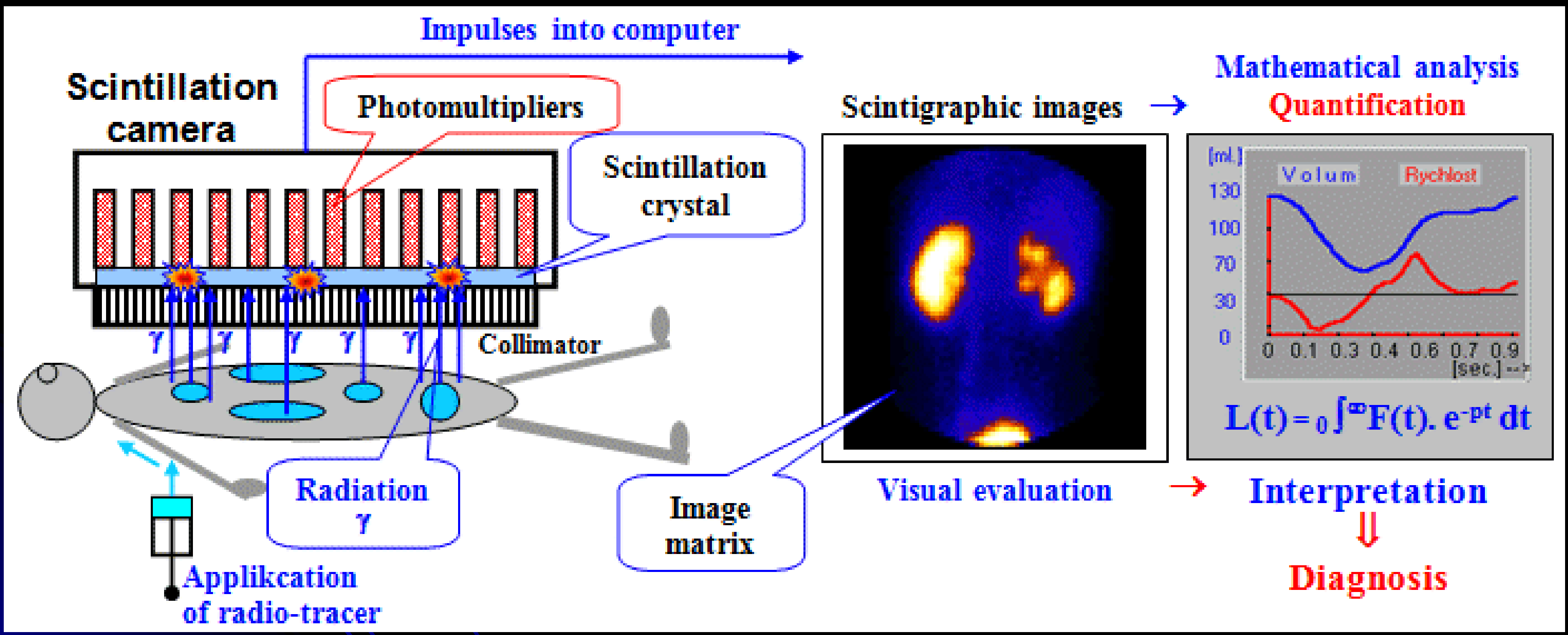
- Anger´s camera – for the first time used 1958, same principle to this day
- Makes it possible to display distribution of radiopharnaceutical in body
- Detector, scoring and imaging and recorder system
- Some or more detectors
- Analog or digital

Scintillation camera II.



Source- detection- comparator+kicksorter-image

Scintillation camera III.



Siemens E.CAM

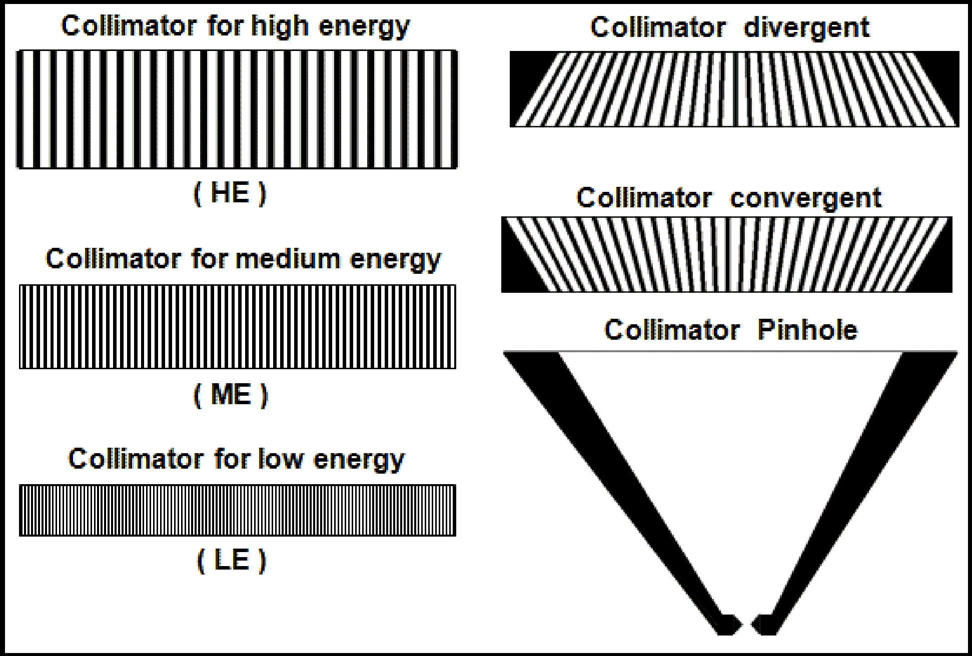
Scintillation camera IV.

Detector:

- Collimator, scintillation crystal, photomultiplier

Collimator:

- Define the geometric field of the crystal and specifically define desired direction of photons to reach crystal



- Effect on sensitivity and spacial resolution

Scintillation camera V.

Scoring, imaging and recorder system

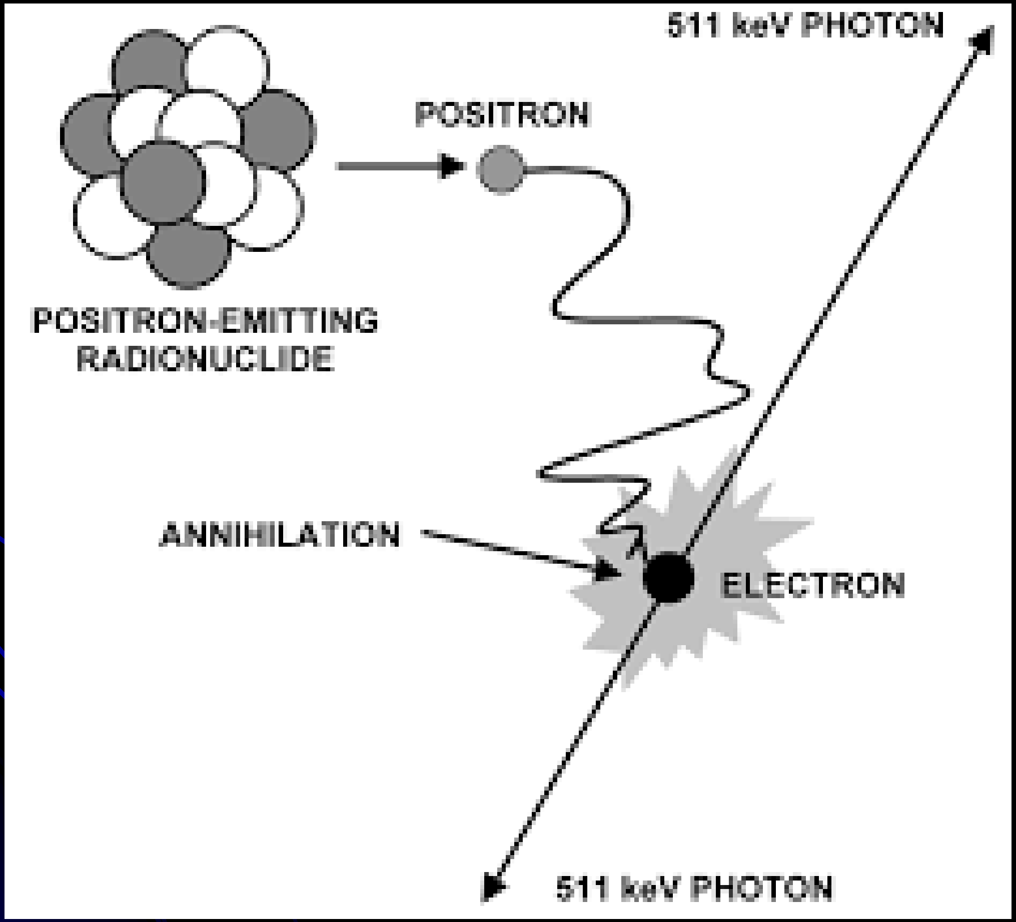
- photopeak window
- Photon position analysis, attenuation correction
- use filters improving image quality /simple filters, filtered backprojection, iterative reconstruction/
- List mode x frame mode
- Gated mode
- Region of interest - ROI

Positron emission tomography – PET camera

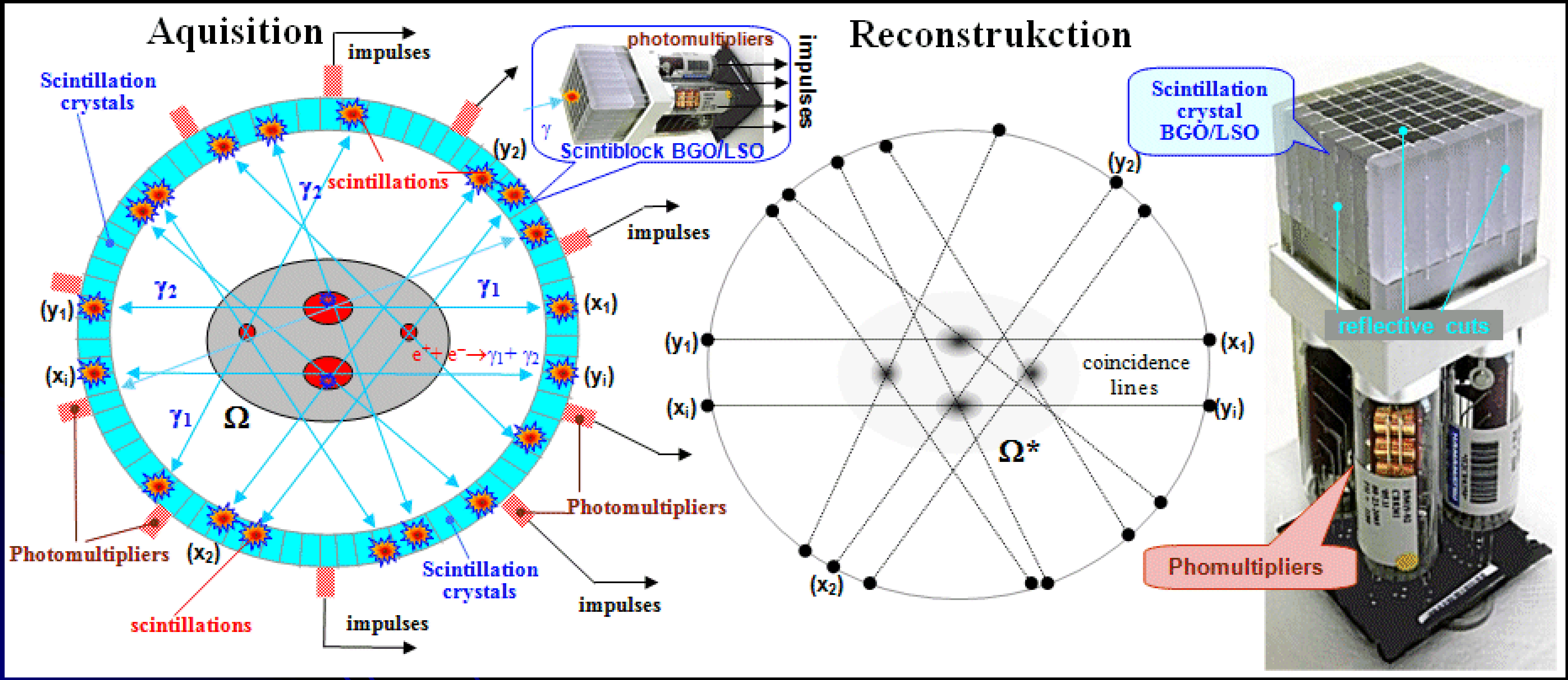
- Pair of annihilation photons is detected
- 20 000 detectors in ring, 30 rings
- Detector materials: BGO (bismuth germanate) or LSO (luteciumortosilicate)
- Electronic collimation – opposite coincidence window
- Radionuclids for PET
  - short half-life – necessity of cyclotron.
  - ^{18}F – half-life cca 2 hours, ^{18}F-FDG
- Interference: Compton scattering, false coincidence
- better sensitivity and spacial resolution than SPECT

PET camera II

- Positron annihilation



PET camera III.

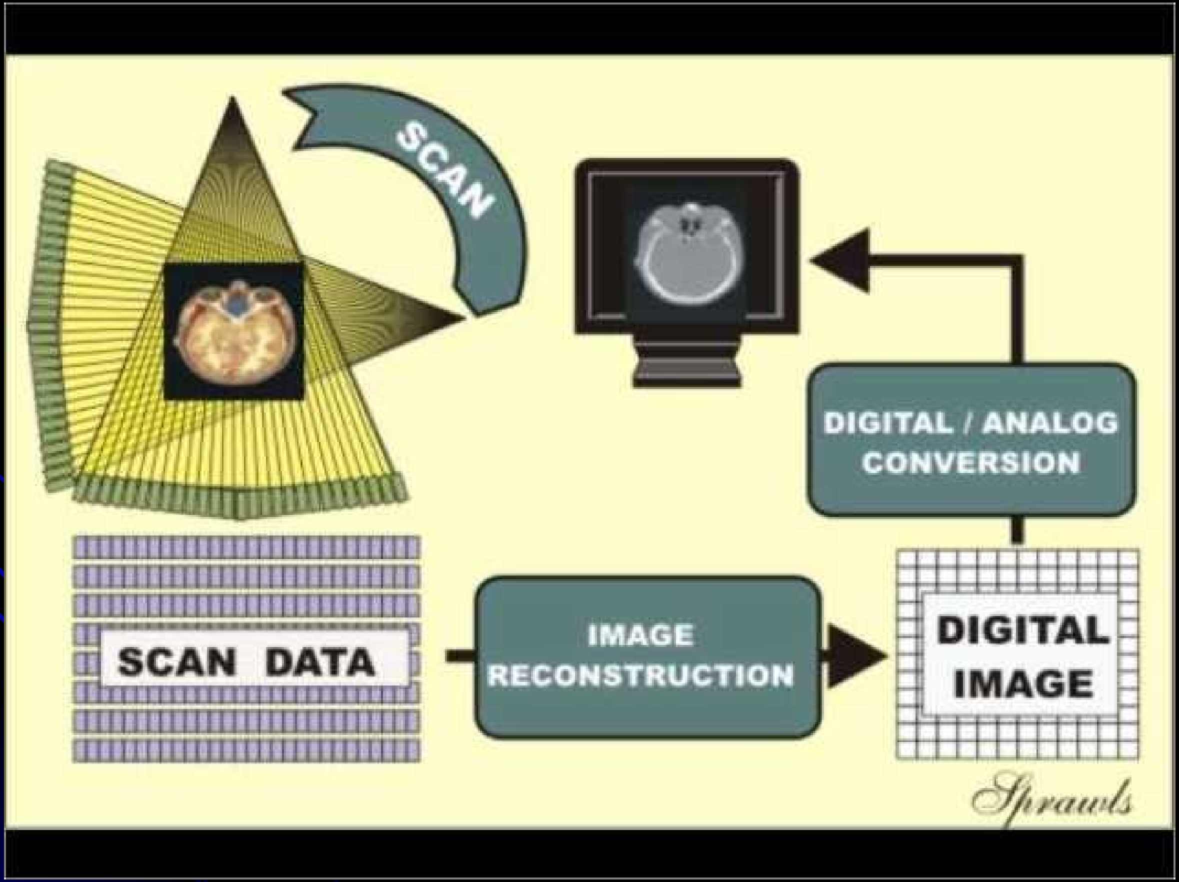


Hybrid systems

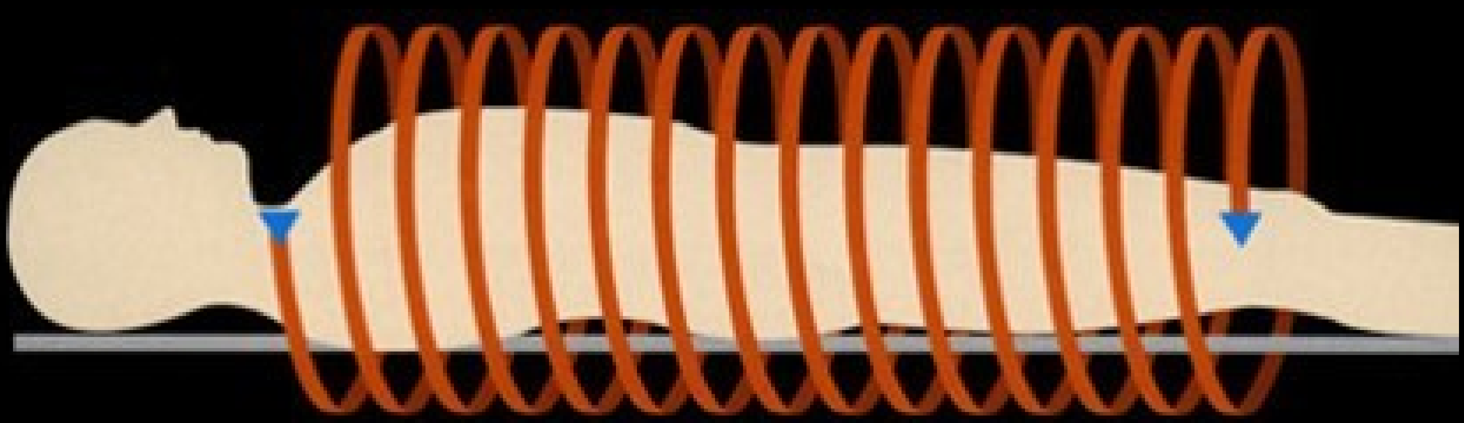
- Camera system consist of two independent systems – scintigraphy camera and CT camera
- Most often SPECT-CT and PET-CT
- Fusion images from both systems – information on function organ gained scintigraphy methods are inosculation with anatomical images from CT

Principle of CT (Computed tomography)

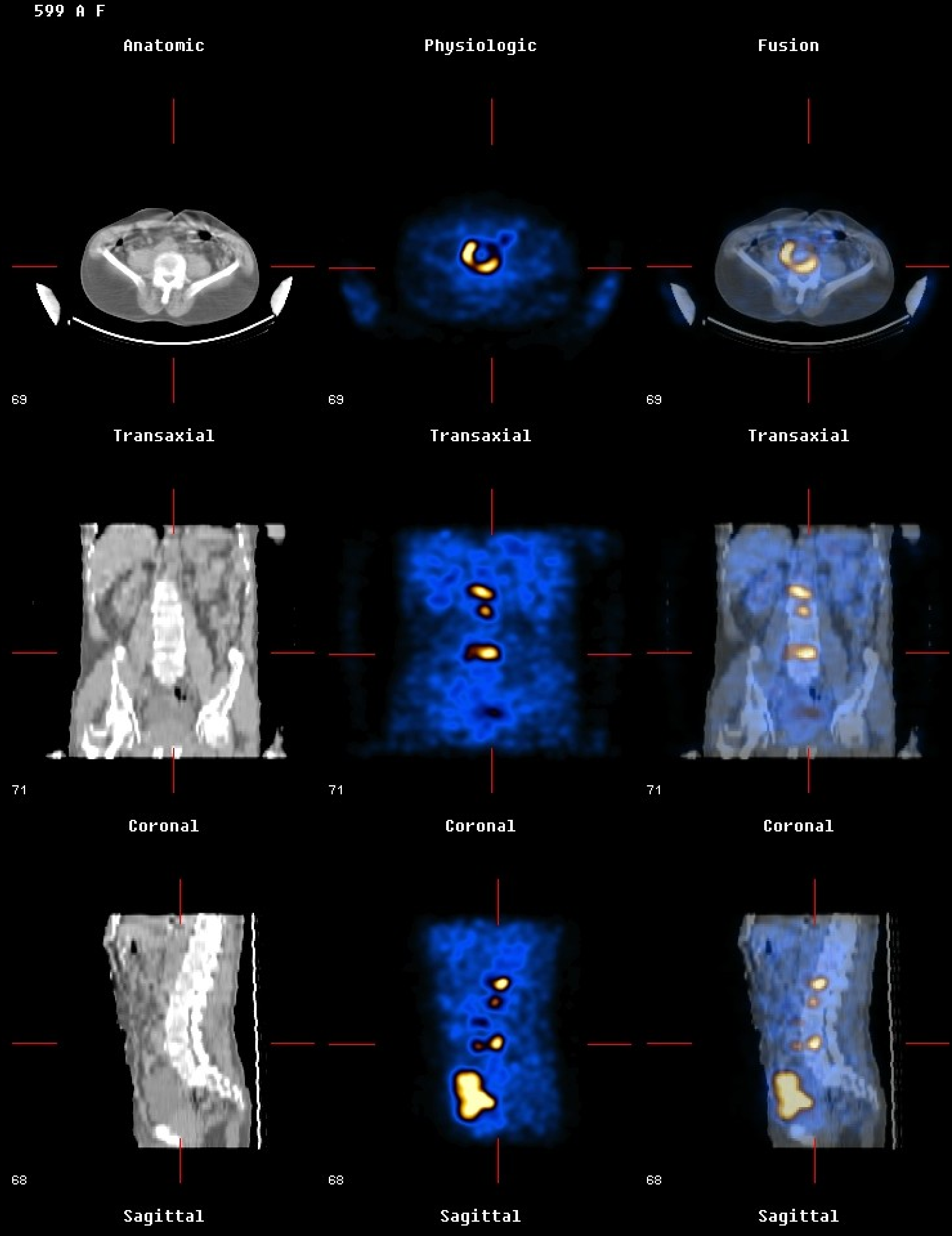
- X-Rays

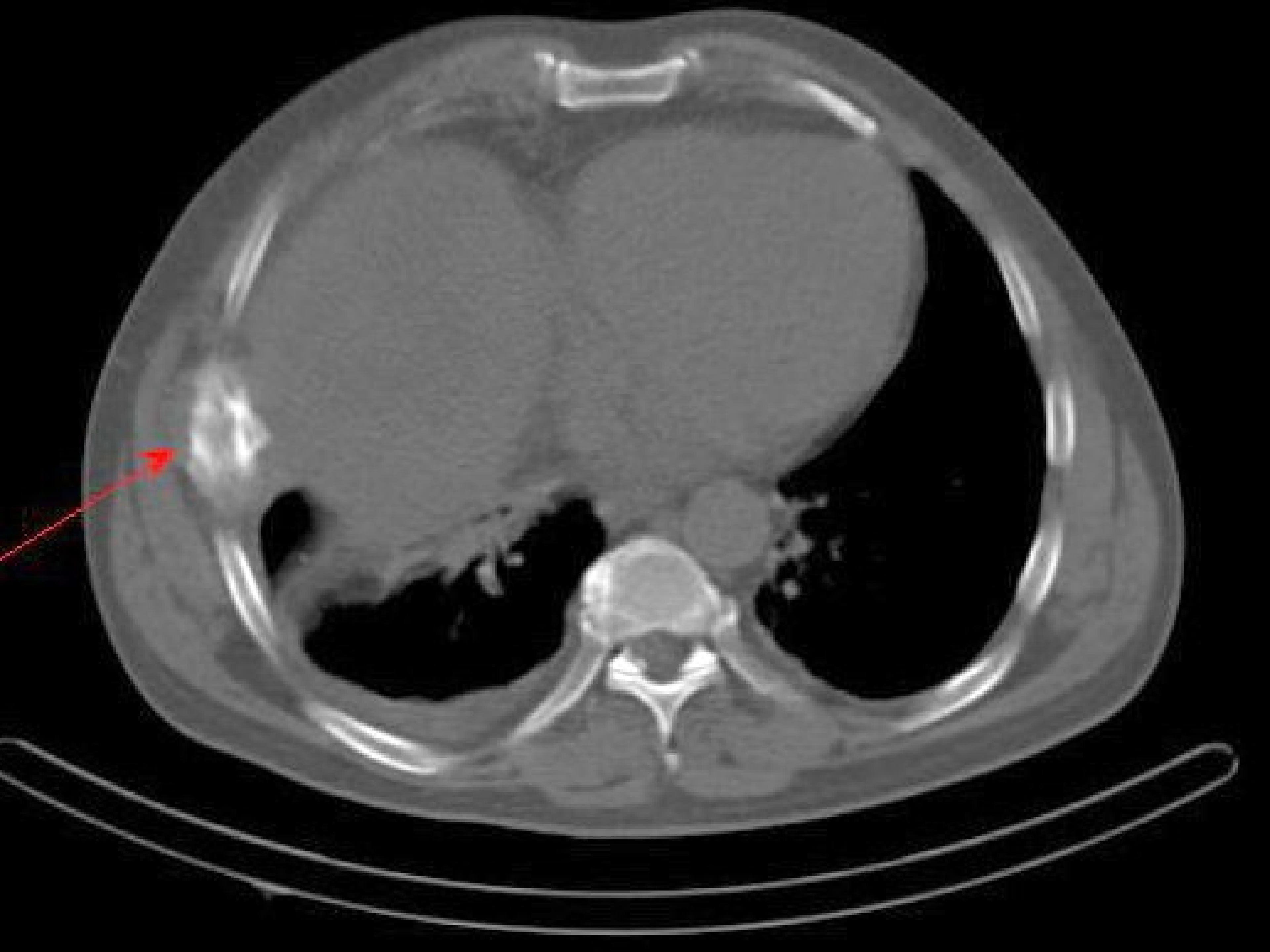


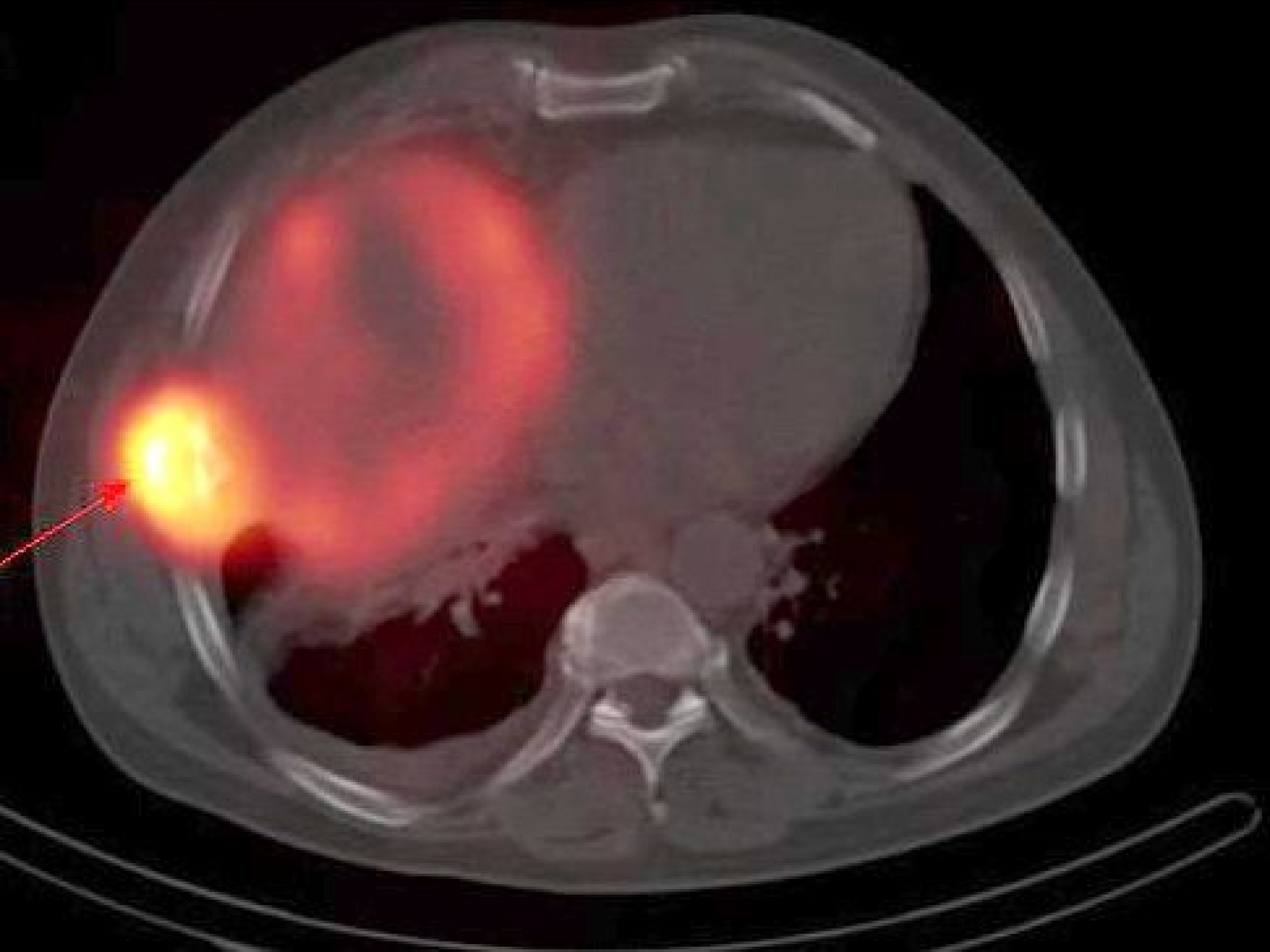
Helical CT
- x-ray tube rotation and patient table shift



Fusion of pictures







SPECT/CT Symbia

Exploring techniques

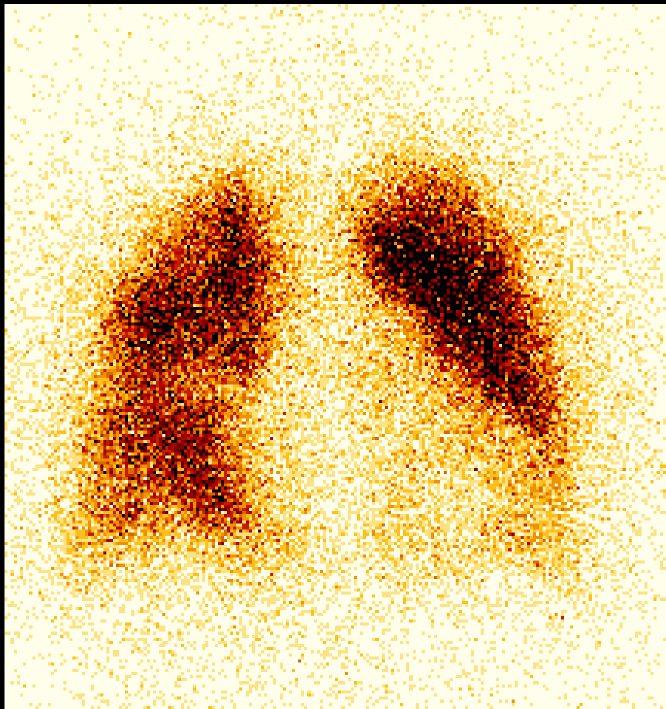
- Static scintigraphy
- Dynamic scintigraphy

- Planar imaging
- Tomography imaging

- Qualitative classification
- Quantitative classification

Static scintigraphy

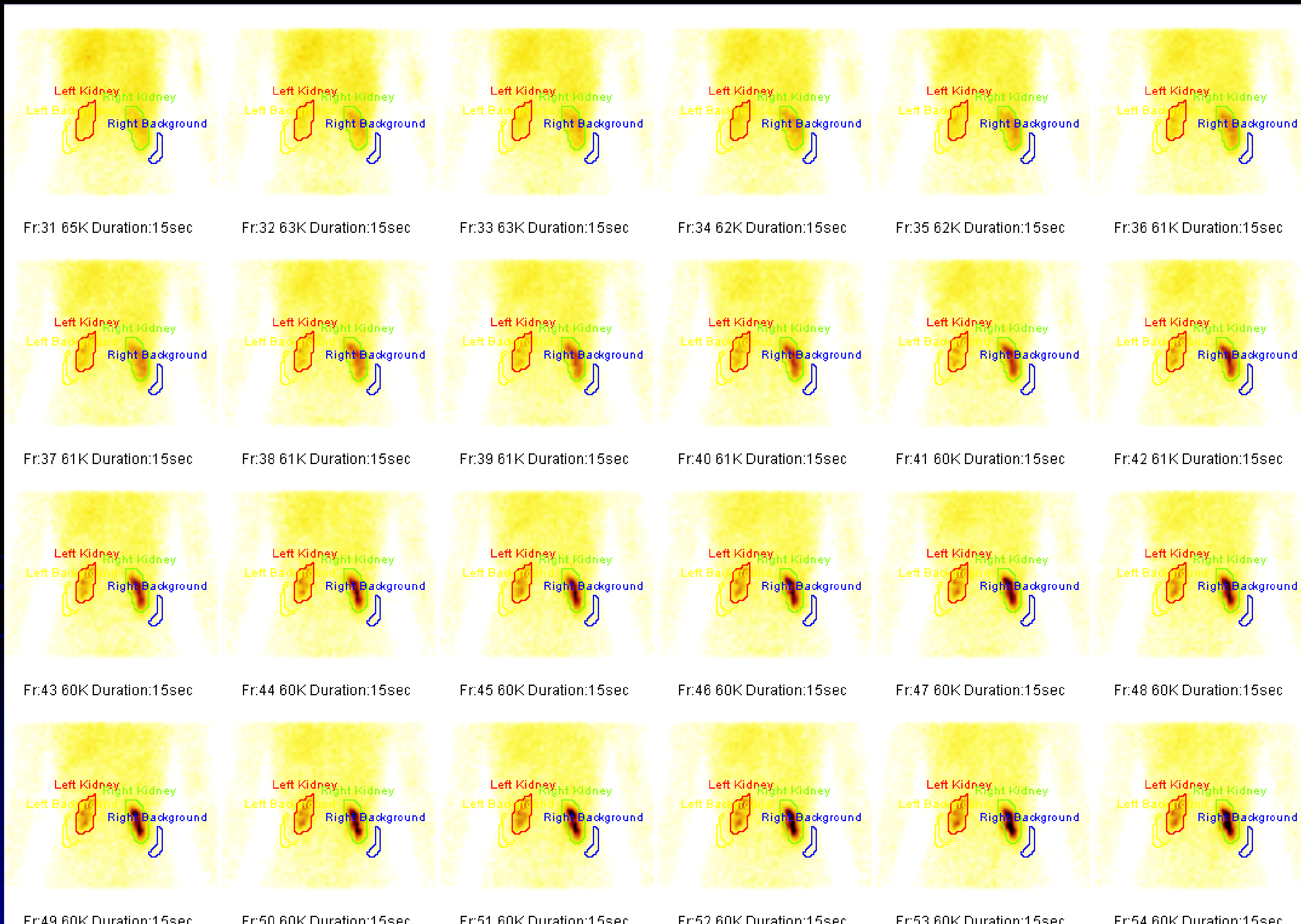
- Scan one picture
- Information on distribution radiopharmaceutical in body
- Partial information about function examinate organ
- Skeletal system, thyroid imaging



Static scintigraphy -lungs

Dynamic scintigraphy

- Scan pictures in predetermined time period
- Following radiopharmaceutical kinetics
- It is possible obtain waveform activities radiopharmaceutical in given areas in time – next evaluation and calculation functional parameters
- Possibility synchronizing studies
- Dynamic scintigraphy kidney, liver


Left Kidney
Right Kidney
Right Background
Fr:31 65K Duration:15sec
Fr:32 63K Duration:15sec
Fr:33 63K Duration:15sec
Fr:34 62K Duration:15sec
Fr:35 62K Duration:15sec
Fr:36 61K Duration:15sec
Fr:37 61K Duration:15sec
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Fr:51 60K Duration:15sec
Fr:52 60K Duration:15sec
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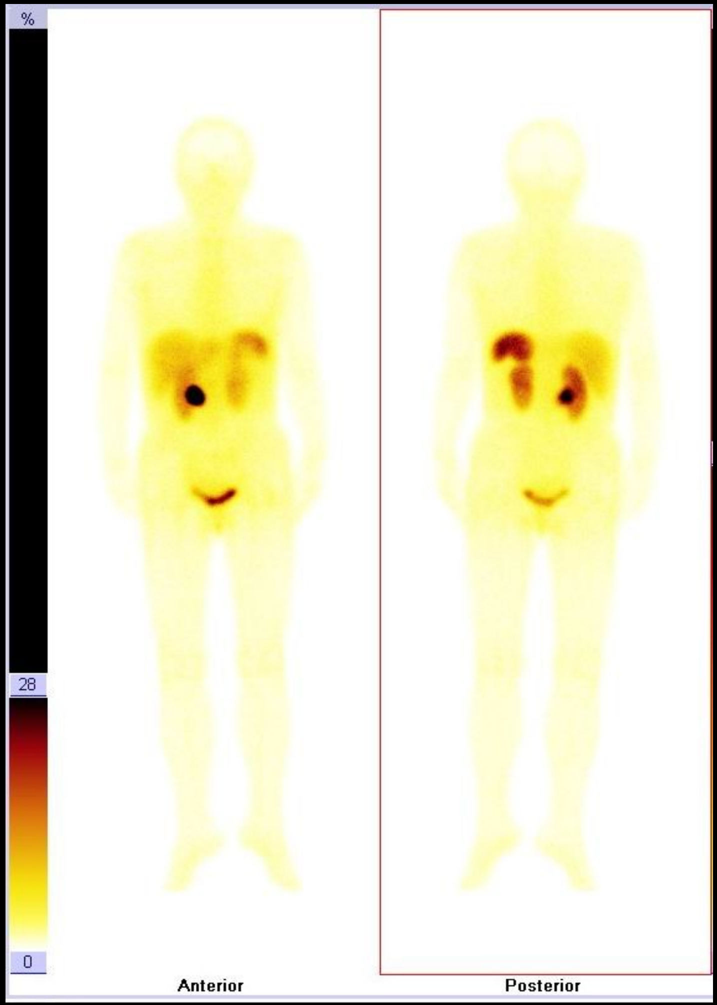
Fr:54 60K Duration:15sec

Planar scintigraphy

- Two - dimensional display
- Detectors are in one position
- general picture is real – it is possible trace him e.g . on oscilloscope
- Summing integrator principle – all tissue layers sum to one picture – overlapping layer
- Summing background too – decrease contrast



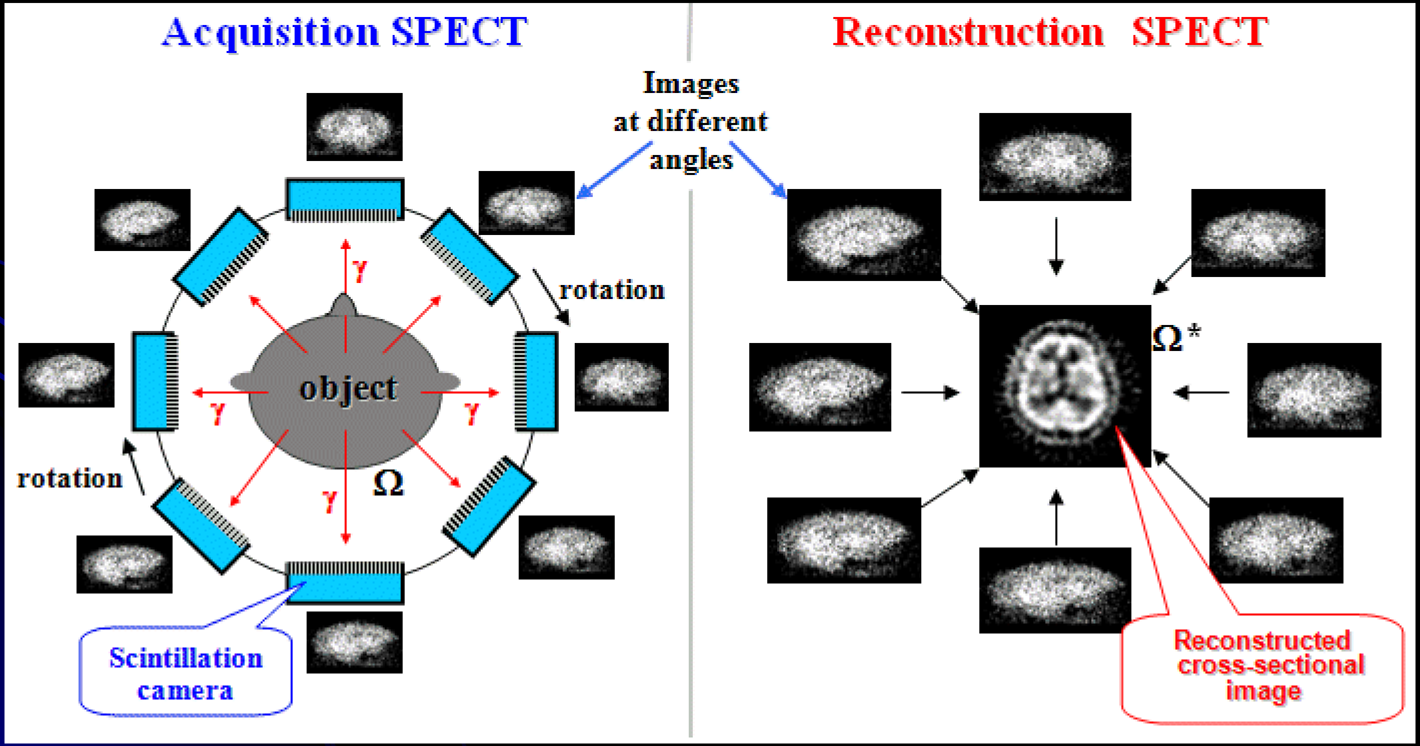
Tomography scintigraphy

- SPECT and PET
- Scan by one or more detectors from many positions (full circle-360°)
- Resulting picture is reconstructed – calculated from impulses of all positions
- Makes it possible to display only one layer tissues, without disturbing influence surrounding layers – increasing contrast 3-5x
- Three-dimensional vision – extract information on depth

Tomography scintigraphy II

Reconstruction techniques

- Backprojection
- Iterative reconstrustion



Benefits and disadvantages SPECT

Benefits:

- Increasing contrast 3-5x
- Information on third proportion – depth of lesion
- Don´t sum one layer with others layers

Disavantages

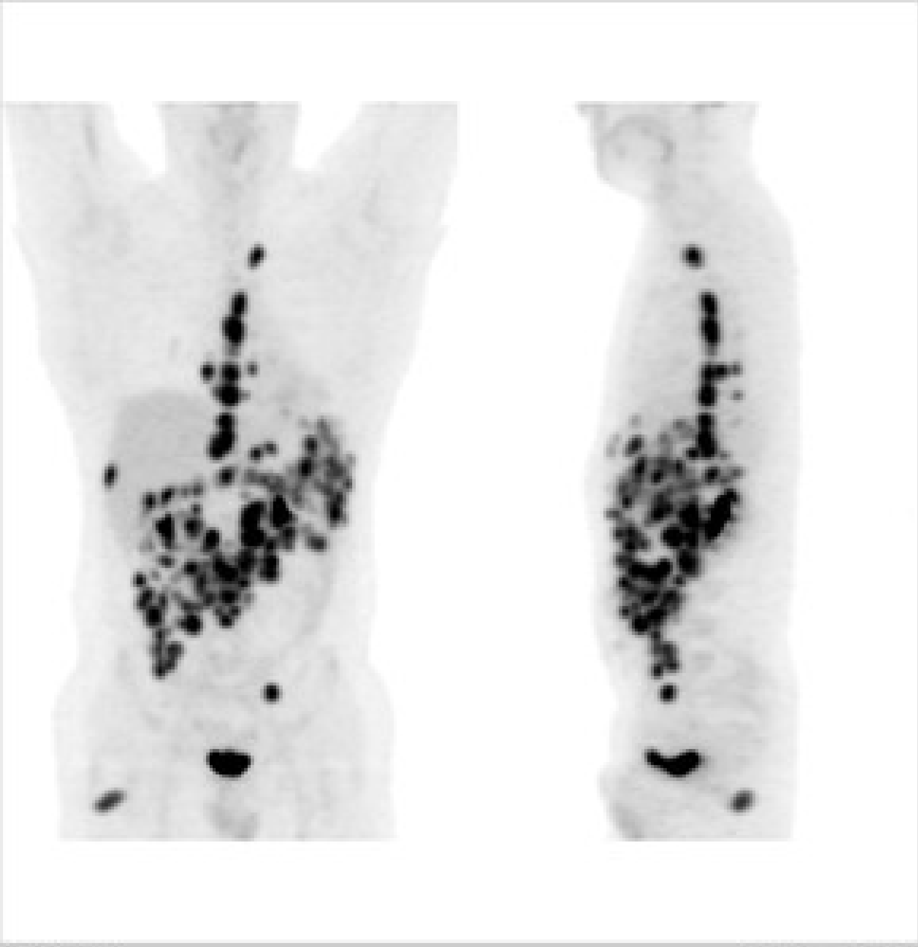
- Field uniformity – generate noise-rings
- Attenuation – reduction radiation from deeper layers
- Increased noise – is freshening at reconstruction, as far as 10x
- Worse spatial resolution – detector mostly cannot be as near to bodies, as with planar scan, resolution SPECT cca 15 mm, planar scan cca 10 mm
- Necessary longer time scan

PET

- As well three-dimensional vision as with SPECT
- 30x higher sensitivity than SPECT
- Better spacial resolution than SPECT 5-6 mm
- Possibility exact quantification of radiofarmaceutical
- Quantitative assesement flow and capacity blood in tissue, metabolism oxygen, glucose

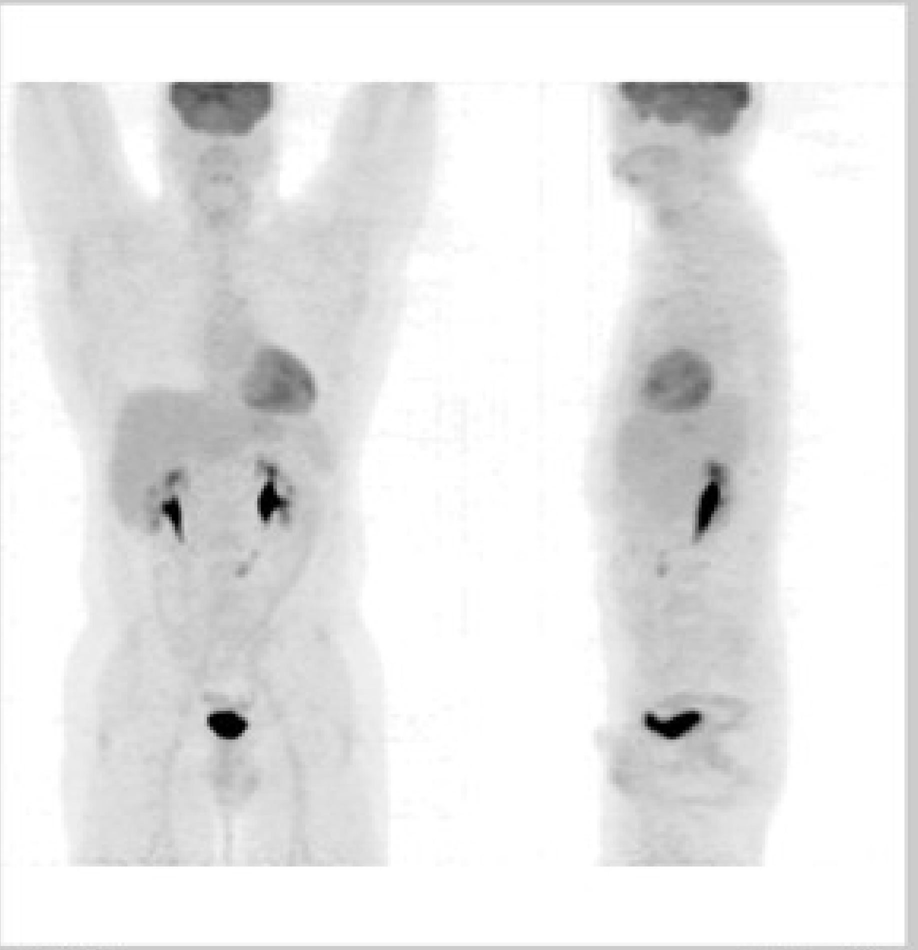
PET camera

Response to therapy– demonstrated by PET



ECAT EXACT

10 Nov 2000



ECAT ACCEL

After Chemotherapy
and Stem Cell Transplant

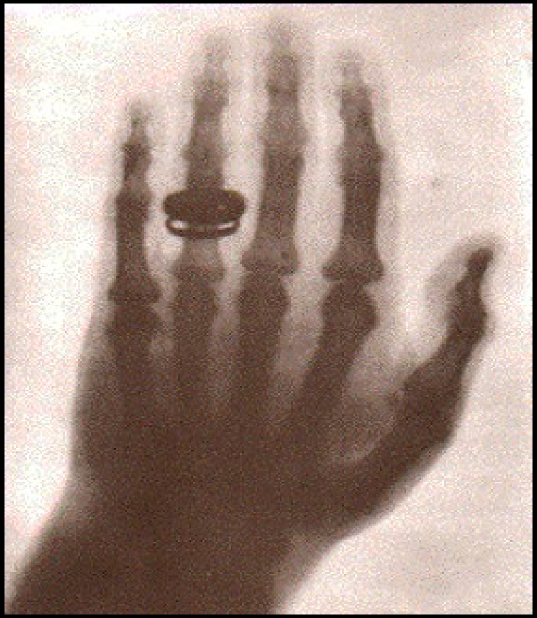
1 Aug 2001

Lymphoma patient with metastases

P8716

Northern California PET Imaging Center

Thank you for your attention ☺



Good luck at exam!