FONDAMENTI DI FISICA MEDICA

PARTE 2: METODI D'IMMAGINE IN MEDICINA NUCLEARE (1CFU)

LECTURE 2 – SCINTIGRAFIA E SPECT

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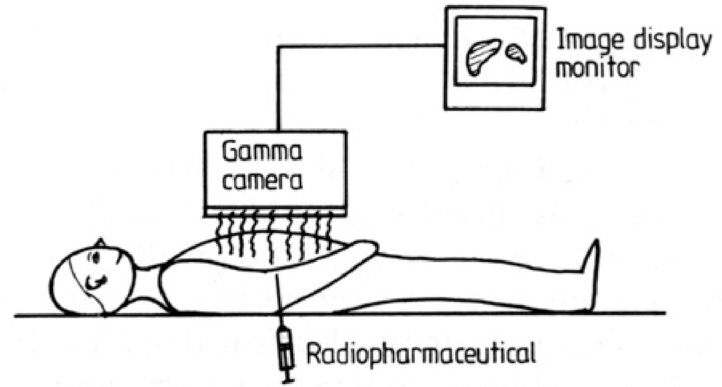
Scintigrafia

- The essential physics of medical imaging
  Section III: Nuclear Medicine
  Jerrold T. Bushberg, *et al*. editors
- Introduction to medical physics
  De Ponti & Bertocchi, Chapter 6,
  Nuclear Medicine Imaging
  Stephen Keevil, *et al*. editors

General Principles

- The basic principle of nuclear medicine (NM) imaging is the administration to patients of **radioactive tracers** (radiopharmaceuticals) that distribute in the body according to specific metabolic processes
- Administration can be by:
  - intravenous injection
  - inhalation
  - oral ingestion
  - direct injection into an organ



- Tracer uptake times may take from a few minutes to a few hours before optimal distribution in the organ is achieved
- The patient can then be scanned and gamma ray photon emissions from the tracer detected

General Principles

- Nuclear medicine imaging is essentially the detection of gamma photons of an energy that:
  - can exit the patient's body

    and
  - can be detected in the imaging system
- Information from the emitted photons is used to create an image (or a sequence of images) showing the radiopharmaceutical (tracer) distribution inside the patient
- Images can be acquired and reconstructed as static planar or tomographic images or can be collected over time in dynamic sequences

General Principles

- Imaging modalities
  - Planar (**Scintigraphy**)
    - Static
    - Dynamic
  - Tomographic
    - **SPECT** (**S**ingle **P**hoton **E**mission **C**omputed **T**omography)
    - **PET** (**P**ositron **E**mission **T**omography)

General Principles

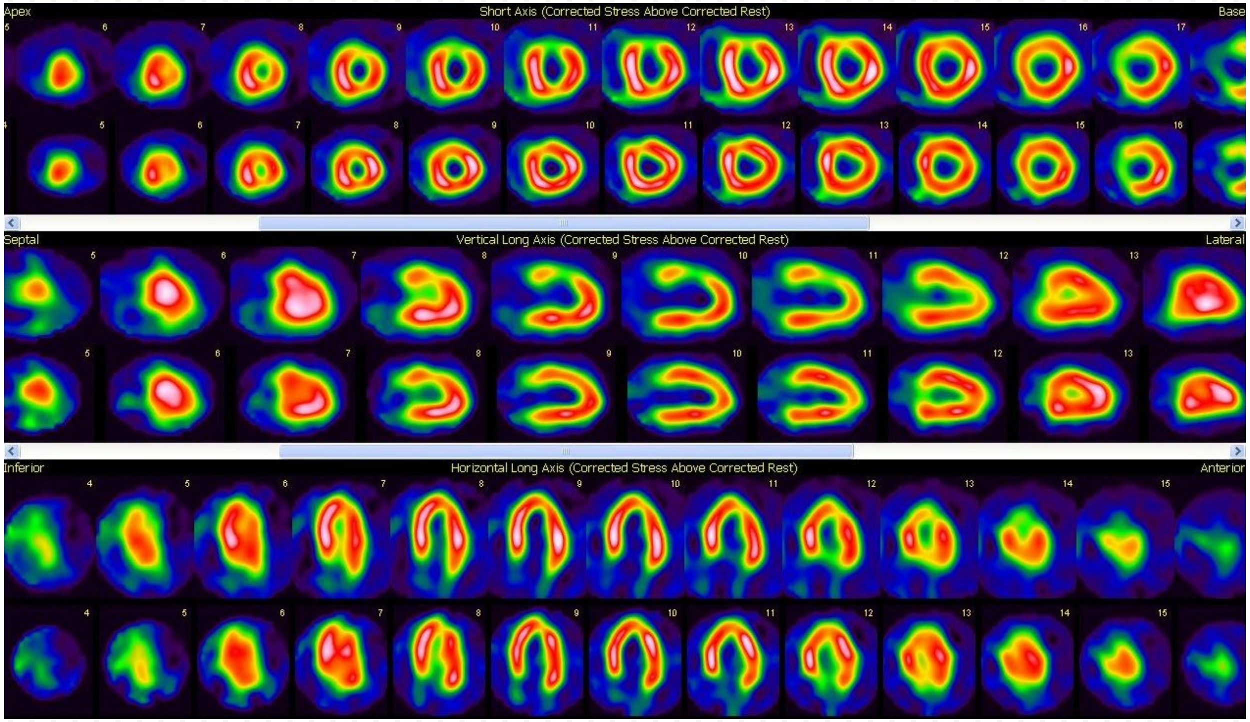
- Half-lives of isotopes used in NM range:
  - from a few minutes (e.g. ^{15}O, 2 min; ^{13}N, 10 min; ^{11}C, 20 min)
  - to a few days (e.g. ^{67}Ga, 3.26 days; ^{111}In, 2.81 days; ^{131}I, 8 days)
- Tracers with very short half-lives can be used only at sites that are very close to where the isotopes are produced
- Isotopes with long half-lives are not used because of radiation protection concerns for both the patient and their contacts

Static planar imaging

- E.g.1: Static planar bone scan (scintigraphy) of prostate cancer patient 3 h after intravenous administration of 99mTc-radiopharmaceutical
- Foci of uptake of the tracer indicate lesions at thoracic and lumbar vertebrae, both shoulders and throughout the pelvis

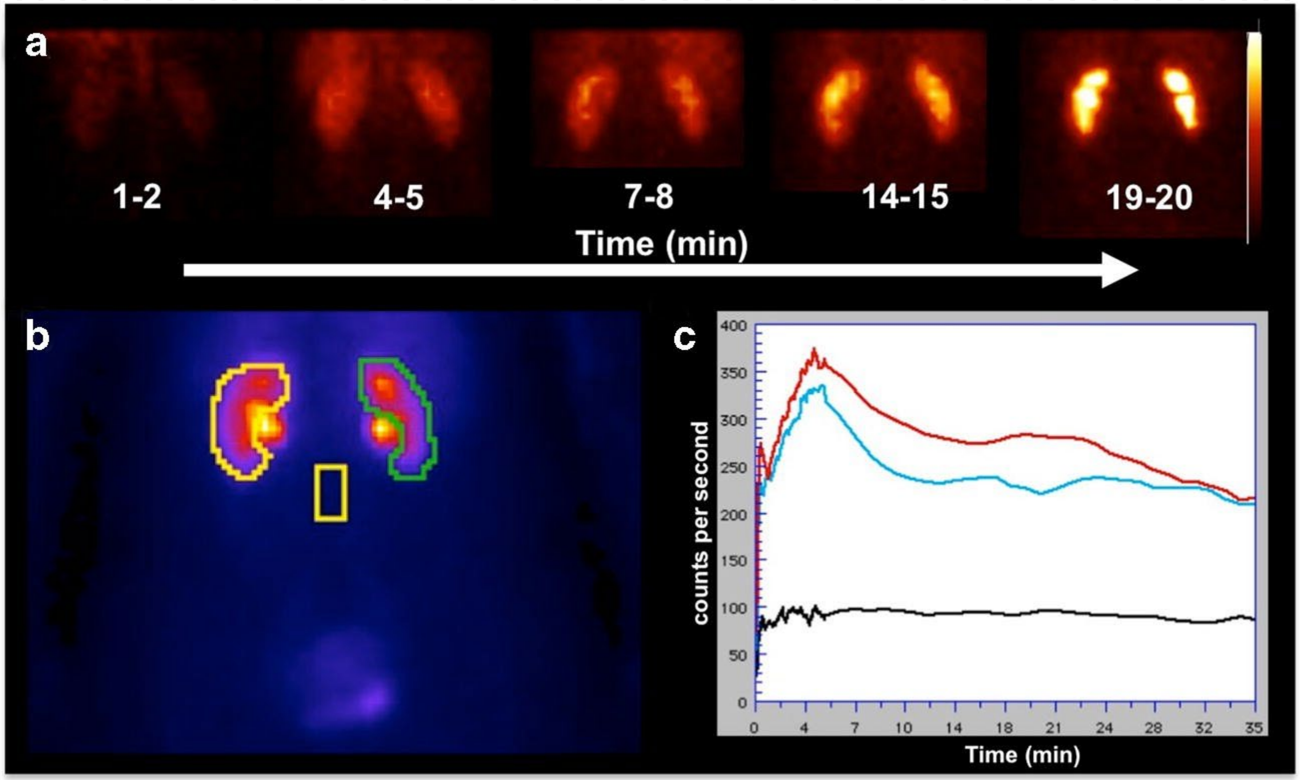
Static tomographic imaging

- E.g.2: Cardiac static tomographic images
- SPECT
  - axial
  - coronal
  - saggittal



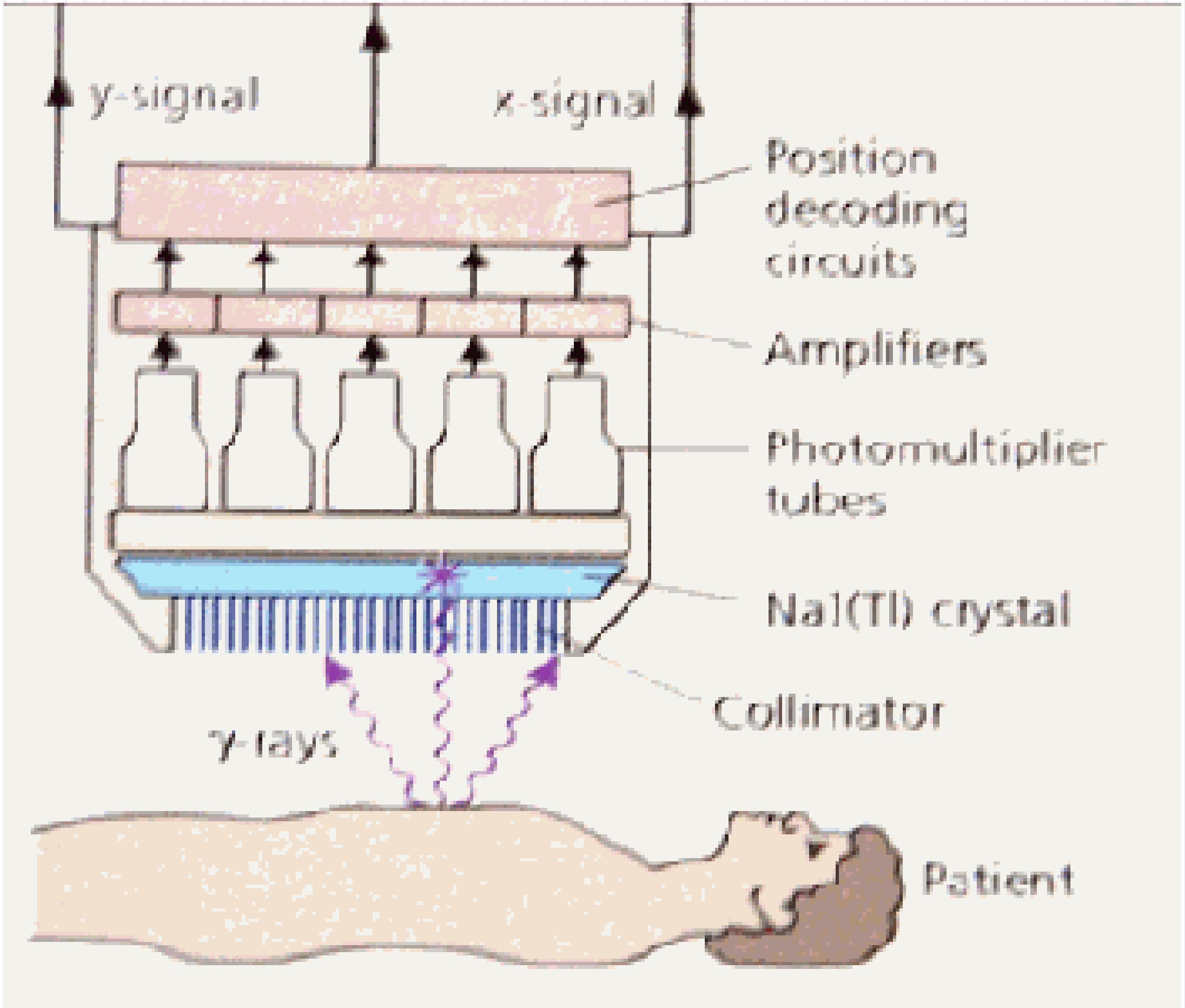
Dynamic planar imaging

- E.g.3: Dynamic renal planar scintigraphy evaluation for living kidney donation.



- a) planar images over time
- b) ROIs used for evaluation
- c) Time–activity curves for the left kidney (red) and the right kidney (blue)

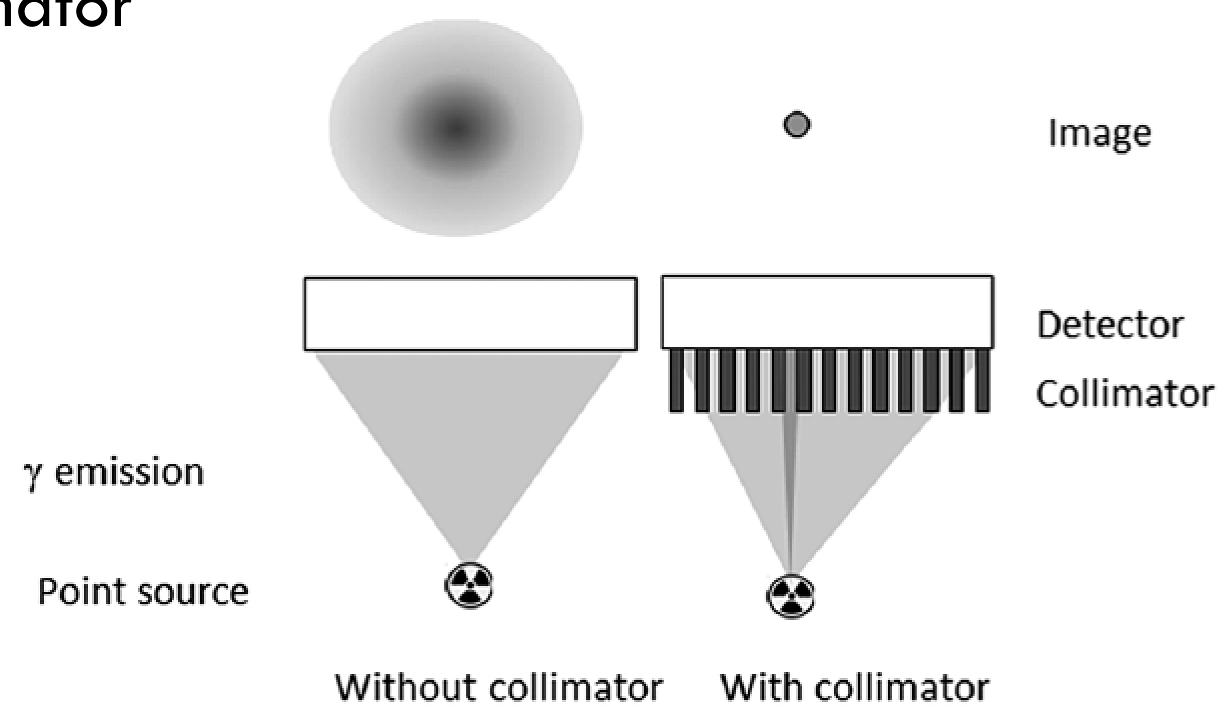
Gamma Camera (Hal Anger, 1957)



- 4
- 3
- 2
- 1

1- Collimator

- In order to image a point source accurately, a collimator is needed to absorb the gamma ray not striking the detector in the orthogonal direction
- Nearly 99.9% of the photons are absorbed by the collimator

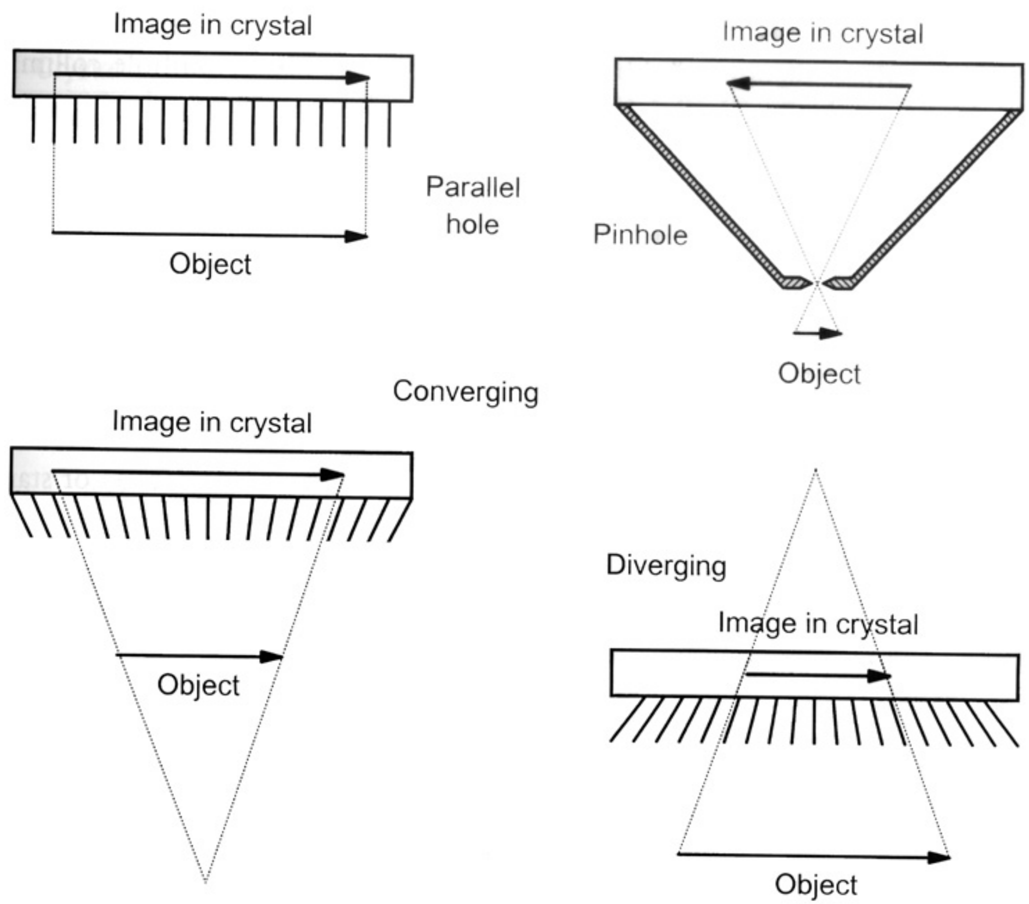


1- Collimator

- Typical materials used are Pb (Z = 82) and W (Z = 74)
- Collimator design requires compromises to be made:
  - Image resolution can be increased by reducing the diameter of the holes in the collimator, but this will decrease sensitivity
  - Conversely, larger holes in the collimator increase sensitivity but decrease resolution
- Higher radioisotope energies require an increase the thickness of the collimator, including the septa
- Collimators are classified in terms of:
  - image characteristics
    (high-resolution, high sensitivity or general purpose)
  - gamma ray photon energy range
    (low, medium, high and ultrahigh energy collimators).

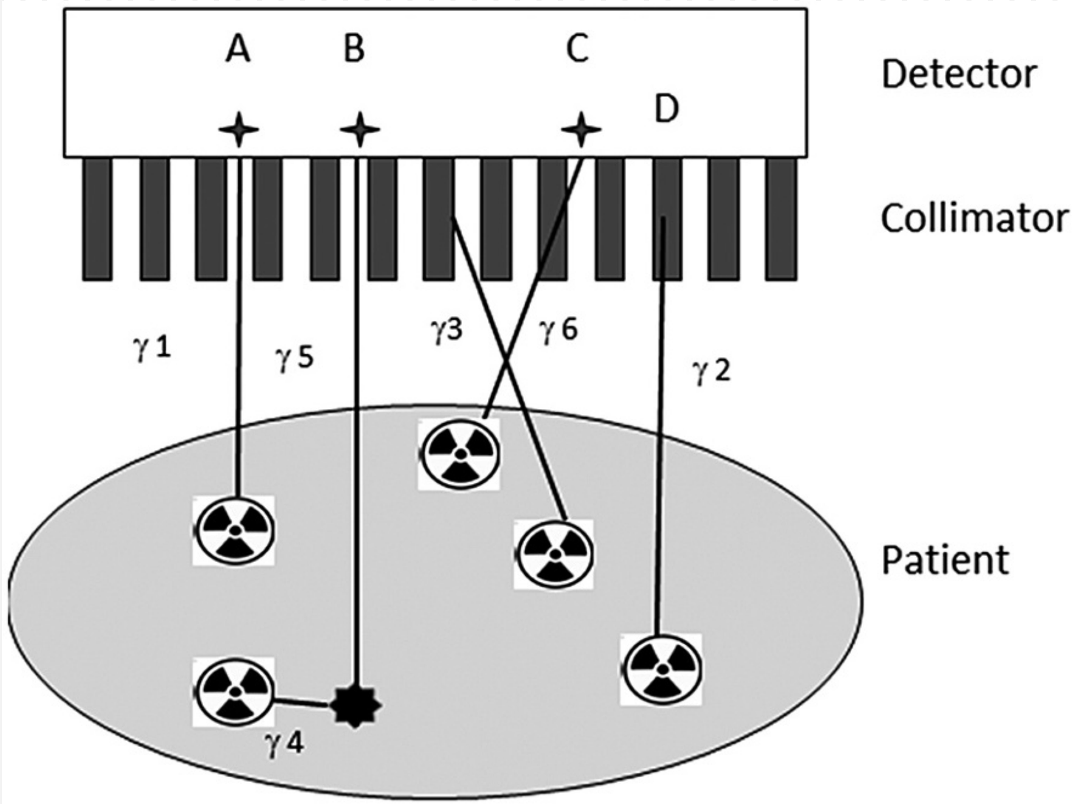
1- Collimator

- In general collimators have parallel holes and septa to provide a direct correspondence between the radiopharmaceutical distribution and the reconstructed image
- Holes and septa can also be divergent or convergent to magnify or compress image size, respectively

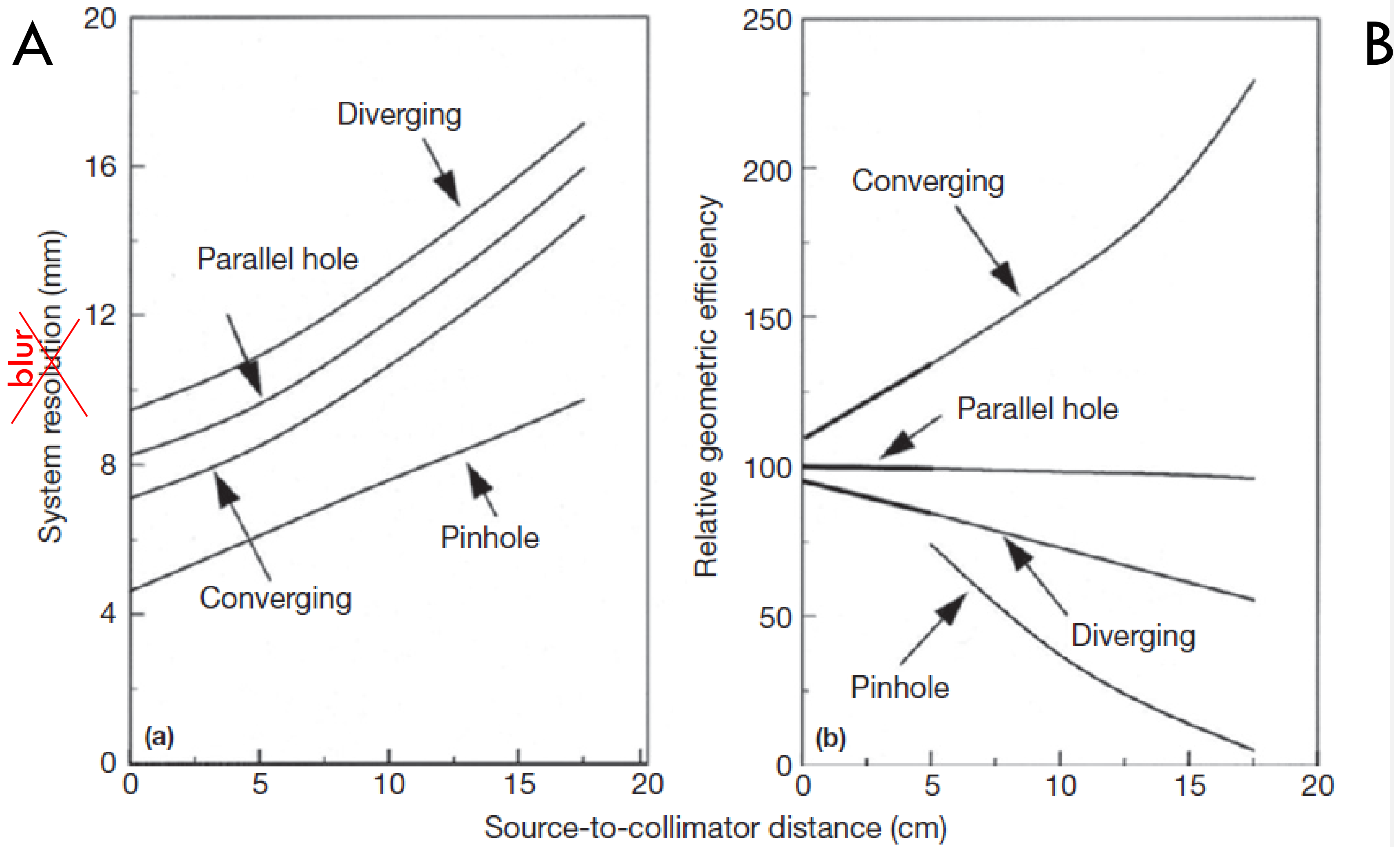


1- Collimator

- Real Vs Ideal behavior of a collimator:
  - A γ1 ✓
  - γ3 ✓
  - B γ4, γ5 ✗
  - C γ6 ✗
  - D γ2 ✗



1- Collimator

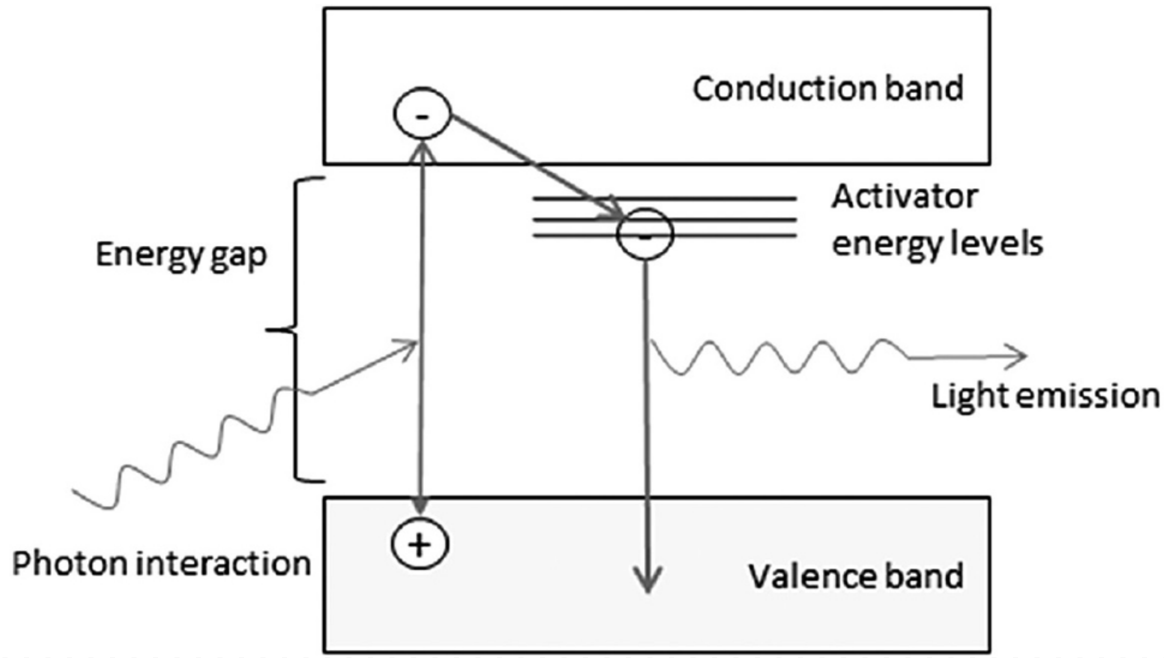


1- Collimator

- A - The geometric intrinsic blur (the reciprocal of the spatial resolution) versus distance from the front face of the collimator for the different style designs
  - the spatial resolution of a collimator worsens with distance
  - in nuclear medicine, it is important to bring the detectors as close to the patient as possible
- B - detection efficiency versus distance from the face of the collimator for the different style designs
  - only for converging geometry the detection efficiency improve with the distance

2- Scintillator Crystal

- Scintillator crystals act as an energy converter



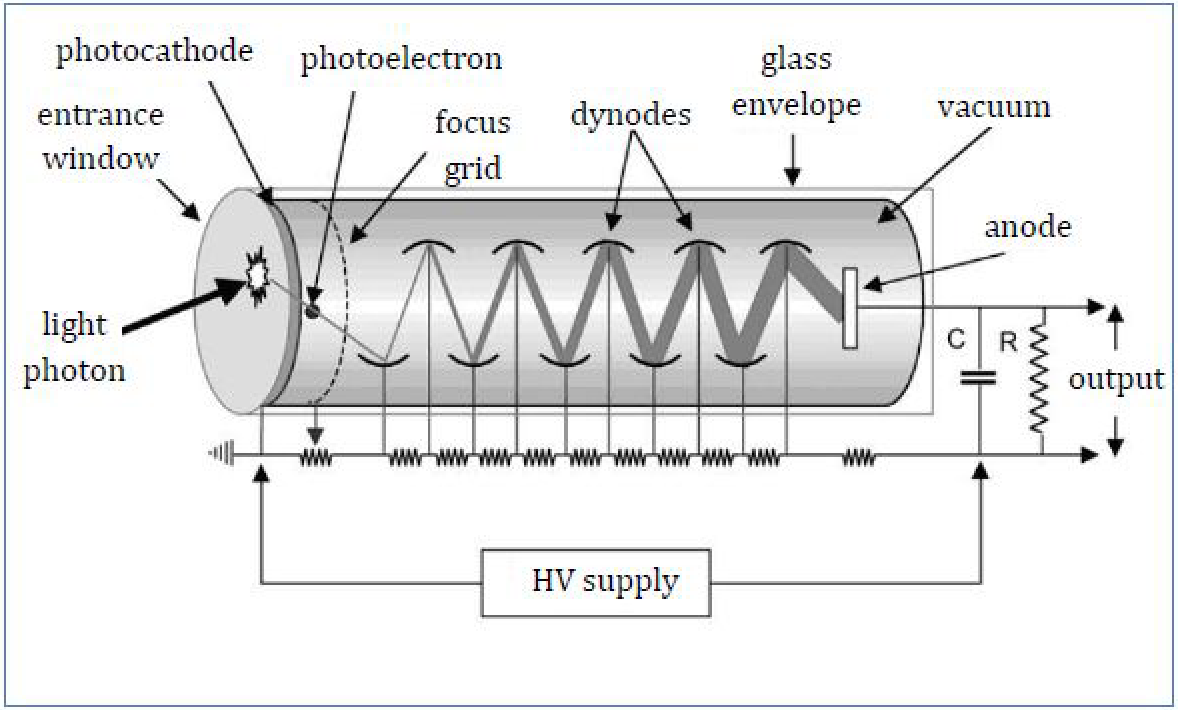
- Scintillators may be organic or inorganic compounds with added impurities to create the activation energy levels
- ~1cm thick inorganic crystals are generally used in NM

2- Scintillator Crystal

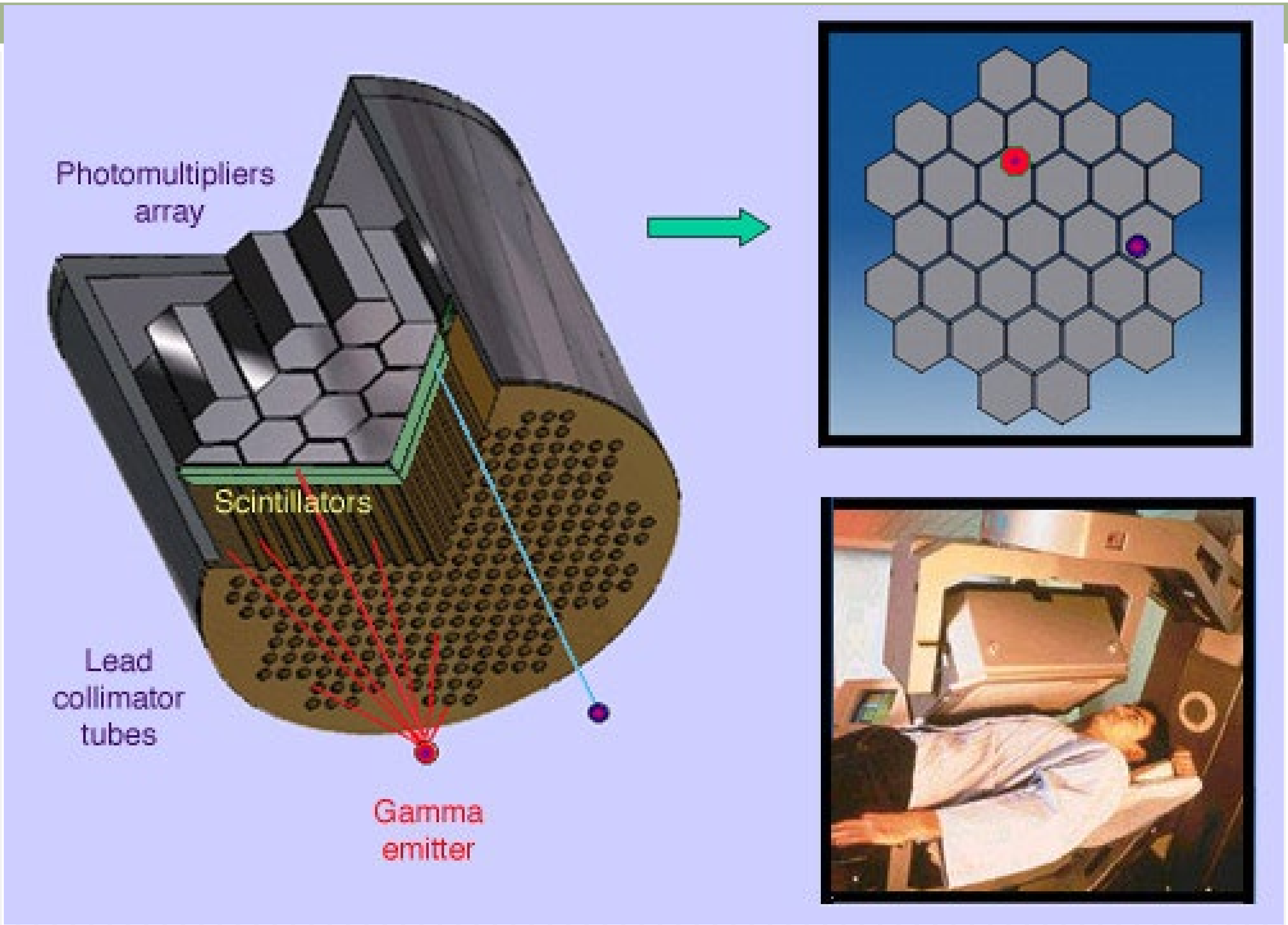
Physical Characteristics of Crystals Used in Nuclear Medicine and PET Applications

	NaI(Tl)	$Bi_4Ge_3O_{12}$ (BGO)	Lu_2SiO_5 (LSO:Ce)
Light yield (photons/keV)	38	8.2	25
Emission peak (nm)	410	480	420
Decay time (ns)	230	300	40
Density (g/cm^3)	3.7	7.1	7.4
$1/\mu$ (cm) – 140 keV	0.41	0.086	0.11
$1/\mu$ (cm) – 511 keV	3.1	1.1	1.2

3- Photomultiplier Tube (PMT)



3- PMT Array

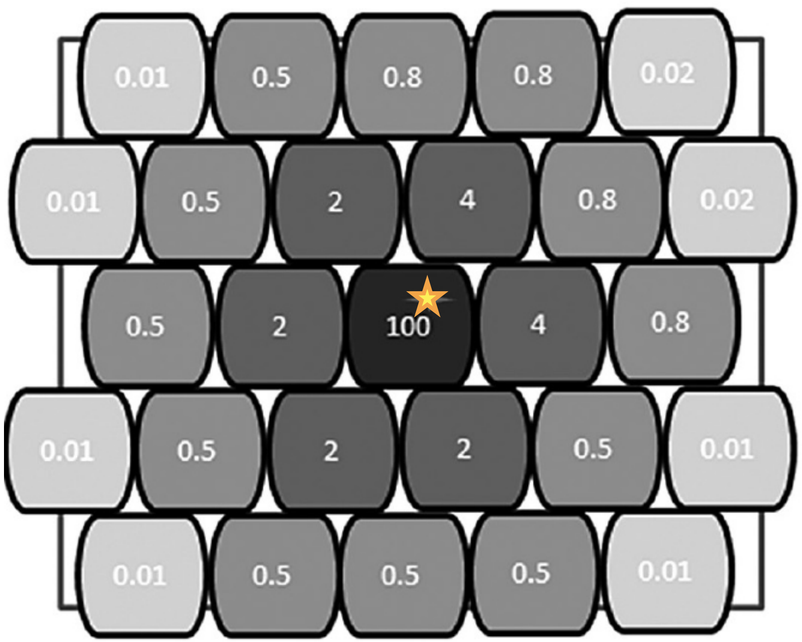

Photomultipliers array
Scintillators
Lead collimator tubes
Gamma emitter

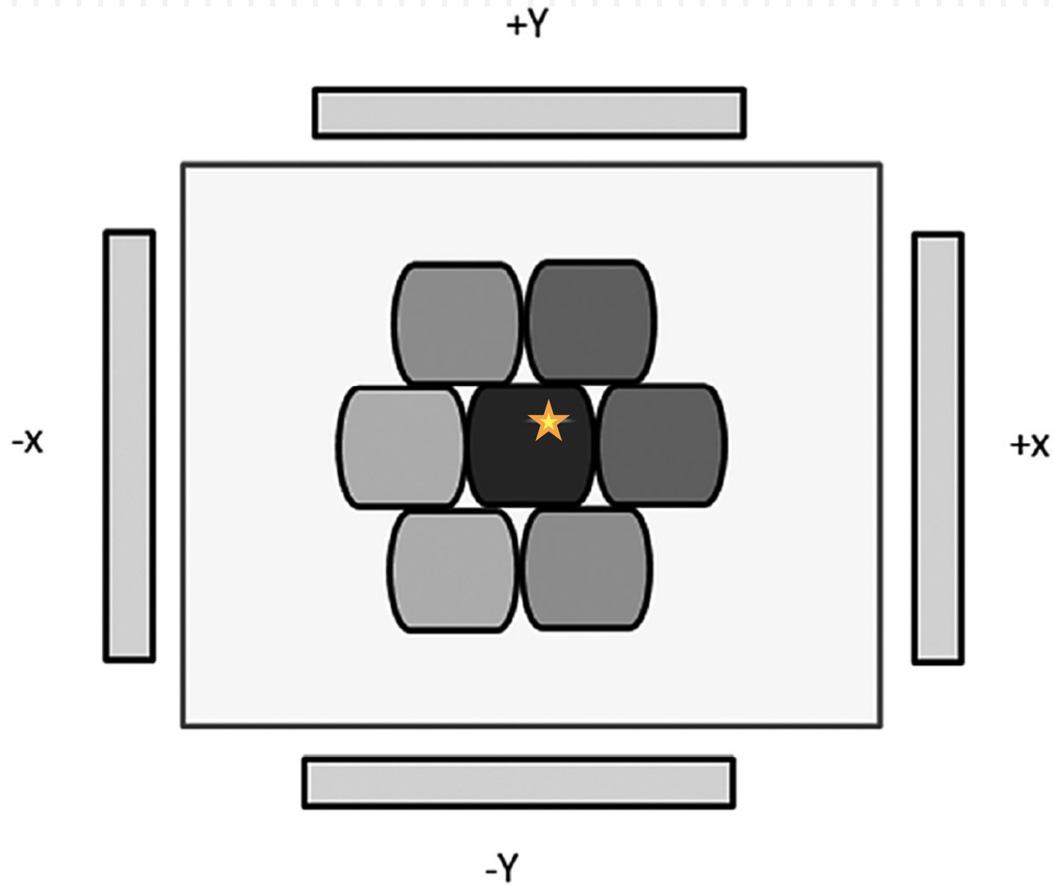
4- Signal Analysis

- Stopping γ ray photons in the scintillator crystal yields isotropic light emission around the point of interaction
- Light is detected in several photomultiplier tubes
- Output signals from all the PMT are summed to produce a 'Z pulse' (total energy deposited by the γ ray photon)
- Energy discrimination circuitry determines whether the Z pulse is from a primary/secondary γ ray photon: secondary γ ray events are rejcted

4- Signal Analysis

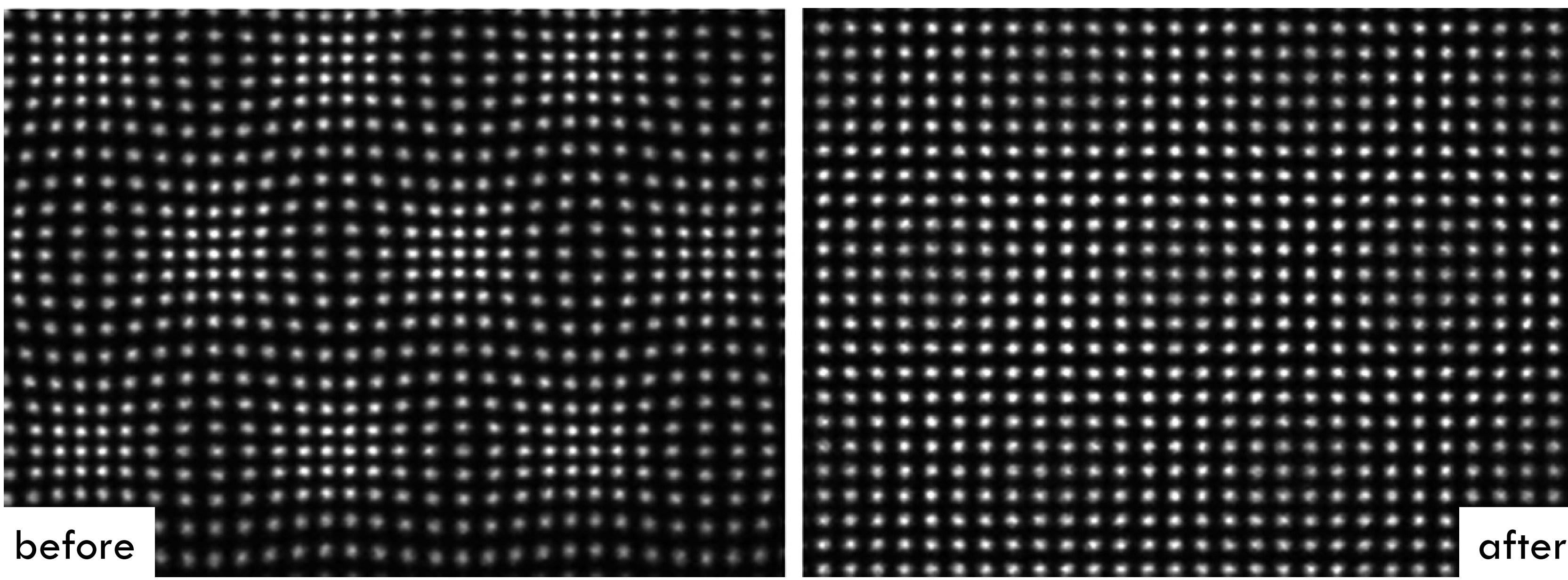
- Interaction positions are identified by using a weighted average of the light contribution from each PMT





Calibration

- Calibration is performed after installation and repeated if quality assurance measurements indicate increases in non-linearity
- This calibration ensures accurate correspondence between the true γ ray photon interaction point and its representation in the image
- Calibration is performed using a line source moved sequentially across the image in the x and y directions or alternatively using a point source



SPECT (Single Photon Emission CT)

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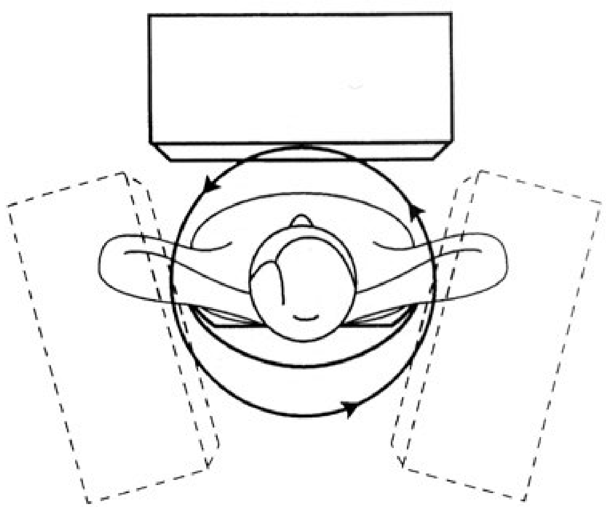
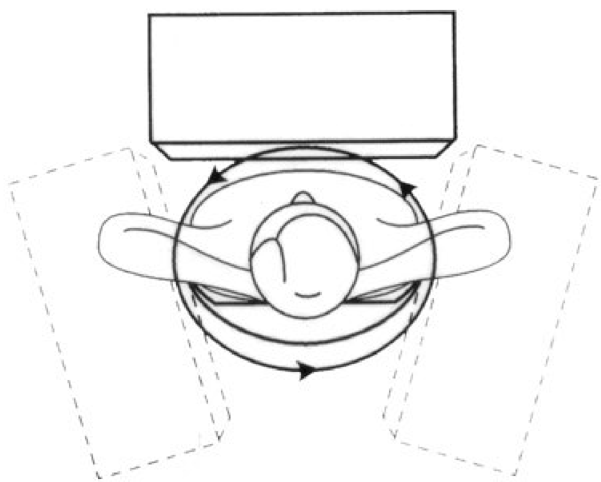
SPECT (Single Photon Emission CT)

- In SPECT the gamma camera is appropriately rotated around the patient acquiring images at discrete angles typically 3° – 6° apart
- Tomographic techniques (the same as in CT, i.e FBP and Iterative methods) are used for 3D reconstruction



Circular orbit



Body contour orbit

SPECT/CT

- A substantial difference of SPECT compared to CT concerns the patient's attenuation of photons:
  - in CT it is precisely this attenuation that creates the image
  - in SPECT instead this attenuation spoils the image, or adds artifacts to the signal coming from the radiopharmaceutical
- Attenuation correction can be implemented in SPECT/CT devices

SPECT/CT fusion imaging

- A hybrid system allows anatomical assessment (CT) and functional assessment (SPECT or PET) in a single examination session, without moving the patient from the couch (and therefore in the same spatial reference system)
- Once reconstructed, the CT and nuclear medicine images are spatially co-registered, thus allowing the reader to see the precise localization of the nuclear medicine data with respect to anatomy

SPECT/CT fusion imaging

- SPECT/CT fusion allows for proper anatomical localization of SPECT findings
- E.g. Labeling of a sentinel lymph node (SLN) using a Tc-99m radiopharmaceutical