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FRCR 2020



Nuclear Medicine Lectures

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FRCR Lectures 2020

- Lecture I - Nuclear Medicine and Gamma Cameras
- Lecture II - Imaging and Optimisation
- Lecture III - SPECT Imaging
- Lecture IV - PET Imaging
- Lecture V - QA/QC, Measurement, Radiation Protection
- Lecture VI - Artefacts, Molecular Imaging, Questions

Bibliography

- Physics for Medical Imaging
  - P. Allisy-Roberts, J. Williams – *Farr's Physics for Medical Imaging*
- Radiological Physics
  - P. Dendy, B. Heaton – *Physics for Radiologists*
- Medical Imaging
  - J. Bushberg et al – *The Essential Physics of Medical Imaging*
  - S. Webb – *The Physics of Medical Imaging*
- Nuclear Medicine
  - S. Cherry – *Physics in Nuclear Medicine*
  - P. Sharp et al – *Practical Nuclear Medicine*

FRCR Lecture I

Nuclear Medicine

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Nuclear Medicine and Gamma Cameras

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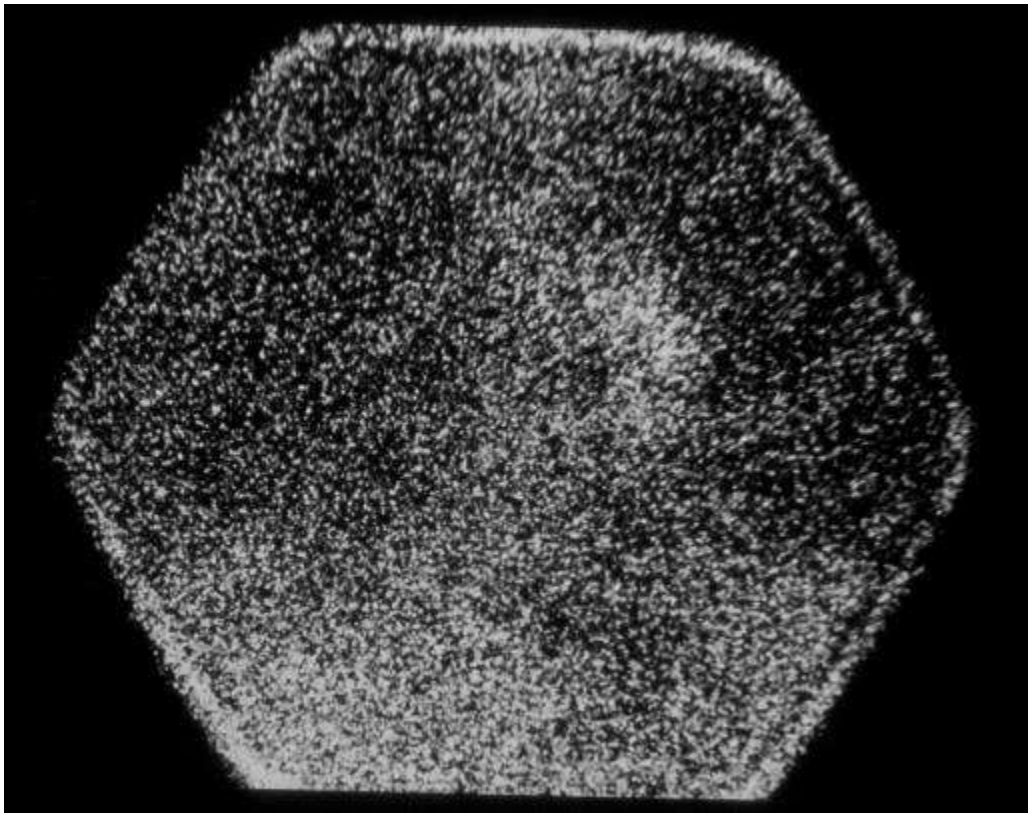
Nuclear Medicine or…

Unclear Medicine ?



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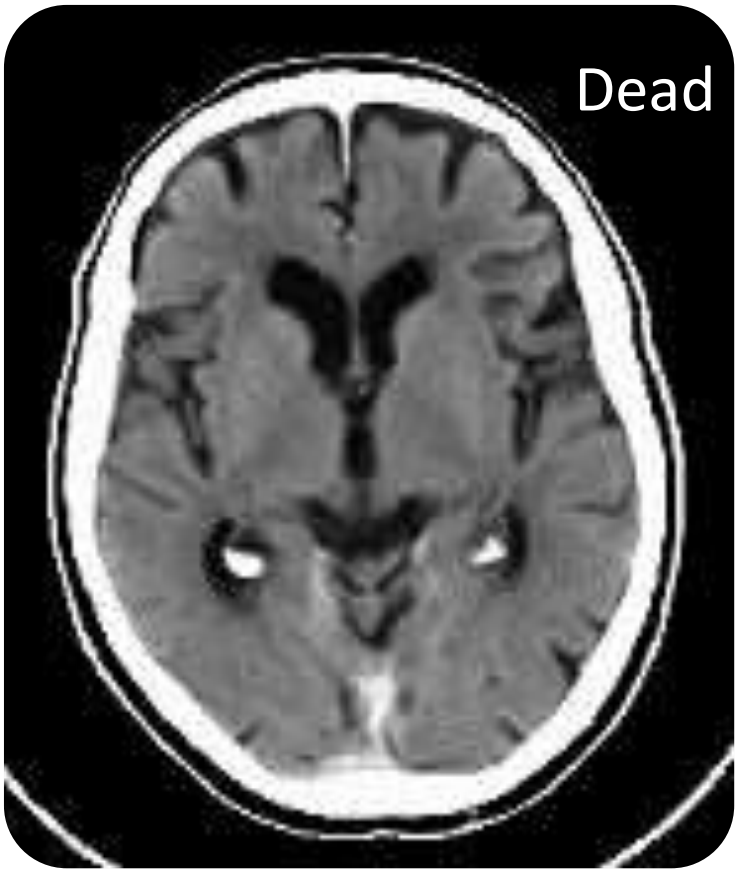
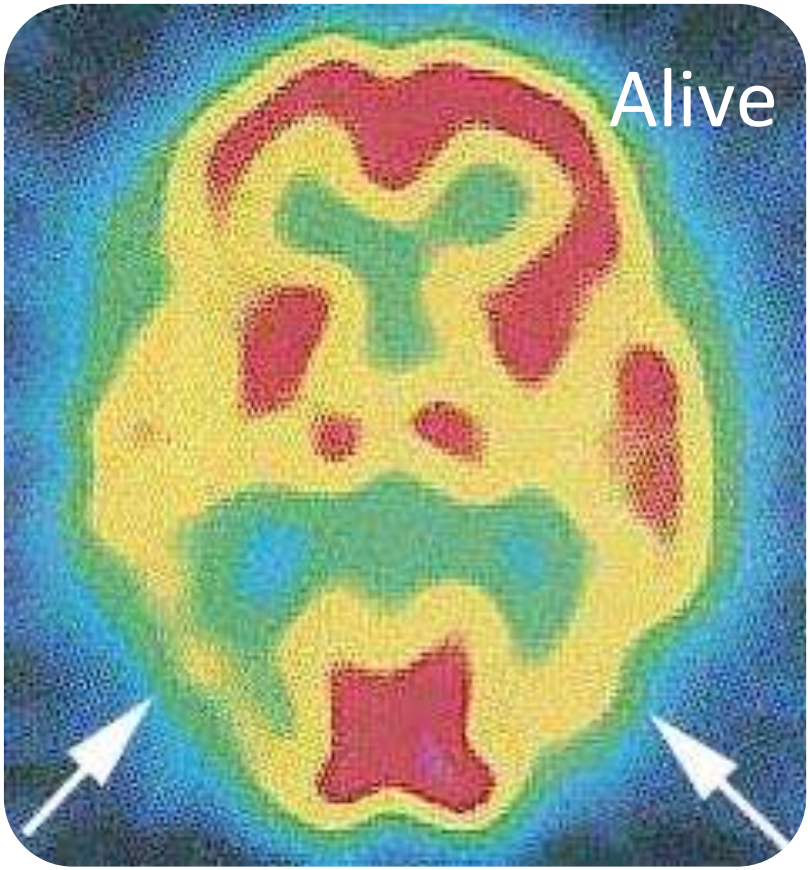
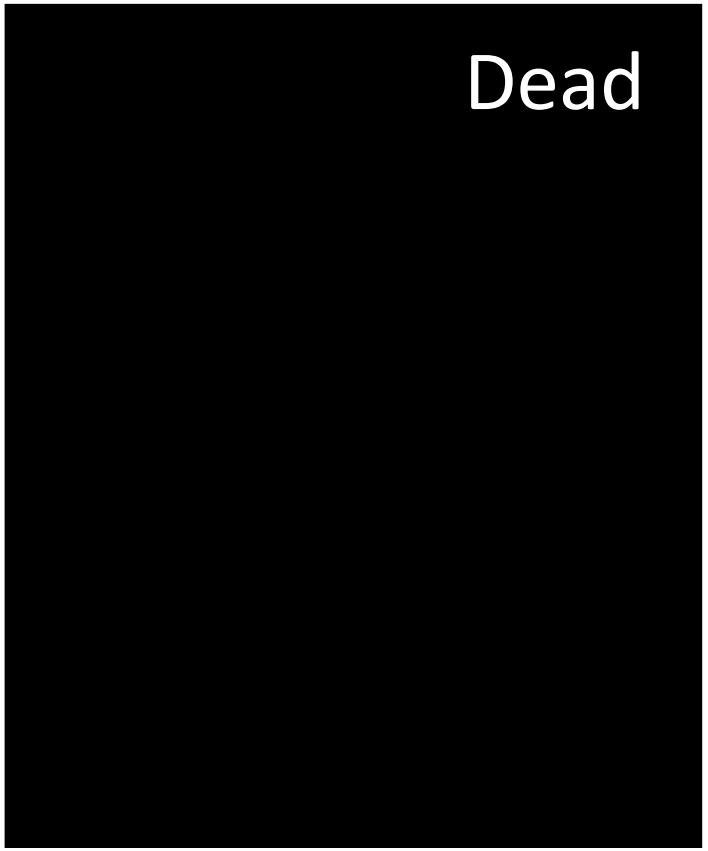
Can you spot the difference ?





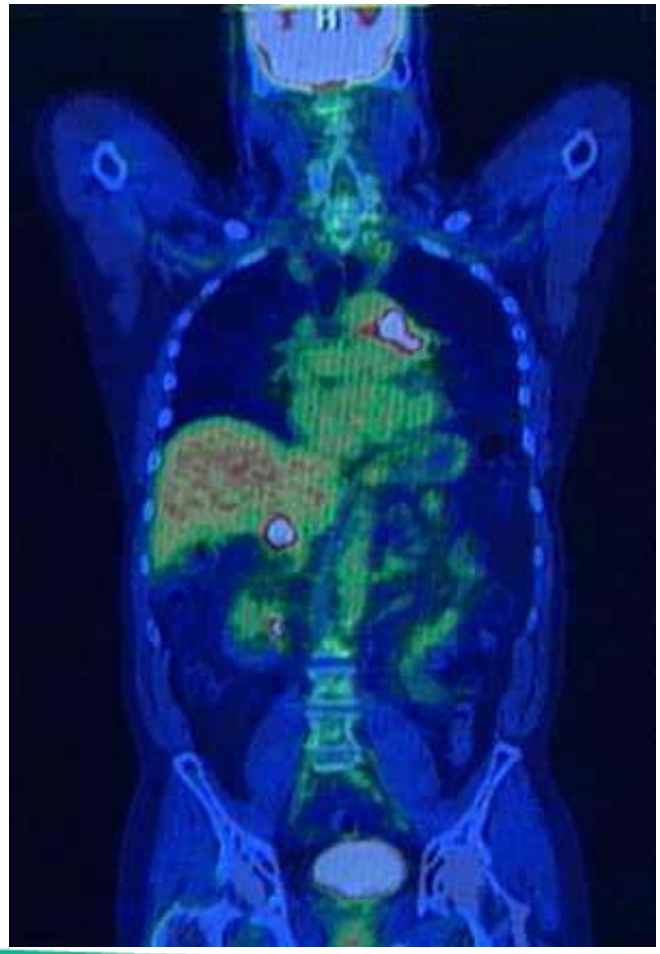
Nuclear Medicine
Brain Imaging





Nuclear Medicine Imaging

- Imaging technique
- Provides functional information
- Administration of radiopharmaceutical
- Localisation of radiopharmaceutical
- Radioactive isotope decays
  - emission of γ-rays
- γ-camera detects source of radiation
- Imaging of body's physiology



Functional Imaging

- To investigate regional tissue function non-invasively
- Nuclear Medicine Imaging
  - Planar and SPECT/CT imaging
- Positron Emission Tomography (PET)



Injection/ inhalation of radio-labelled molecules → **Detection of emitted γ-rays (photons) in tomographic scanner** → **Production of image ("map") of radionuclide distribution** → **Production of functional image**

Radiopharmaceuticals

Pharmaceutical	Radionuclide
Physiological properties determine distribution in-vivo	Radiation emitter
Rapid and complete absorption by biological system of interest	Allows location of tracer to be determined
e.g. MIBI, HDP, MAG3	e.g. ^{99m}Tc, ^{123}I, ^{201}Tl

Radiopharmacy



Radiopharmacist PPE



Why no lead apron ?

The Ideal Radiopharmaceutical

- Pharmaceutical should
  - localise only in area of interest
  - elimination time similar to length of test
  - be simple to prepare
- Radionuclide should
  - have a half-life similar to length of test
  - emit γ or X-rays
  - have no charged particle emissions
  - have energy between 100-200 keV
  - be chemically suitable
  - be readily available





Commonly Used Radionuclides

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Radionuclide	Production	Photon Energy (keV)	Half-life
^{67}Ga	Cyclotron	92, 182, 300, 390	78 hours
^{99m}Tc	Generator	140	6 hours
^{111}In	Cyclotron	173, 247	2.8 days
^{123}I	Cyclotron	160	13 hours
^{131}I	Nuclear Reactor	280, 364, 640	8 days
^{201}Tl	Cyclotron	68-80	73.5 hours

Radionuclide Generators

- Solution to the problem of supply of short-lived radionuclides
- The principle is:

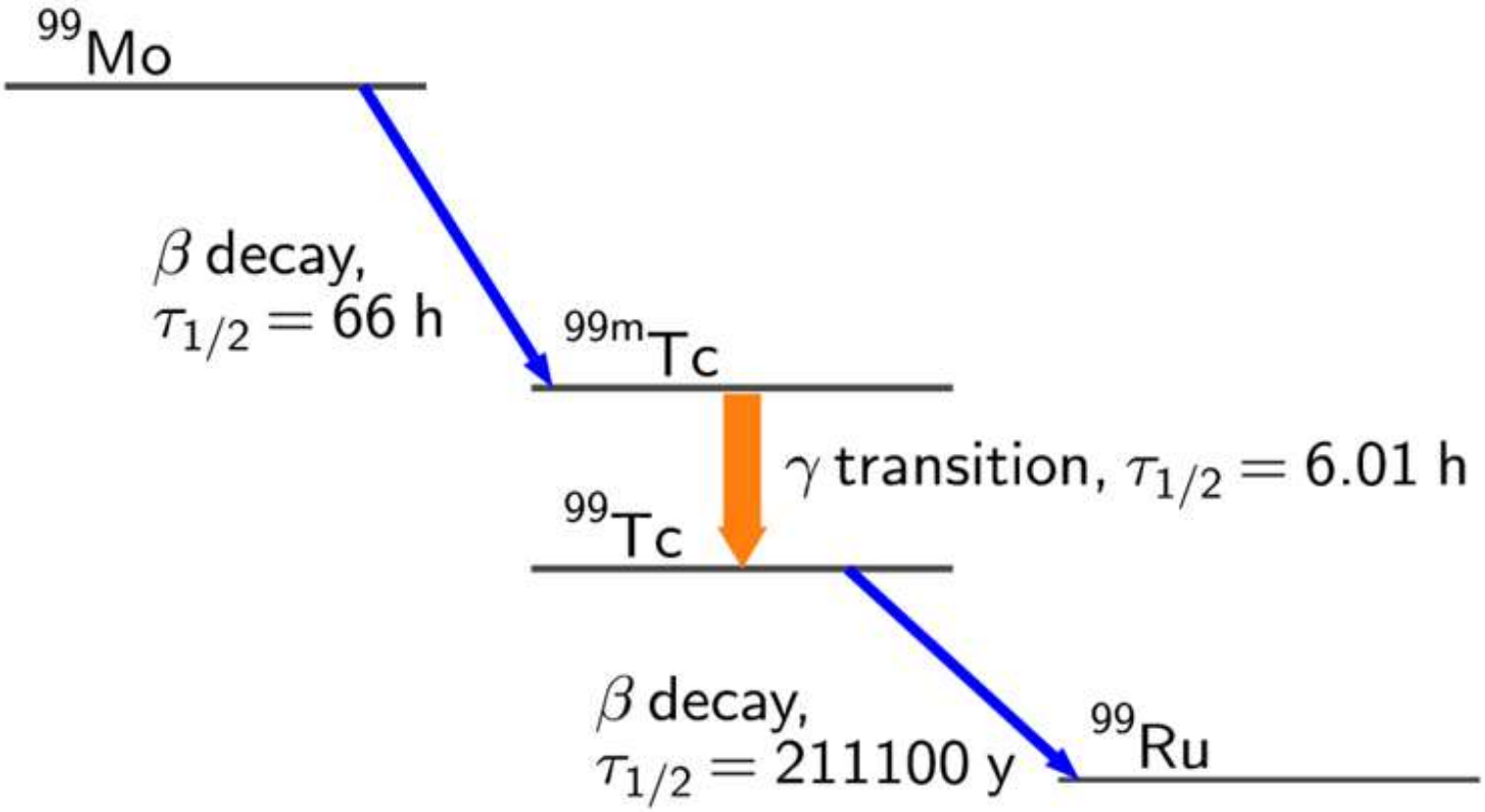
Parent radionuclide with relatively long half-life

Radioactive Decay

Daughter radionuclide with shorter half-life

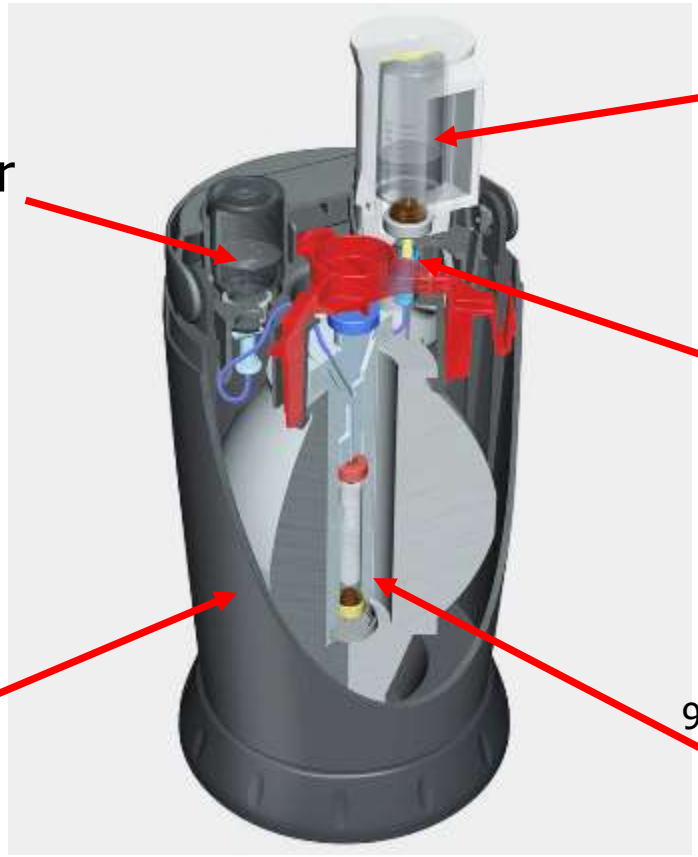


^{99}Mo Decay Scheme



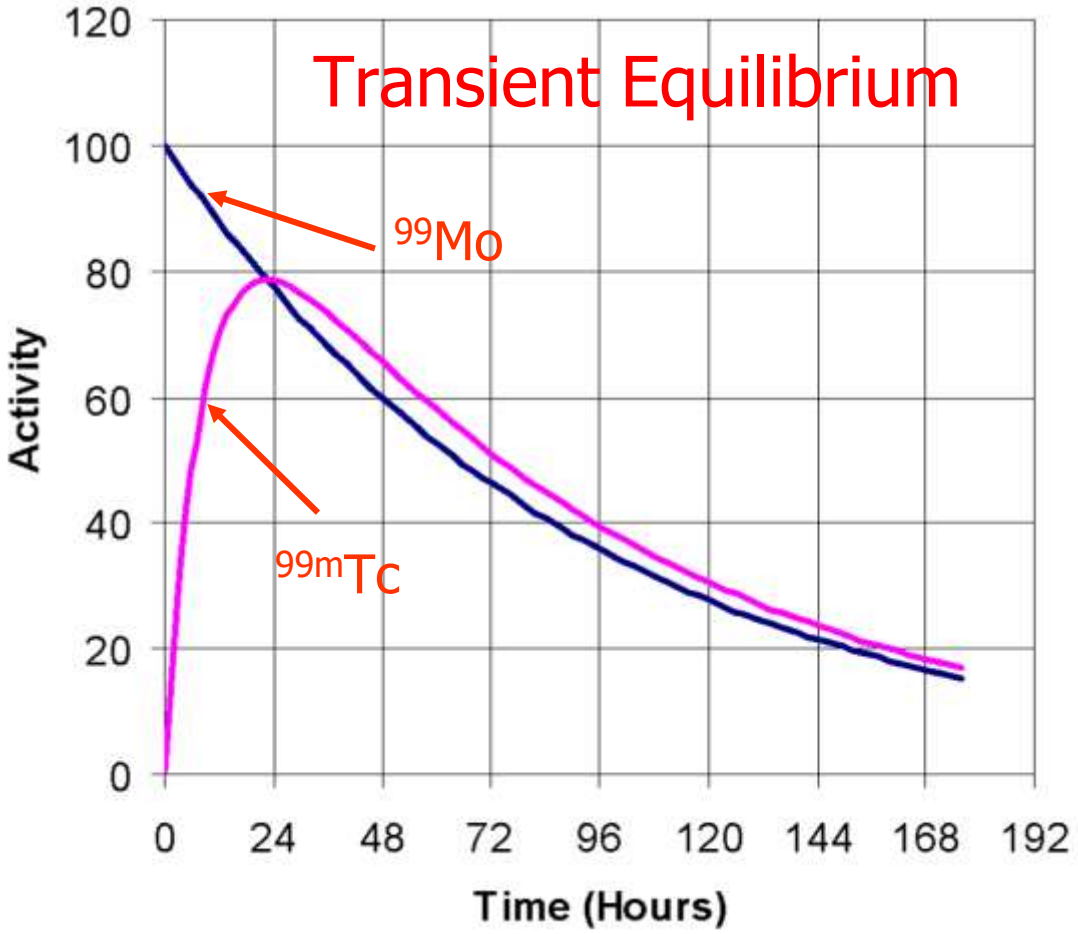
$^{99}Mo/^{99m}Tc$ Generator



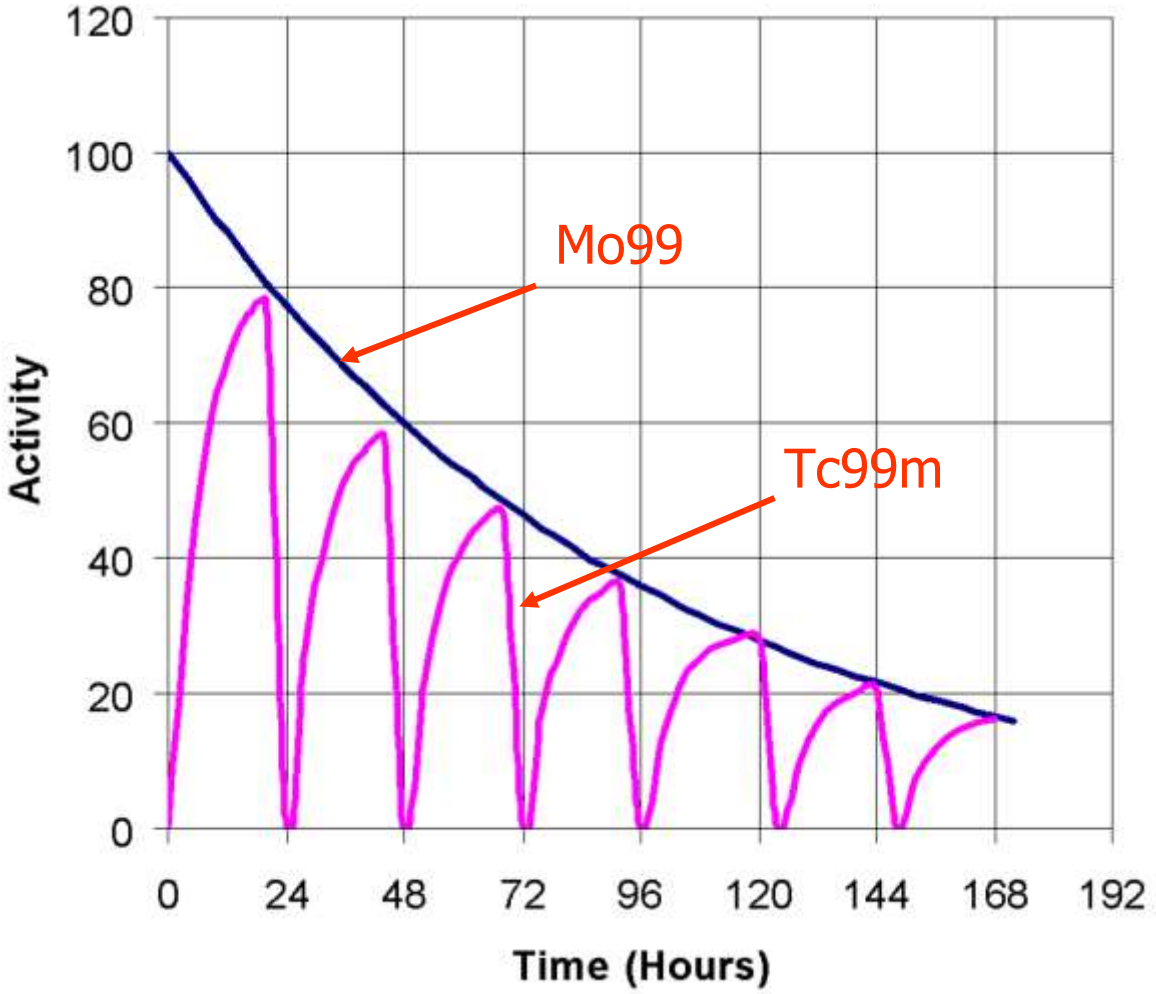


Na^+Cl^- → Generator → $Na^+(TcO_4)^-$

$^{99}Mo/^{99m}Tc$ Generator



$^{99}Mo/^{99m}Tc$ Generator with Elution



Radiolabelling with ^{99m}Tc

- Cold (non-radioactive) kits (vials)
  - pre-packed set of sterile ingredients designed for the preparation of a specific radiopharmaceutical
  - Typical ingredients of the vials might be MDP (methylene diphosphonate) to be complexed to ^{99m}Tc

Radionuclide Calibrator

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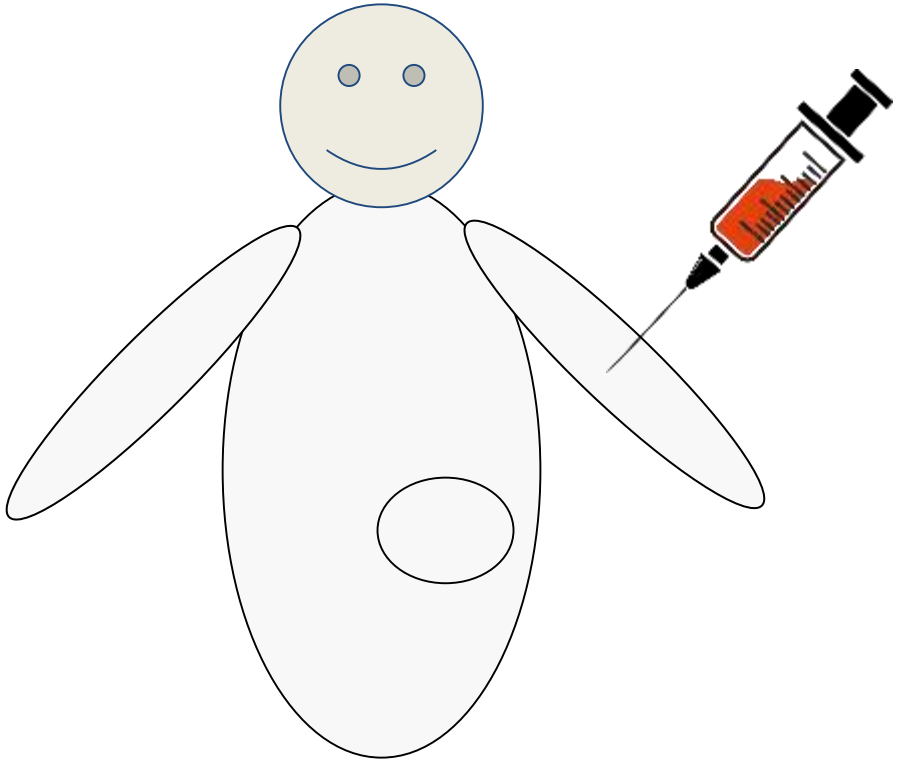
- Confirms correct activity prior to patient administration
- Well-type ionisation chamber
  - pressurised argon gas (increases efficiency)
- Electrometer
  - measures small ionisation currents
- Protective sleeve
  - removable if activity spilt
- “Dipper”
  - reduces finger dose
  - ensures fixed geometry
- Shielding
  - reducing background radiation
  - protects the user

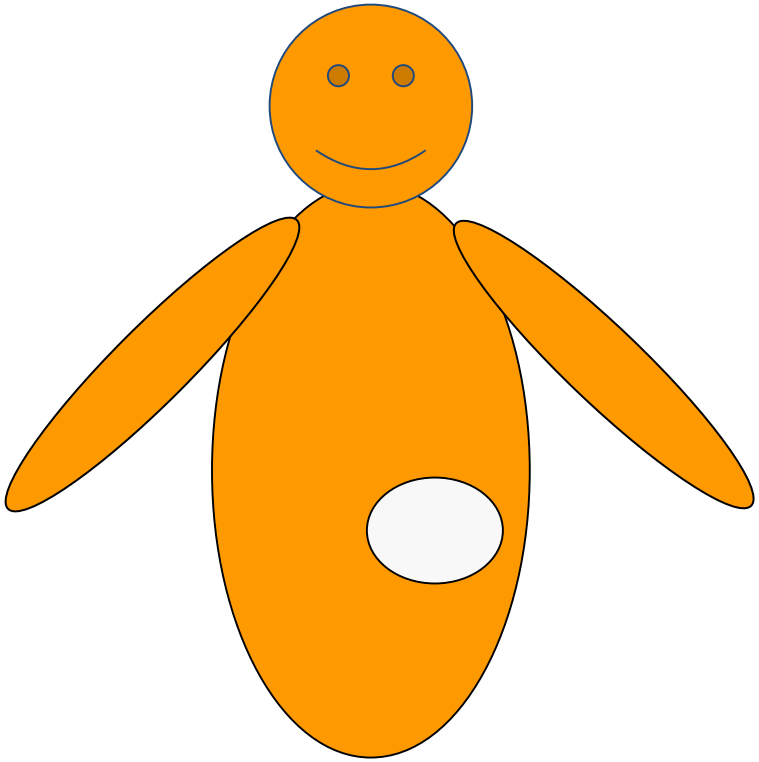


Nuclear Medicine Administration



- IV most common administration
- Others include :
  - Oral
  - Inhalation
  - Subdermal
  - Subcutaneous

Nuclear Medicine Localisation and Uptake

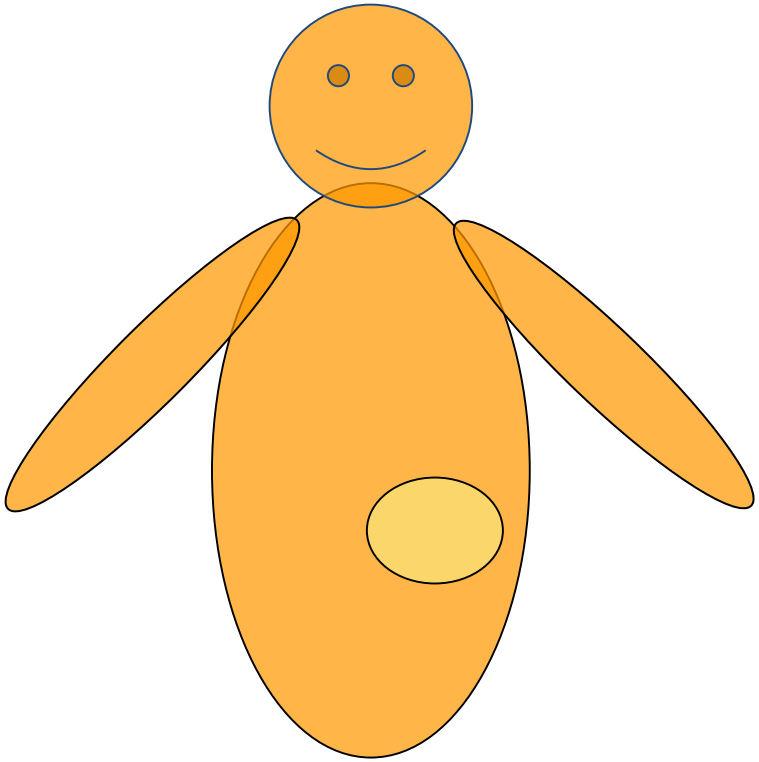


Initially

- Tracer circulates in the vasculature

- No physiological uptake in the organ/area of interest

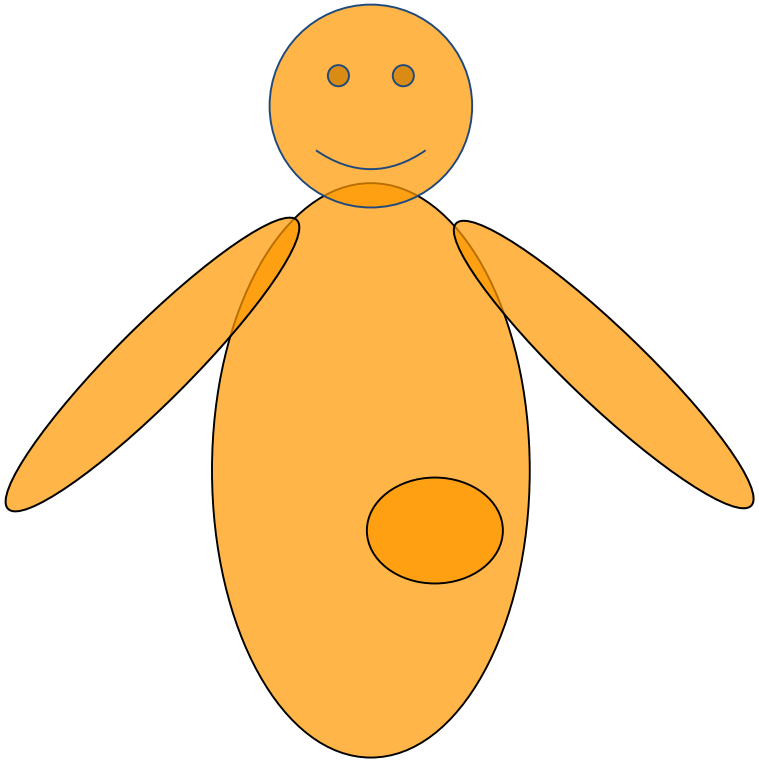
Nuclear Medicine
Localisation and Uptake



After a time

- Physiological uptake occurs
- Organ/area of interest becomes more radioactive.

Nuclear Medicine Localisation and Uptake

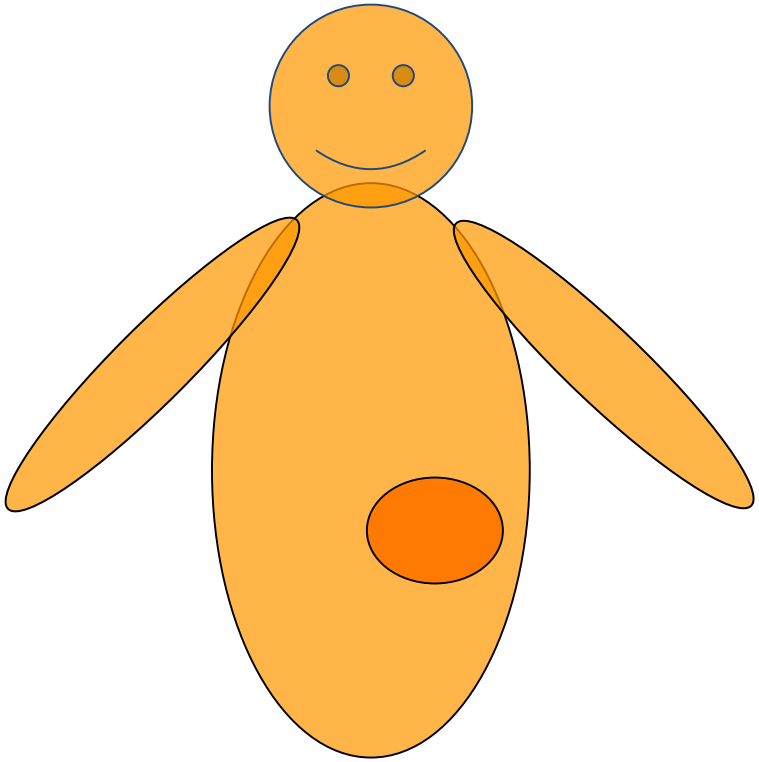


At some point

- Organ/area of interest indistinguishable

- Relatively equal amounts of radiopharmaceutical in all areas of body

Nuclear Medicine
Localisation and Uptake

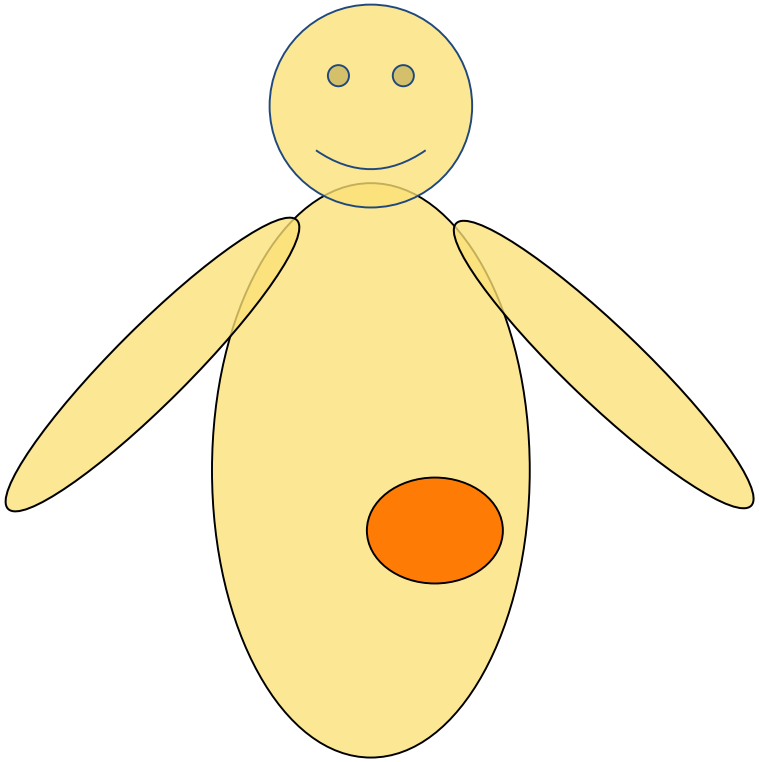


Organ/area detectability

- Organ of interest indistinguishable

- Relatively equal amounts of radiopharmaceutical in all areas of body

Nuclear Medicine
Localisation and Uptake



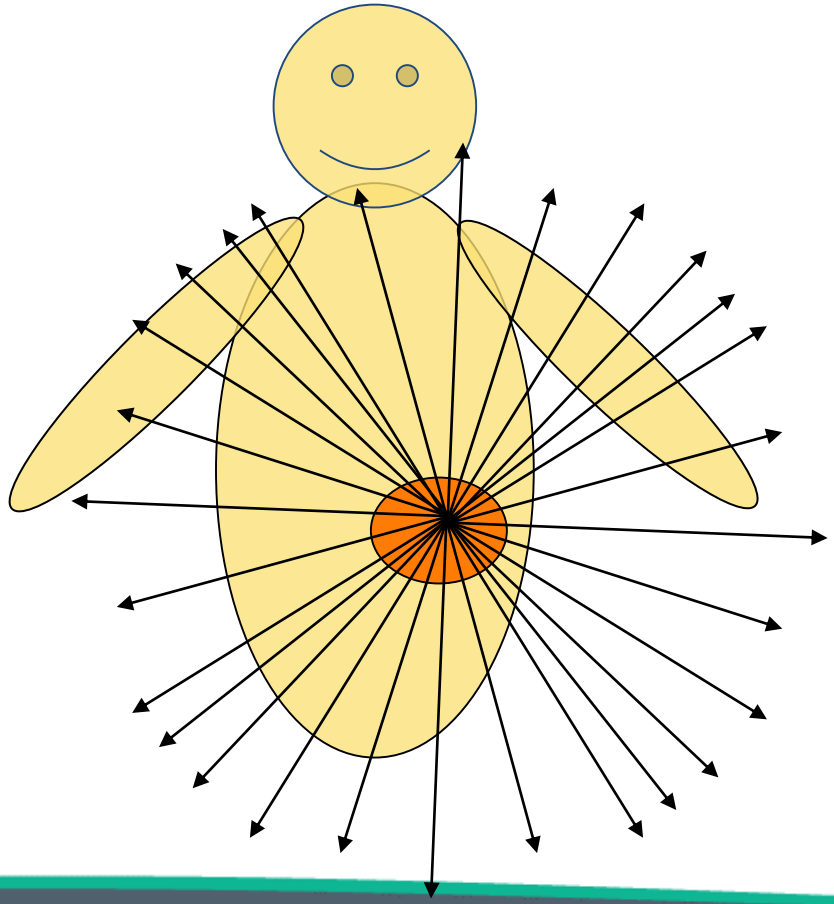
Enhanced contrast

- Between organ/area and rest of body

- Time window to image

Nuclear Medicine Imaging

Imaging the distribution of the tracer



- Image formed from gamma-rays emitted by radiopharmaceutical
- Gamma rays emitted in all directions from the patient
- The whole patient is radioactive including ALL bodily fluids

The Gamma Camera







The Gamma Camera

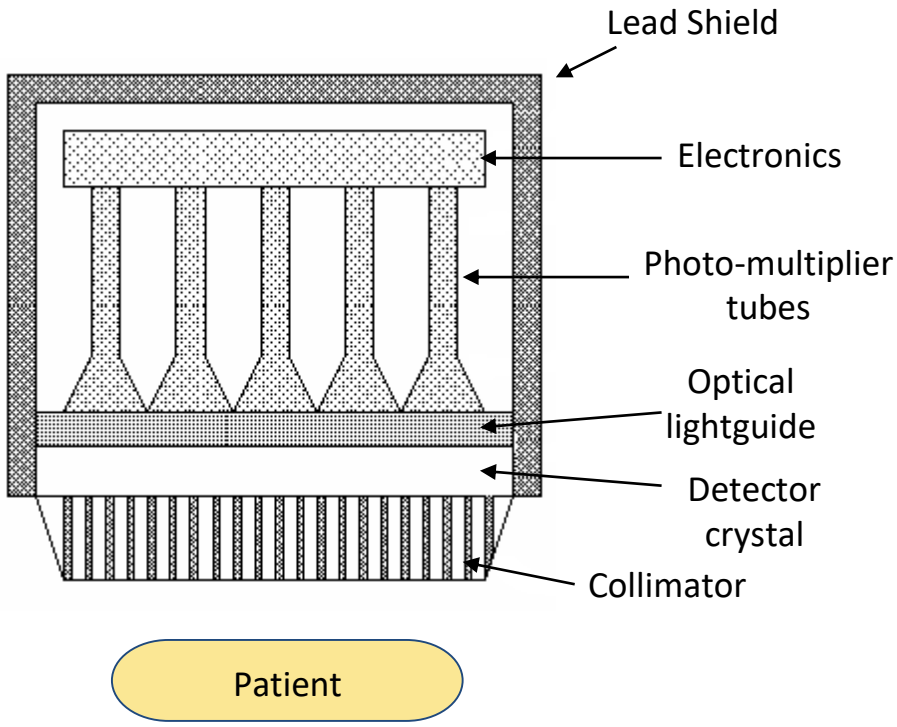
All gamma cameras have :

- a gantry
- at least one detector
- a patient bed
- a dedicated computer



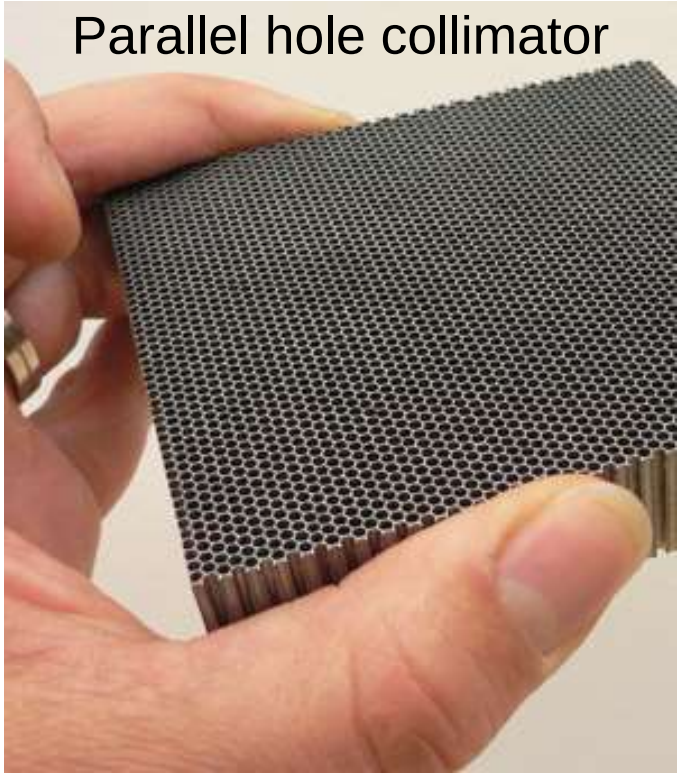
The Detector

- The components of a gamma camera detector (head) :
  - Collimator
  - Detector crystal
  - Optical light-guide
  - Photomultiplier tube array
  - Position logic circuits
  - Data analysis computer
  - Lead shield to minimise background radiation effects

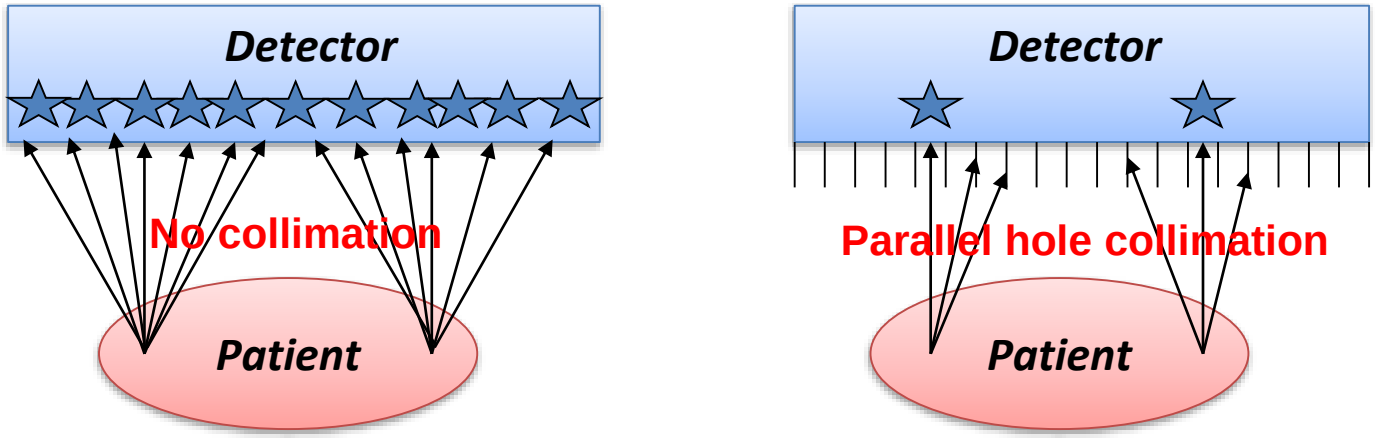


The Collimator

- A lead array of hexagonal holes
- Preferentially selects gamma photons incident at 90^0 to the detector face
- Defines geometrical field of view of the camera



The Collimator



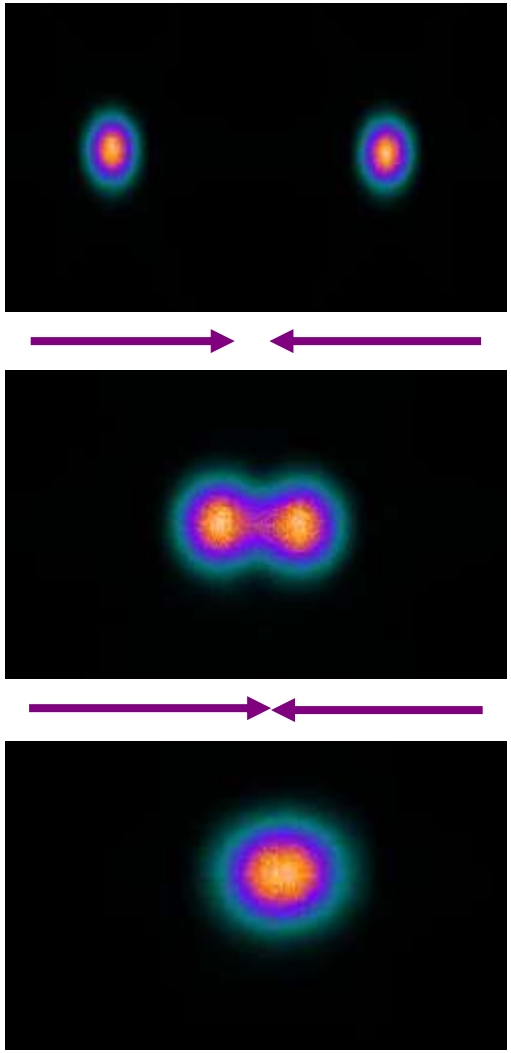
- No collimation = no positional relationship

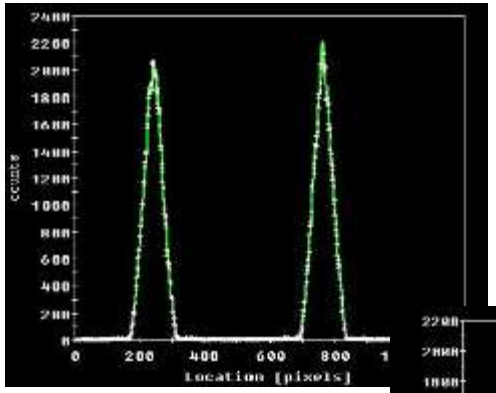
- Collimation = ‘true’ positional image formation

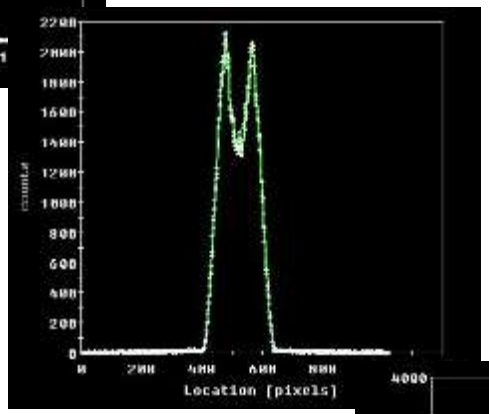
Collimator Parameters

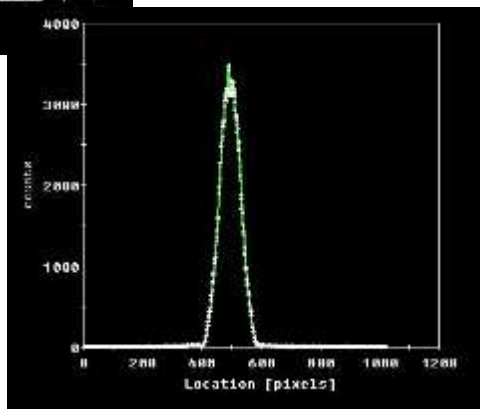
- Sensitivity (cps/MBq)
  - the proportion of the emitted photons which pass through the collimator and get detected
- Spatial resolution (mm)
  - a measure of the sharpness of an image

Spatial Resolution



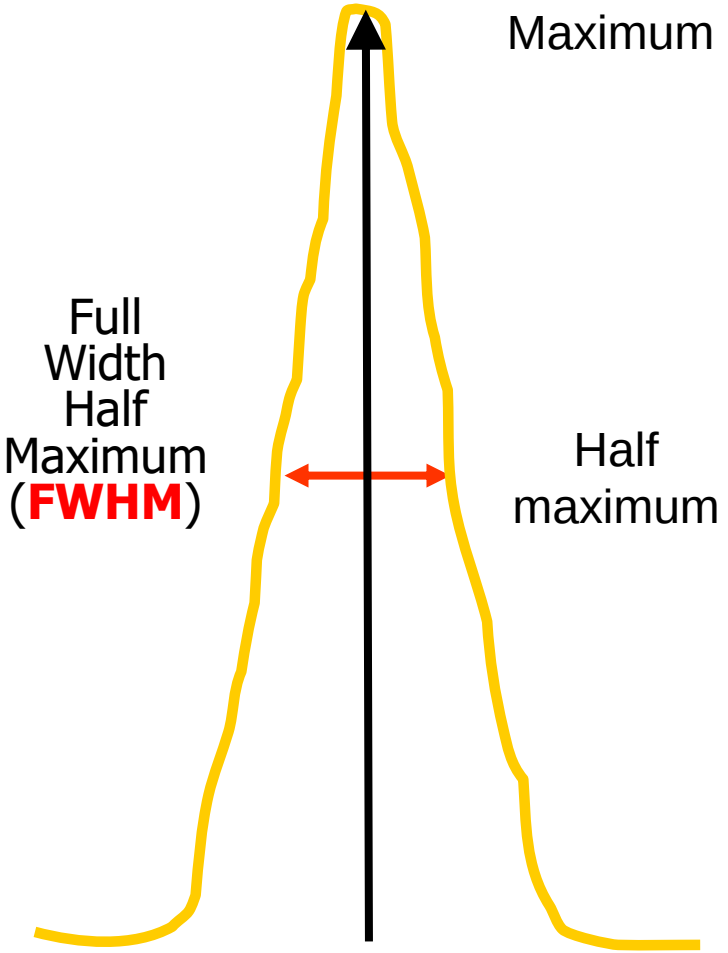






Significance of FWHM

- ➔ Width of peak is limiting factor
- ➔ Measure width at half maximum height
- ➔ Smaller FWHM = <u>better</u> spatial resolution



Distance from Collimator

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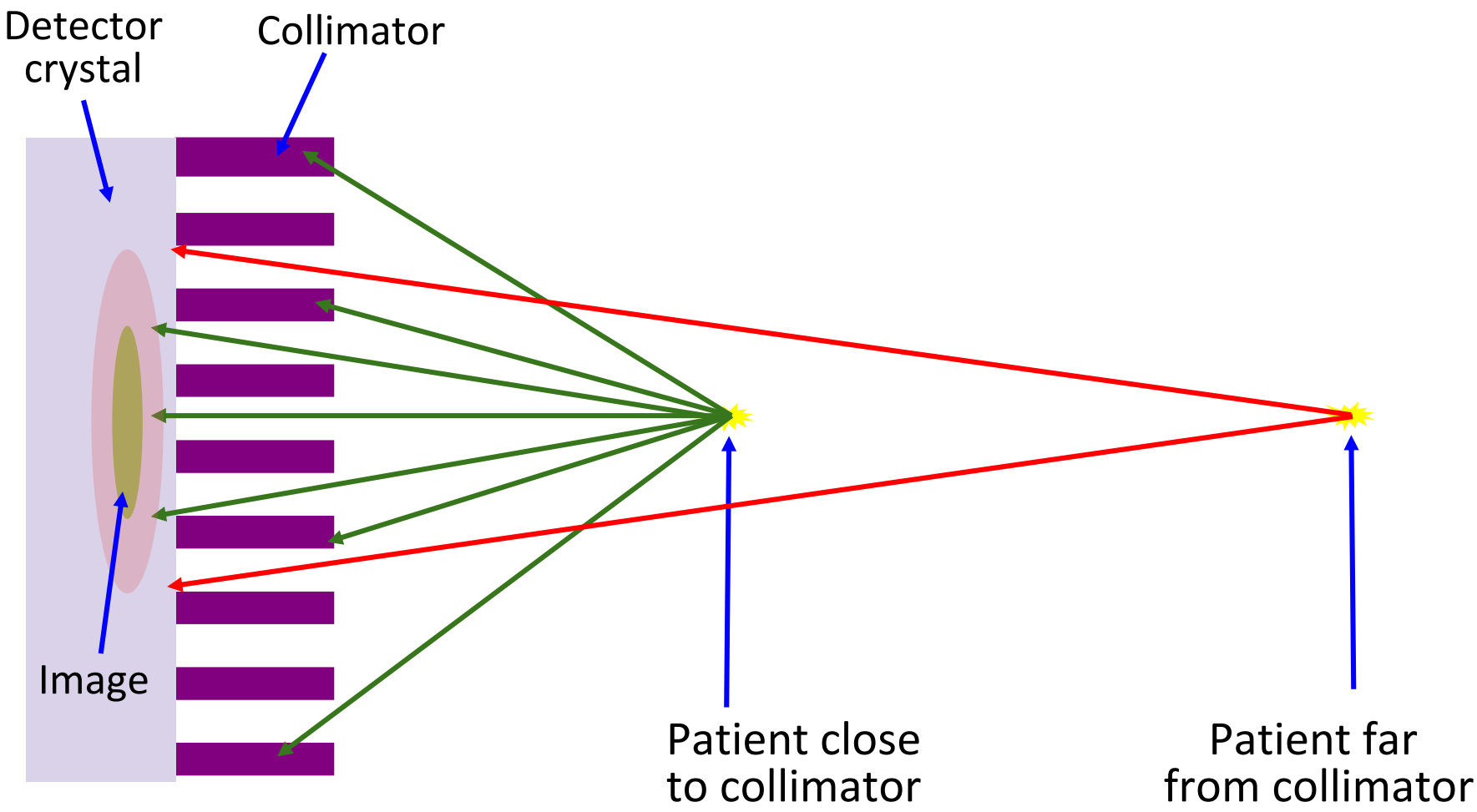
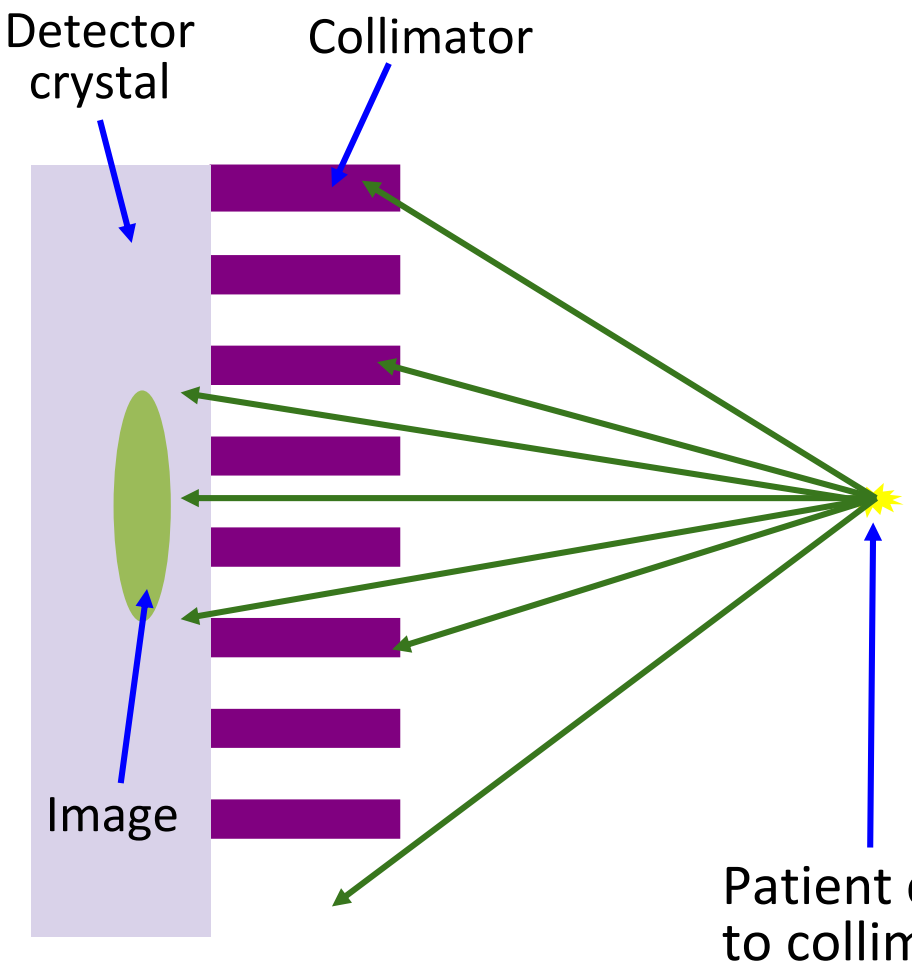


Remarkable people.
Extraordinary place.

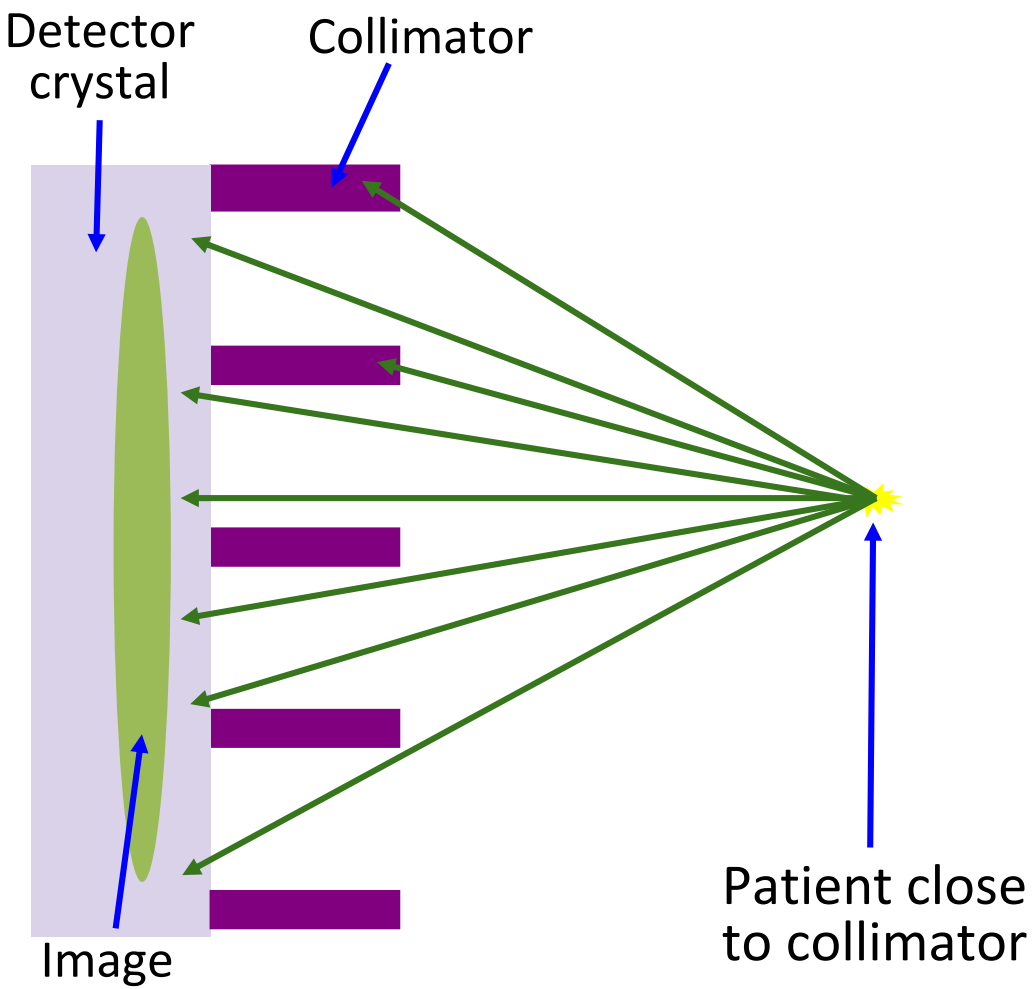
Collimator Hole Size



Small holes :

- Limit further the acceptable incident angle of gamma photons
- Increase spatial resolution but reduce sensitivity of the imaging system

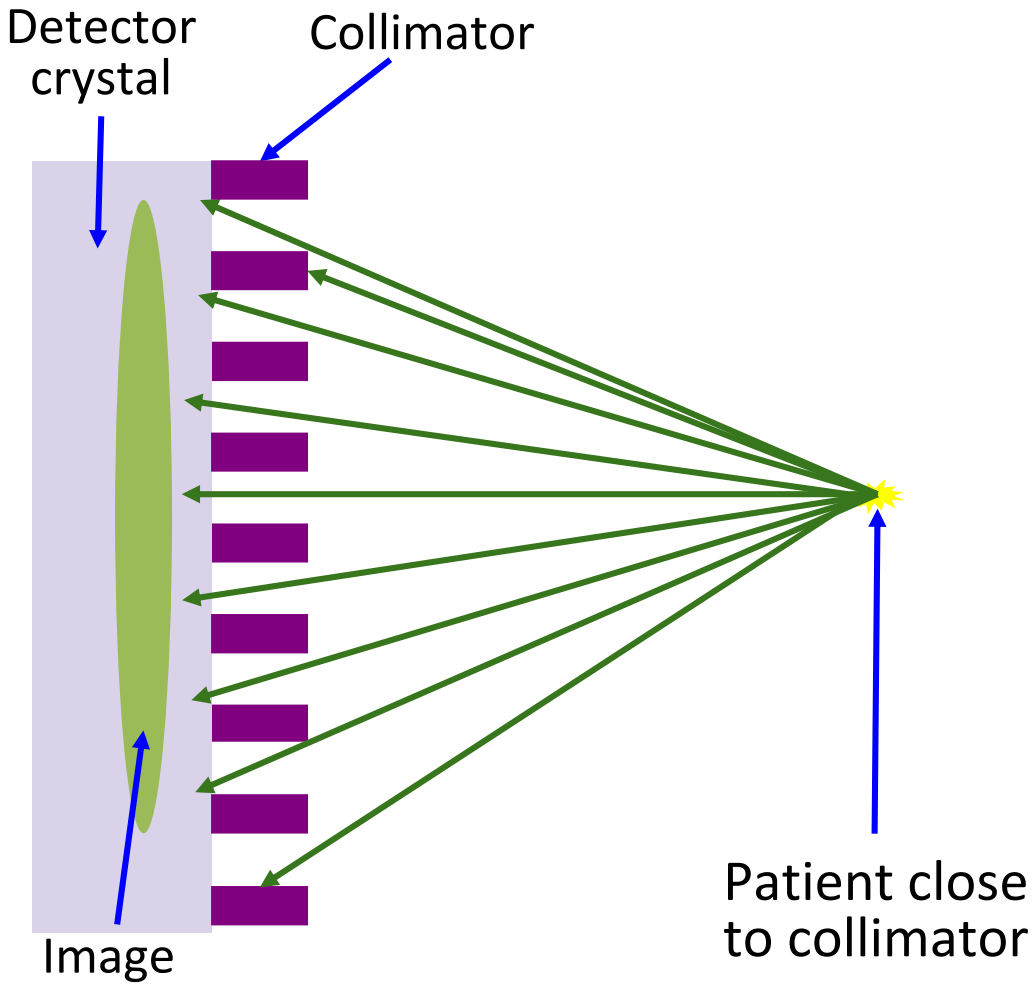
Collimator Hole Size



Large holes :

- Allow more gamma photons to produce scintillation events within the detector
- Increase sensitivity but reduce spatial resolution of the imaging system

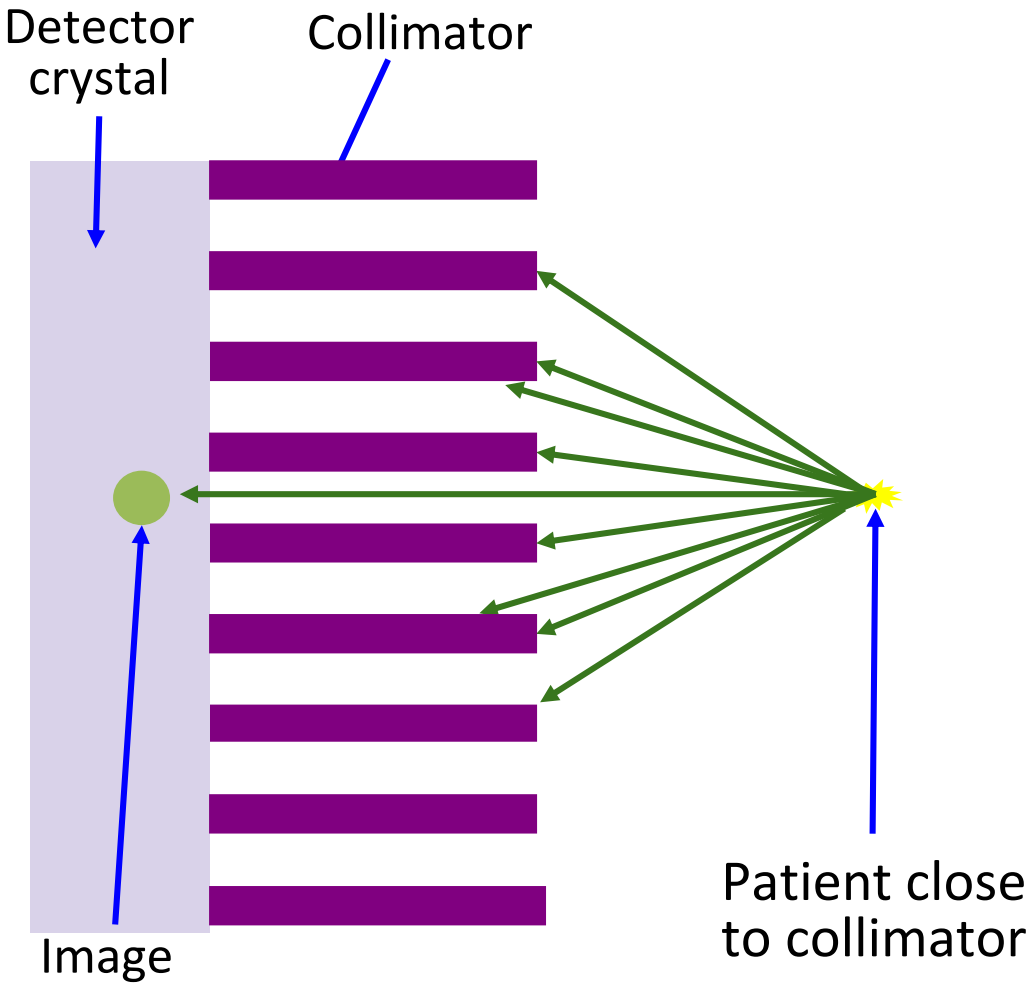
Collimator Hole Length



Short length :

- More gamma photons reach the detector
- Sensitivity increased but spatial resolution decreased

Collimator Hole Length

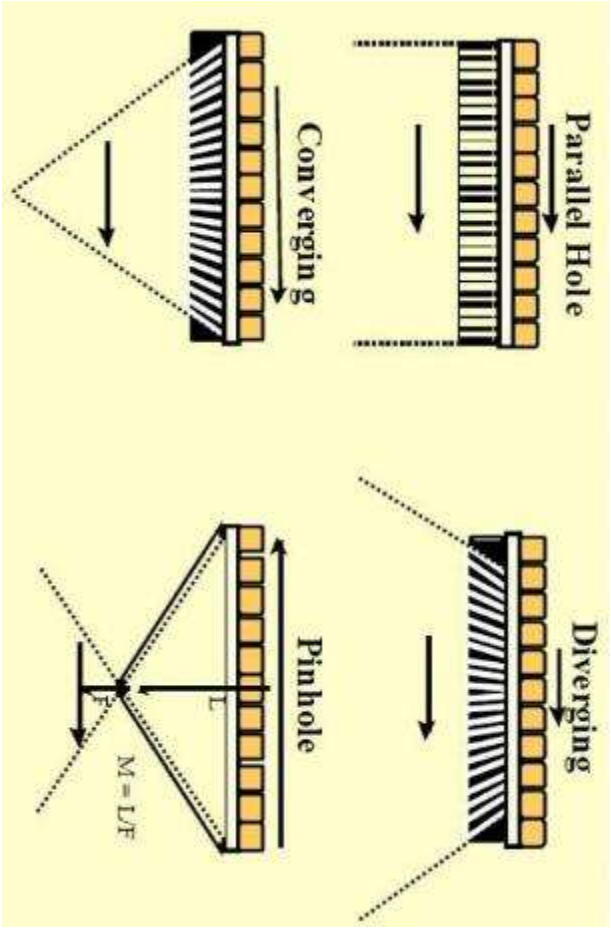


Long length :

- Fewer gamma photons reach the crystal
- Decreased sensitivity but increased spatial resolution

Types of Collimators

- Many types :
  - Parallel-Hole collimator
  - Converging collimator
  - Diverging collimator
  - Pin-Hole collimator
- Depending on the energy:
  - LE: 0 keV < energy < 200 keV
  - ME: 200 keV < energy < 300 keV
  - HE: 300 keV < energy < 400 keV



Collimator Measurements

Type	Hole Size (mm)	Number of Holes	Hole Length (mm)	Septal Thickness (mm)
LEHR	1.5	86,300	35	0.20
LEGP	1.9	56,560	35	0.20
MEGP	3.0	15,210	58	1.05
HEGP	4.0	7,410	66	1.80

Collimator Performance Factors

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Type	Resolution* (mm)	Sensitivity (cps/MBq)
LEHR	7.4	72.0
LEGP	9.0	121.5
MEGP	9.4	64.8
HEGP	10.7	65.25

*spatial resolution at 10 cm from collimator face

The Scintillation Crystal Na(Tl)

- γ-ray photon
  - detected by interacting with crystal
  - converted into scintillations
- Crystal shape:
  - circular
  - rectangular
- The crystal size
  - ~ 60 x 45 cm^2
  - FOV ~ 54 x 40 cm^2
- Crystal thickness
  - ~ 9.5 mm (3/8 inch)



Scintillation Crystal Properties

- **Desirable properties** :
  - High stopping efficiency for γ-rays (~ 90%)
  - Stopping without scatter
  - Blue light emitted at 415nm wavelength.
  - Crystal is transparent to visible light
  - The detector crystal is thin

Disadvantages of the NaI(Tl) Scintillator

- Crystal hermetically sealed in aluminium as hygroscopic
- Although 90% gamma photons absorbed only ~ 10% energy conversion to light photons
- Light pulse ~ 25 µsec
- Crystal expensive ~ £50,000 (x2)
- Fragile and sensitive to both mechanical stress and temperature changes



Lightguide and Optical Coupling

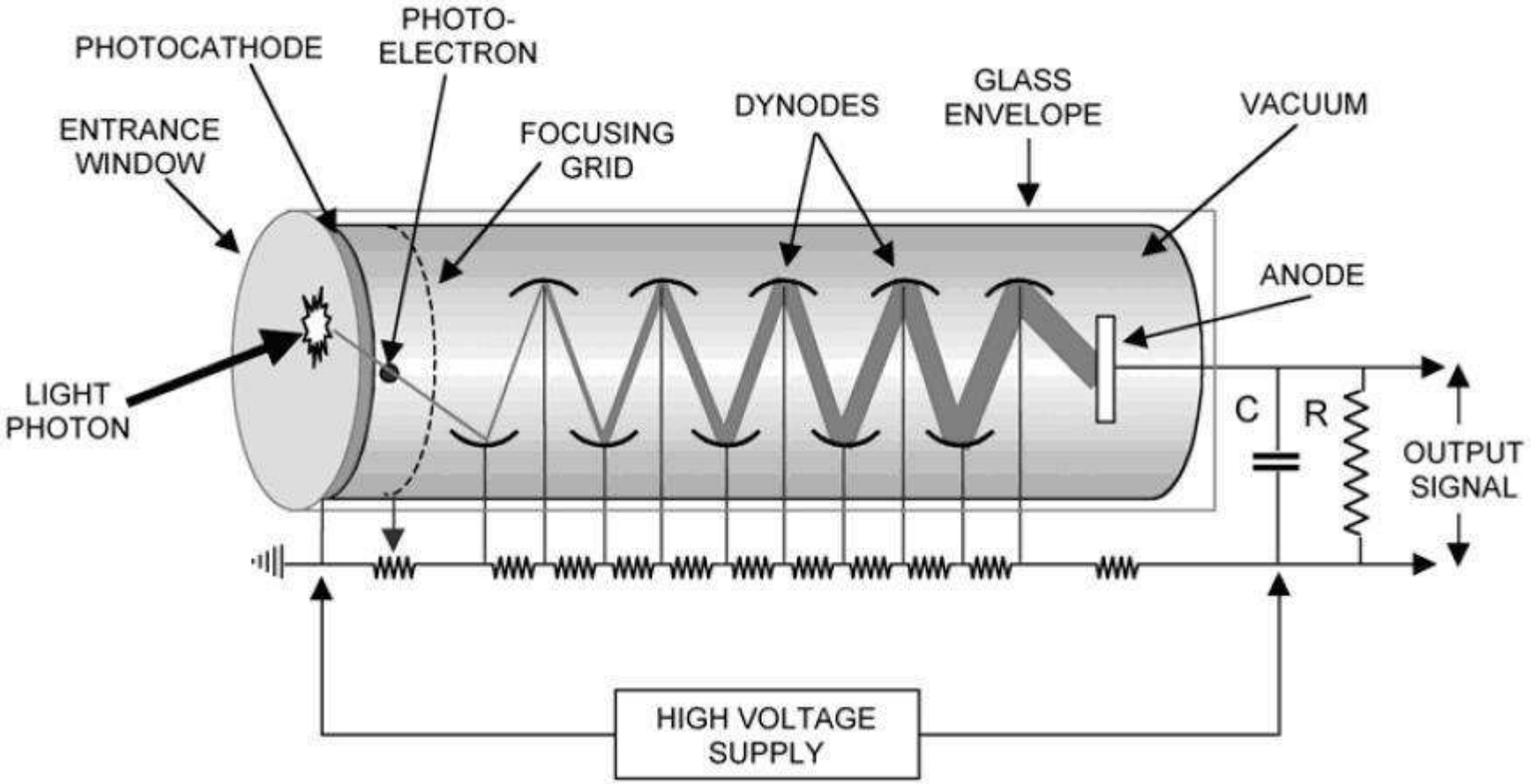
- Lightguide
  - acts as optical coupler
  - usually quartz doped plexiglass (transparent plastic)
  - should be as thin as possible
  - should match the refractive index of scintillation crystal
- Silicone grease between
  - lightguide and the PMTs
- No air bubbles trapped in the grease
  - photon reflections
  - reduced light transmission

The Photomultiplier Tube (PMT)

- A PMT is an evacuated glass envelope
- It consists of:
  - a photocathode
  - an anode
  - ~ 10 dynodes



The Photomultiplier Tube (PMT)



The PMT Array

- Hexagonal array of detectors
- PMTs mounted on the crystal
- Cross Section of PMT
  - Circular or hexagonal
- Arrays of 7, 19, 37, 61 and 91



- The number of PMTs affects the spatial resolution of the camera
  - smaller diameter – improved resolution
  - increased number – uniformity problems

Thank you for listening



