

Regional (AFRA) Training Course on Maintenance and Repair of Mediso Spirit Gamma Cameras - 11-15 August 2008 Seibersdorf – Austria

1. Short overview about ionizing radiation and its interaction with matter
2. Revision about the main radiation detectors
3. Scintillation based detectors
4. Diagnostic images
5. Gamma Cameras
6. Quality Control
7. Radiation protection

Ionizing radiation

Ionizing radiations are those which interact with matter through processes which generates ionization

Ionizing radiation types

Indirectly ionizing:

Particles:

Neutrons

Electromagnetic:

Gamma, X rays

Directly ionizing:

**Charged particles: Alpha, Beta (+ or -),
Protons**

How these radiations interact with matter?

Charged particles:

Ionization

Excitation

Electromagnetic:

Rayleigh Effect

Photoelectric Effect

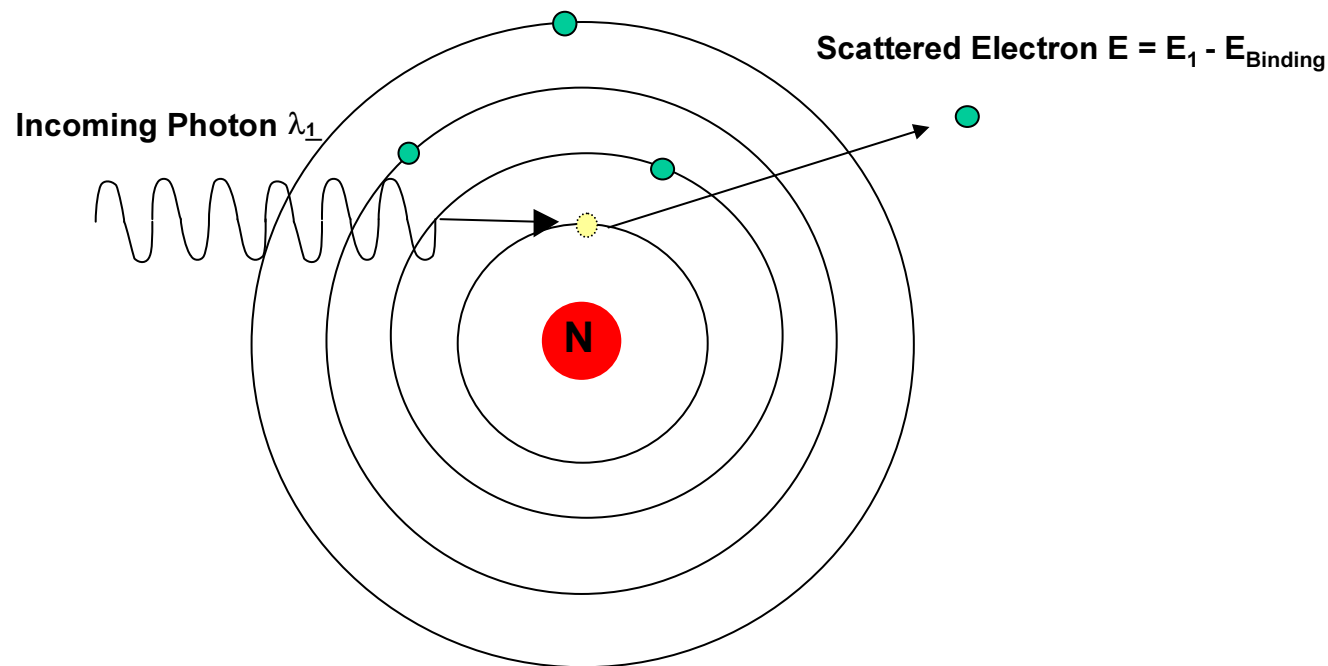
Compton Effect

Pair production

Photonuclear Effect

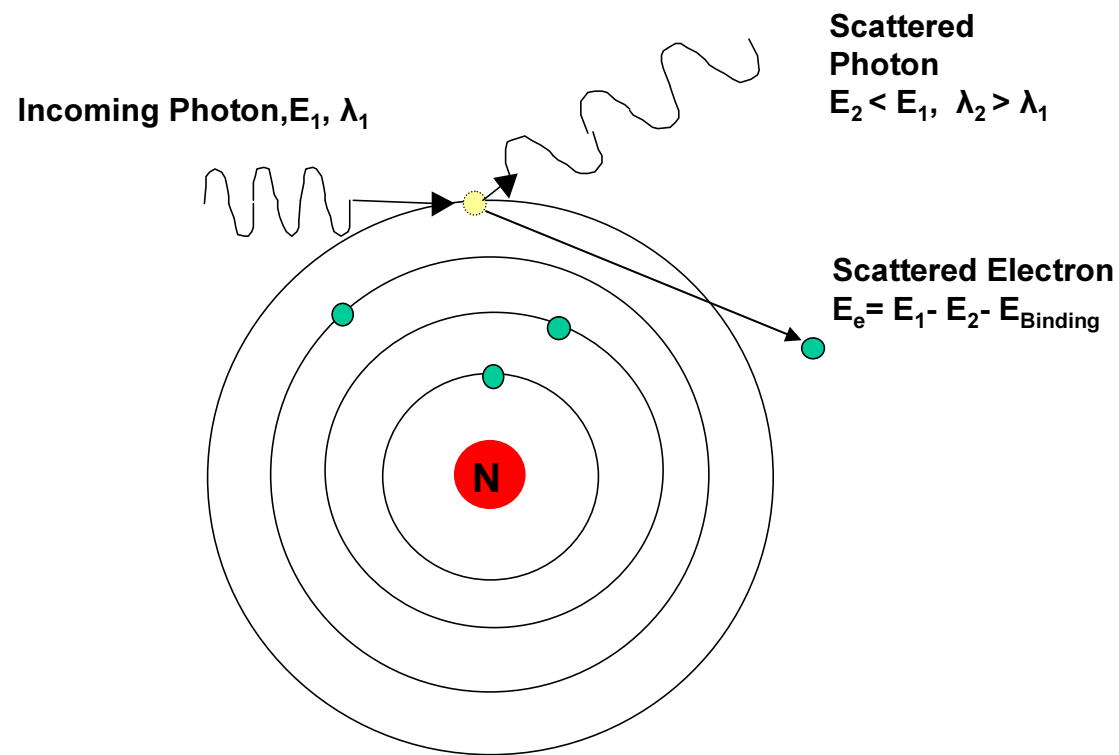
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Photo electric effect [1.swf](#)

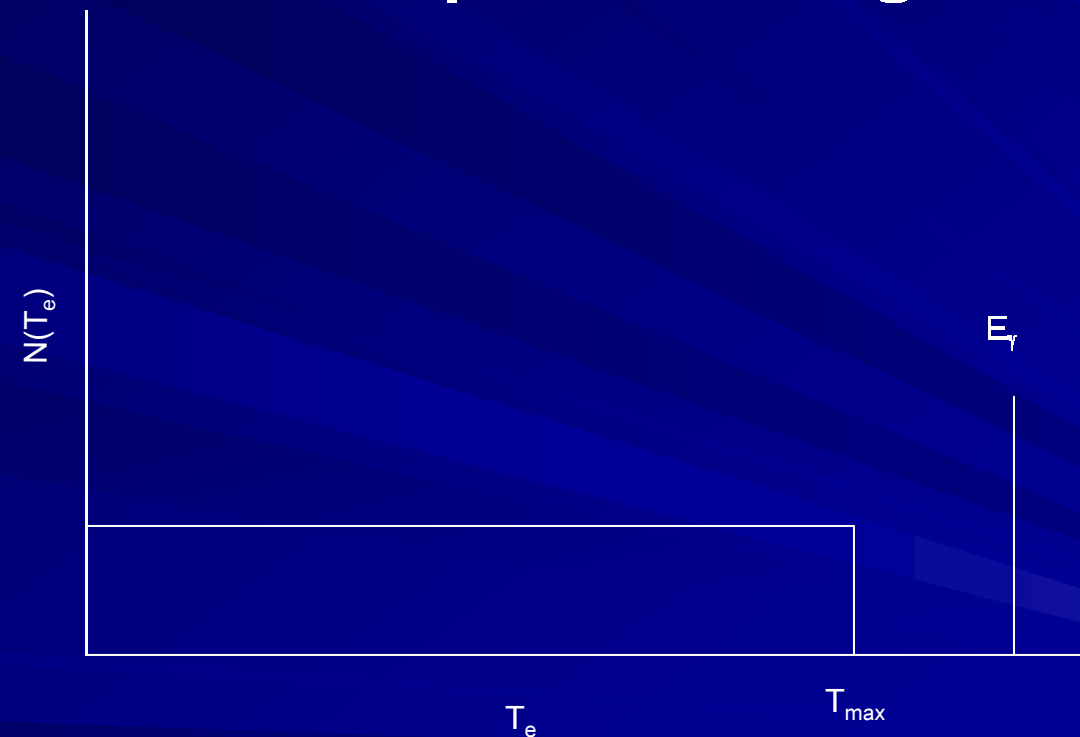


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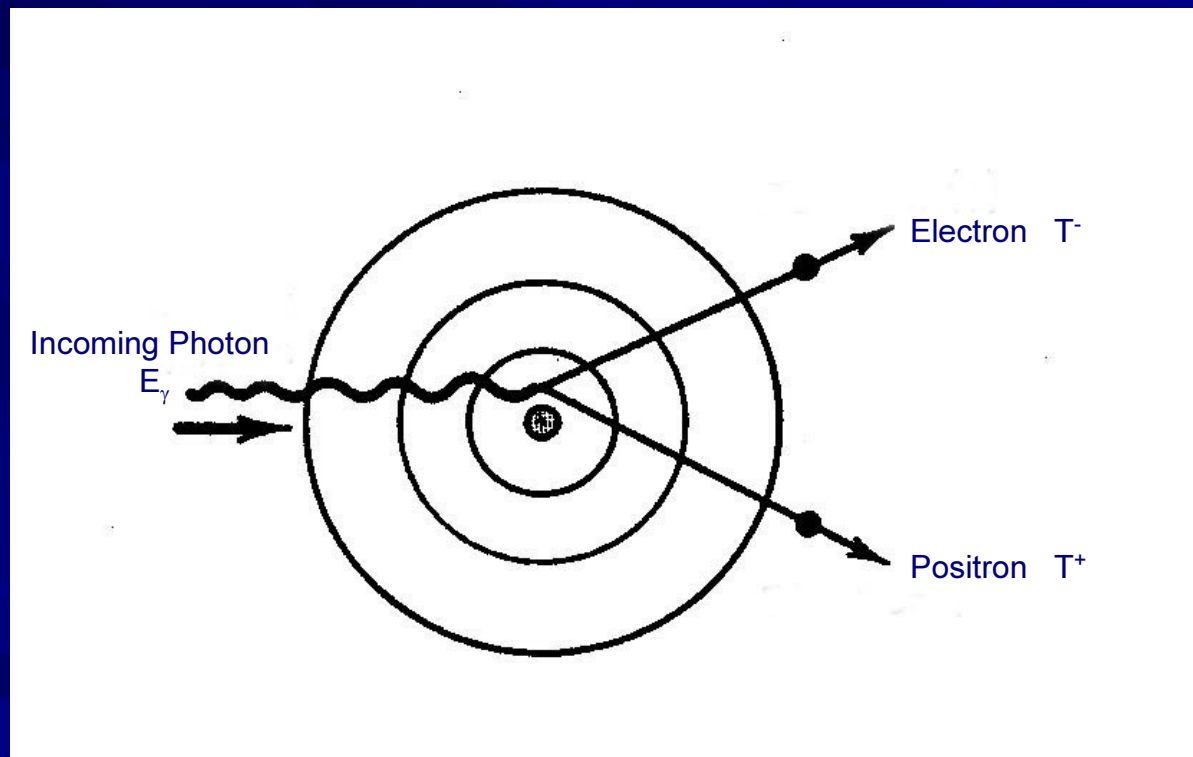
Compton Effect



Energy Distribution of Electrons from Compton Scattering



Pair production



What happens after the interaction?

- **Characteristic X rays**
- **Bremsstrahlungen**
- **Heat**

Which are the effects of ionizing radiation in matter?

Which parameters are important to be considered?

- Density
- Conductivity

Which would be the best material to detect ionizing radiation?

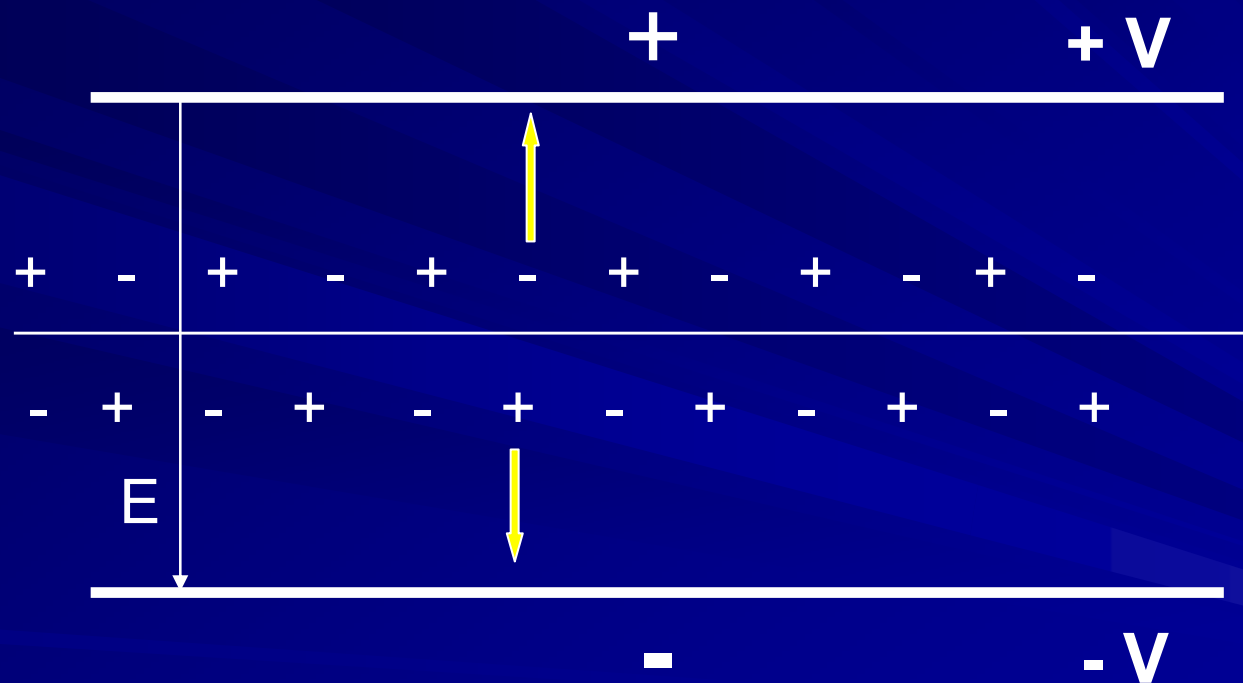
- A solid?
- A liquid?
- A gas?

Gas based detectors

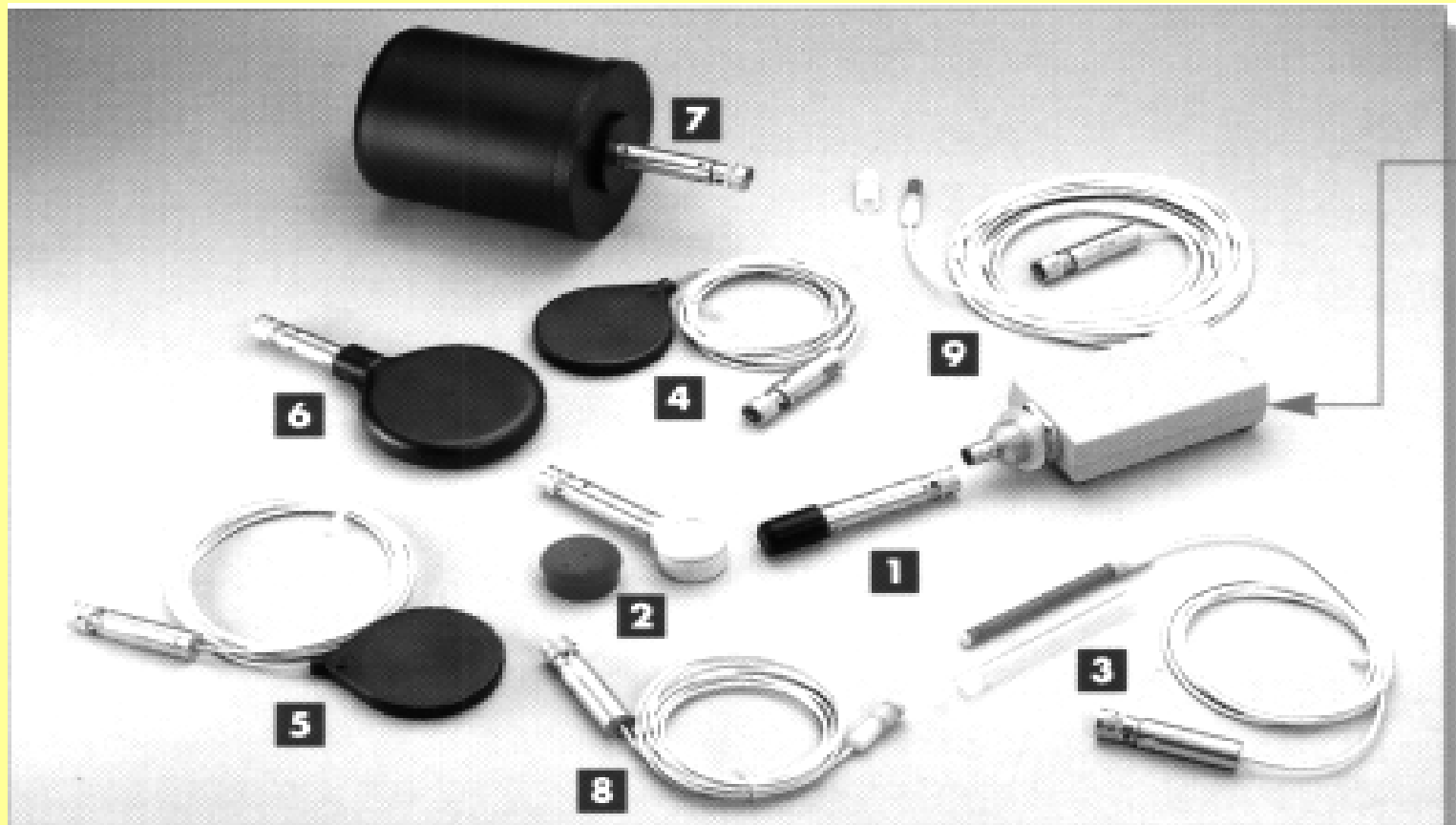
Ionization chambers

- Pulse mode**
- Charge mode**

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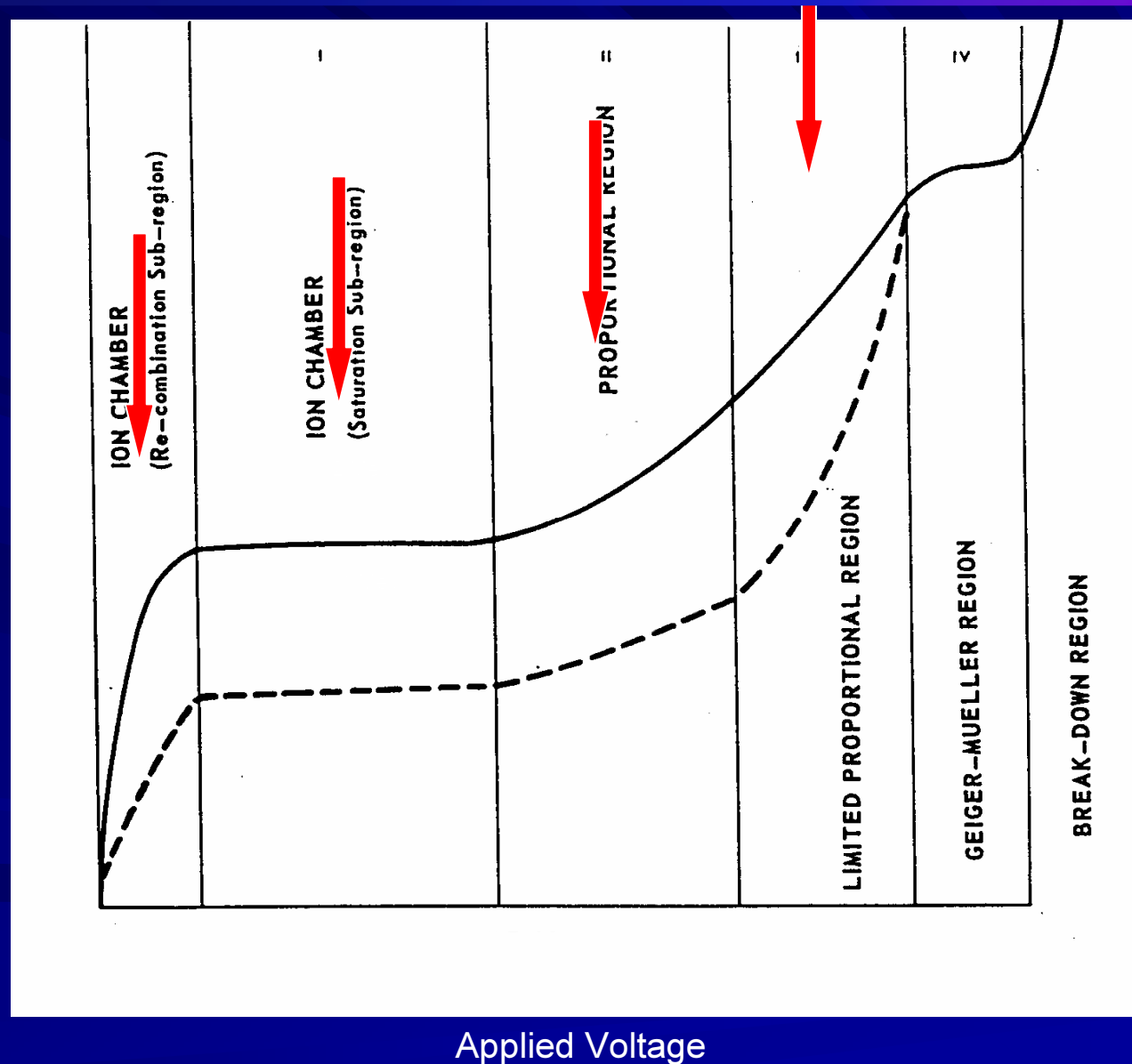


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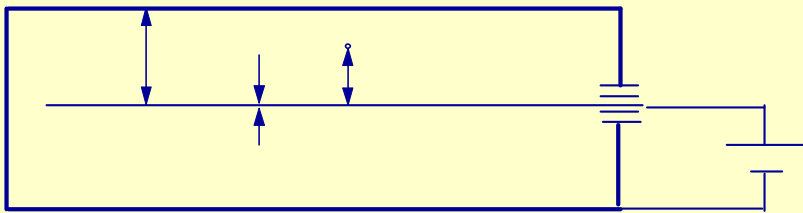
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Log Pulse Height

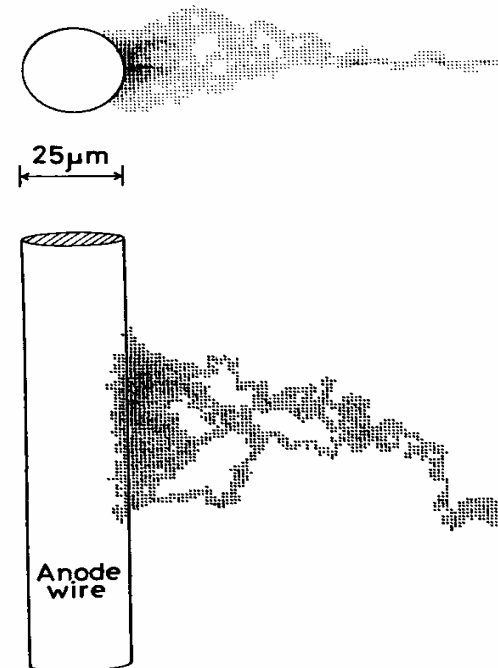


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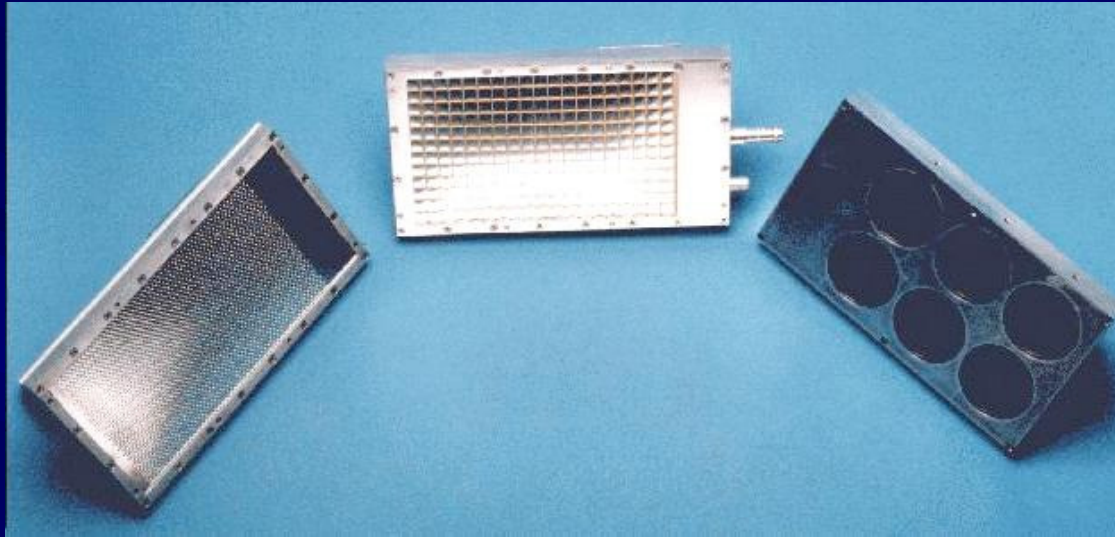
Proportional counters



$$\varepsilon = \frac{V}{r \ln(b/a)}$$

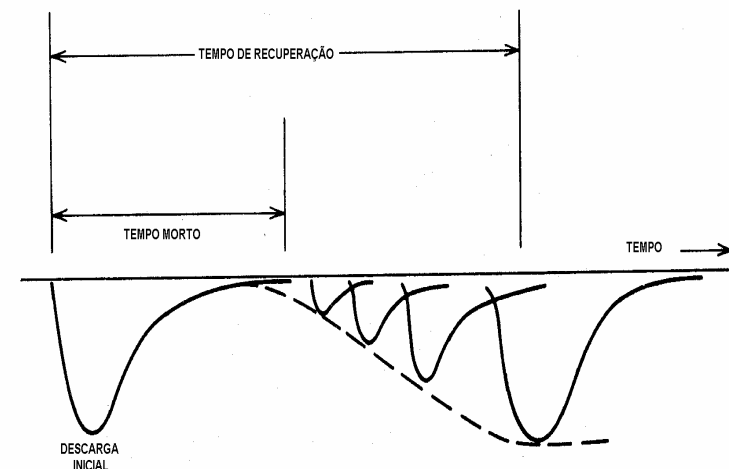
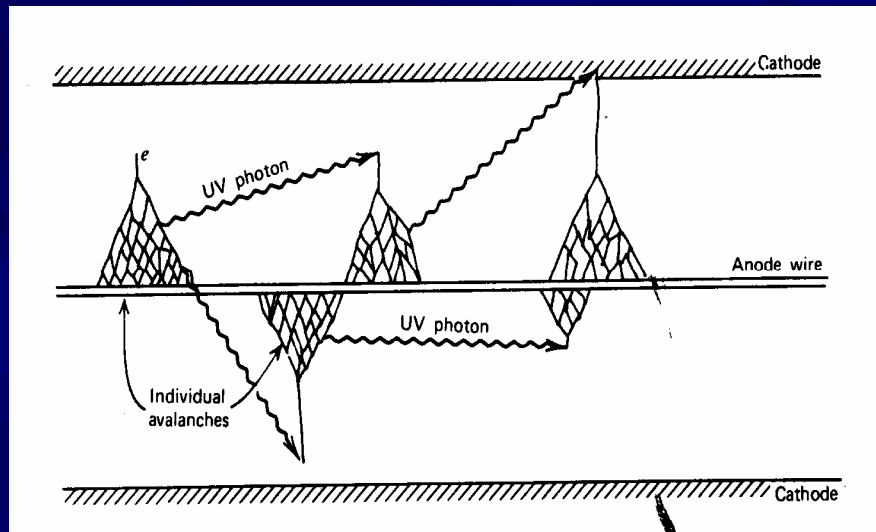


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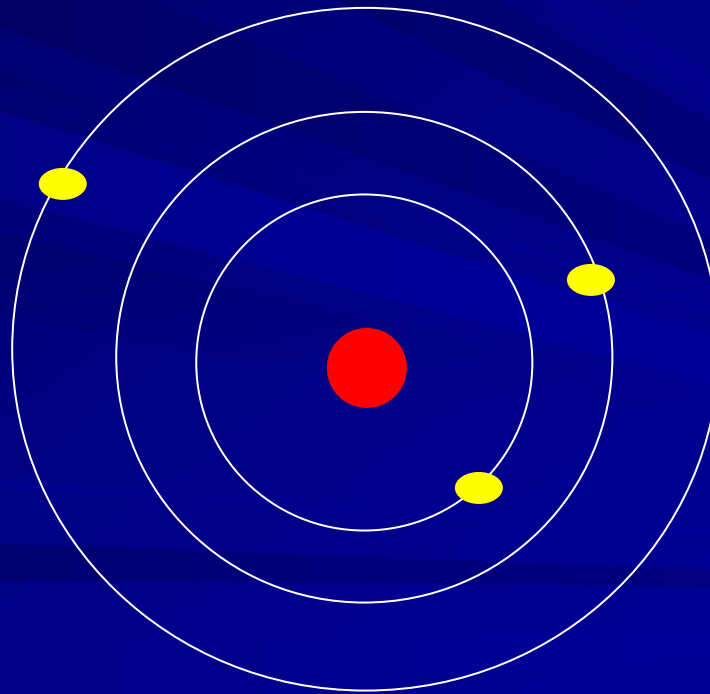
Geiger-Müller Counters



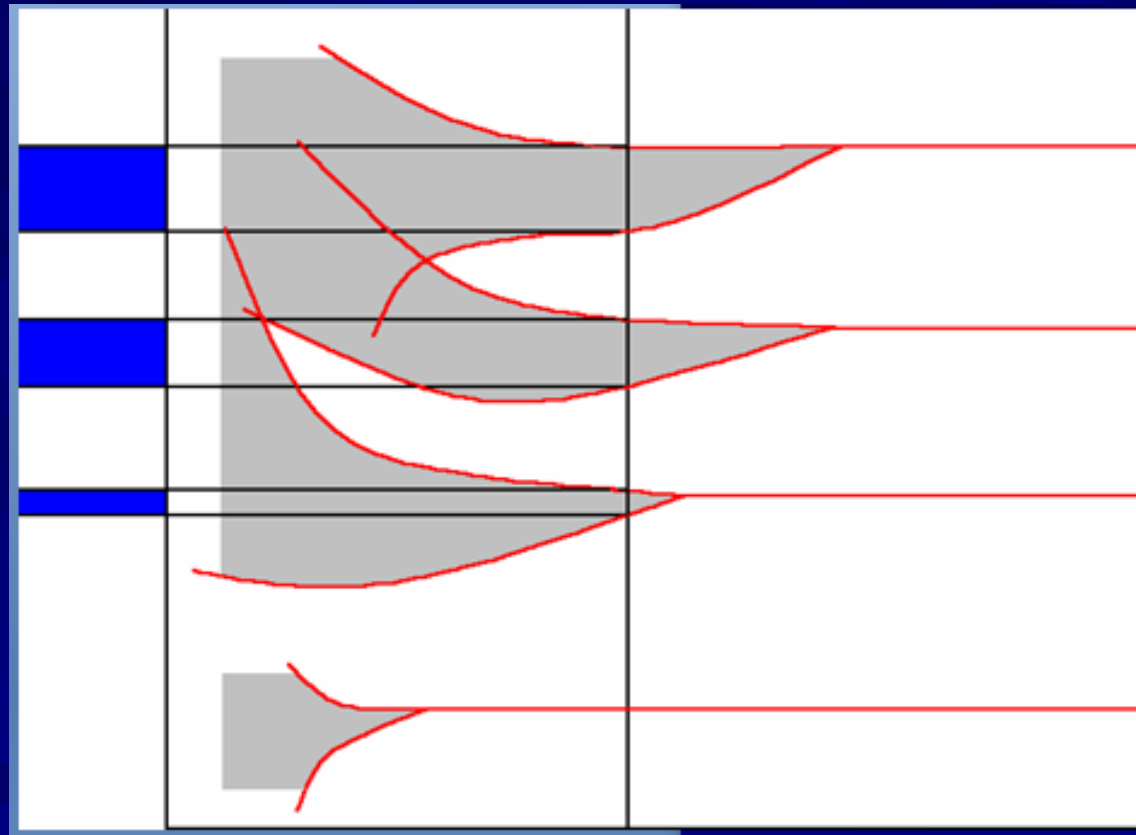
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Semiconductors, metals, insulators



What happens when the electronic shells become closer?



Distance between
atoms

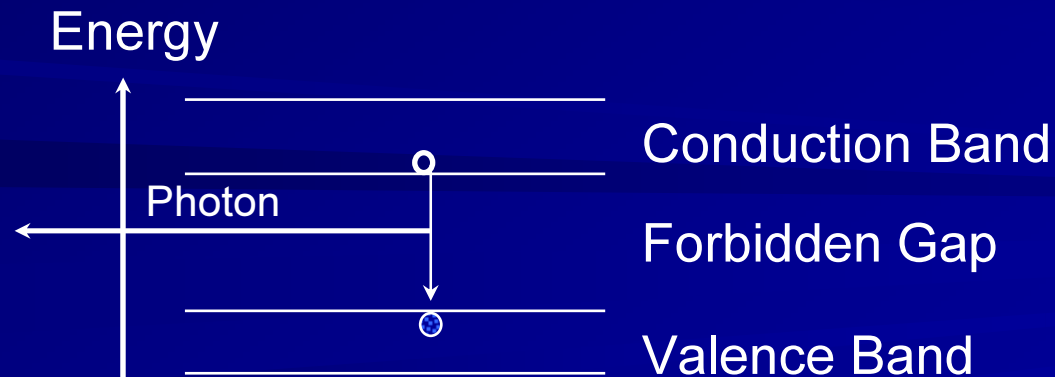
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Atom Excited by Radiation



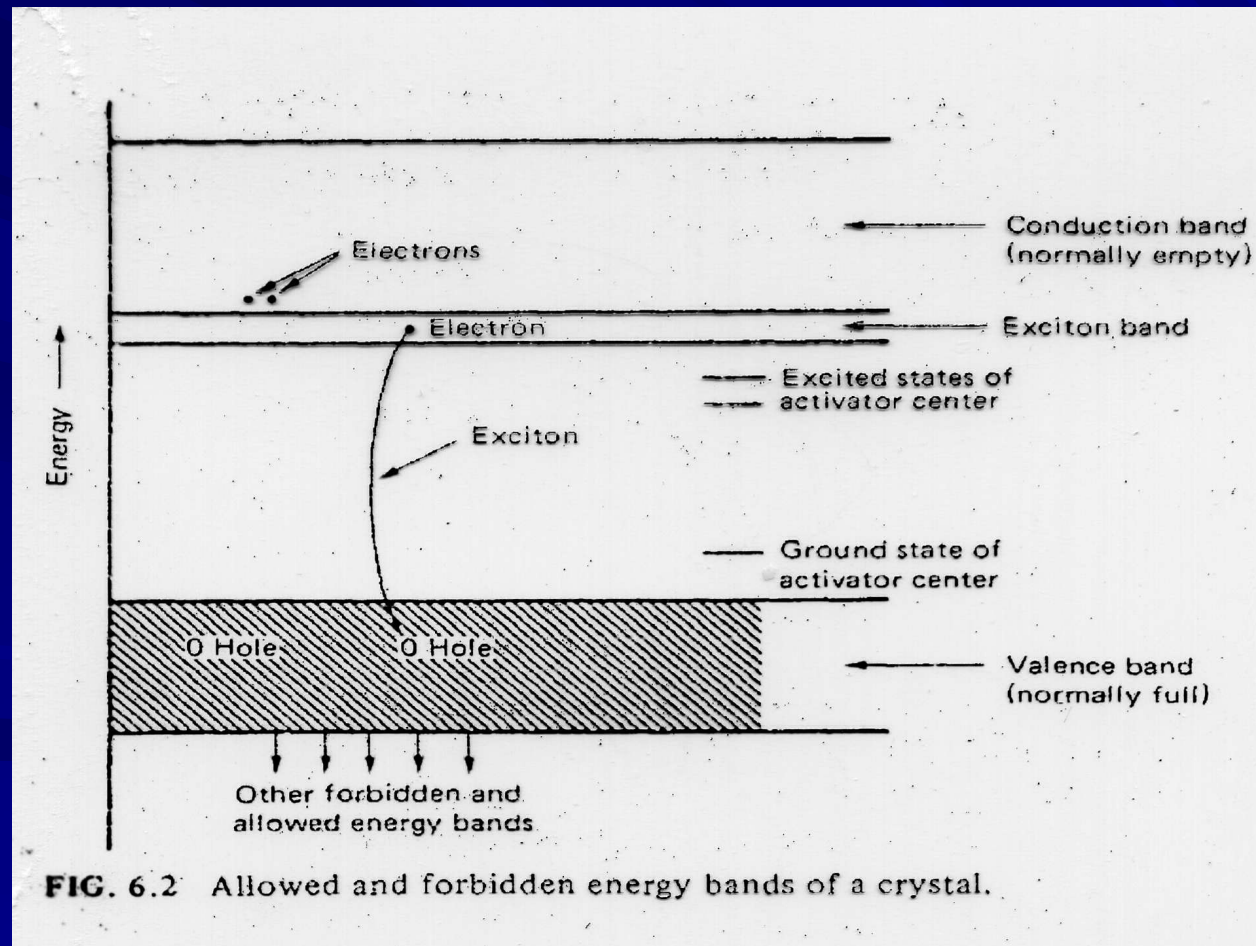
Atom is excited by interaction with radiation, moving an electron from the valence band to the conduction band.

Atom De-excites Emitting Light Photon



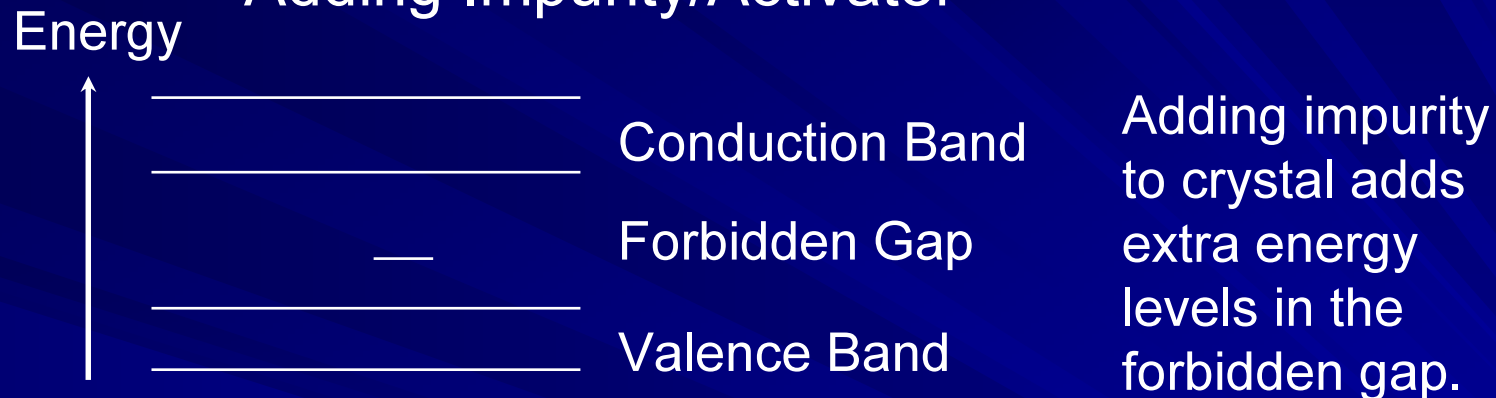
Energy of emitted photon equals the energy of the gap and wavelength is too short.

Inorganic Scintillators [2.swf](#) [3.swf](#)

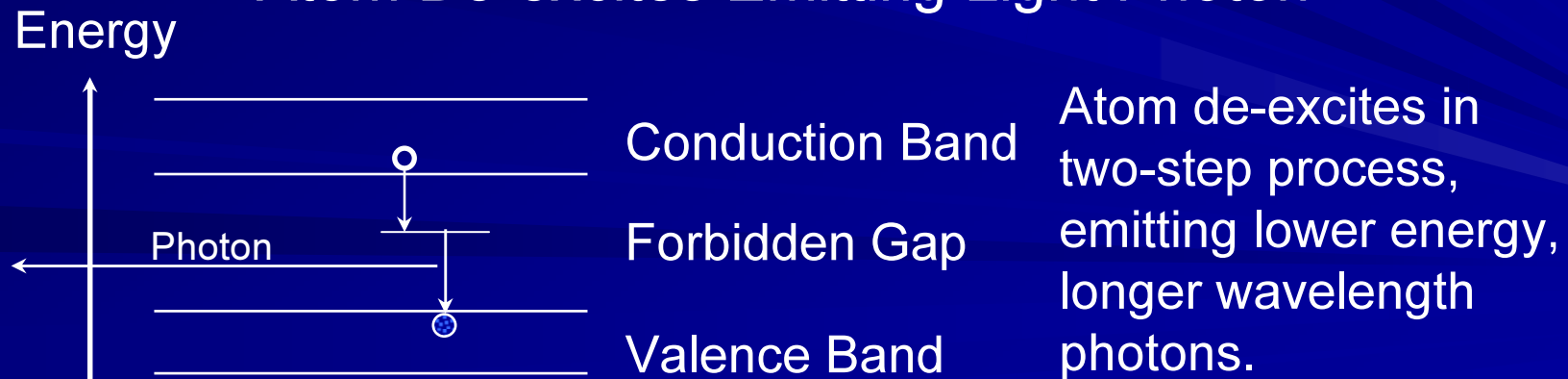


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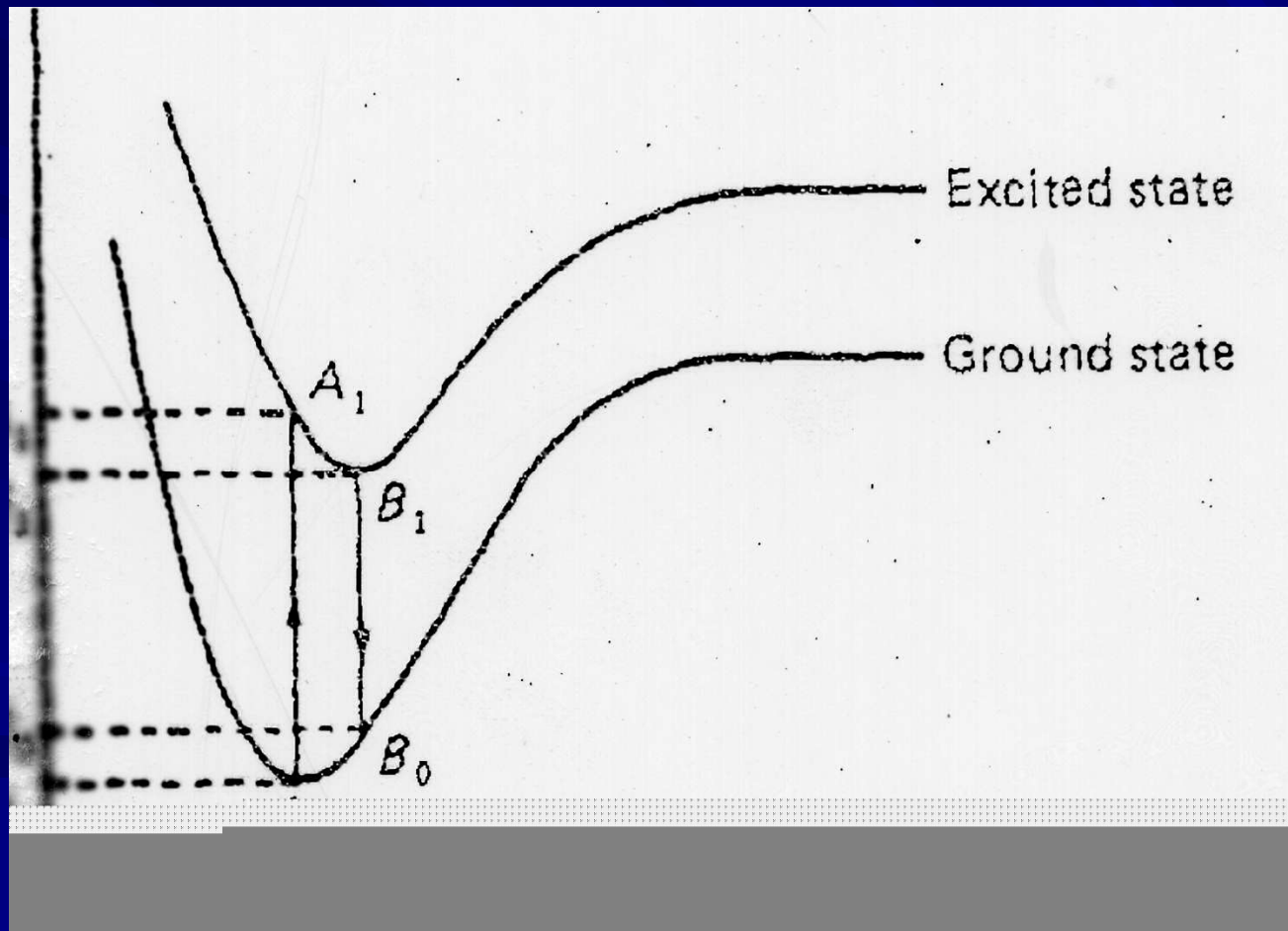
Adding Impurity/Activator



Atom De-excites Emitting Light Photon

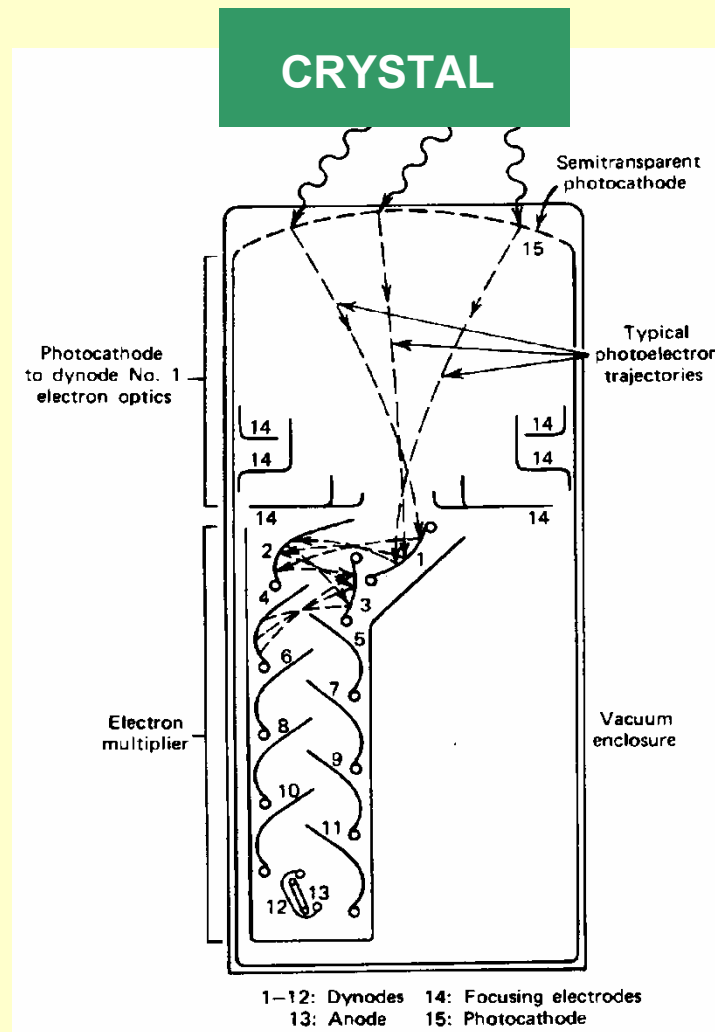


Organic Scintillators



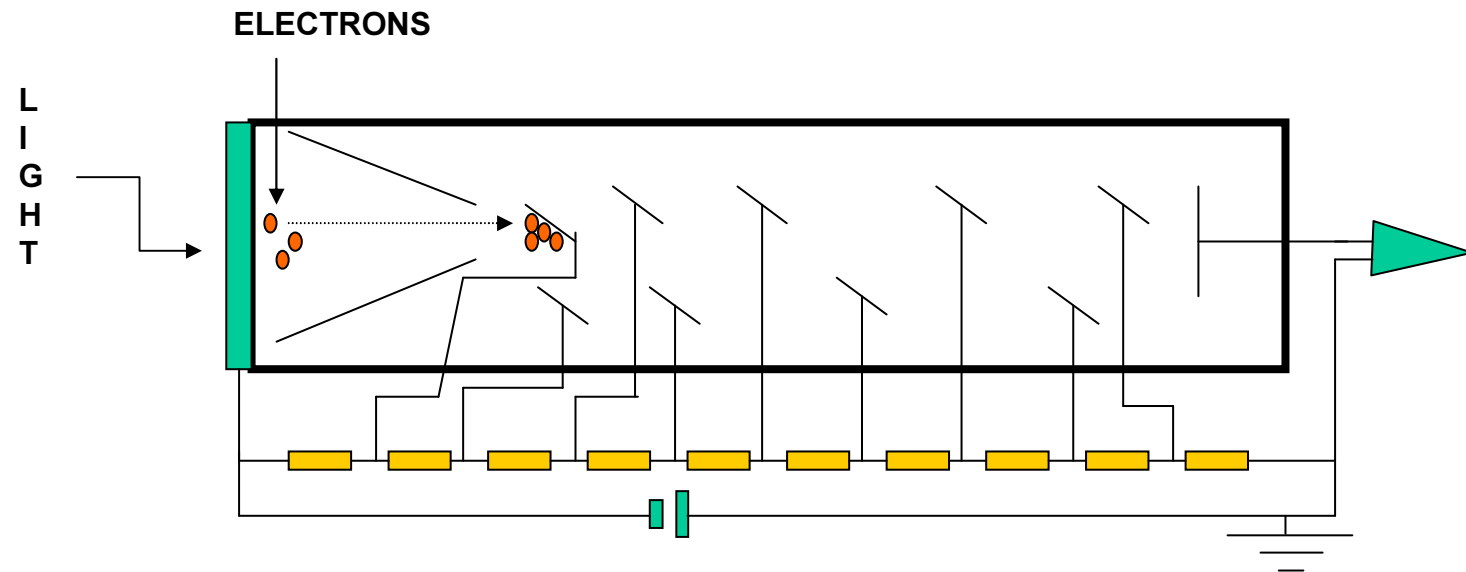
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Photomultiplier tubes



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Photomultiplier tube



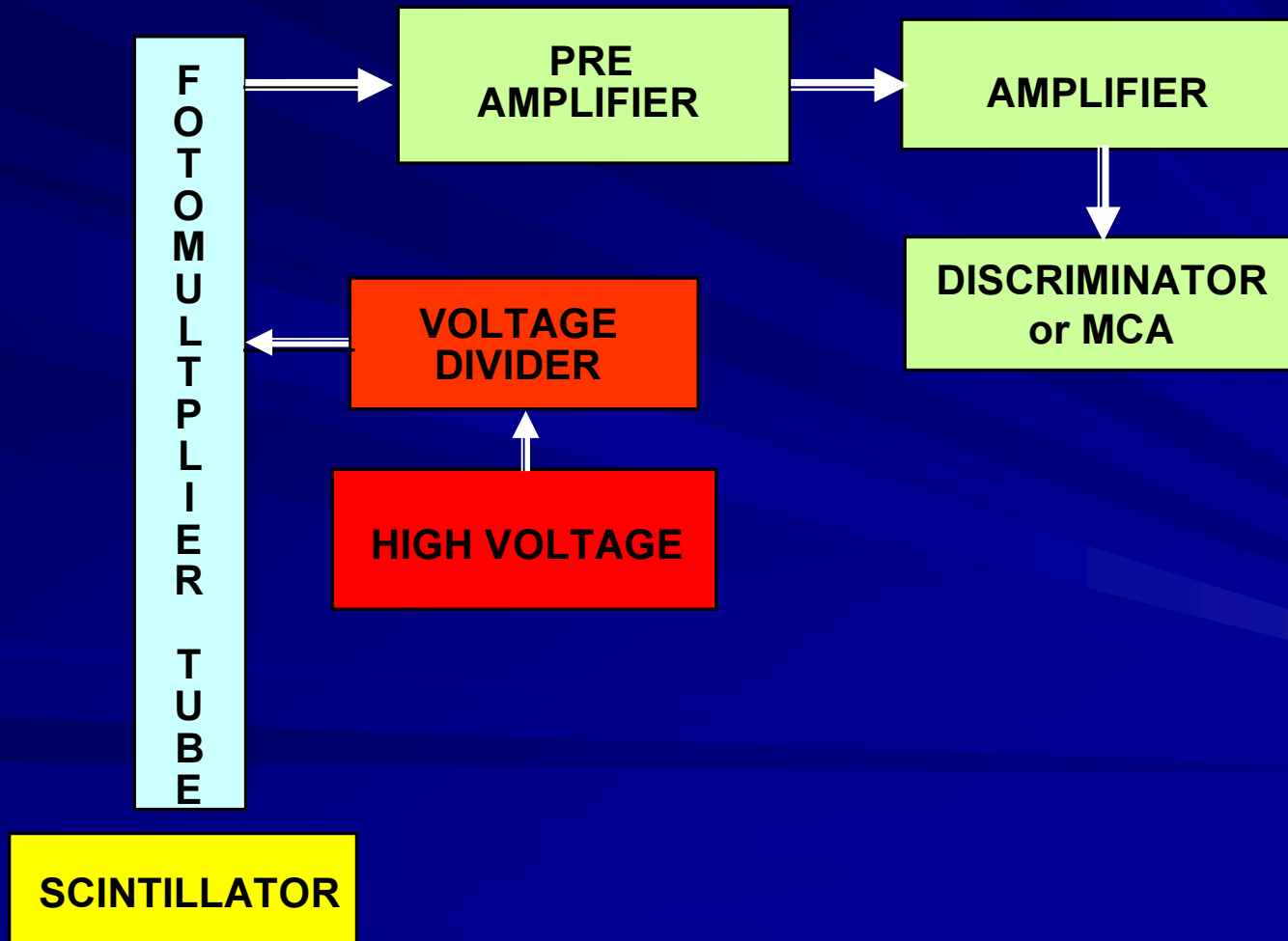
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Photomultiplier tube



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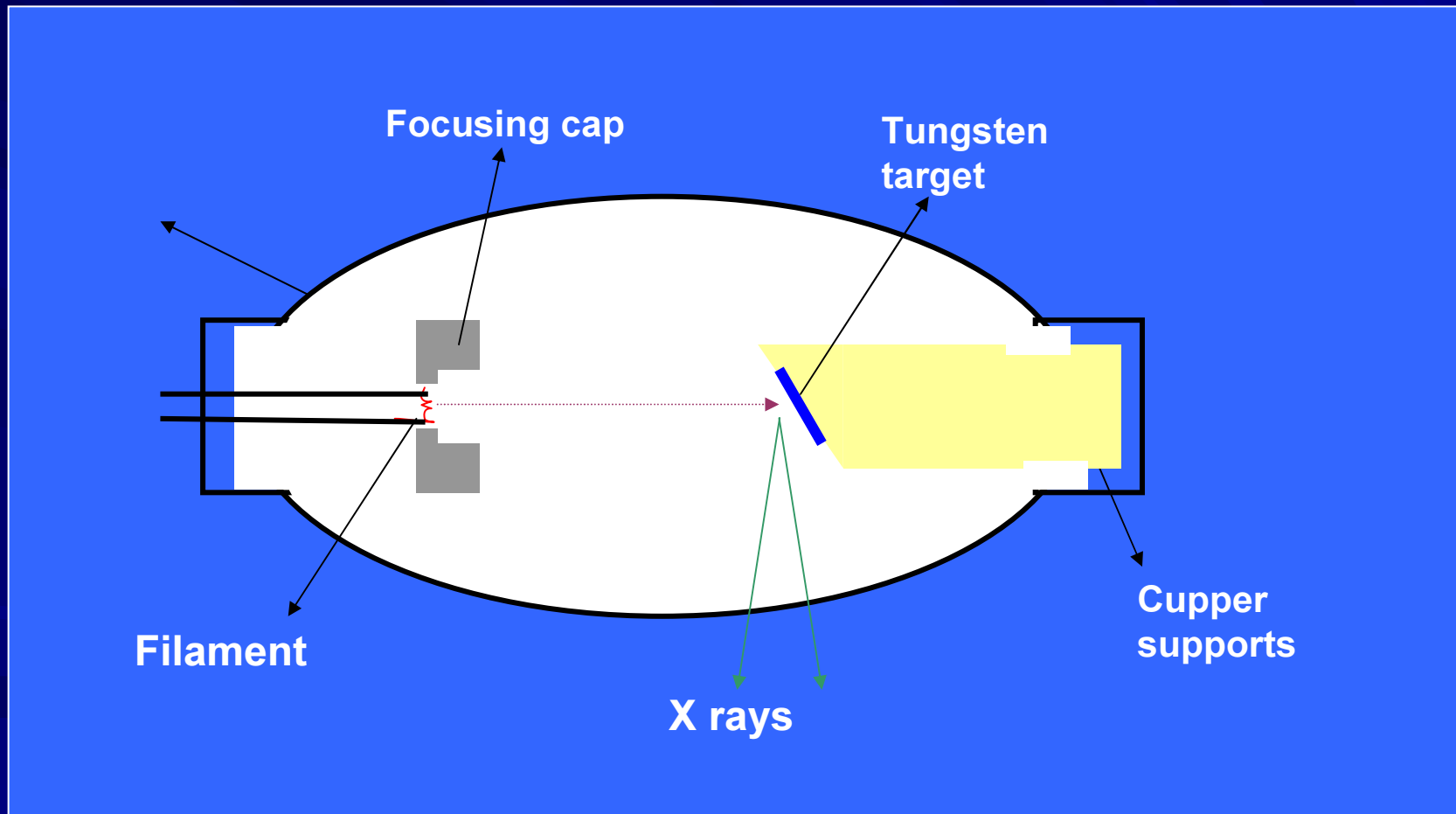
**BLOCK DIAGRAM OF A RADIATION DETECTOR BASED ON A
SCINTILLATOR (Pulse Mode)**



Diagnostic Imaging

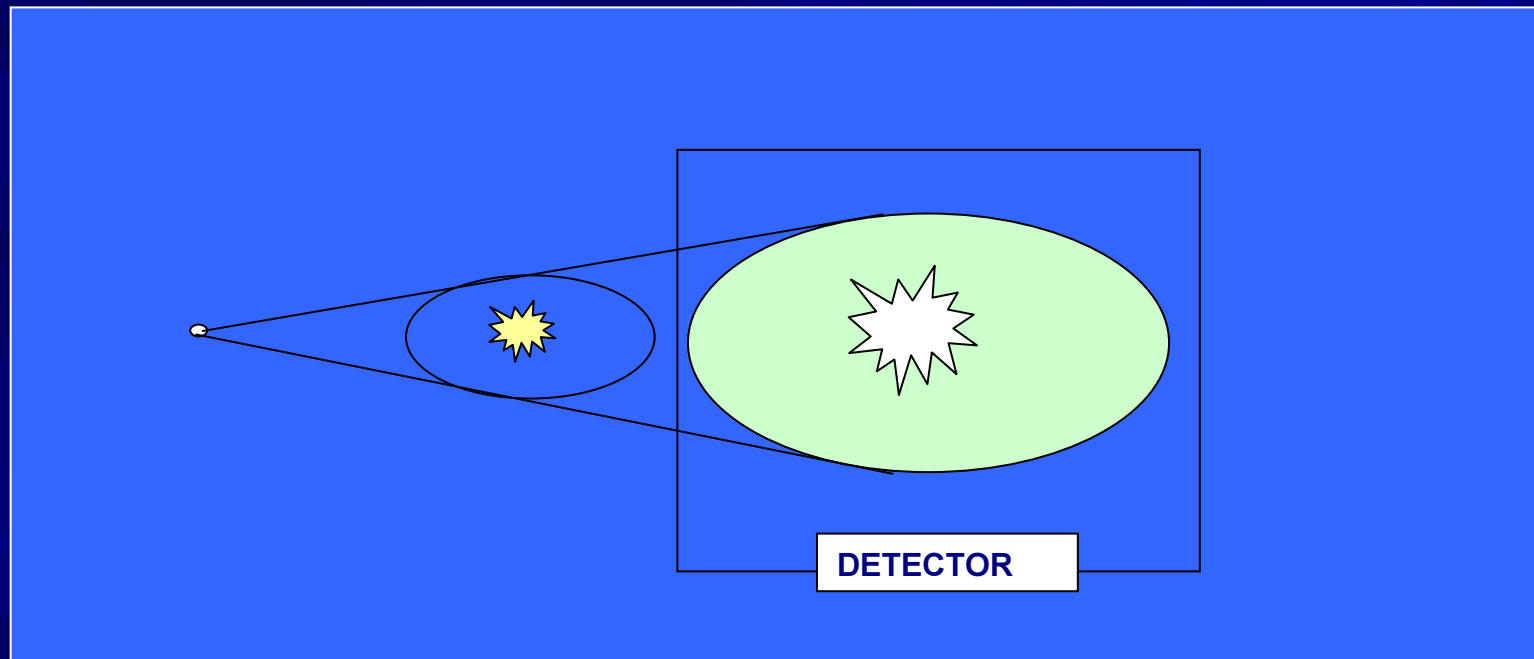
- **Radiology – x-ray machines, CT**
- **Nuclear Medicine Gamma cameras, PET**
- **Magnetic resonance**

X-ray tube



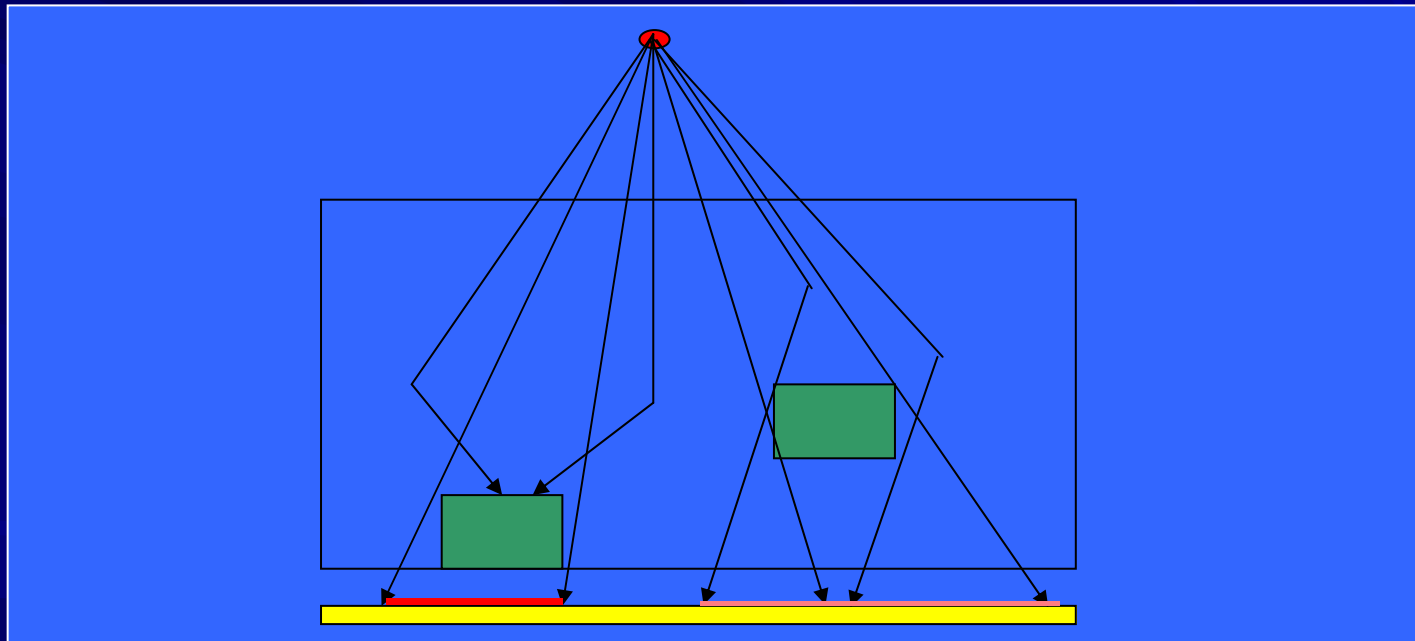
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Radiology



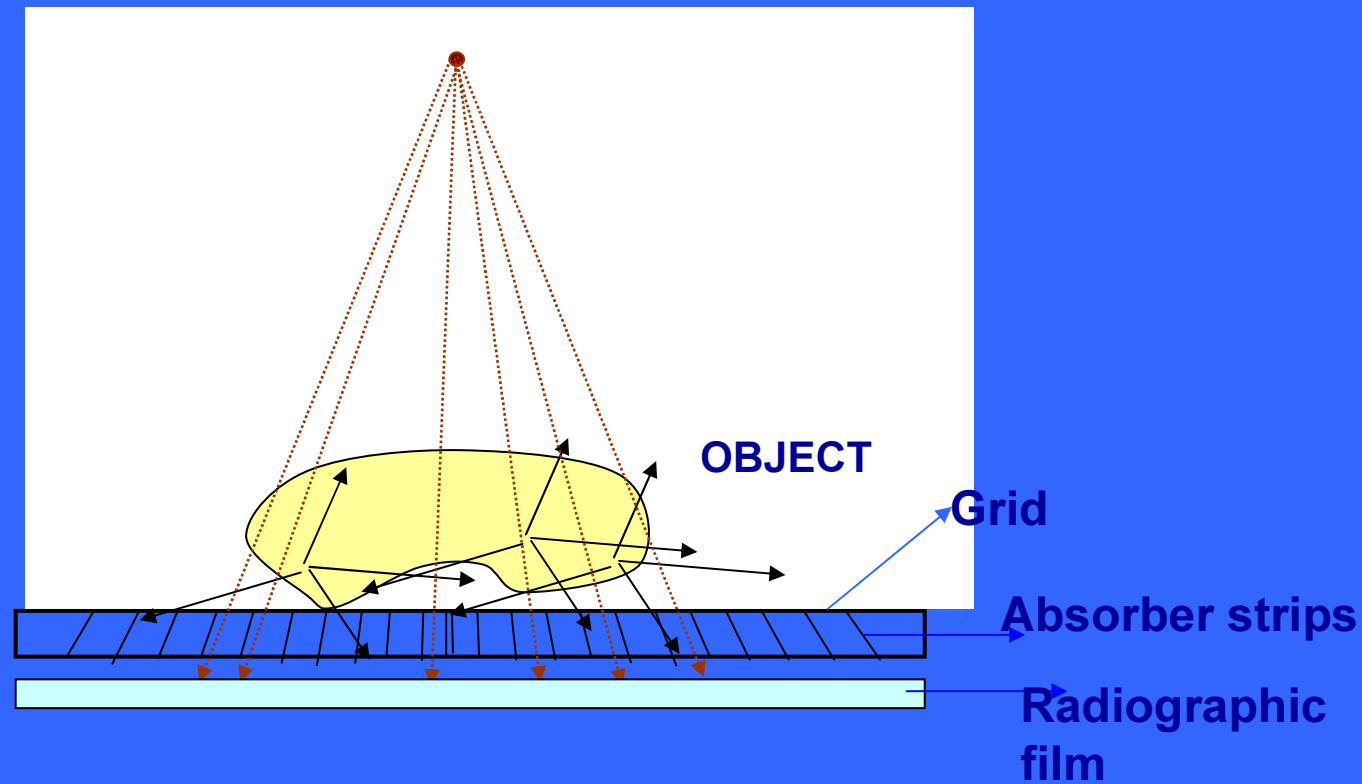
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Effect of the scattered radiation



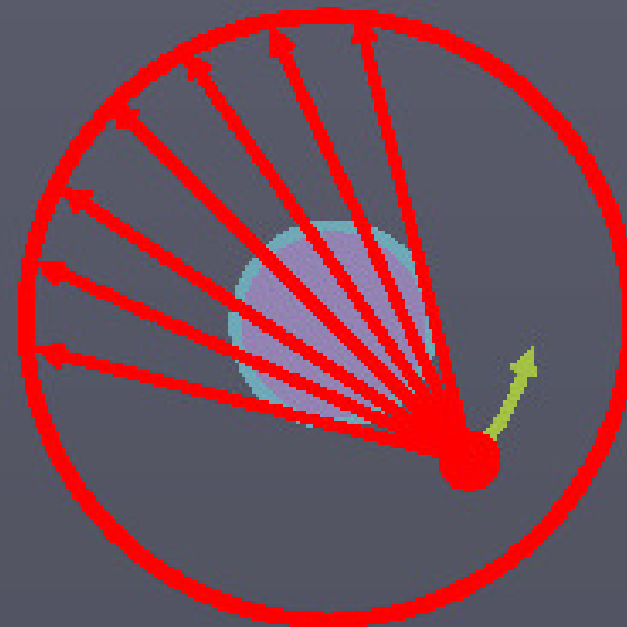
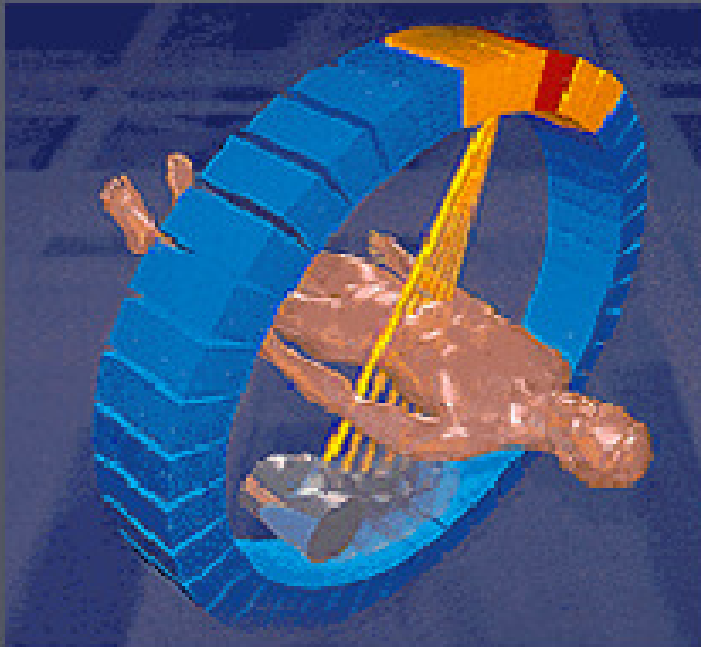
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Grids



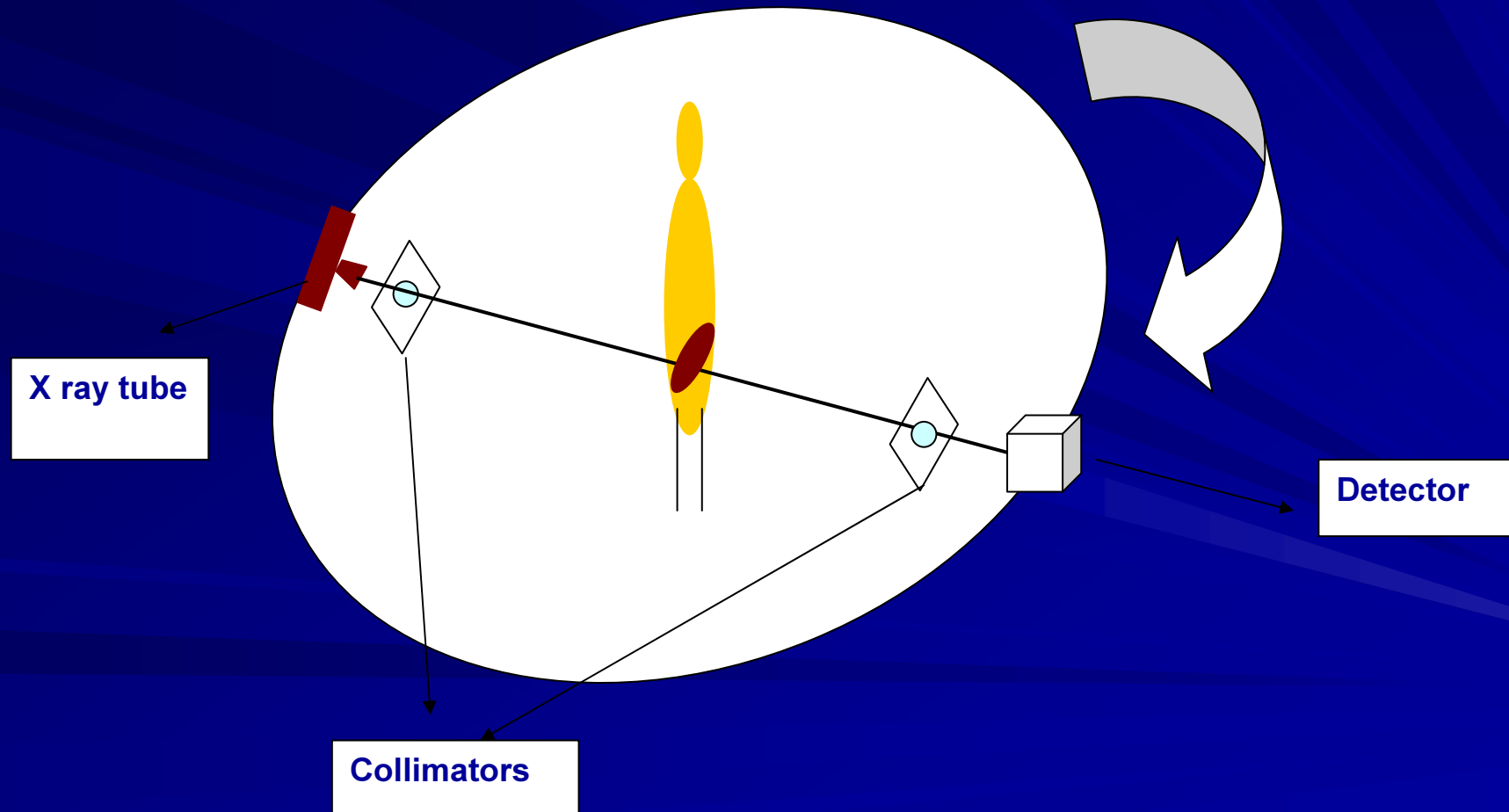
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CT – technique



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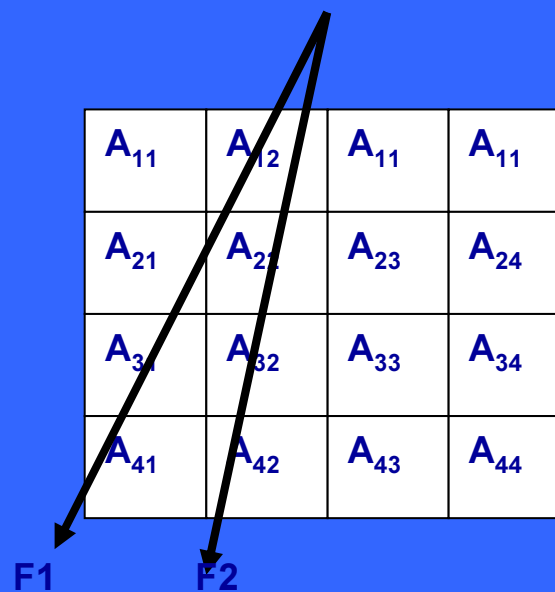
CT Computerized Tomography



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CT is based on the calculation of the absorption of radiation in a determined value of a material. This calculation is performed with information obtained in different position through the movement of the set x ray tube – detectors.

Considering the following figure, each square represent a cube which is named "voxel". The attenuation of each beam will be derived from the sum of the individual contribution of each voxel.



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The attenuation of a radiation beam after crossing a determine layer of a material is given by:

$$I = I_0 e^{-\mu x}$$

Where μ is the linear attenuation coefficient for the energy of the incident radiation an x the material thickness.

For the beam F_1 the total attenuation will be given by the sum of the attenuation in A_{12} , A_{21} , A_{31} , A_{41} . Therefore, $I(F_1)$ will be equal to $I_0(F_1)$ multiplied by the individual attenuations;

$$I = I_0 e^{-\mu(A_{11})x} \cdot e^{-\mu(A_{21})x} \cdot e^{-\mu(A_{31})x} \cdot e^{-\mu(A_{41})x}$$

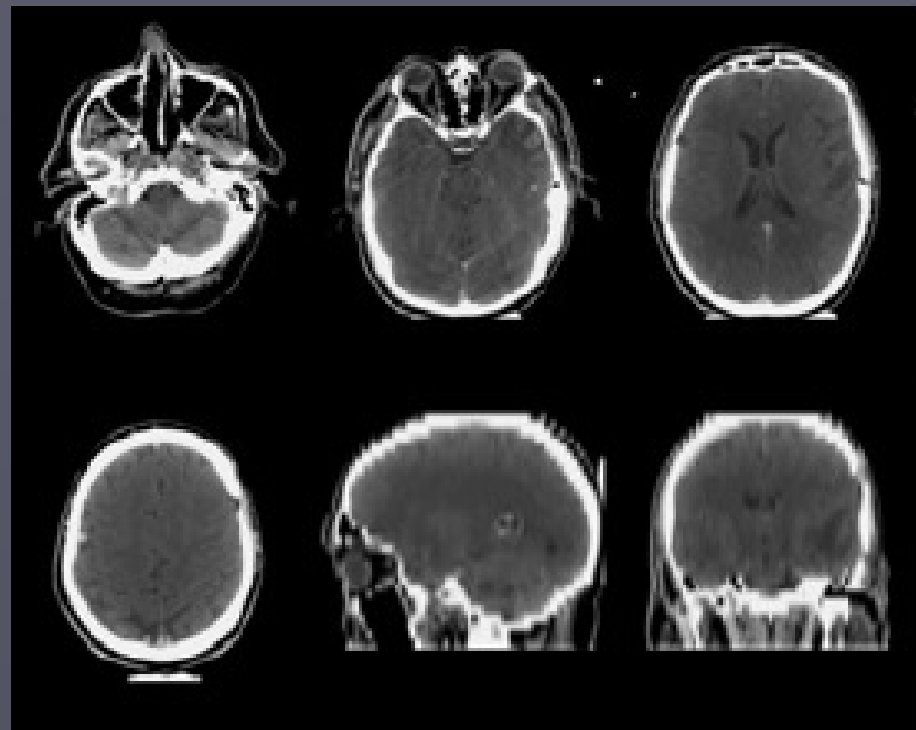
Applying the Neperian logarithm to both sides of this equation we have:

$$\ln(I) = \ln(I_0 e^{-\mu(A_{11})x} \cdot e^{-\mu(A_{21})x} \cdot e^{-\mu(A_{31})x} \cdot e^{-\mu(A_{41})x}) = \ln I_0 - \mu(A_{11})x - \mu(A_{21})x - \mu(A_{31}) - \mu(A_{41})x.$$

The same is valid for the beam F_2 . Using a set of beams, we get a set of equations which variables are the attenuation coefficients for the "voxels". This set of equations can be solved applying numeric methods. Having the linear attenuation coefficients for each voxel available it is possible to generate an image of this set of "voxels" providing a gray scale greater or smaller depending on the calculated attenuation coefficient.

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Computed tomography



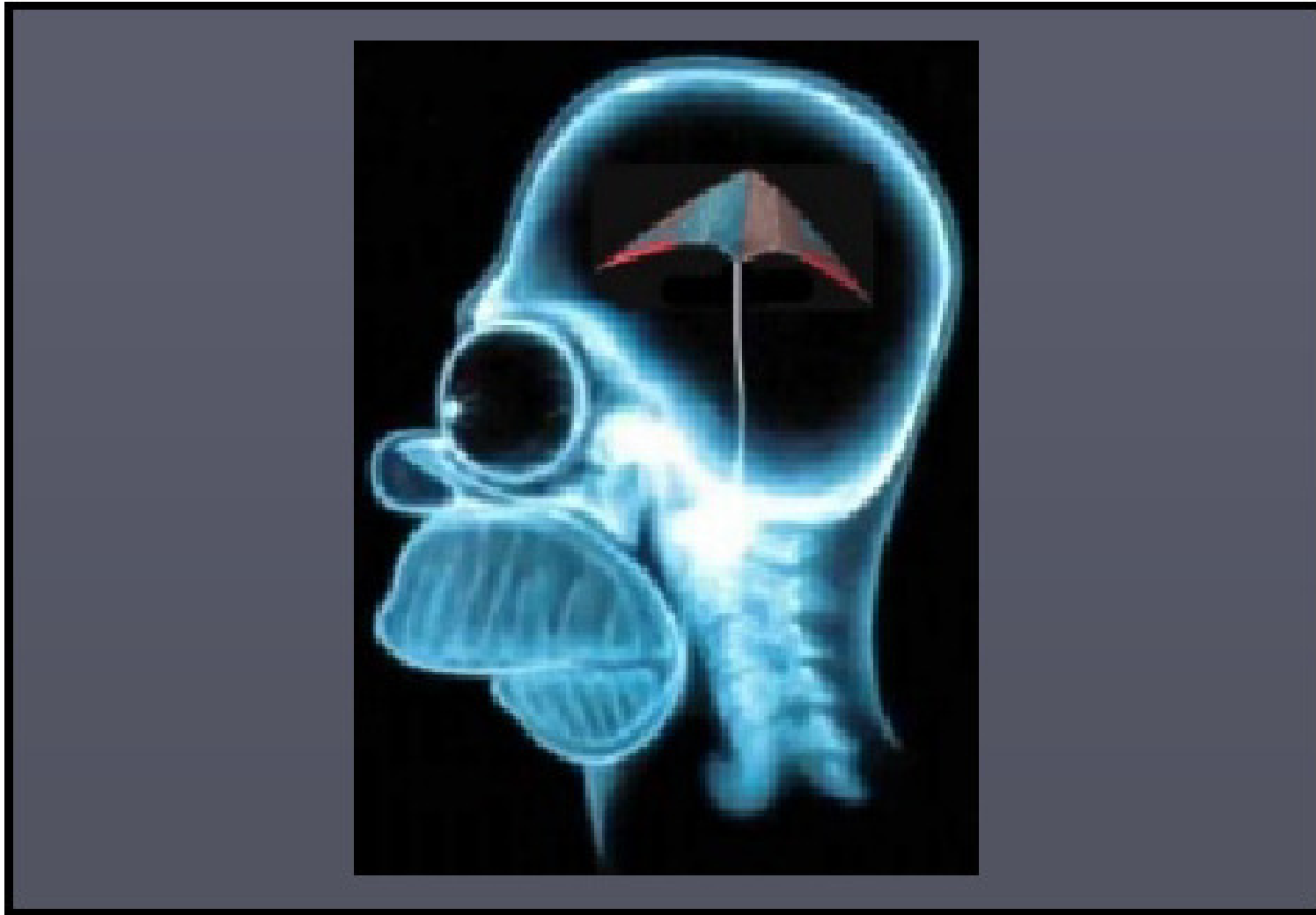
CT gives anatomical information

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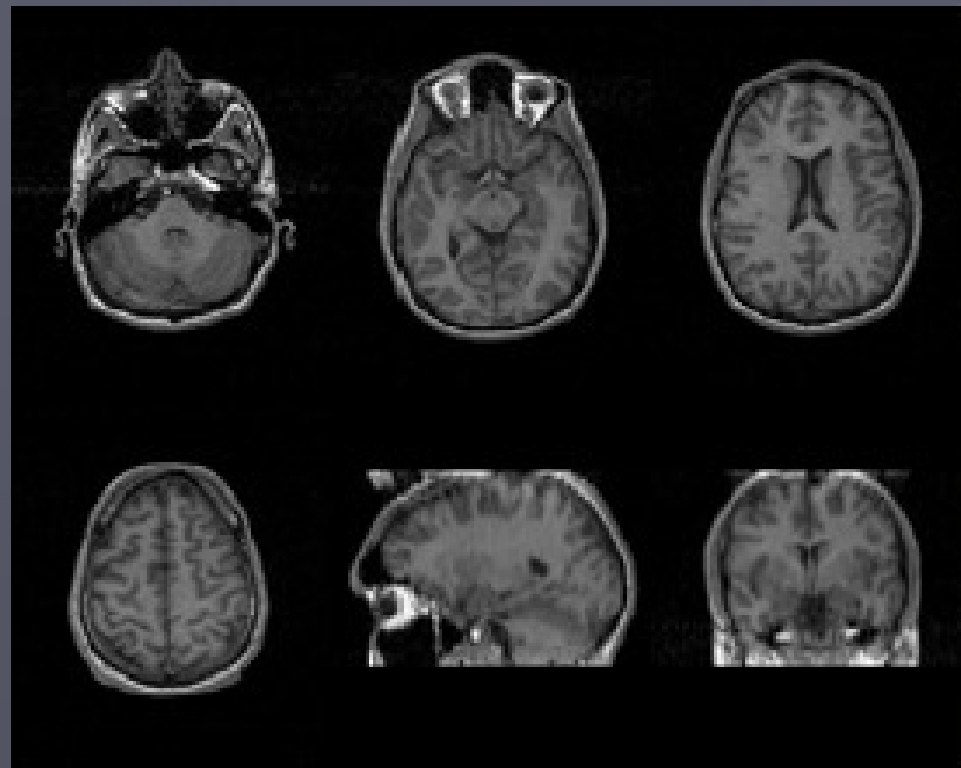
CT: skeleton - neuro



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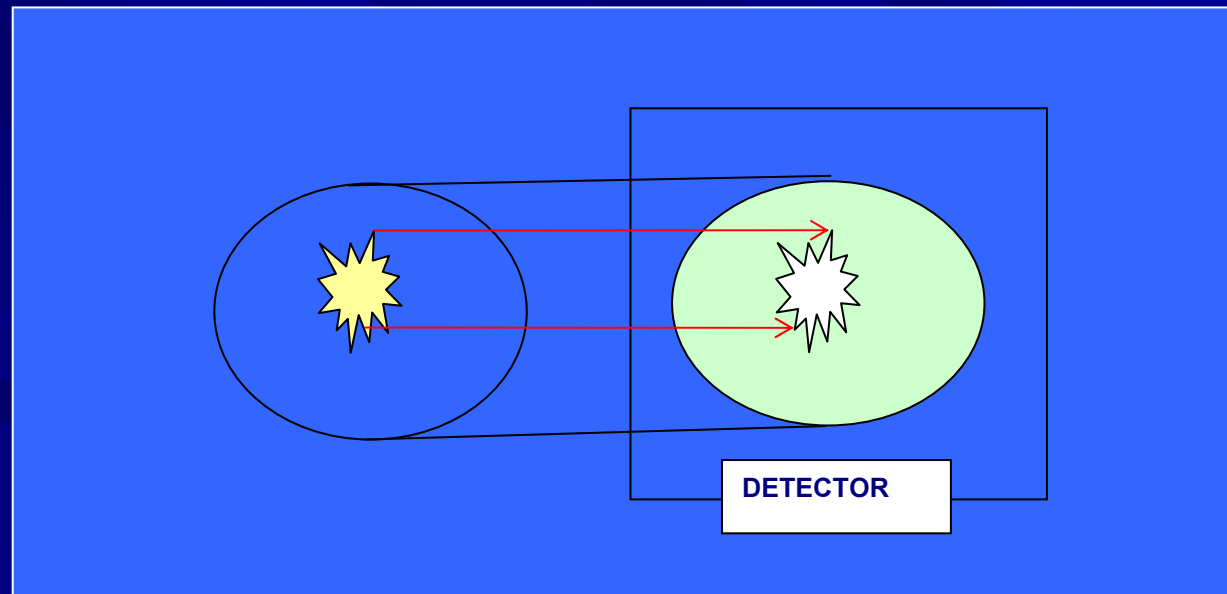
Magnetic Resonance Imaging



MRI gives anatomical information

Nuclear Medicine

- 1) A labeled material (carrying a radioactive material) is injected in the patient
- 2) The tumor cells or the tissue of interest will concentrate more or less the labeled material
- 3) A “picture” of the radioactive material is obtained utilizing a special detector



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What is needed?

- 1) A radioactive material that can be used as a label and which has the appropriated energy range of photons and with a short live time
- 2) A large detector (Scintillator)
- 3) A system for measuring the light produced by the radiation (PMT tubes)
- 4) A system for determining the position of the interaction of the radiation with the detector (Weighting and calculation systems)
- 5) The scattered radiation is not contributing for the image, it should be avoided and discriminated (Collimator and MCA)
- 6) A system for computing and processing the data (Image processor)
- 7) A mechanical system for positioning the detector and the patient.

Radioactive materials

- 1. Not toxic**
- 2. Low half life**
- 3. Appropriated energy**
- 4. Gamma only emitter**

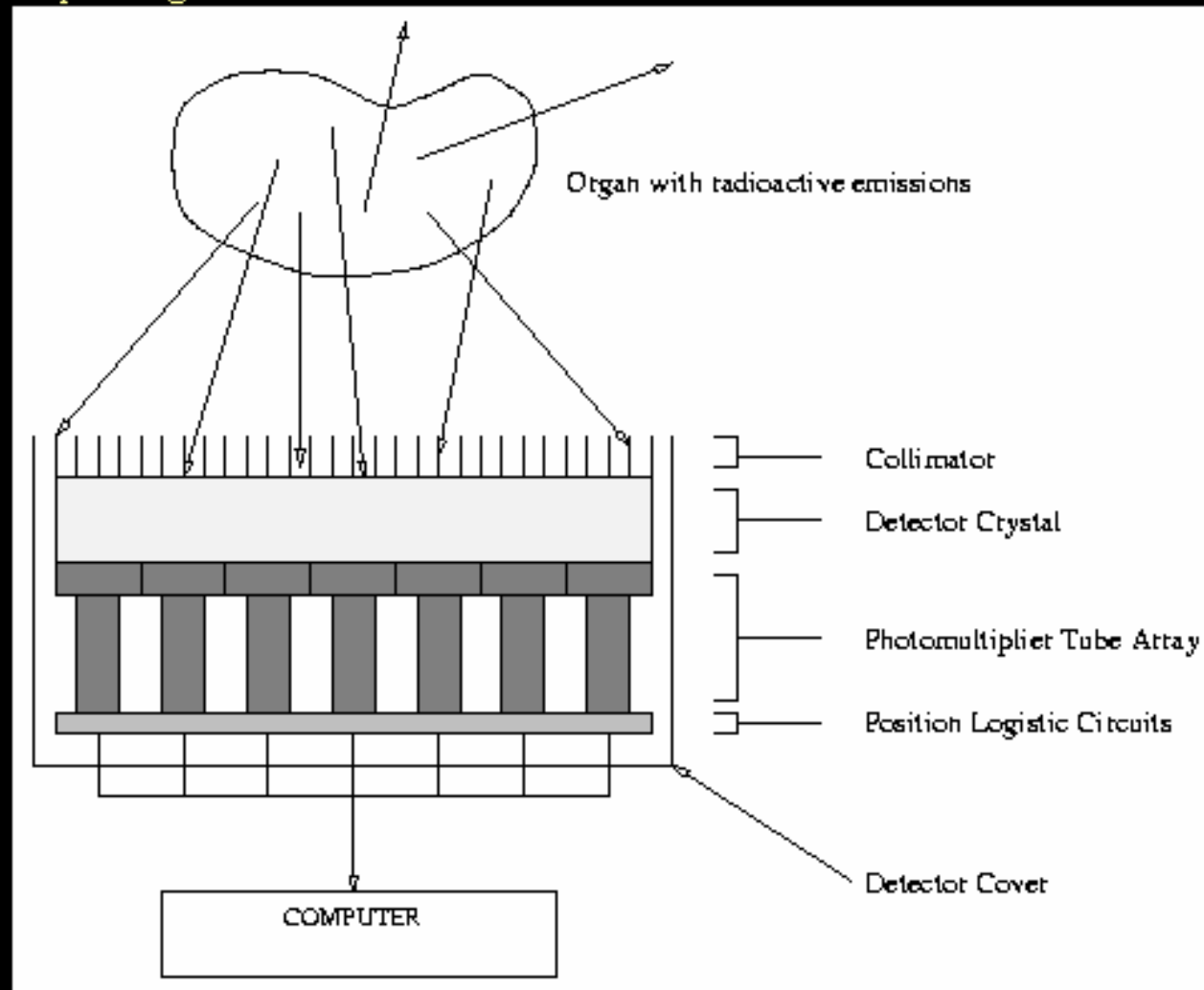
Tc 99m

I 133

Ga

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Simple Diagram



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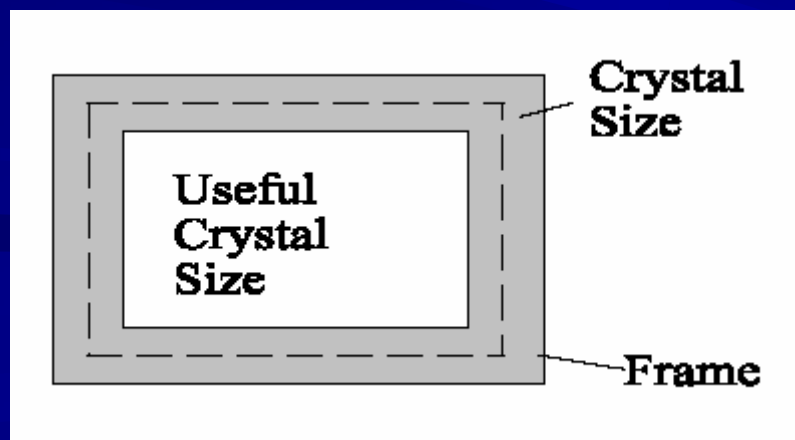
Crystal materials

Material	Density (g/ml)	Relative Output	Decay time (ns)	Wavelength (nm)
NaI(Tl)	3.67	1.00	230	410
BGO	7.13	0.12	300	480
BaF ₂	4.89	0.05	0.6-0.8	220
		0.15	630	310
CsF	4.61	0.06	2.5	390

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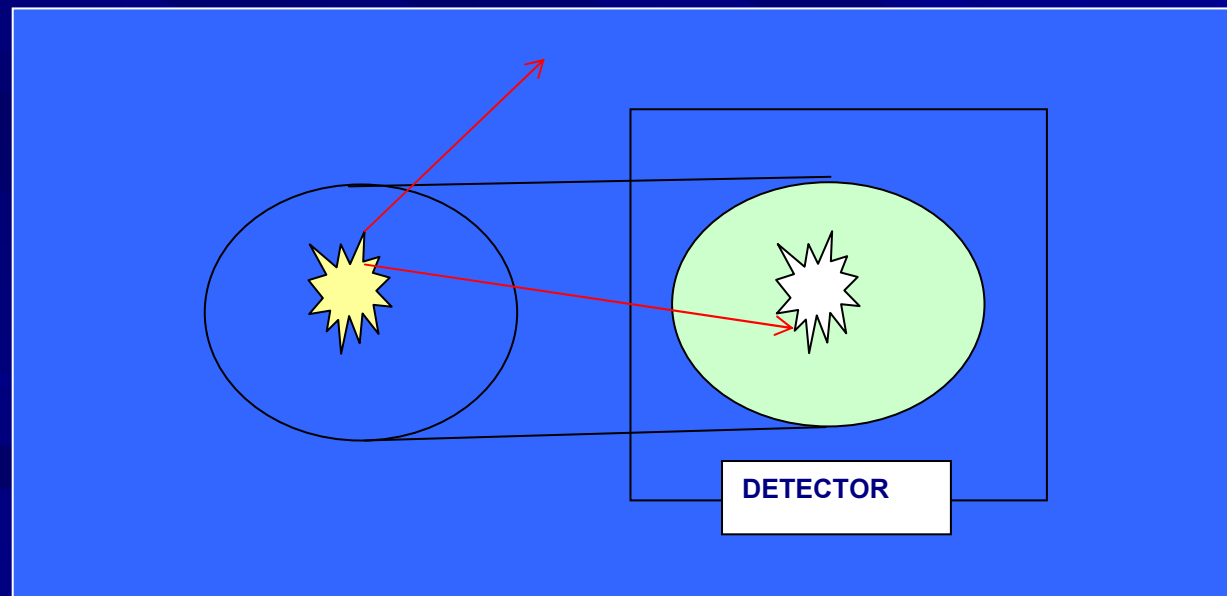
Crystal thickness

	140 keV			363 keV		
	3/8"	1/2"	3/4"	3/8"	1/2"	3/4"
Total efficiency	88%	94%	98%	35%	41%	60%
Photopeak efficiency	82%	89%	95%	24%	30%	46%



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In nuclear medicine, the radiation comes from the organ not from outside, so, since the radiation is isotropic it is needed to apply a collimator. The collimator also avoid the scattered radiation to reach the detector.



Collimators

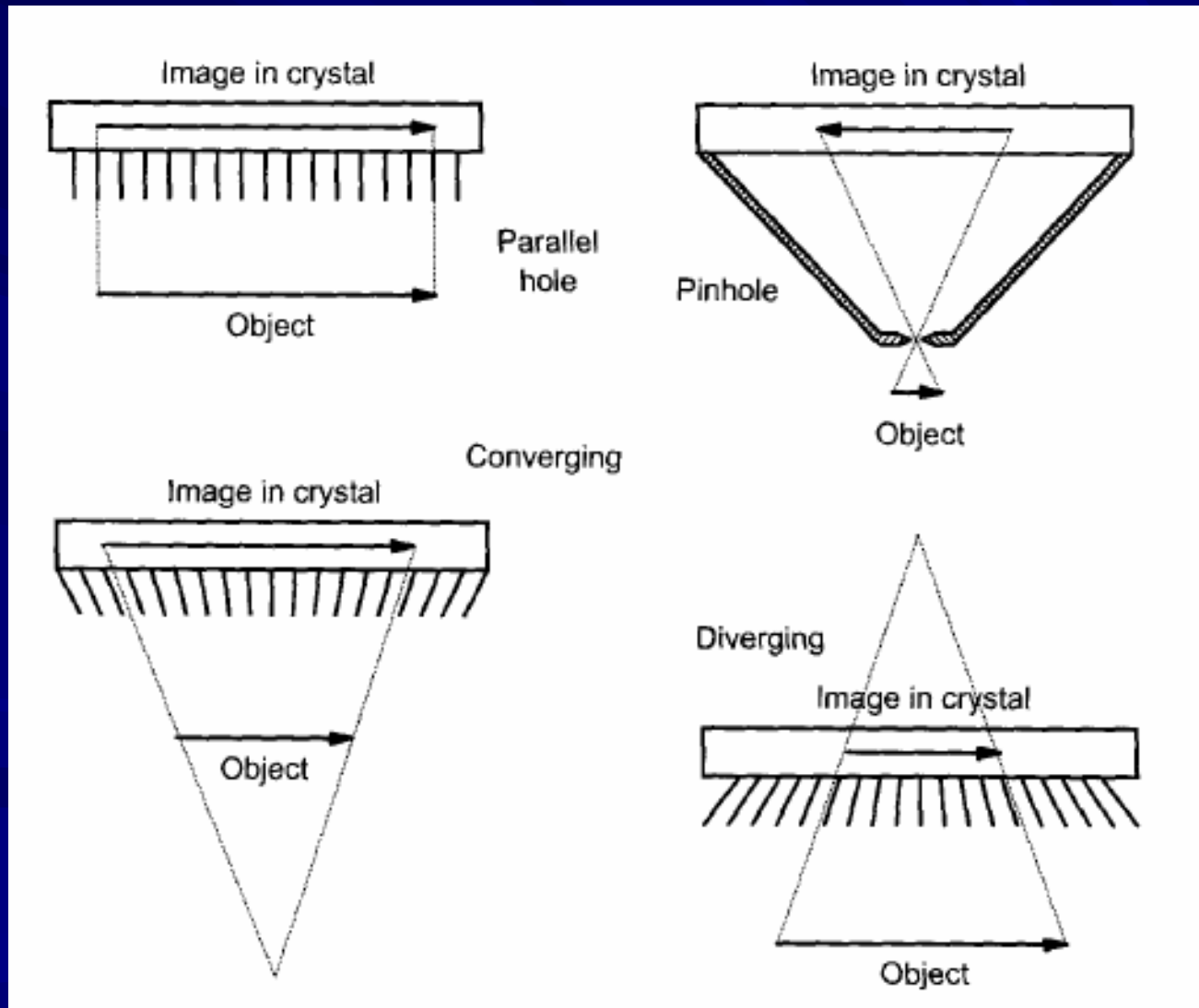
- **Device used to minimize the effect of scattered radiation.**
- **Usually it is constructed with lead**

Types:

- **Parallel multihole**
- **Diverging**
- **Converging**
- **Slant hole**
- **Pinhole**

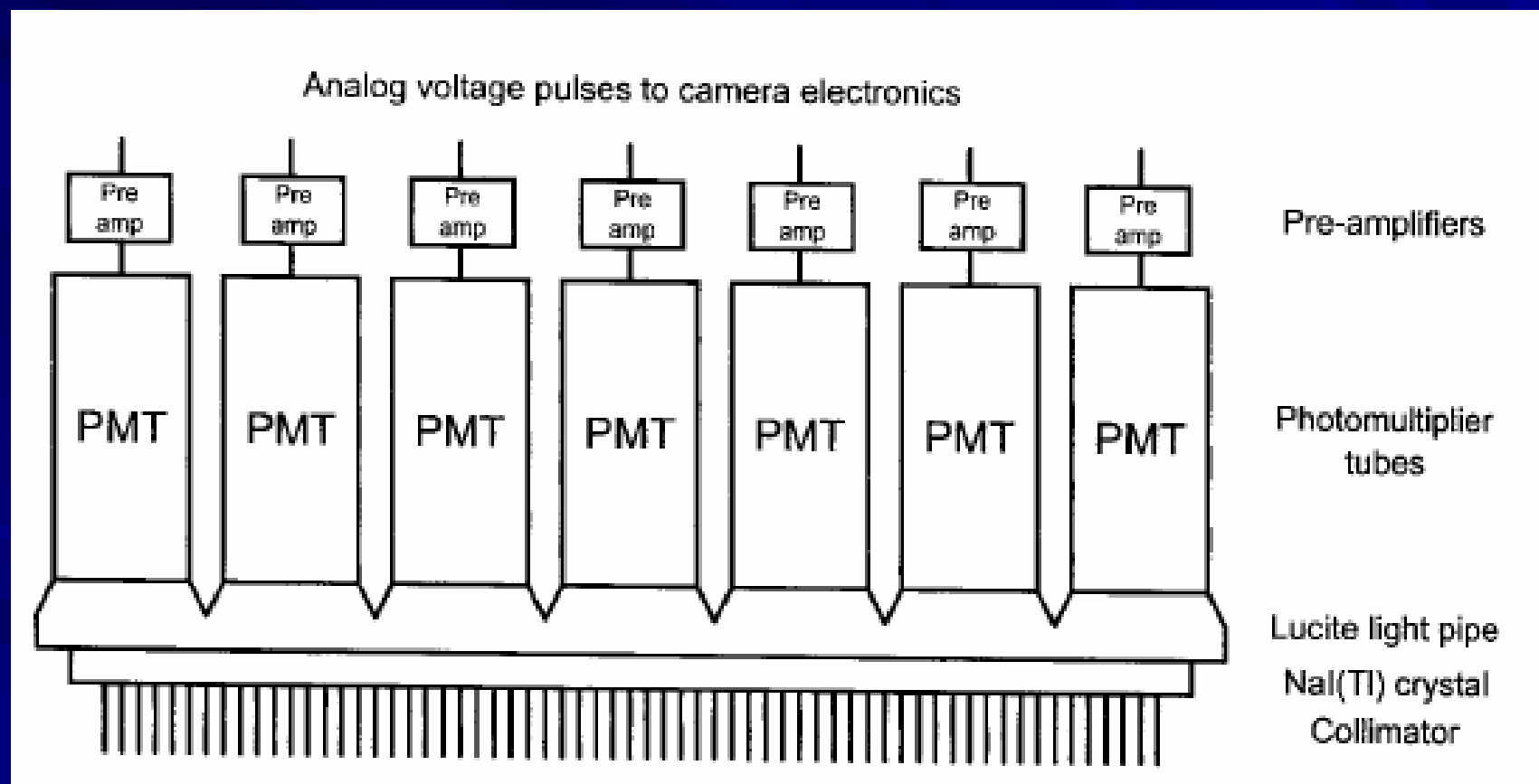
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Collimators



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Light guide/PMTs/Preamplifiers



Position calculations

For a scintillation event in the crystal, the amount of light given off is proportional to the amount of energy imparted in the crystal

This light will be detected by more than one PMT. Thus depending on how much light the PMT sees, the output signal will be different. The amount of light seen by a PMT is a function of the distance between the scintillation event and the PMT. (Except at the edges)

Thus, the closer the PMT is to the scintillation event, the larger the output signal, and conversely, the further away the PMT, the smaller the output.

The total of all output signals is proportional to the total energy deposited in the crystal by the incoming γ ray.

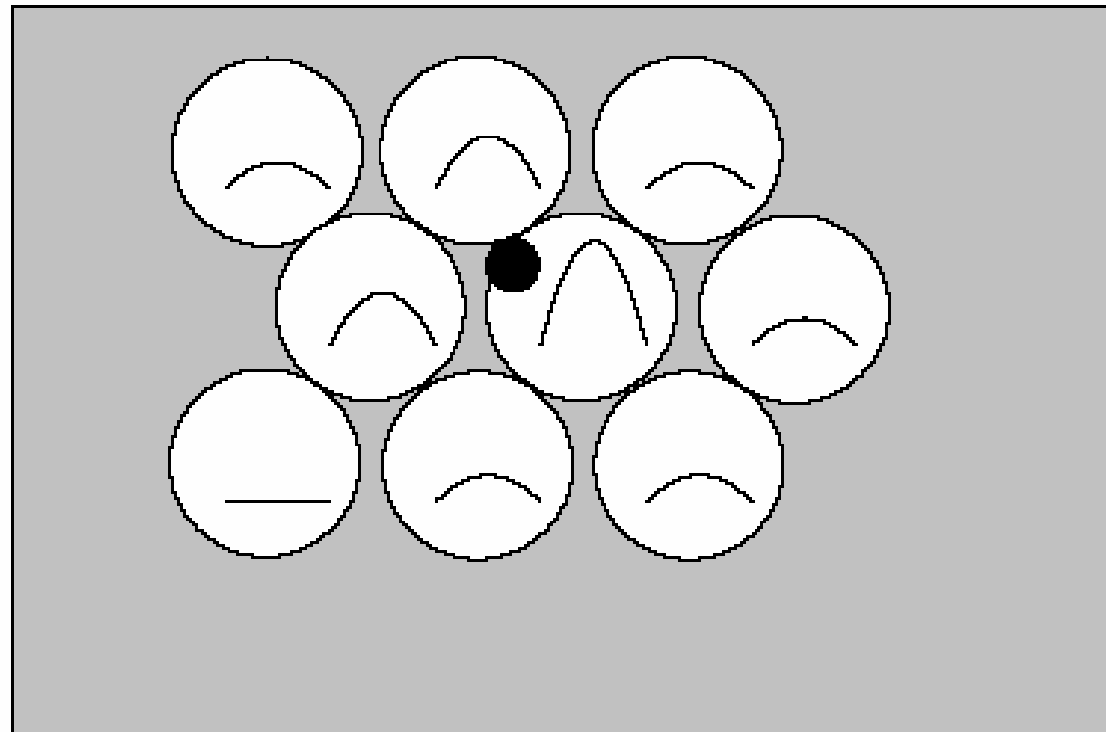
So if we combine the relative output signals from each PMT according to its XY location on the detector, we can determine the XY location of the scintillation event. This is performed with a position encoding matrix.

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The output from each PMT tube is wired into a capacitor (resistance) array that determines 4 outputs signals: X^+ , X^- , Y^+ , Y^- .

X^+ consists of increasing capacitance moving across the X direction

X^- consists of increasing capacitance moving in the opposite direction across the X direction. Similar for Y directions.



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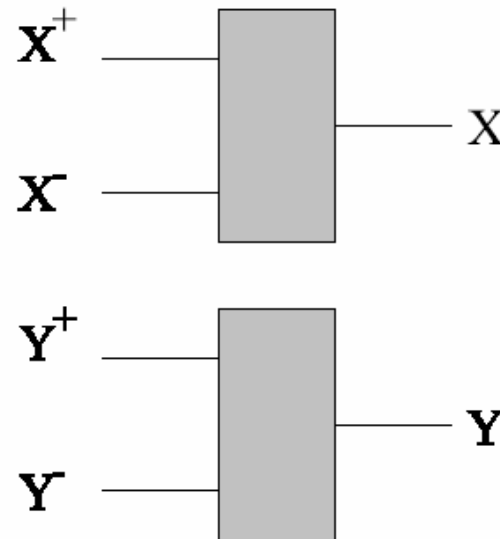
Difference Circuits

X position is found by the difference between the X^+ and X^-

$$X = X^+ - X^-$$

Y position is found the same way

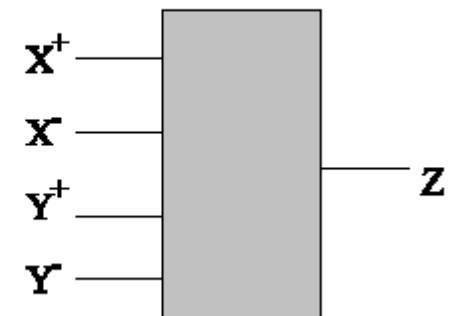
$$Y = Y^+ - Y^-$$



Summing Matrix Circuit (SMC)

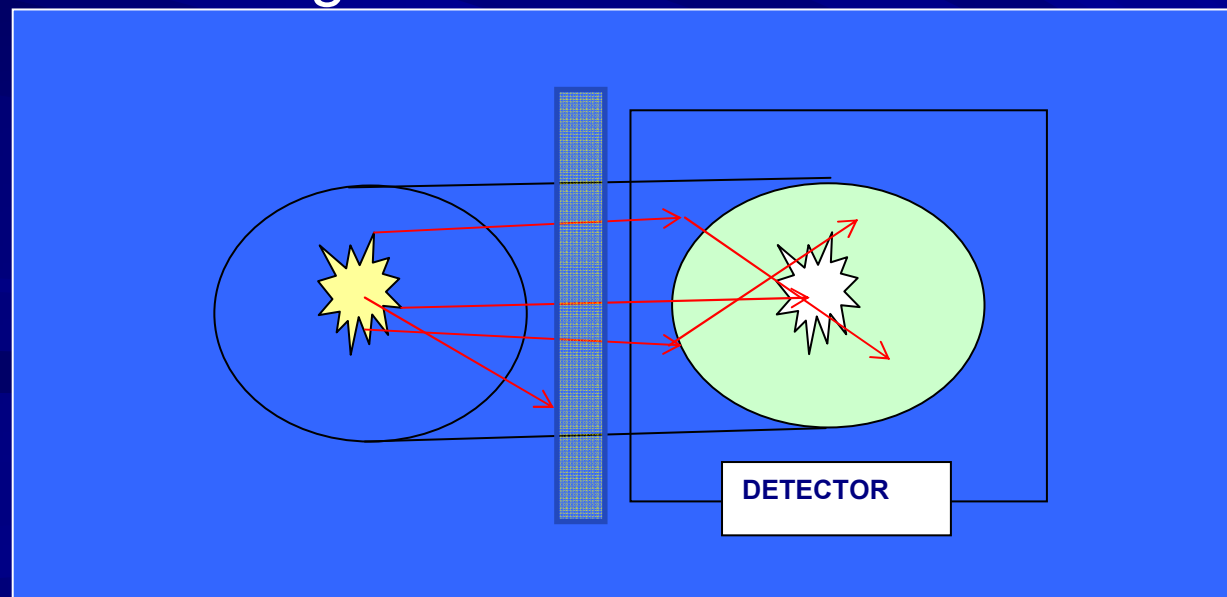
Total signal (equivalent to total light output)

$$Z = X^+ + X^- + Y^+ + Y^-$$



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As discussed before, the scattered radiation (incoming or produced inside the detector) is not contributing for the image and should be minimized. The collimator is reducing the incoming external scattered radiation but for minimizing the effects in the image, it is necessary also to try to eliminate the scatter produced inside the detector. This is performed by a multichannel analyzer which discriminates the pulses produced by the photons not depositing all their energies in the detector.



Pulse height analyzer

Determines the energy of the incident γ ray that interacts within the NaI(Tl) crystal. The total light produced in the scintillator is proportional to the energy of the γ photon.

Output voltage from PMTs gets summed into Z pulse. Size of the Z pulse represents the energy of the detected gamma photon.

Windowing is also done to bin energies within a certain range into energy channels $\rightarrow$ result is a histogram of measured counts/channels

Use PHA to select the photo peak of the gamma emitter we are using.

The Gamma Camera

History

- 1956** Hal Anger at Donner Labs
 - $\frac{1}{4}$ " NaI(Tl) Crystal
 - 5" diameter containing 7 PMTs
- 1960** First commercial units available by Nuclear Chicago, Searle and Siemens
 - $\frac{1}{2}$ " Crystal
 - 7" diameter containing 7 PMTs
- 1963** Crystal size $\frac{1}{2}$ " thick NaI(Tl)
 - 11,5" diameter with 19 PMTs
- Now** Crystal thickness from $\frac{1}{4}$ " to $\frac{3}{4}$ "
 - up to 24 " diameter
 - Up to 91 PMTs

Types of Gamma Cameras

Analog – Acquisition and processing analog

Semi-digital – Acquisition analog and processing digital

Full-digital – Acquisition and processing digital

Planar

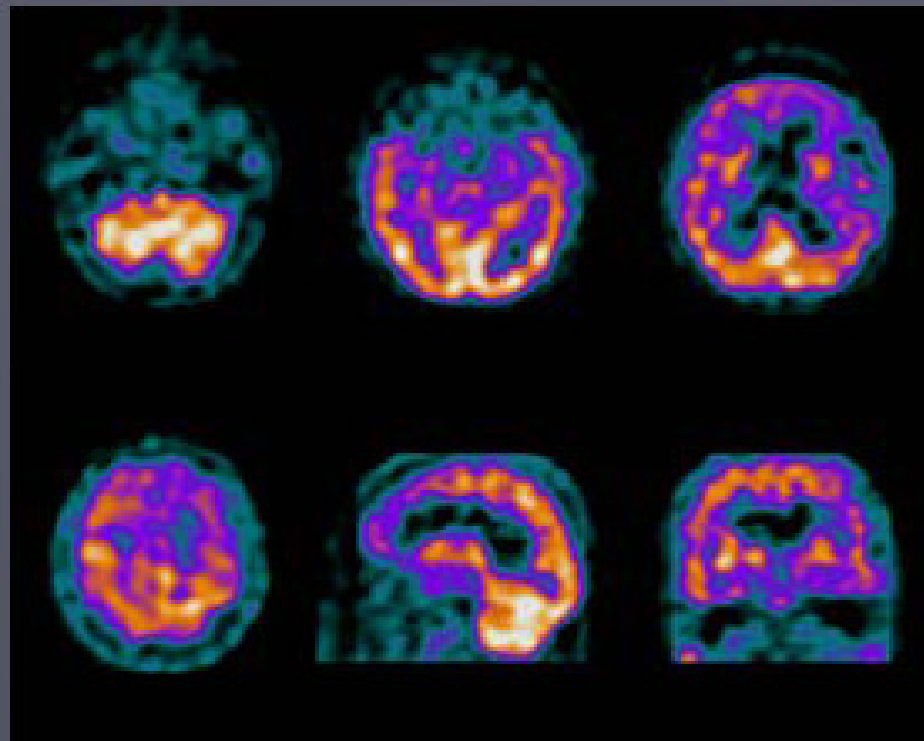
SPECT (Single photon emission computerized tomography)

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Scintigraphy (SPECT): imaging device

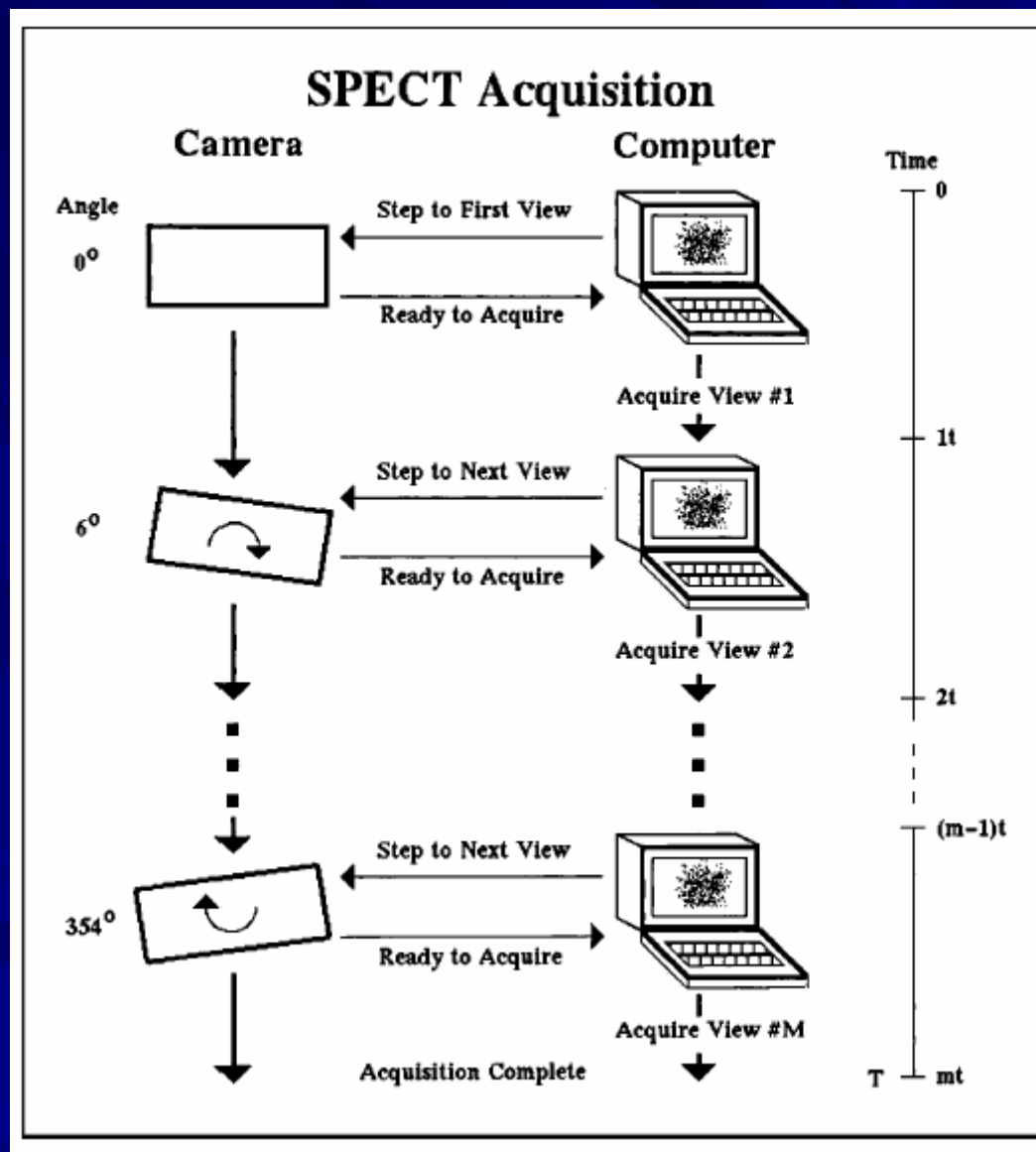


Single Photon Emission Tomography

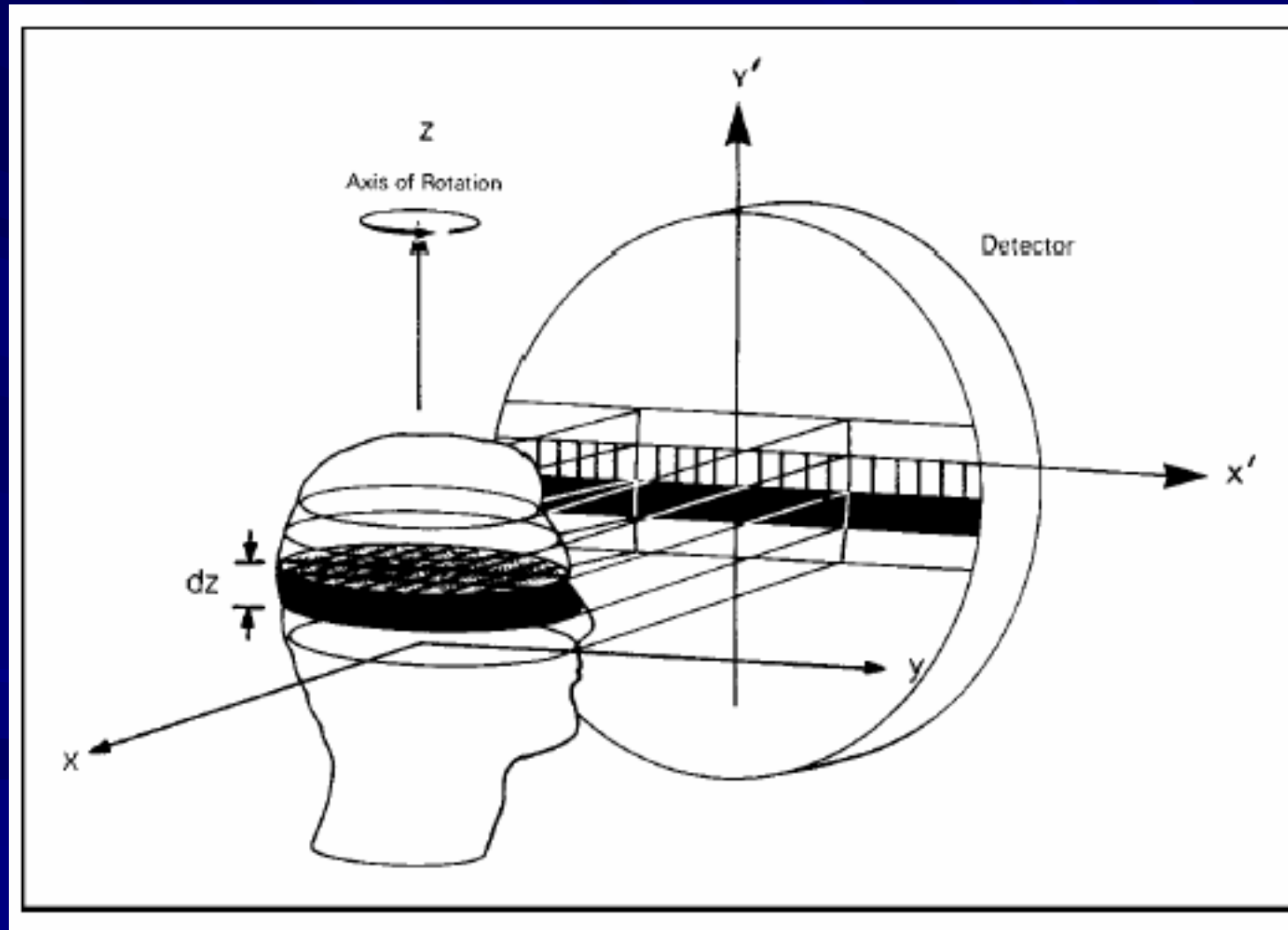


SPECT gives functional information

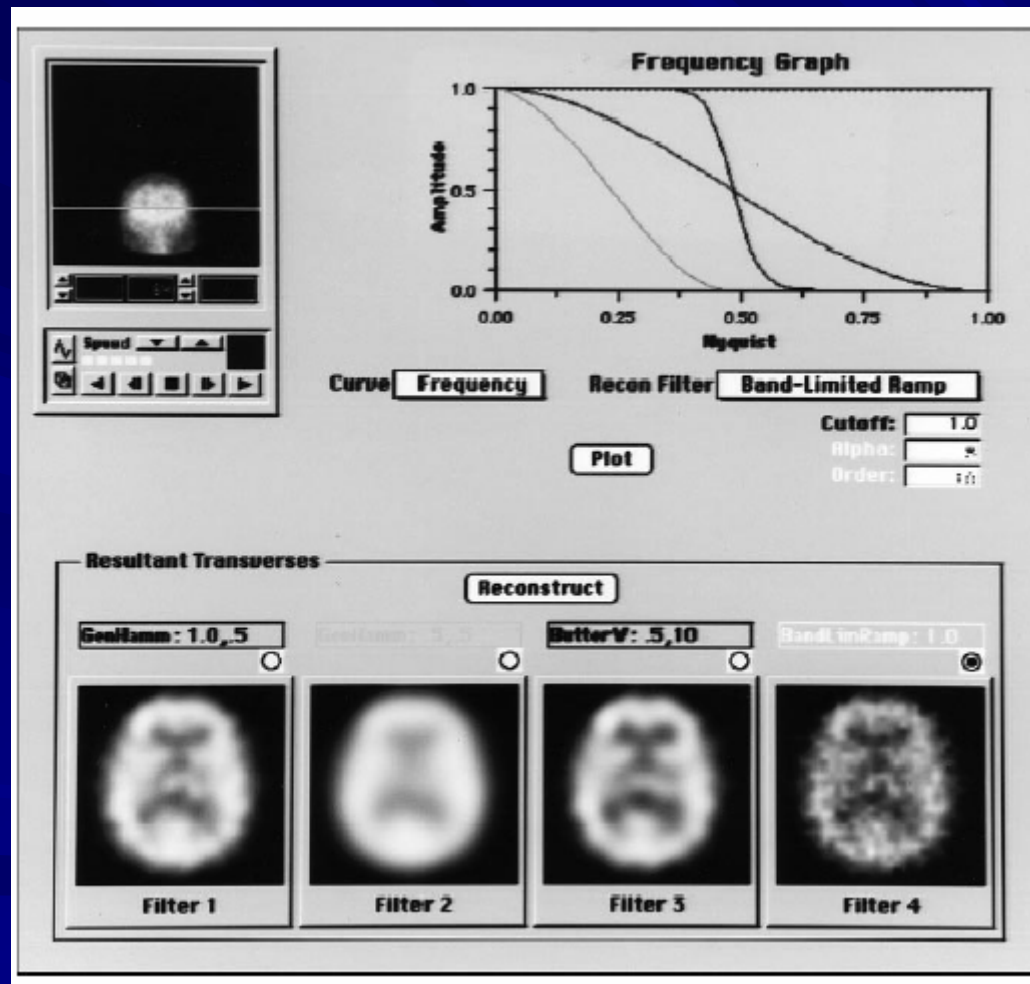
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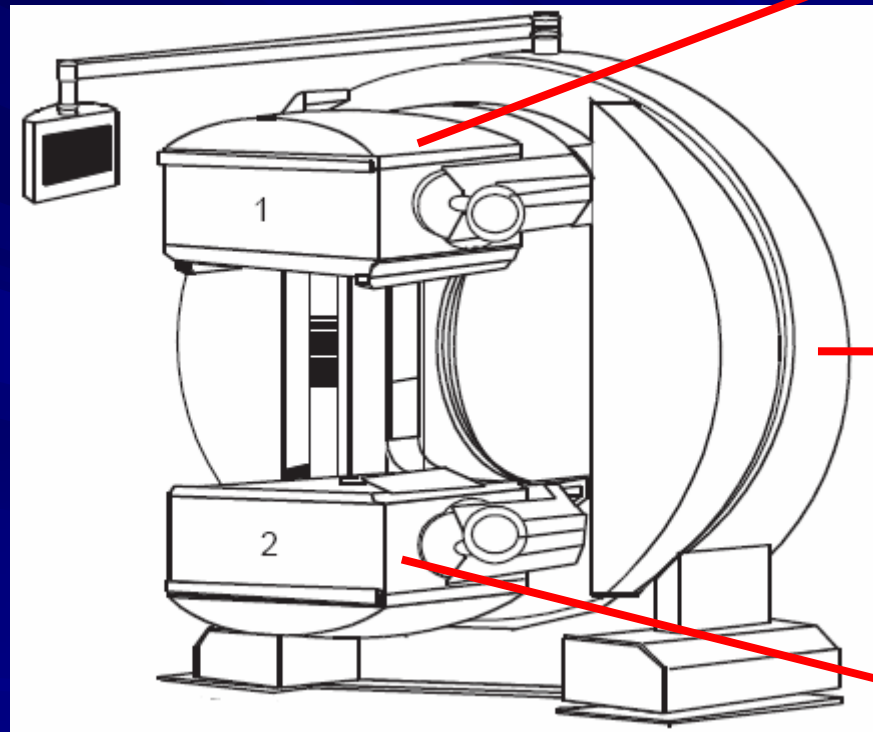


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Additional components in the SPECT GCs

- One or two heads
- Rotation of the gantry (one strong motor)
- Axial movement of the heads (two motors)
- Lifting the patient table (two or three motors)
- Movement of the pallet (one motor)
- Electrocardiogram system

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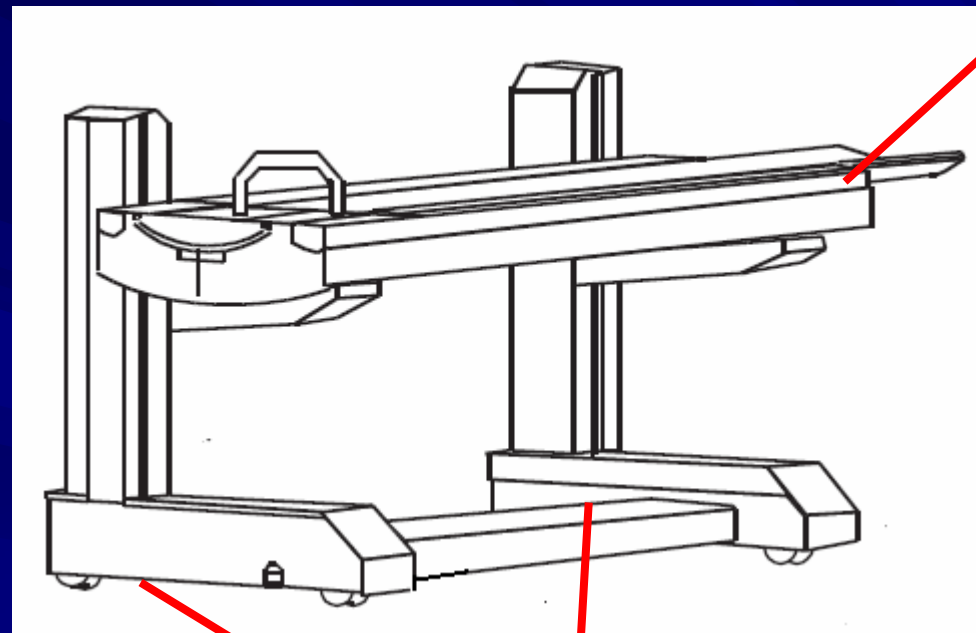


Head 1 axial
movement
control

Heads rotation
movement
control

Head 2 axial
movement
control

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Pallet movement
control

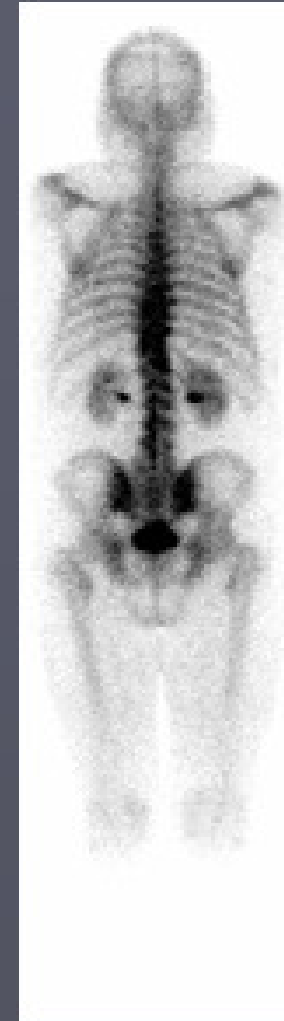
Table height
control

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Nuclear Imaging

Application to the
detection of bone
metastases



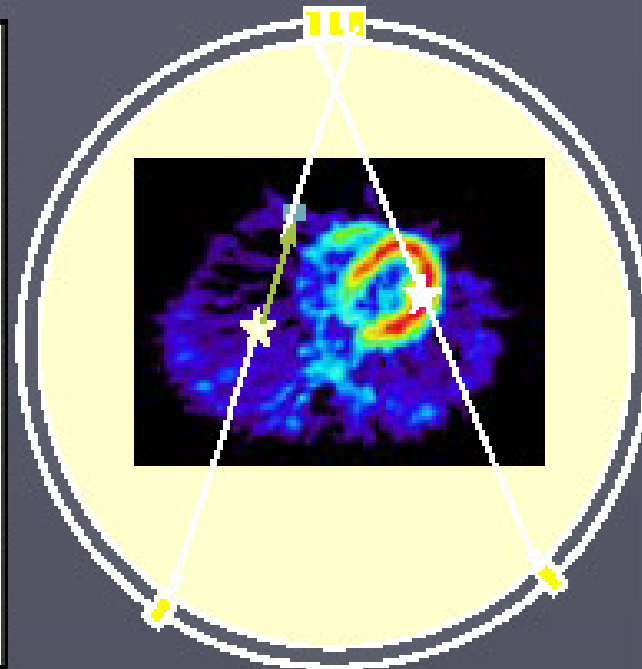
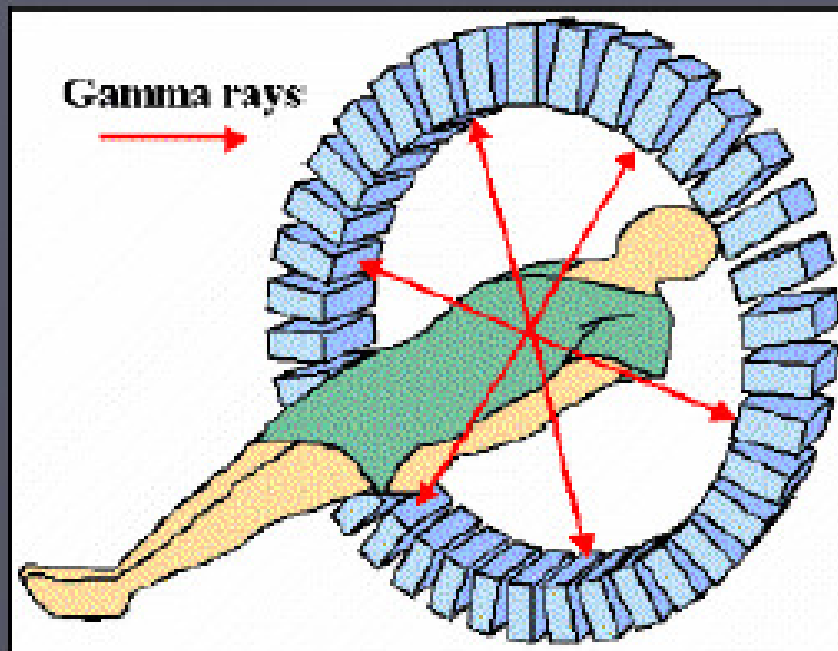
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SIEMENS ECAM

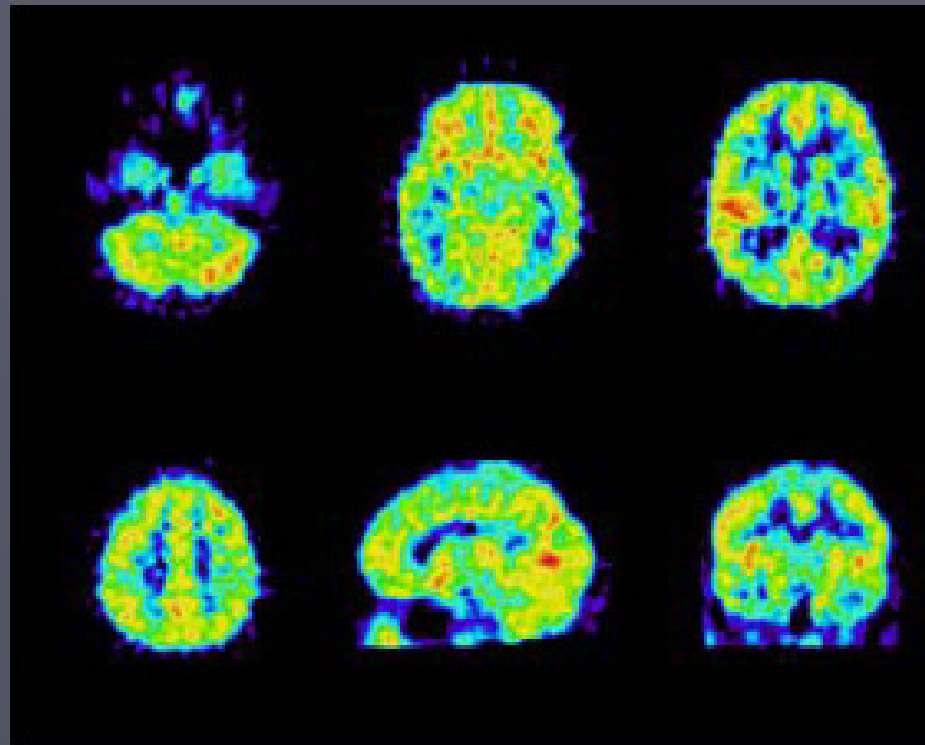


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PET: principles

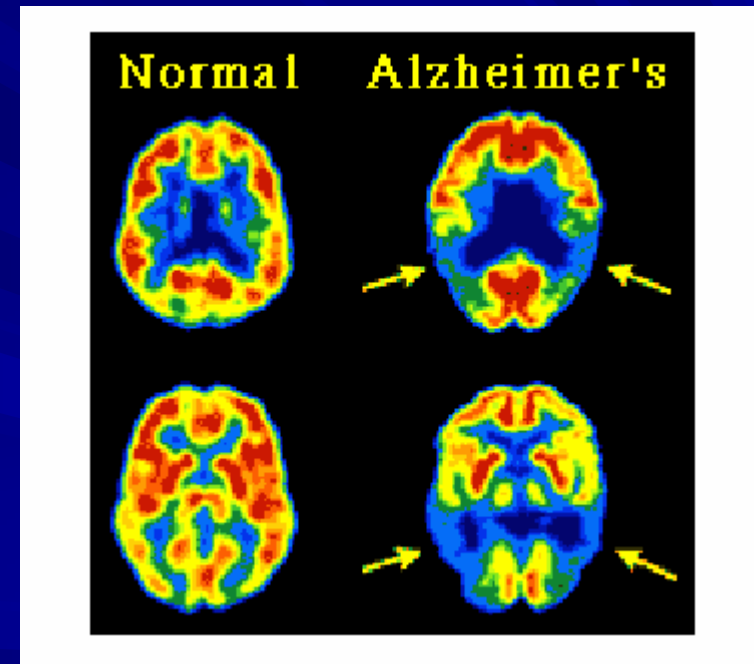
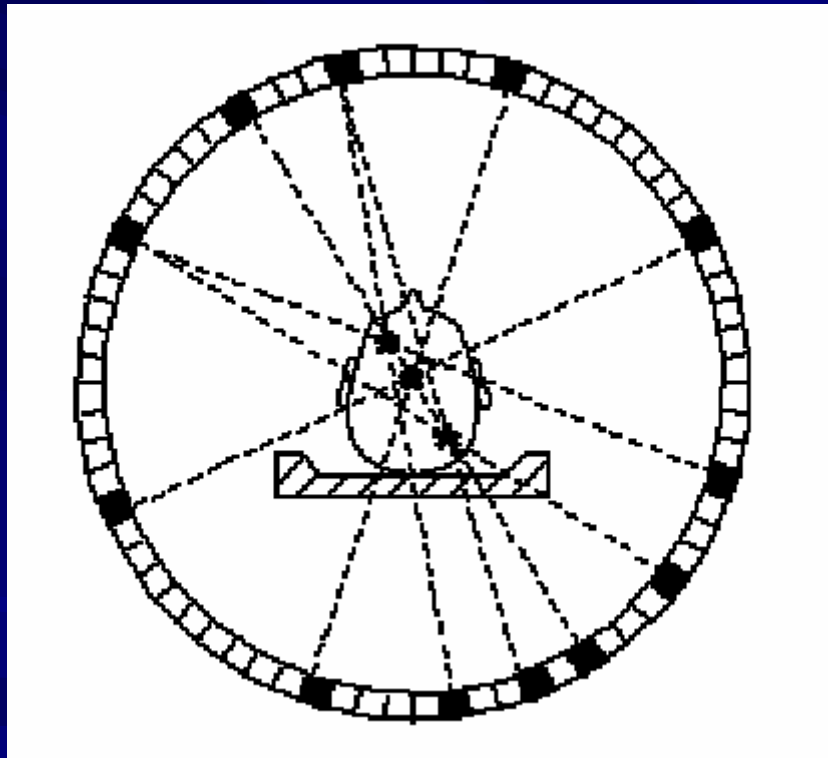


Positron Emission Tomography



PET gives functional information

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Quality control

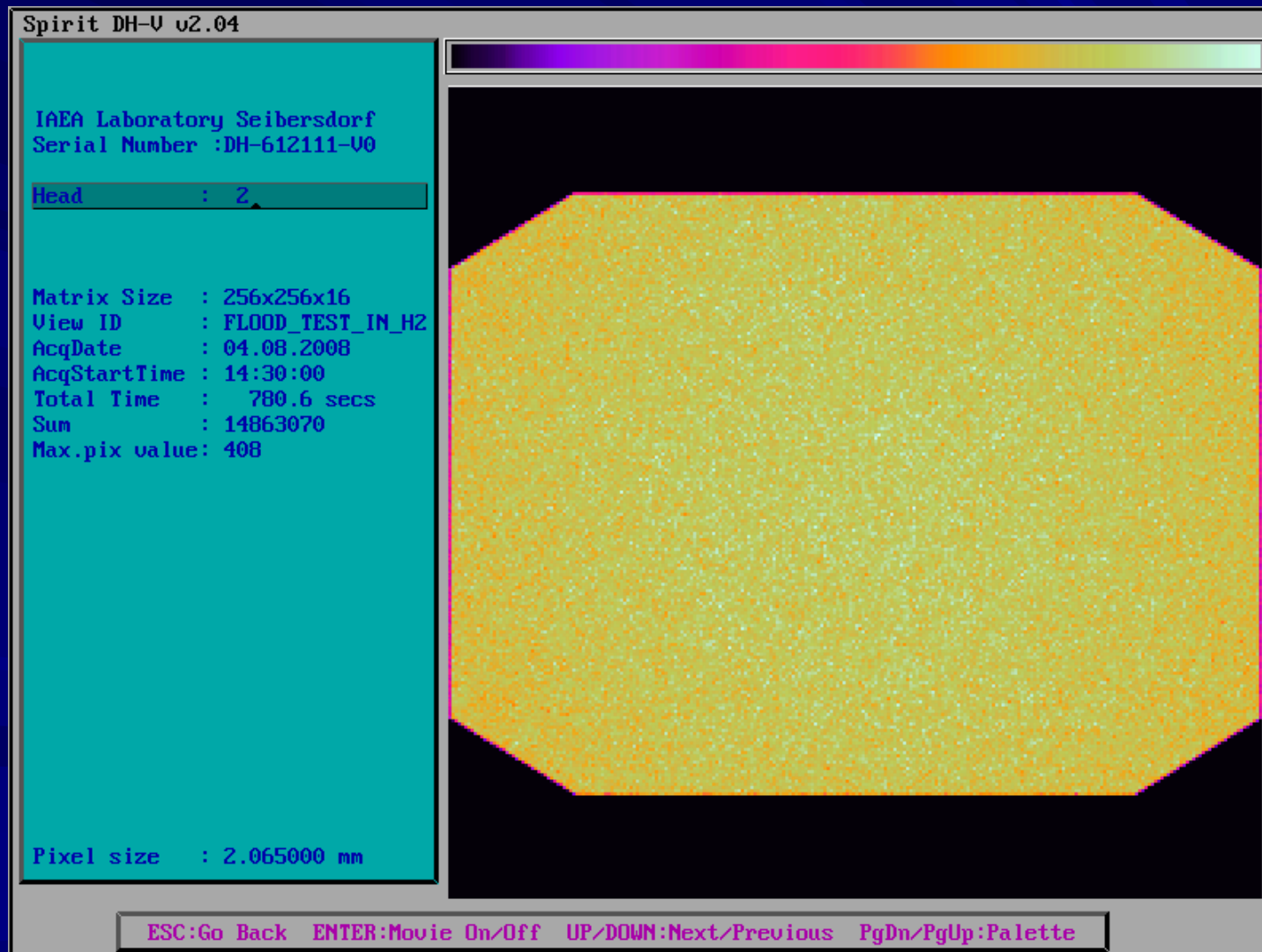
Homogeneity

Linearity

Center of rotation (SPECT)

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Homogeneity



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Homogeneity

Intrinsic and extrinsic



Flood phantom

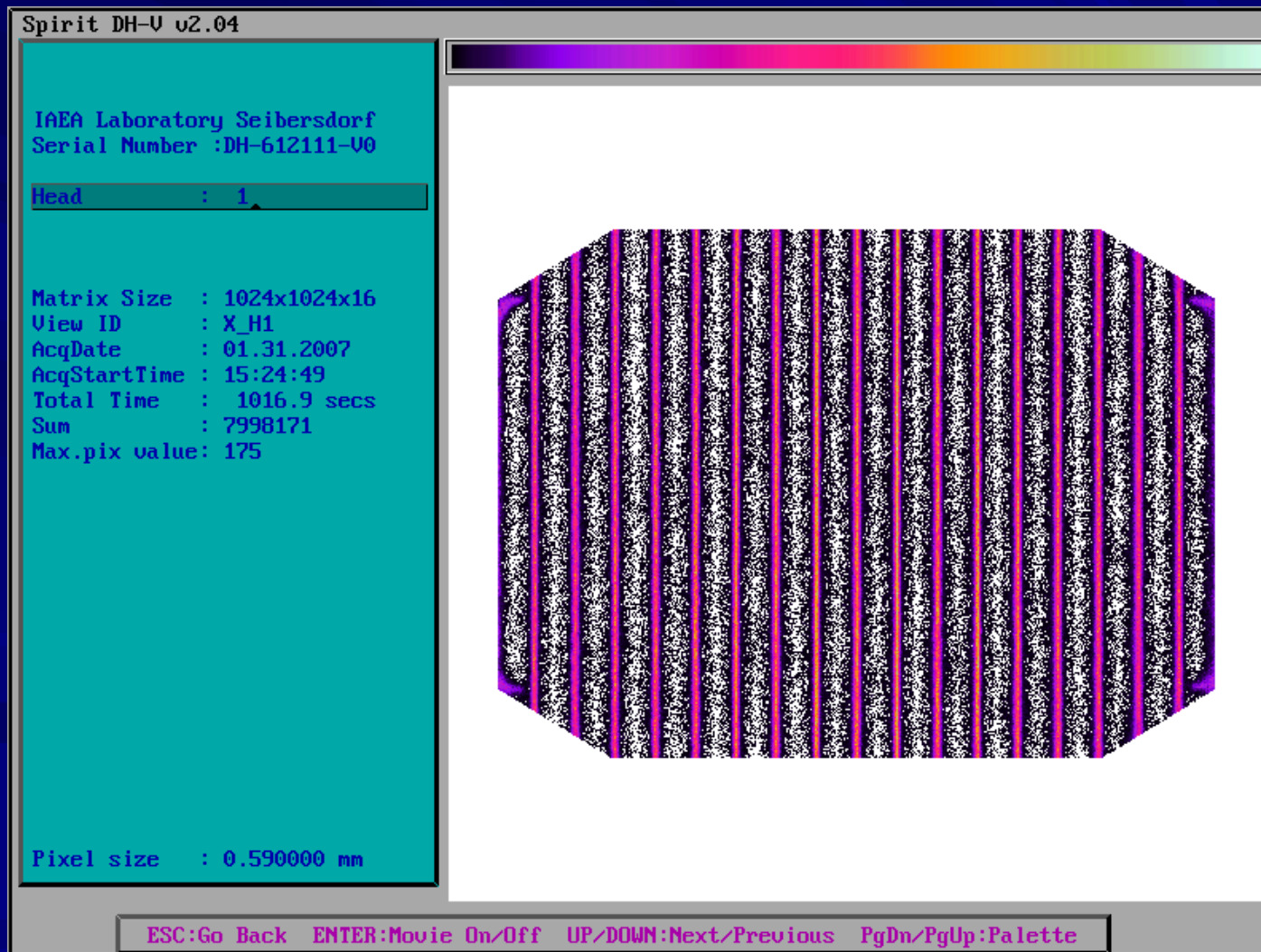


Co-57 flat source

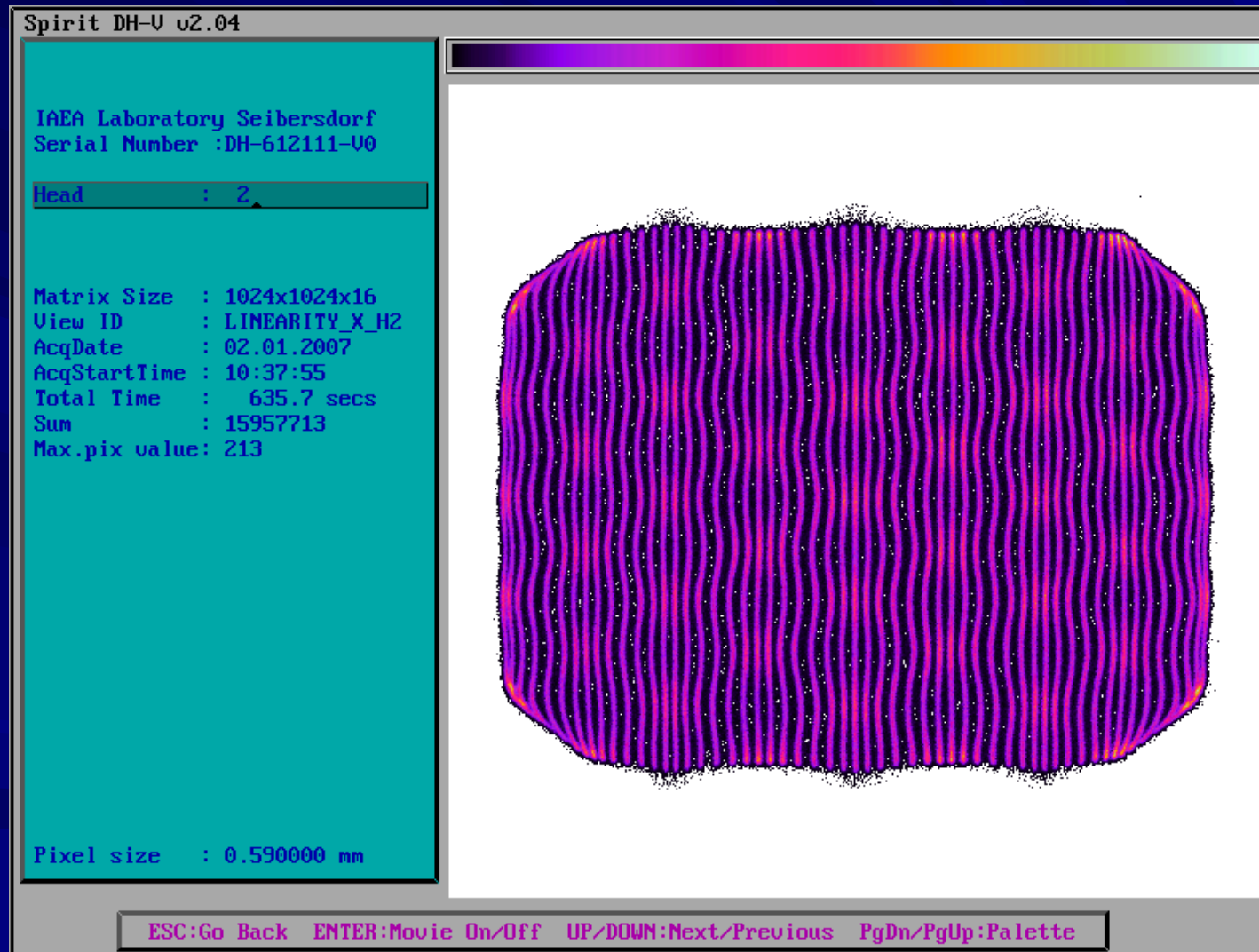
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Linearity

Integral and differential

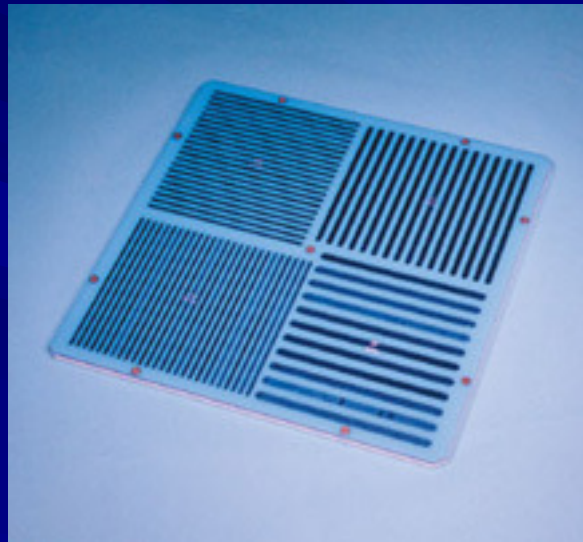


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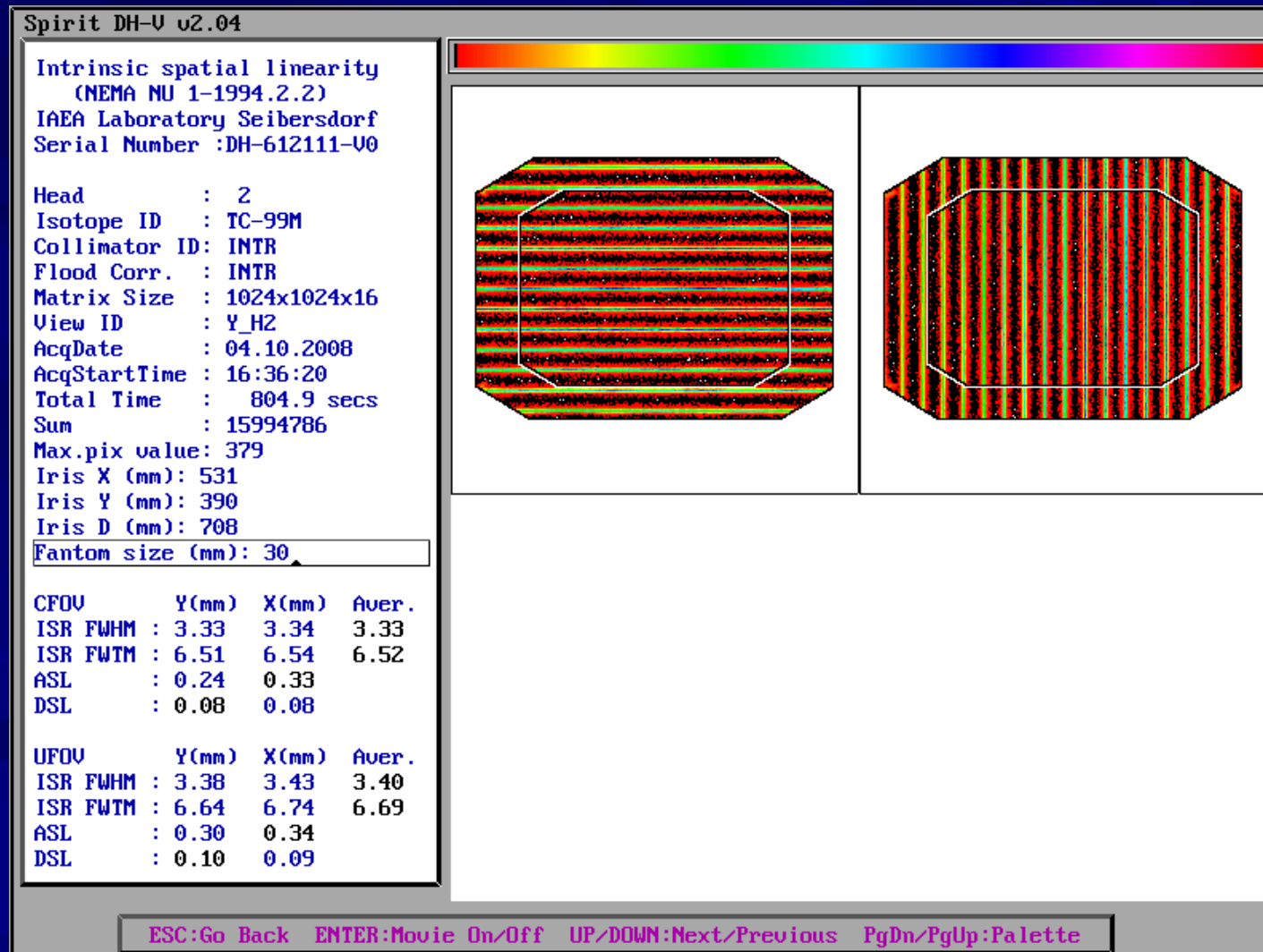
Resolution



Bar phantom

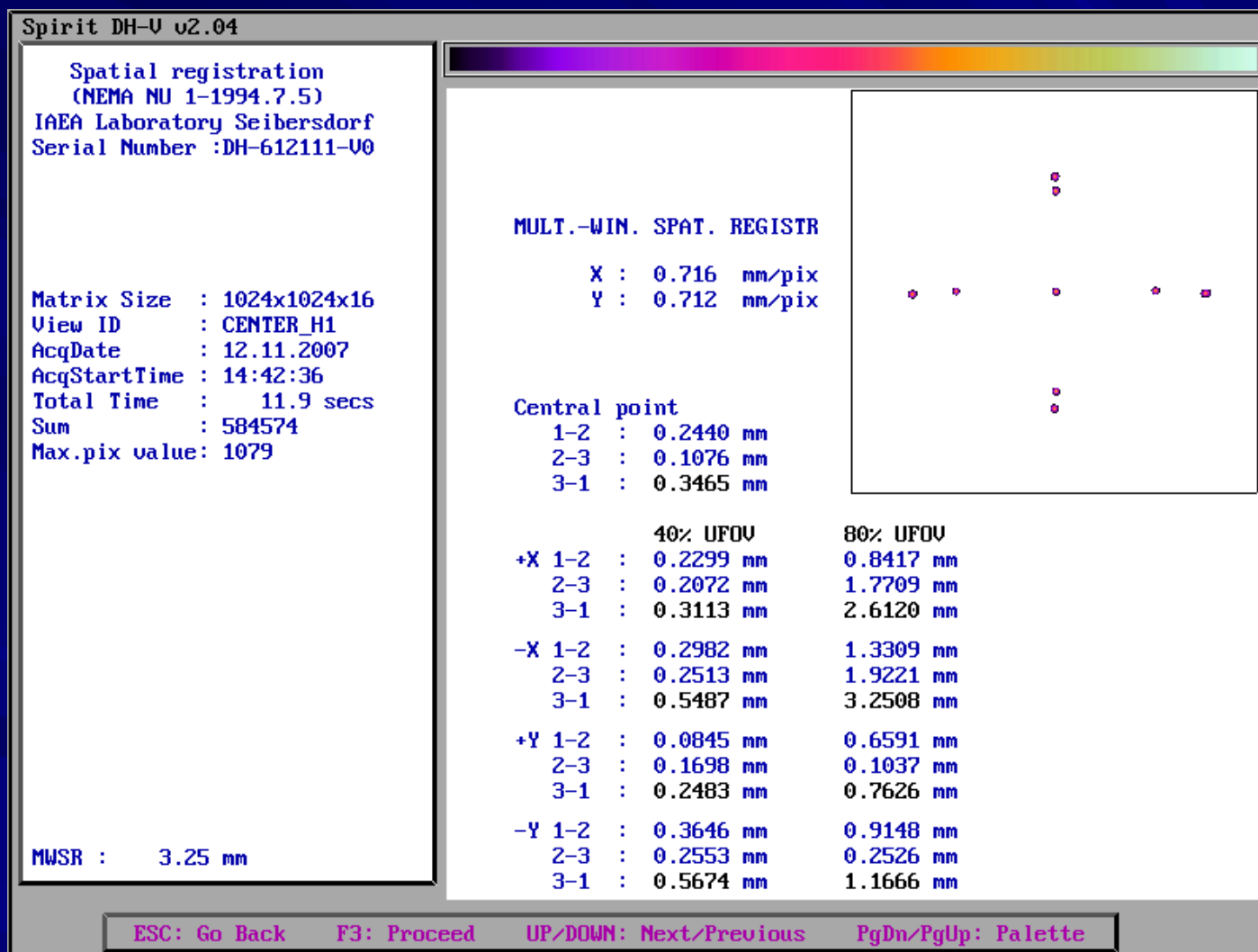
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NEMA Tests



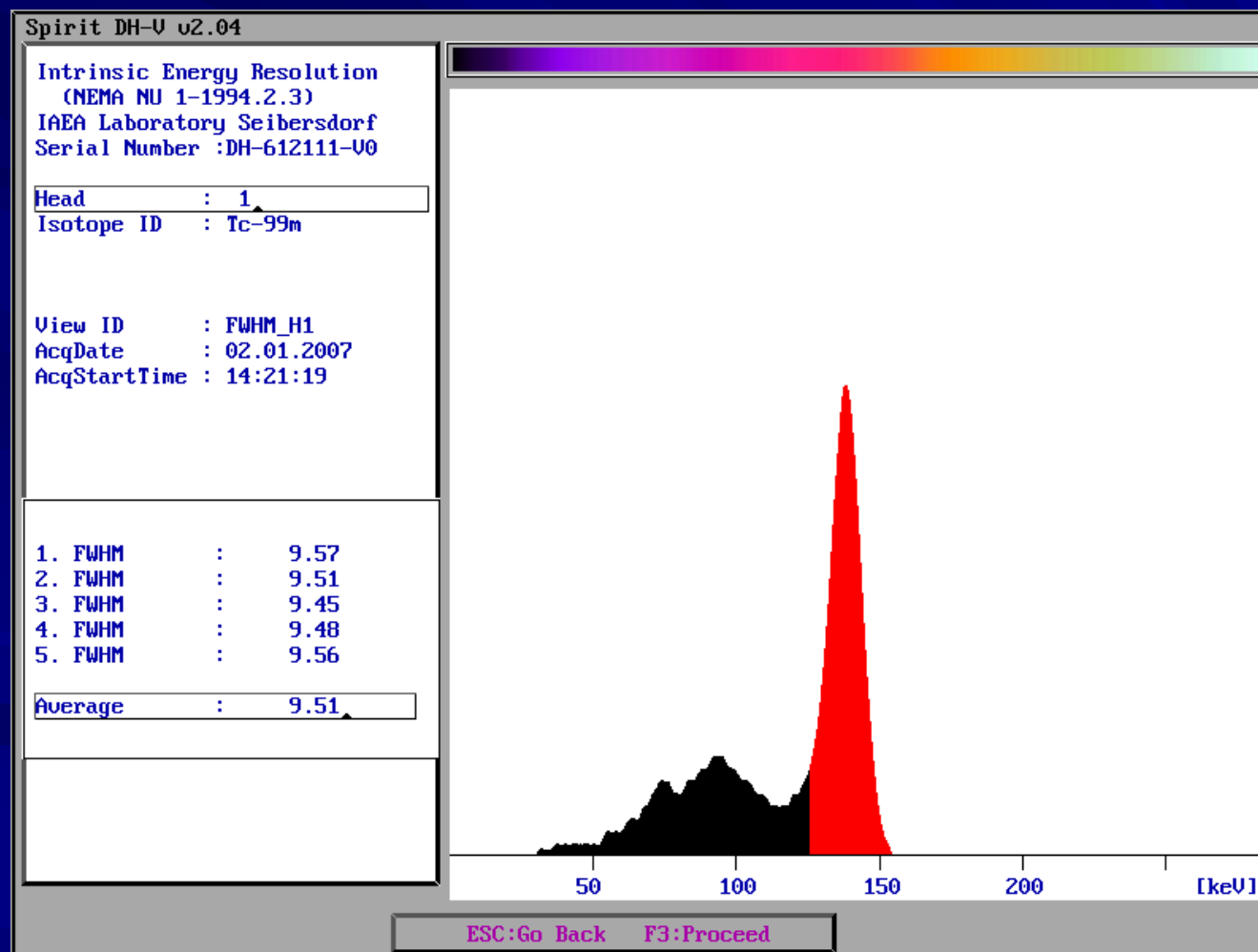
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Spatial registration



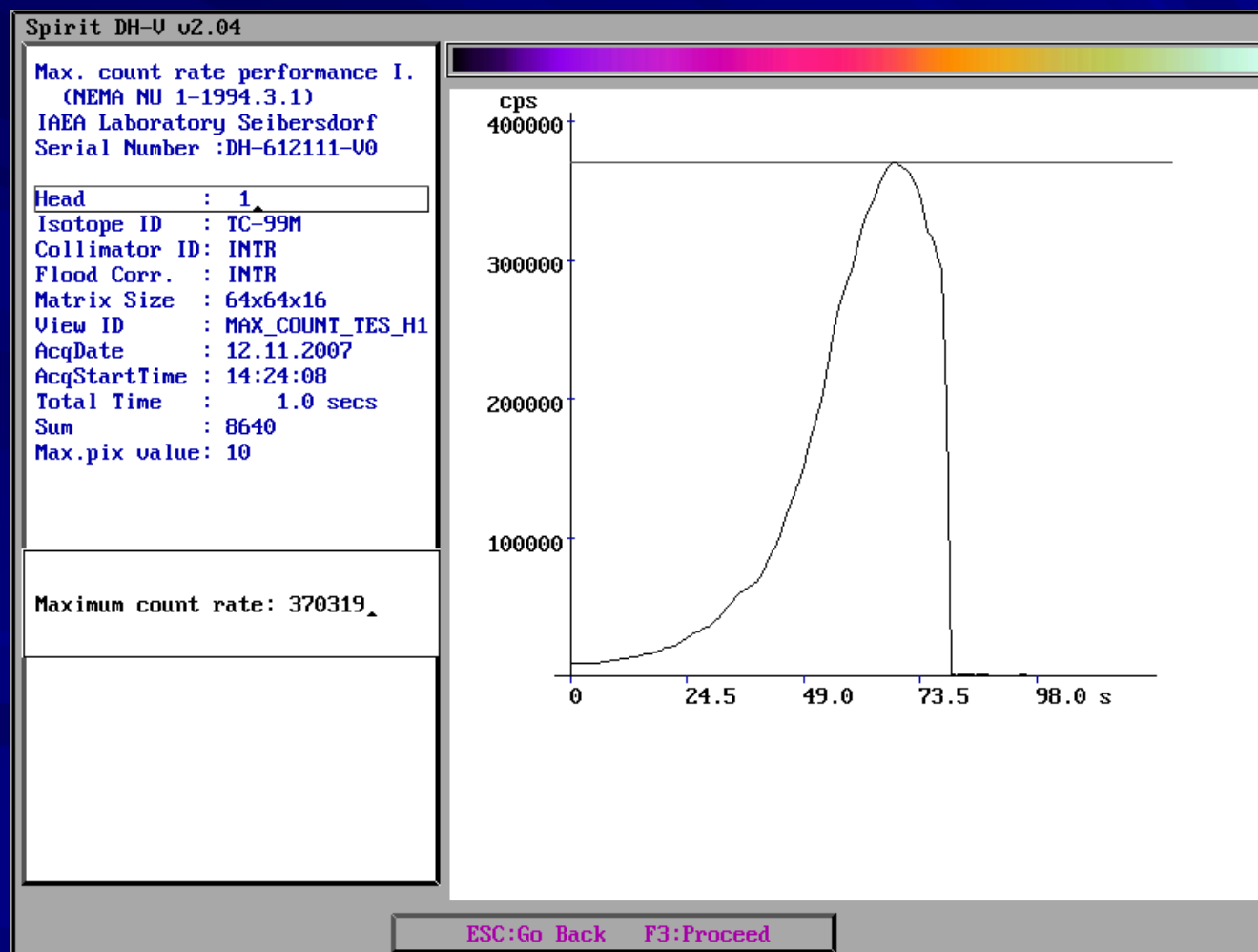
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Energy resolution



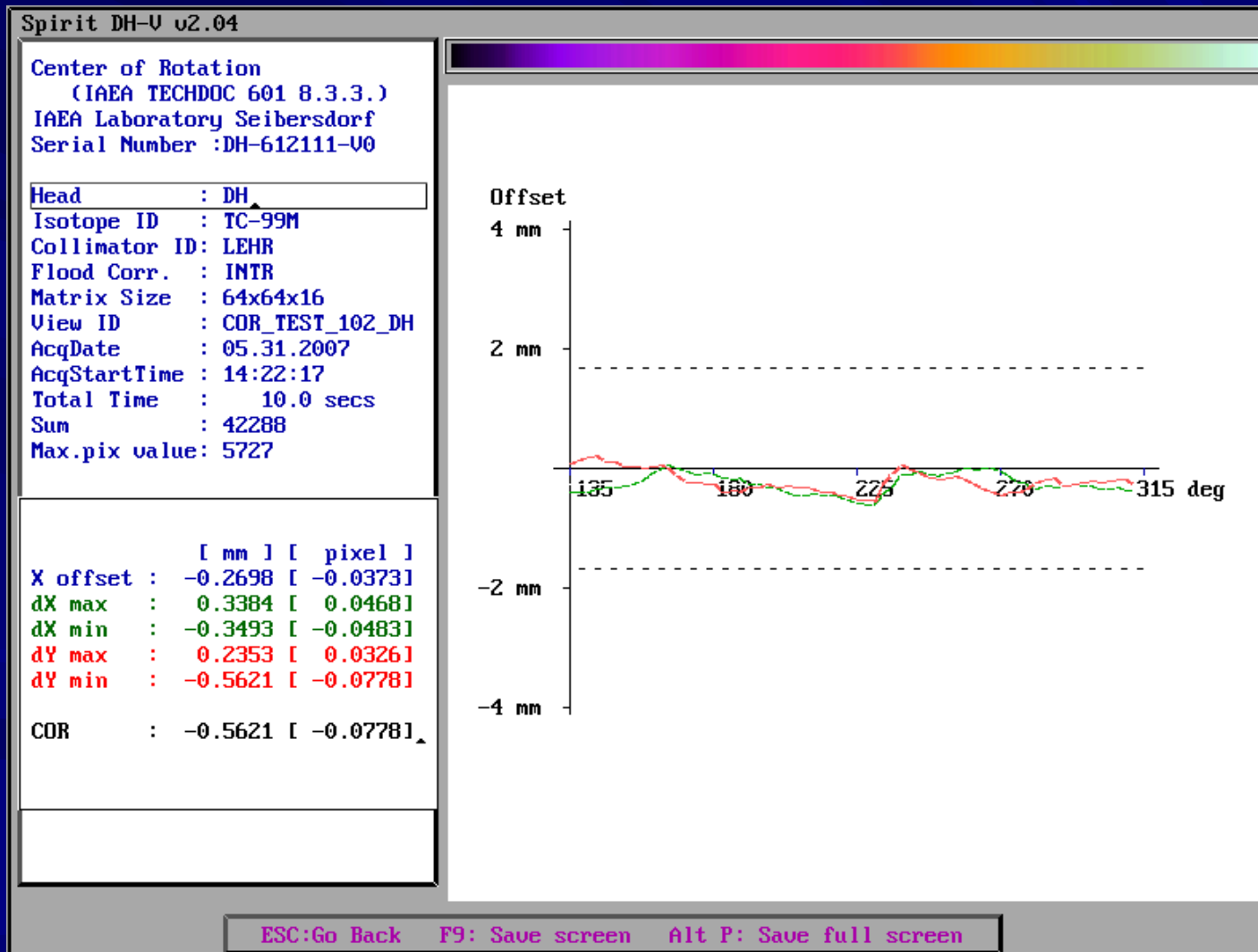
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Maximum counting rate



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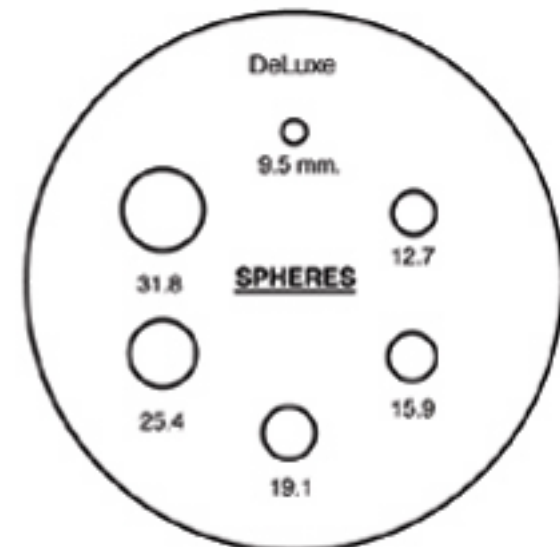
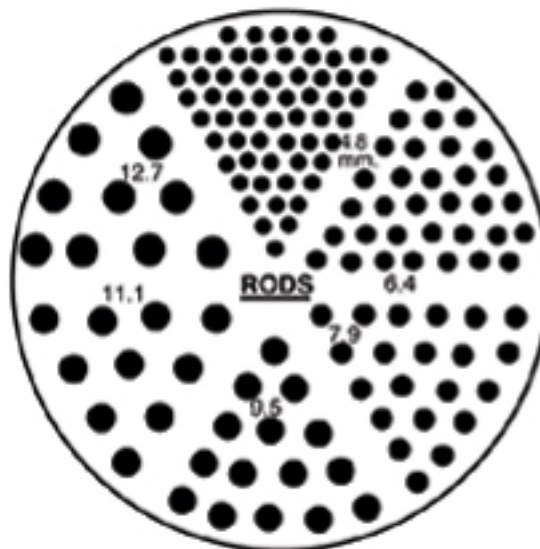
Center of Rotation



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Jaczjacks Phantom



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Triple lines



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Shielding



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Radiation protection

The x ray discover of x ray produced a great advance for science. Very soon after its discover some harmful effects appeared. The first victims where the physicists and medical doctors involved in the research and utilization of ionizing radiation.

In 1928 was created a commission that later generated the actual **International Commission for Radiation Protection (ICRP)**. This commission produces guides and information for the secure use of ionizing radiation.

ICRP divided the ionizing radiation in the following way regarding the risk of a particular effect:

Somatic stochastic - (occurs with the irradiated person and have random nature). In these effects, the involved cells are modified by radiation but not destroyed. Later there is a possibility of producing cancer.

Stochastic hereditary – In these effects the cells can be damaged in a way that they will transfer modified genetic information for a descendent.

Deterministic (non stochastic) – In these effects the cells of an organ or tissue are destroyed and loose their function.

Quantities associated to radiation protection

A similar committee was created for defining the quantities related to radiation, the International Committee for Radiological Units (ICRU). The main quantities defined looking to associate the effects of the ionizing radiation in the human body are:

Absorbed Dose (Unit: Gray (Gy)) - It a measure of the energy deposited by radiation in a specific tissue per unit of mass of this tissue ($1 \text{ Gy} = 1 \text{ J kg}^{-1}$).

Equivalent Dose (Unit: Sievert (Sv)) – This quantity associates the absorbed dose to the type of radiation involved using weighting factors. In case of Gamma, X rays and Beta particles, this factors is equal to one in case of alpha particles in equal to 20, etc.

$$H = w_T \cdot D_T$$

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Type of Radiation	ICRP w_T Values
X-rays, γ -rays, β -rays	1
neutrons ($E < 10$ keV)	2 to 5
neutrons ($E = 0.01$ MeV)	2.5 to 10
neutrons (0.1 MeV)	7.5 to 10
neutrons (0.5 MeV)	10 to 20
neutrons (0.1 to 2 MeV)	20
neutrons (2 to 20 MeV)	5
neutrons (general)	10
high-energy protons, α -particles, fission fragments, or heavy nuclei	20

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Effective Equivalent Dose (Unit Sievert (Sv)) – This is the dose that once applied to the whole body will involve the same risk of mortality as if applied to a specific part of the body. In this case, in addition to the weighting factor for the involved radiation, other weighting factor are applied for each organ or tissue.

Organ or tissue	Weighting factor
Gonads	0,20
Bone marrow (red)	0,12
Lungs	0,12
Stomach	0,12
Liver	0,05
Thyroid	0,05
Skin	0,01

The effective equivalent dose is calculated as:

$$E = \sum W_T \cdot D_T \cdot w_T$$

**Where: W_T is the weighting factor for the organ or tissue involved,
 D_T is the absorbed dose in the organ or tissue involved,
 w_T is the weighting factor for the radiation type.**

Main cares to have when working with ionizing radiations:

Distance - To be as further as possible from the radiation source;

Time – To be exposed to radiation for the lowest time as possible;

Shielding – To use shielding (lead for example) (walls, gloves, etc);

Area – To use the smallest radiation beam as possible (in area);

Simulators - To apply test instruments and simulators for calibration and adjustment, never use the body for checking or calibrating radiation.