Kingdom of Morocco
Ministry of Higher Education,
Scientific Research and Innovation

THE EIGHTH BIENNIAL AFRICAN SCHOOL OF FUNDAMENTAL PHYSICS AND APPLICATIONS (ASP2024)

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The use of radiations in medical imaging and the treatment of patients

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Introduction to medical imaging

What is medical imaging?

- Medical imaging is the visualization of body parts, tissues, or organs

Types of Radiation used

- ✓ **X Rays :** ionizing radiation
  - Radiography
  - CT scan (Computed Tomography)
- ✓ **Gamma rays:** ionizing radiation
  - Nuclear Medicine
- ✓ **Sound waves**
  - Ultrasound
- ✓ **Magnetic field/ radiofrequency waves**
  - MRI (Magnetic Resonance imaging)

Sources of images

- **Structural/anatomical information** (CT, MRI, US) within each elemental
- **Anatomic information and functional information** (SPECT/CT PET/CT) resulting in better ionizition and definition of scintigraphy finding

- **The uniqueness of nuclear medicine studies lies in their ability to demonstrate function, physiology, and metabolism**

What is radiology?

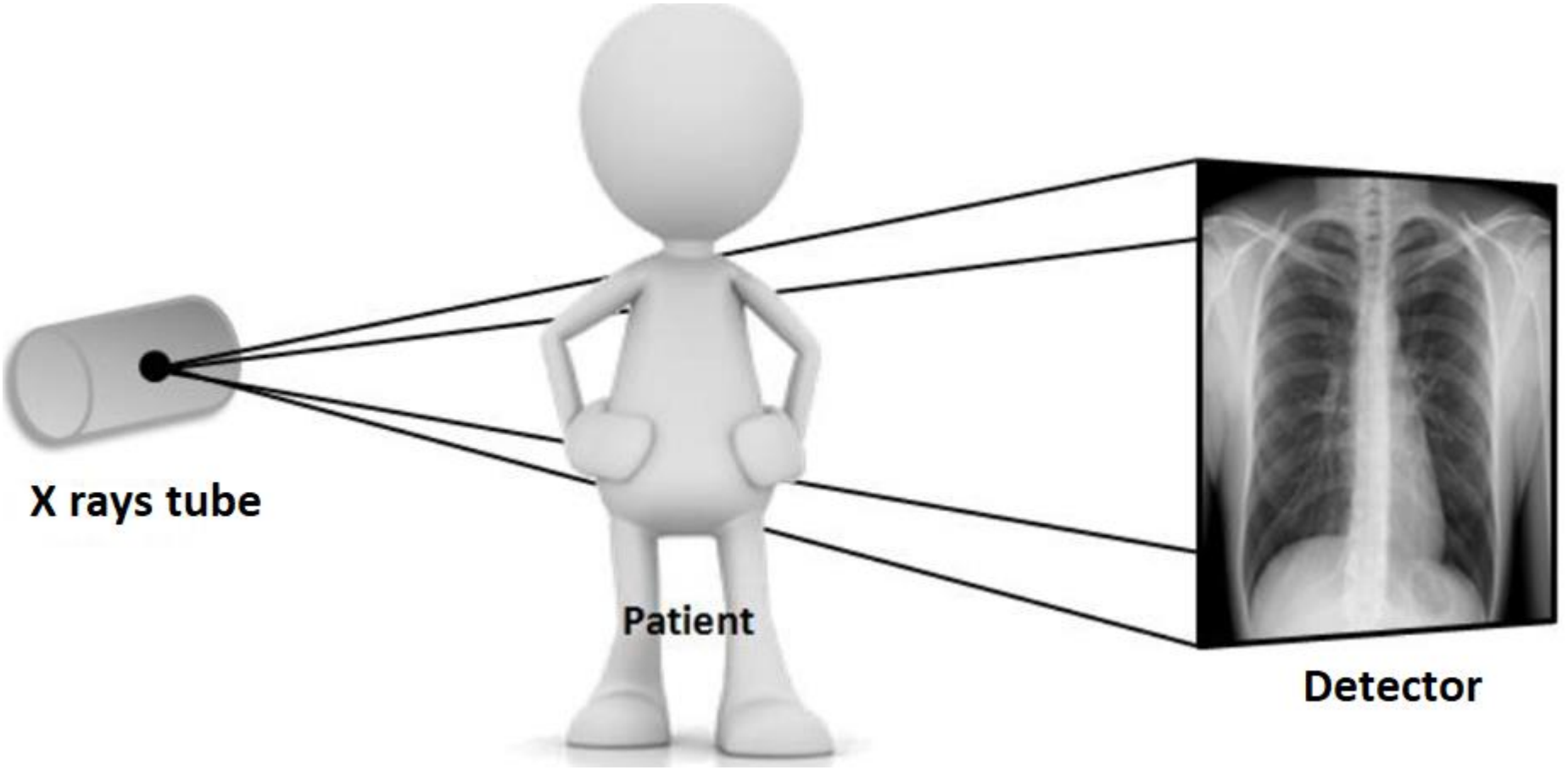
- This field can be divided into two broad areas.

✓ **Diagnostic radiology**

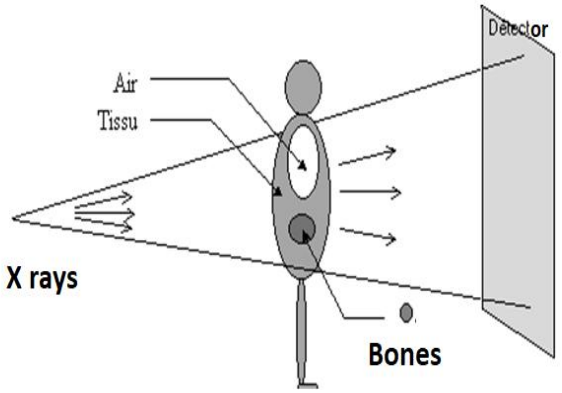
✓ **Interventional radiology**

Radiodiagnosis

X ray radiography

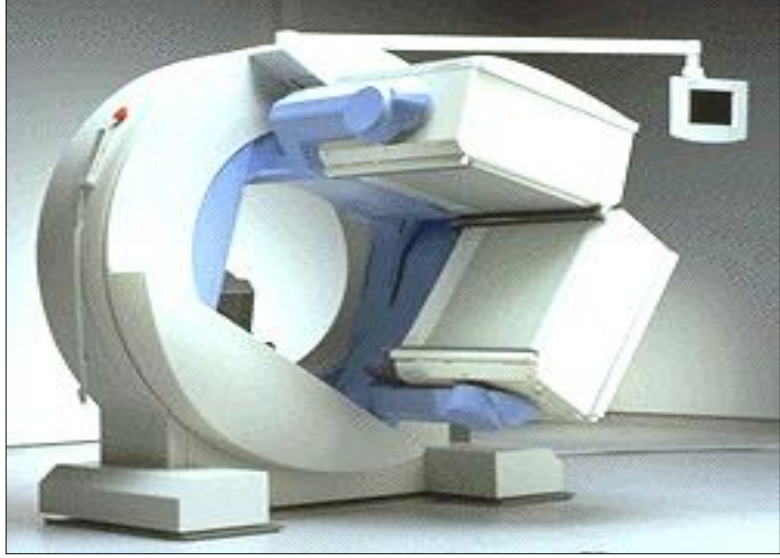


Projection radiography/Xray radiography



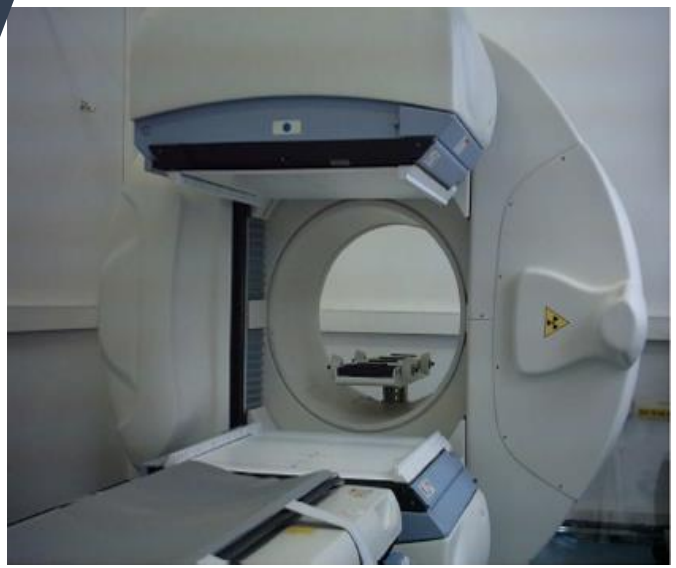
PET CT

Nuclear Medecine

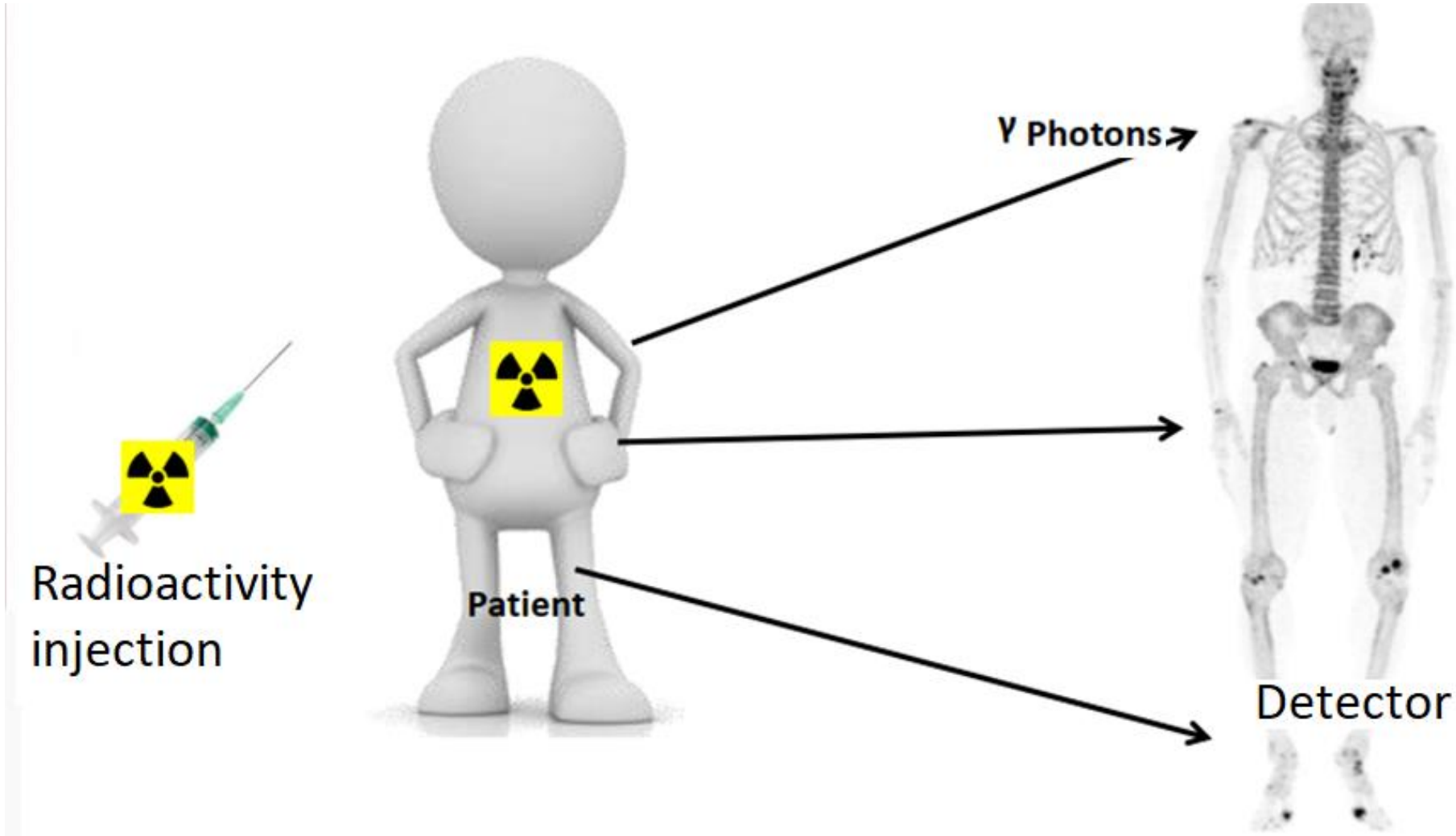


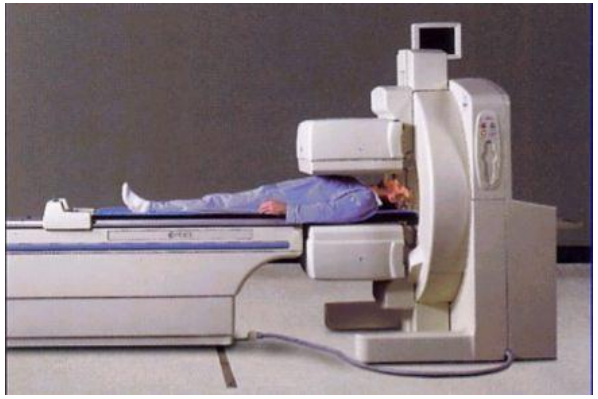
Gamma camera

SPECT CT

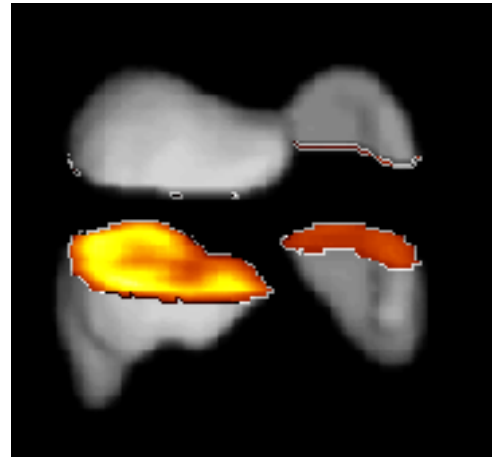


EMISSION IMAGING – NUCLEAR MEDICINE

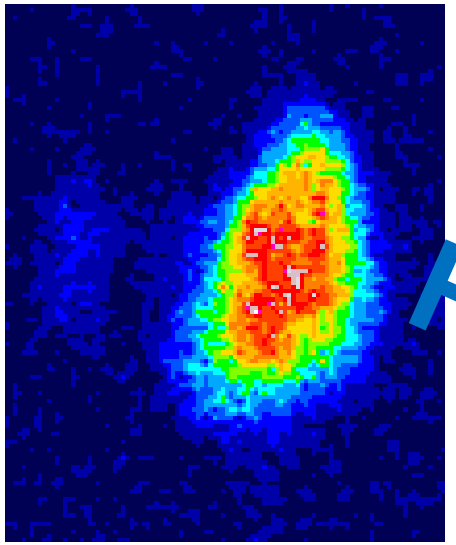


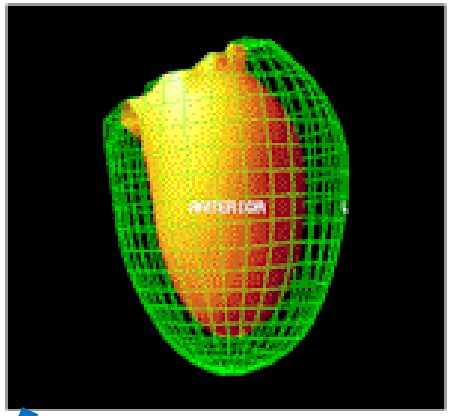


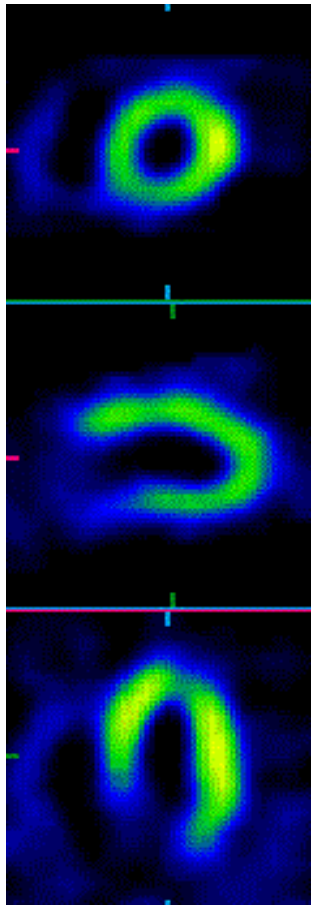
Scintigraphy



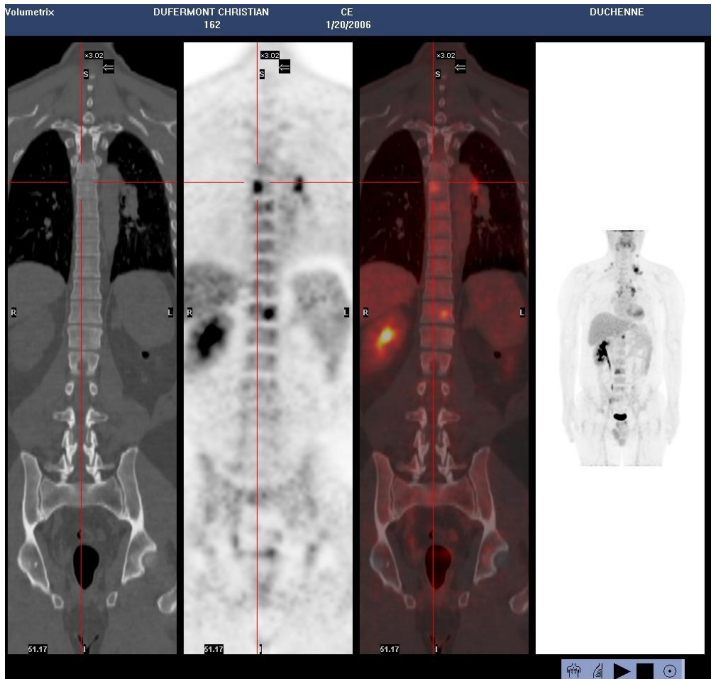
Nuclear Medecine

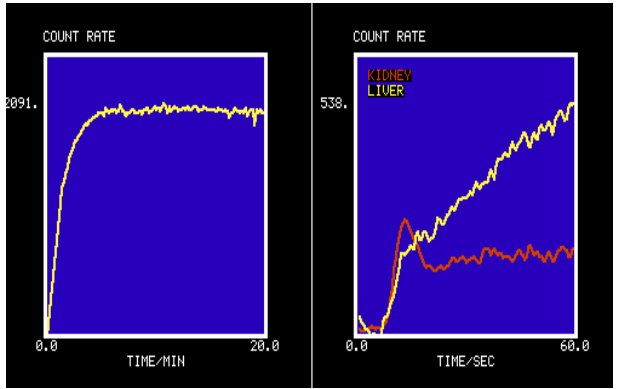


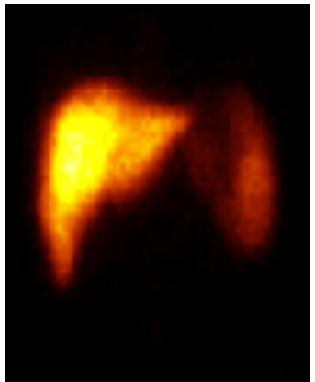




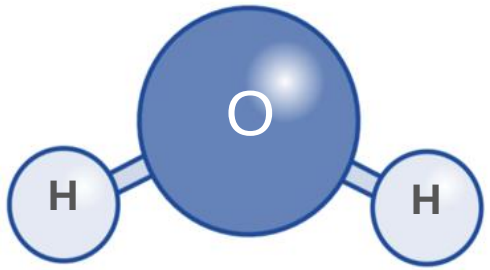
Functional imaging



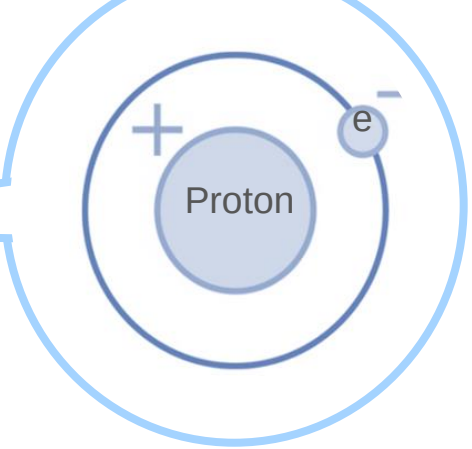




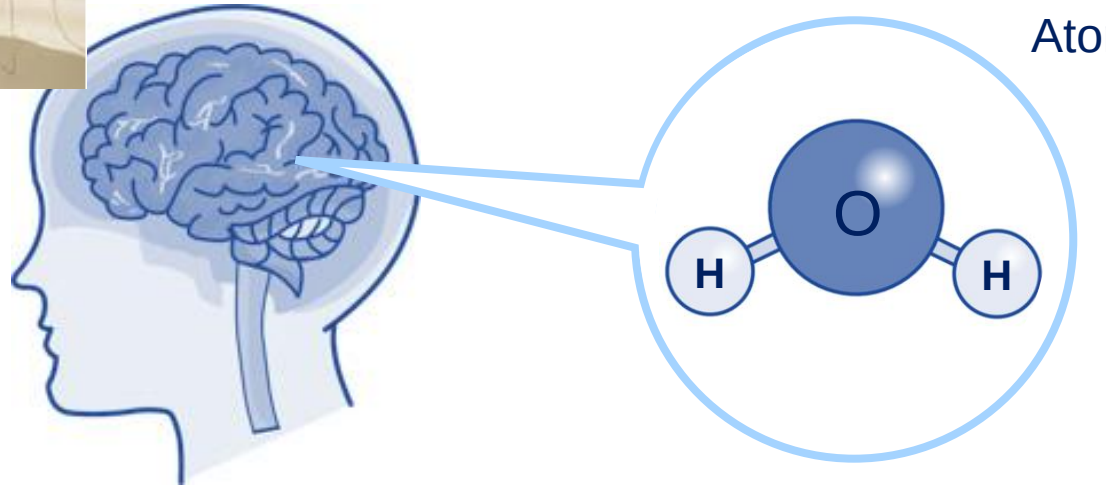
MRI

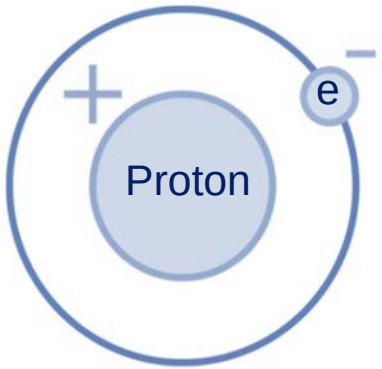


Molécule d'eau



Atome d'hydrogène





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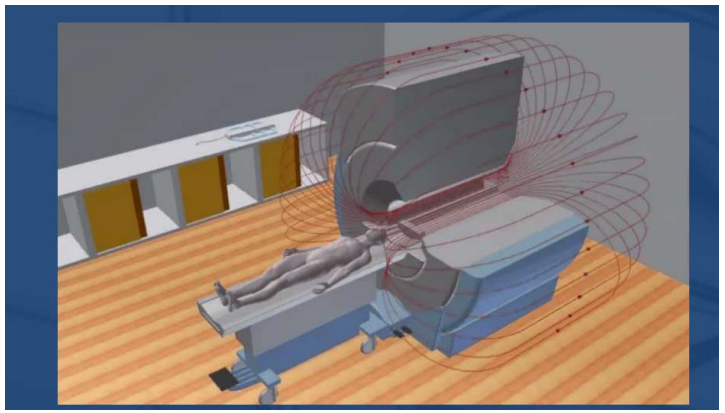


Ultrasound imaging

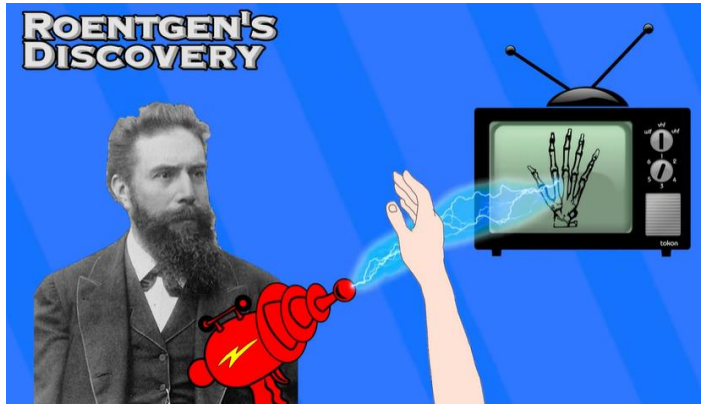
Use of sound above human hearing range to image body structures, including soft tissues

Safety

Modality	Radiation Type	Comments
X-ray imaging	Ionising Radiation	Biological effect , need protection against unnecessary doses
Radioisotope scanning		
Ultrasound Imaging	Non-ionising Radiation	Less harmful effects. Better for the foetus.
MRI		

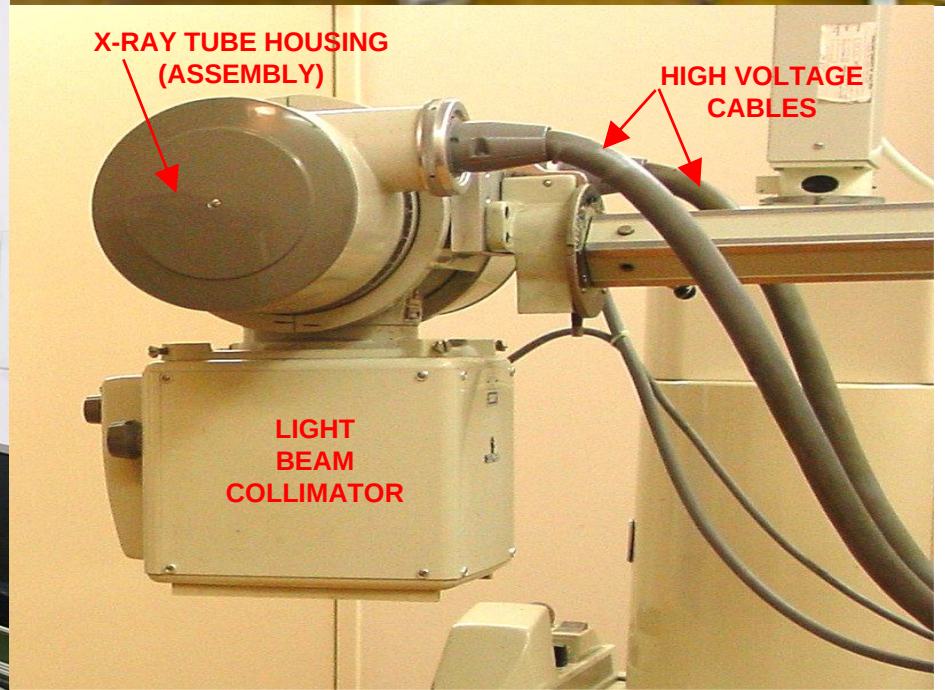
Book:

- ✓ **Medical Imaging: Technology and Applications (Devices, Circuits, and Systems) 1st Edition,** by Troy Farncombe, Kris Iniewski



Radiology Imaging devices

Conventional Radiology Imaging Chain

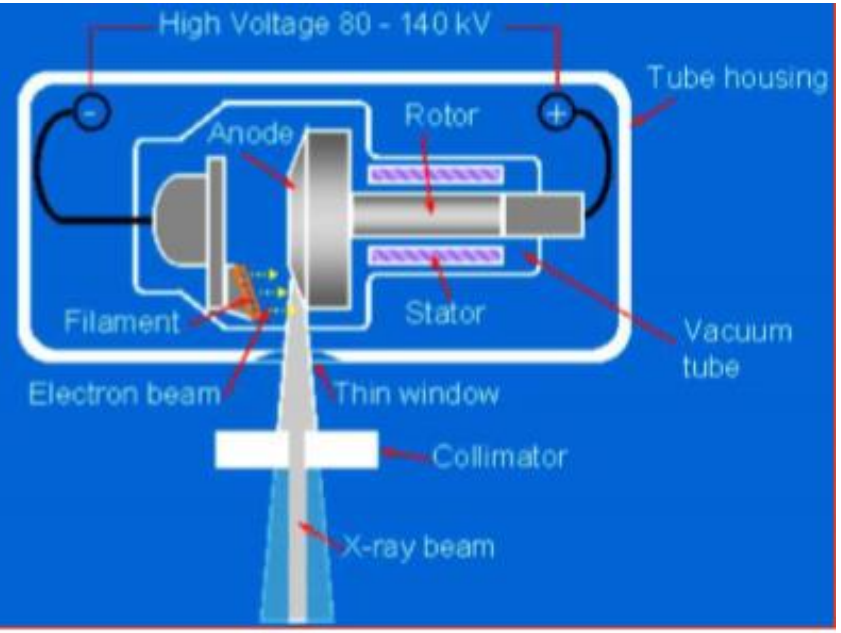


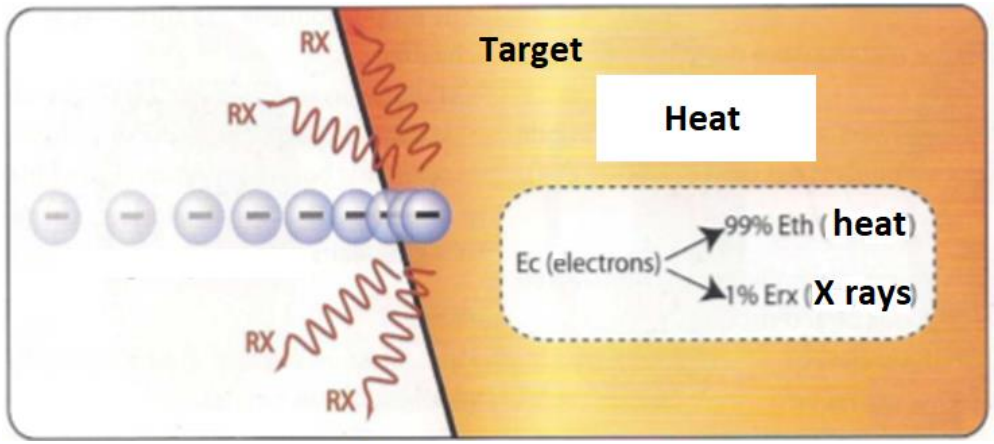
1- X rays production

- Two types of X ray generated

✓ Characteristic radiation

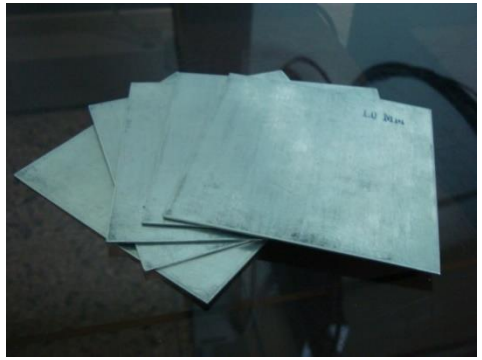
✓ Bremstralung radiation

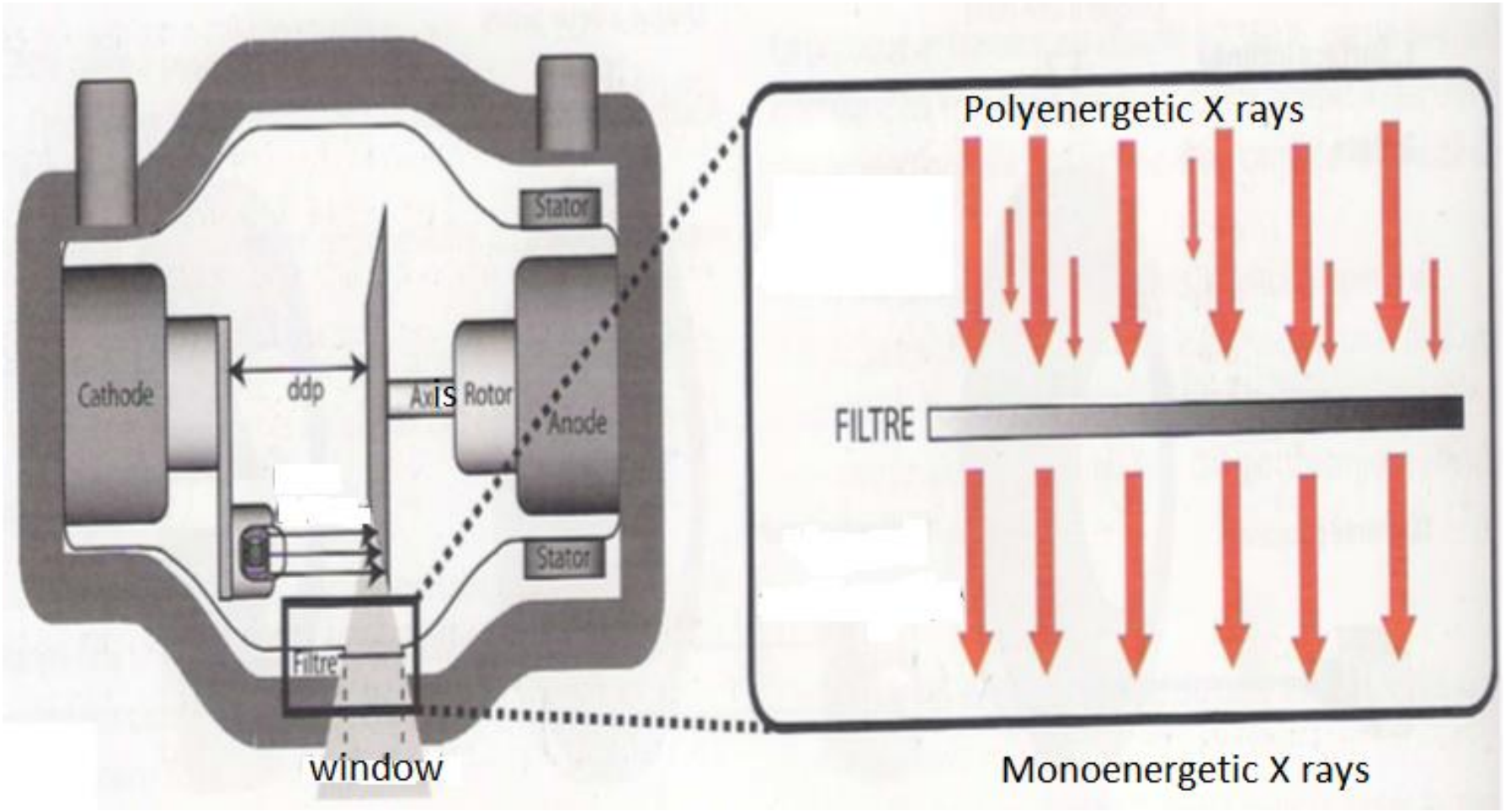




2- Filtration

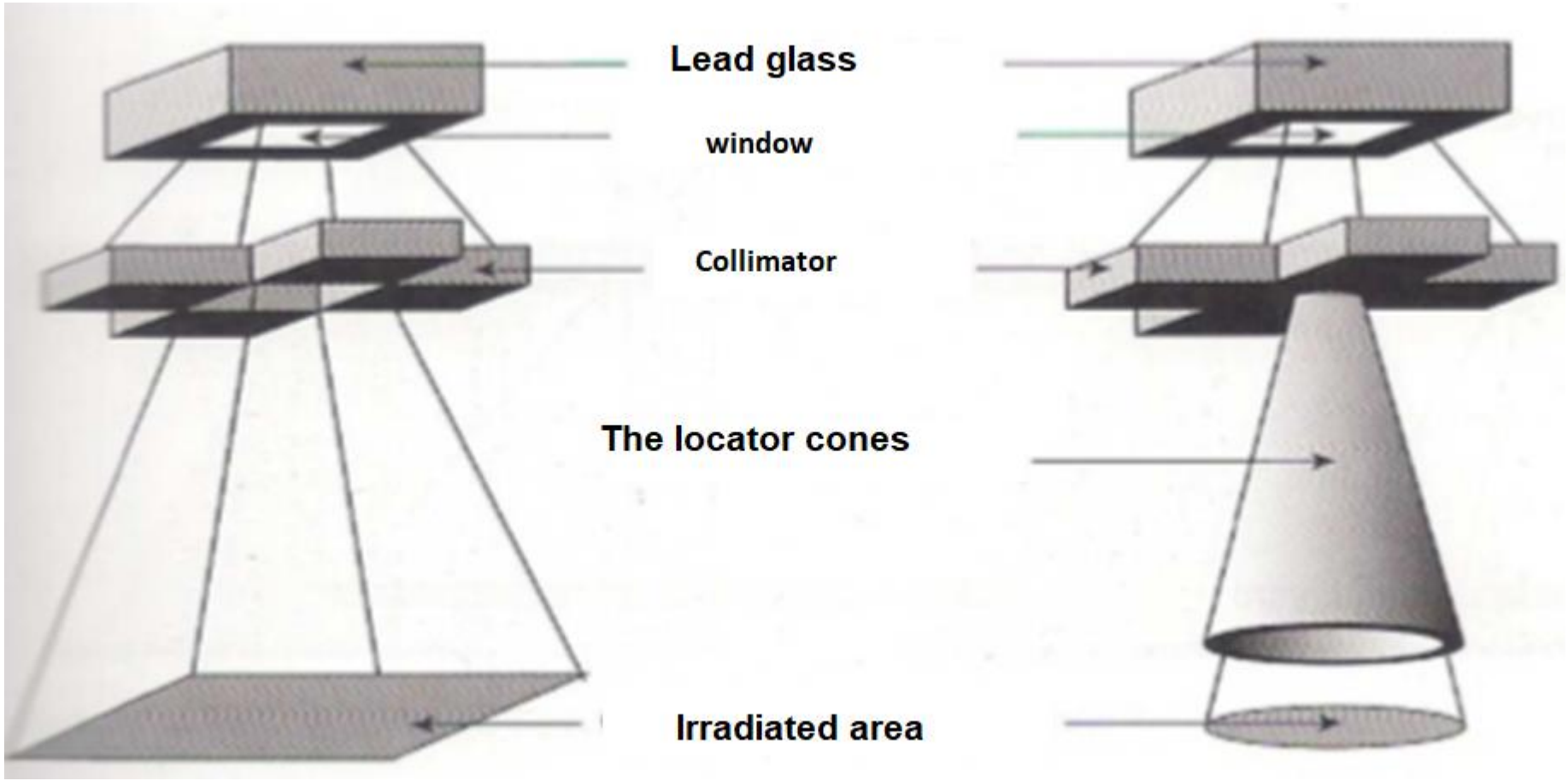
- A **filter** is placed at the tube window to homogenize the beam energy and **eliminate very low energy photons.**



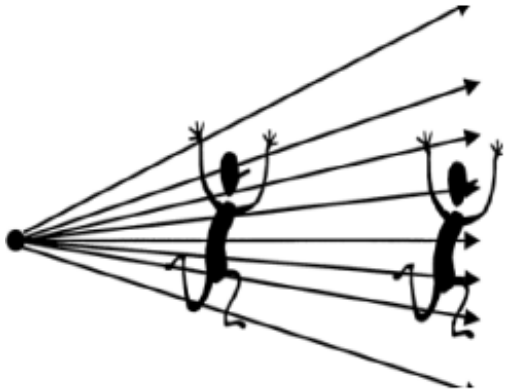


3 - Collimation

- To determine the field size, the collimation is used



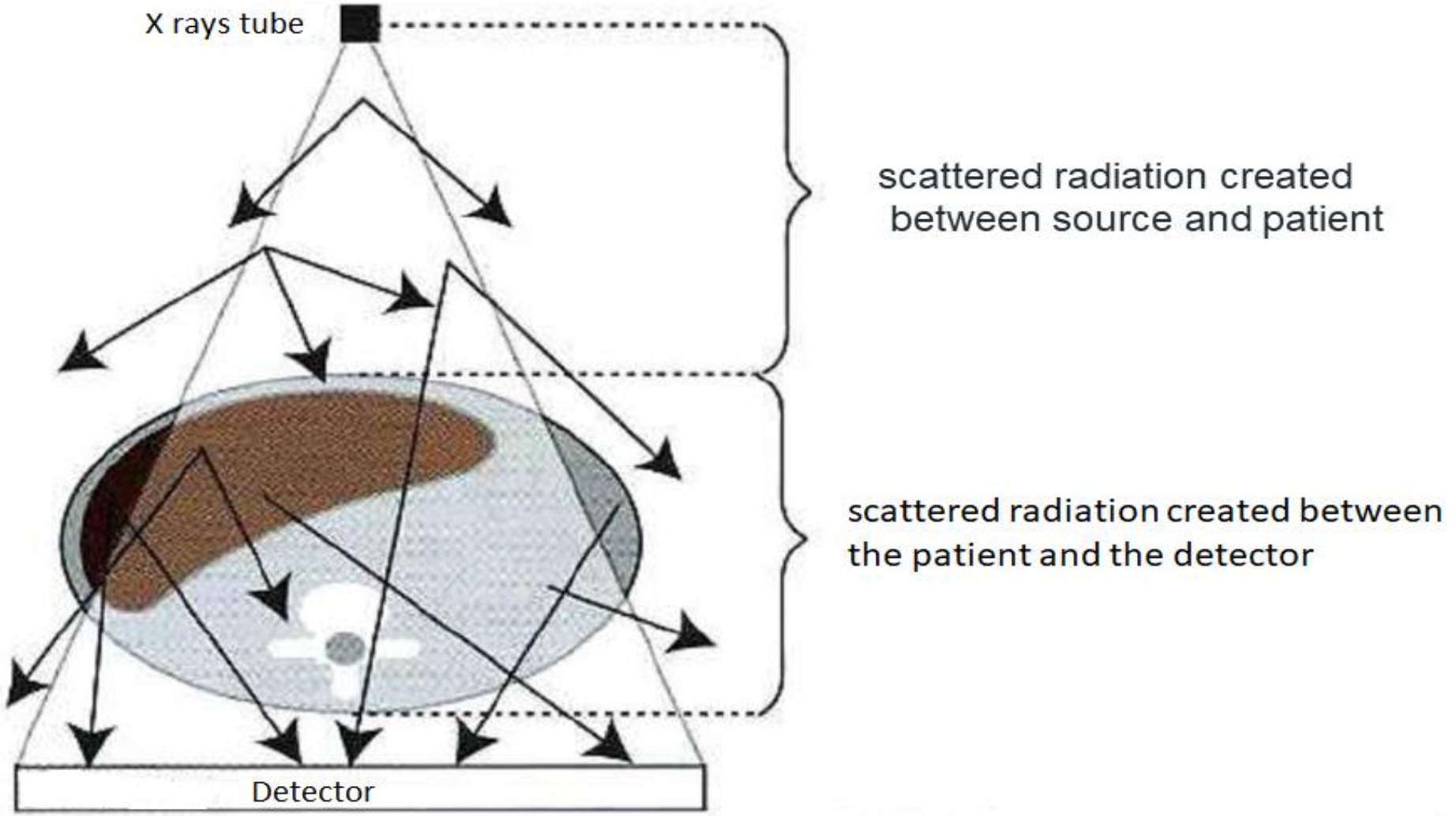
4- Removal of scatter



Scattered radiation

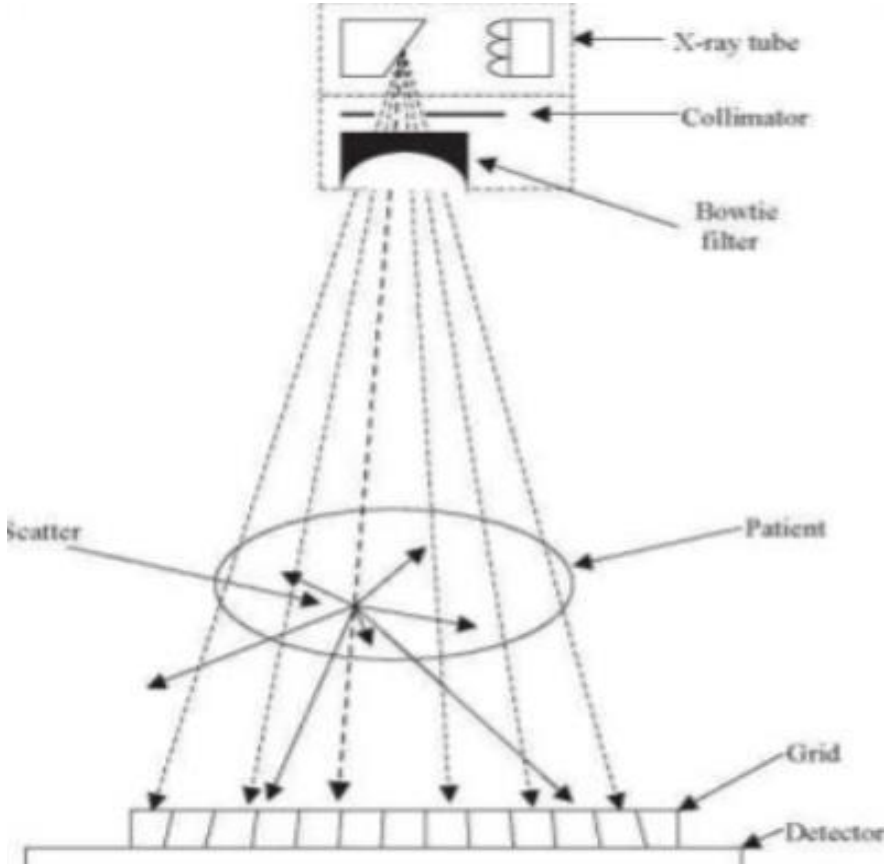
How to eliminate scattered rays?

By avoiding its formation or by preventing it from reaching the film



How to eliminate scattered rays?

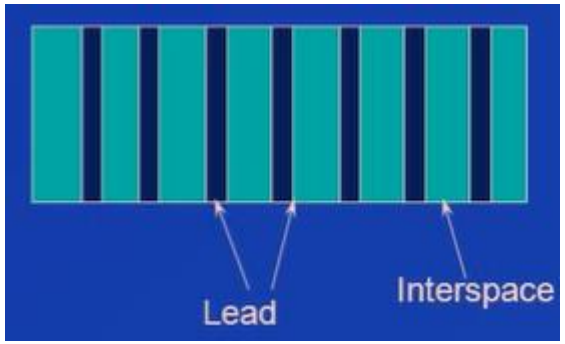
- The collimator
- The locator cones
- The anti-scatter grid

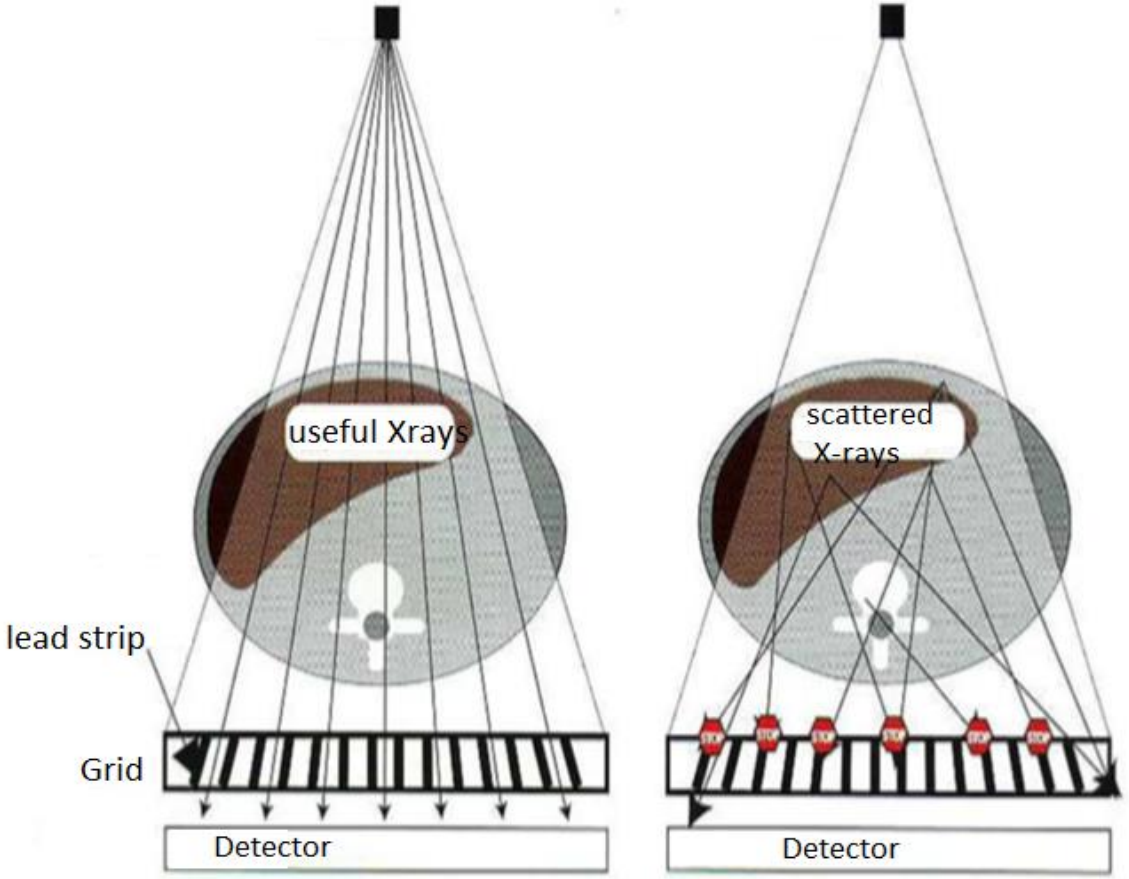


The locator cones

Grid construction

- ✓ **Lead**: 0,5 thick upright strips
- ✓ Interspace: material between lead strips materials: fiber, aluminium, wood)





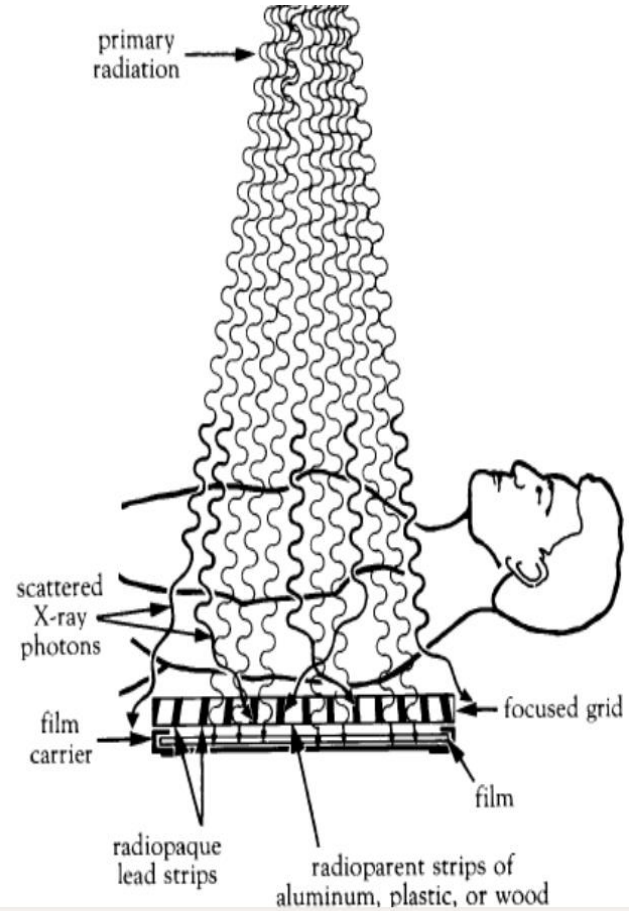


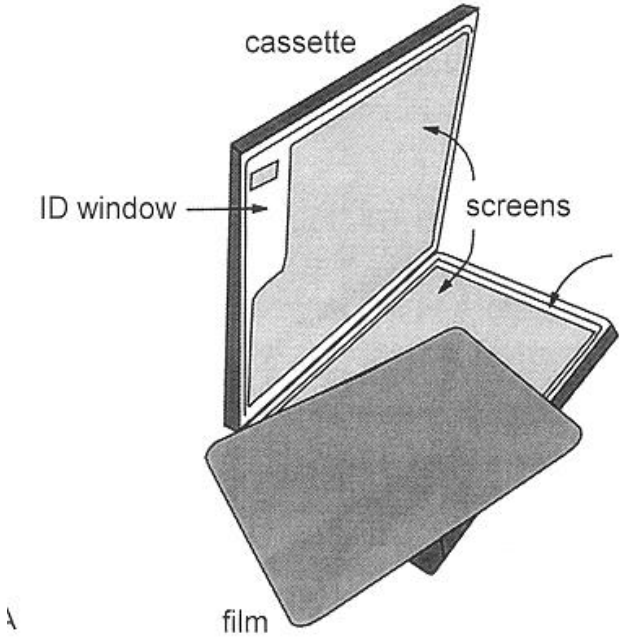
Image receptor for conventional radiography

- **Pair of screens that sandwich the film.**
- **three parts** of the image receptor for conventional radiography

✓ **Film** to record the image

✓ **Intensifying screens** to expose the film

✓ **Cassette** to protect the screens and film



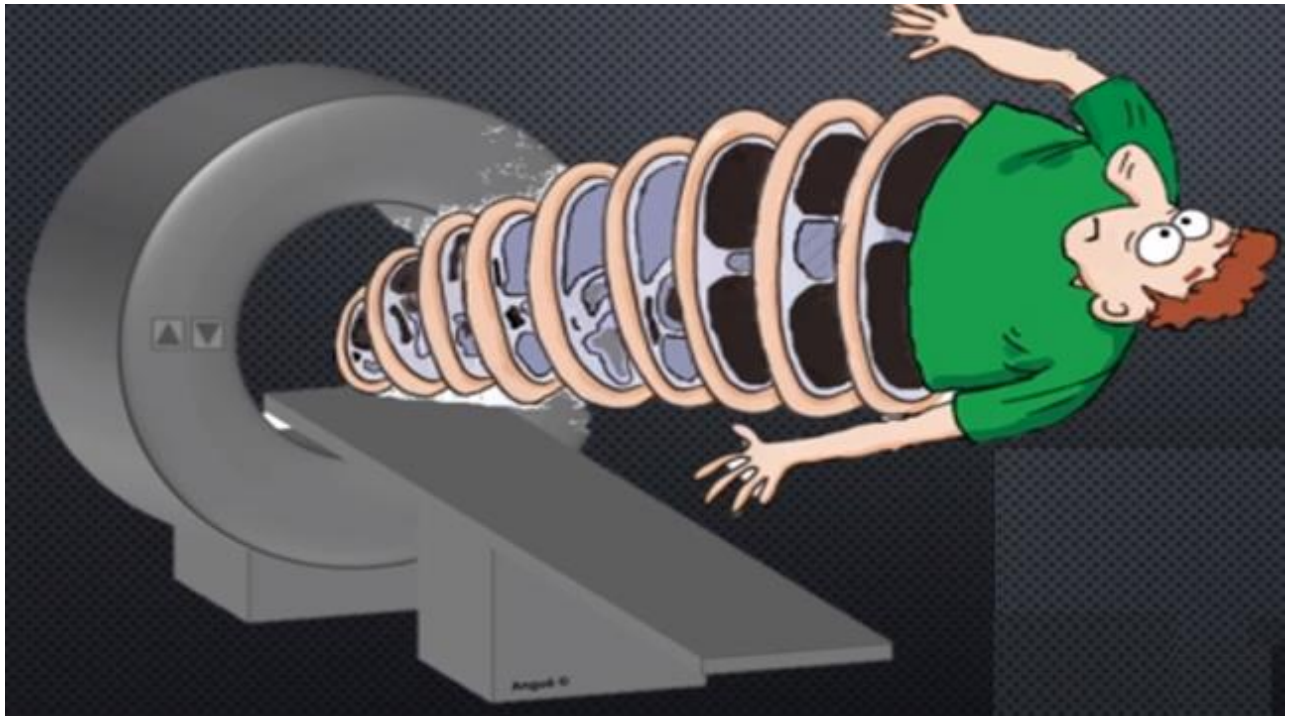
CT scan

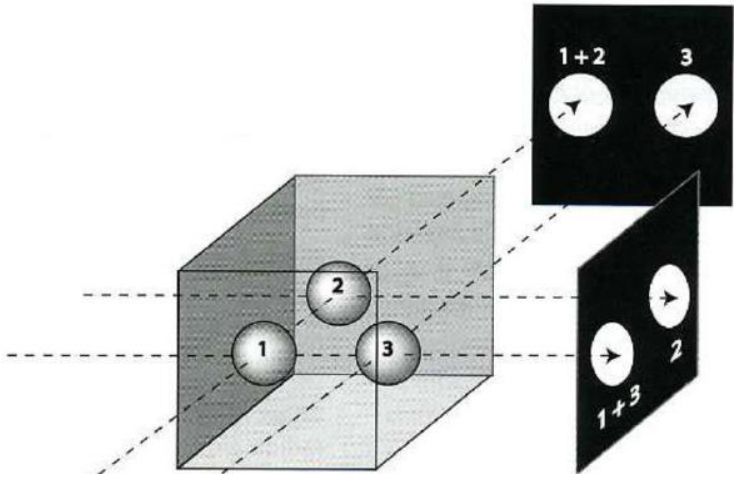
CT (computed Tomograpgy) scanning

- ✓ Tomography
- ✓ Tomo: slice, graphein, to write
- ✓ Imaging of an object by analyzing its slices

Nobel man ... Godfrey Hounsfield with an early version of the CT scanner, then called the EMI Scanner.

CT (computed Tomograpgy) scanning

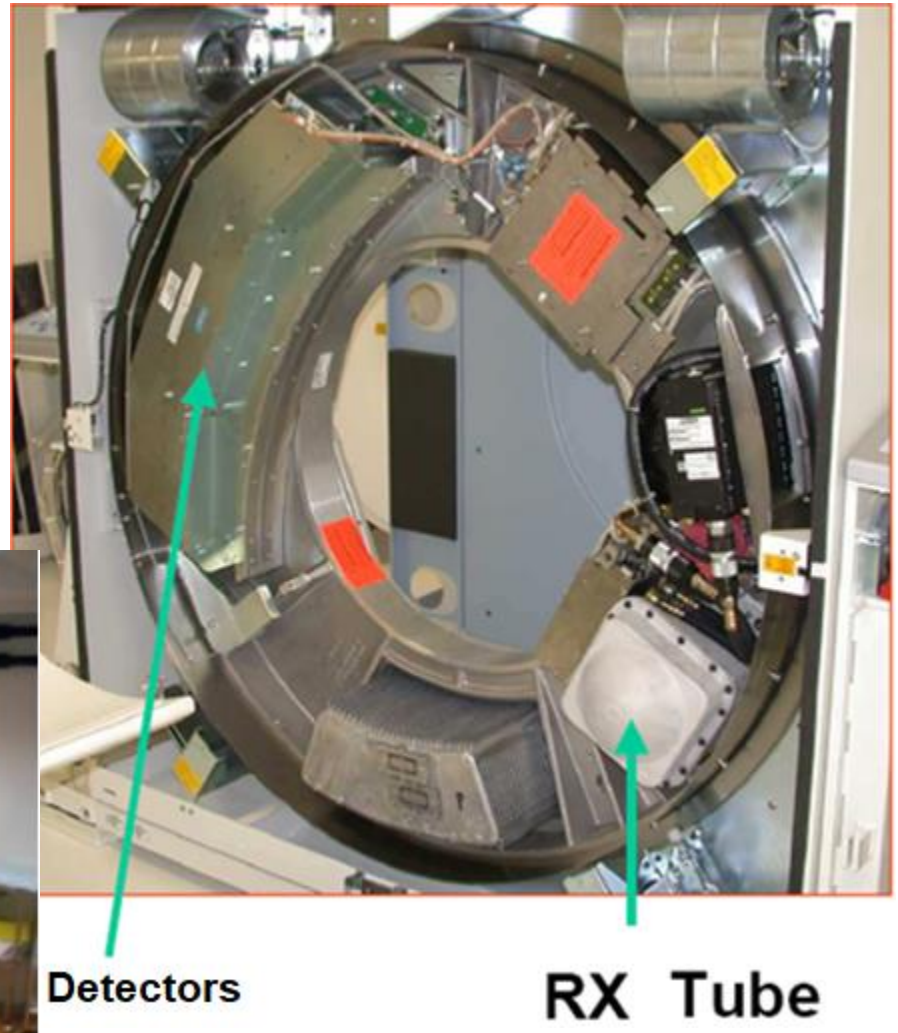




Conventional radiology

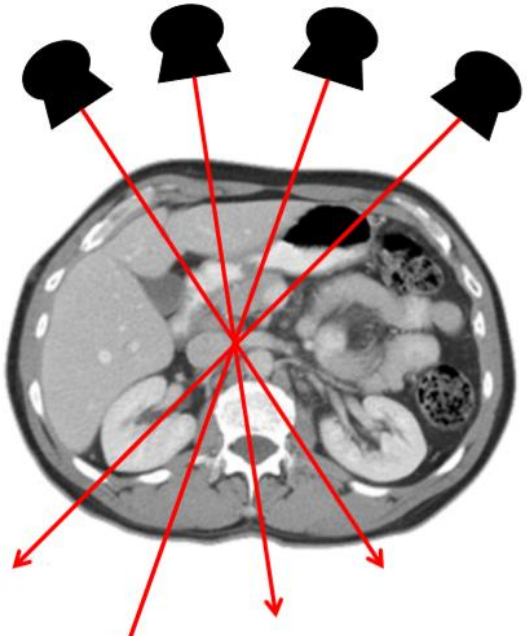
Computed tomography components

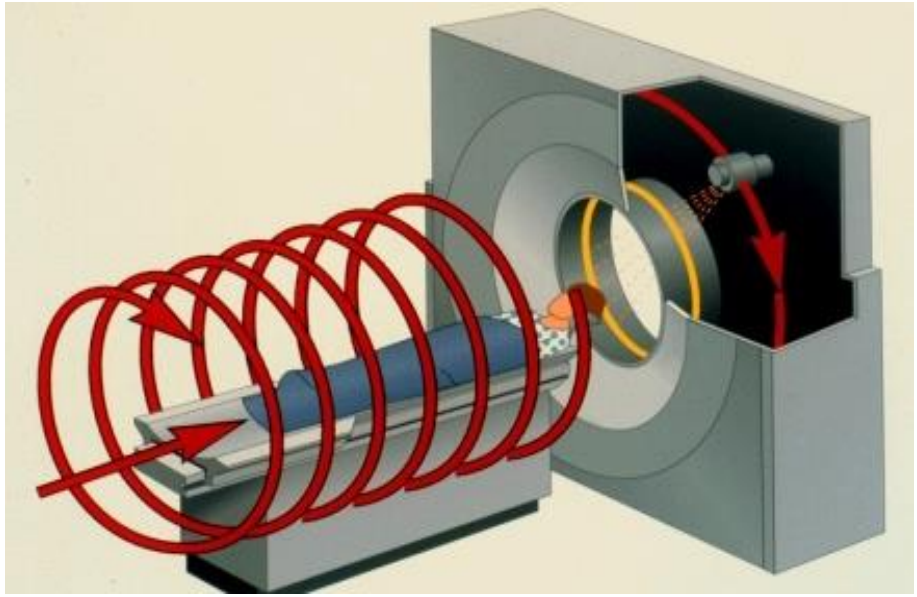
- ✓ Gantry
- ✓ X ray tube
- ✓ Detector
- ✓ Table



How does CT work

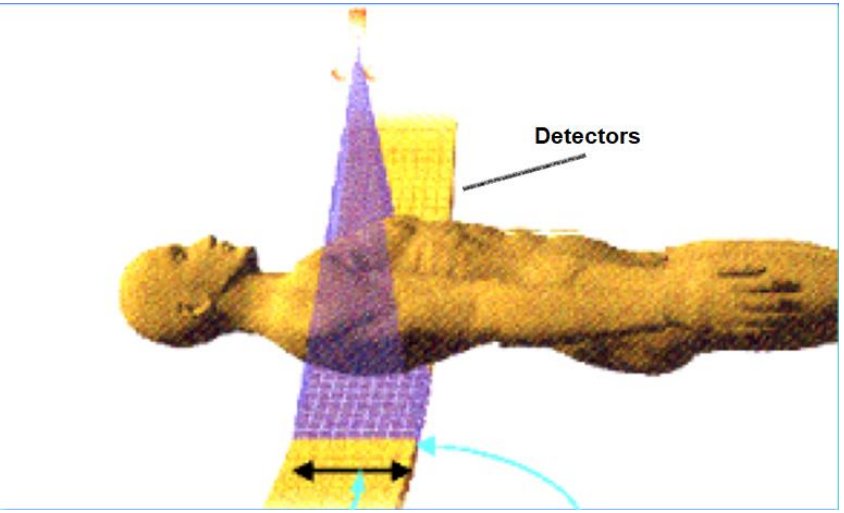
- Unlike a conventional X ray which uses a **fixed Xray tube** a CT scanner use **motorized Xray source** that **rotates** around the circular opening called a gantry
- **During a CT scan the patient lies on a bed that slowly moves through the gantry while the Xray tube is rotating**.

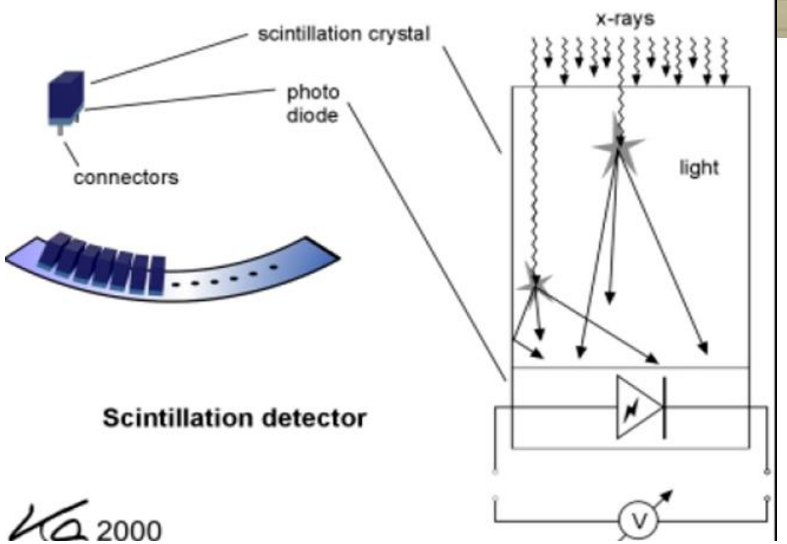




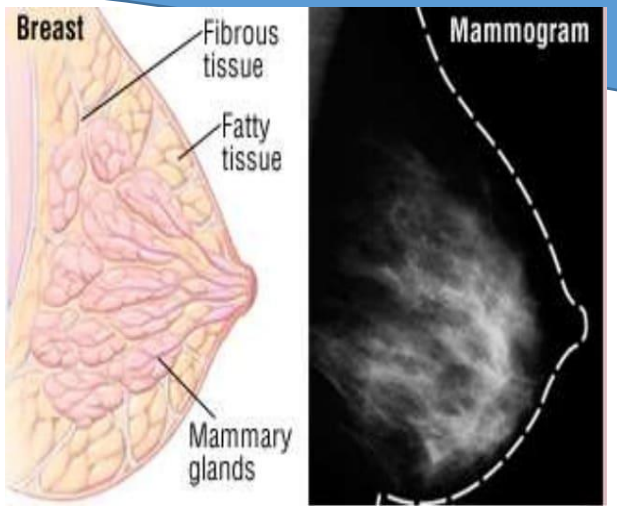
CT (computed Tomograpgy) scanning

- A narrow beam of X rays is aimed at a patient and quickly rotated around the body, producing signals that are processed by the machine‘s computer to generate cross sectional images of the body

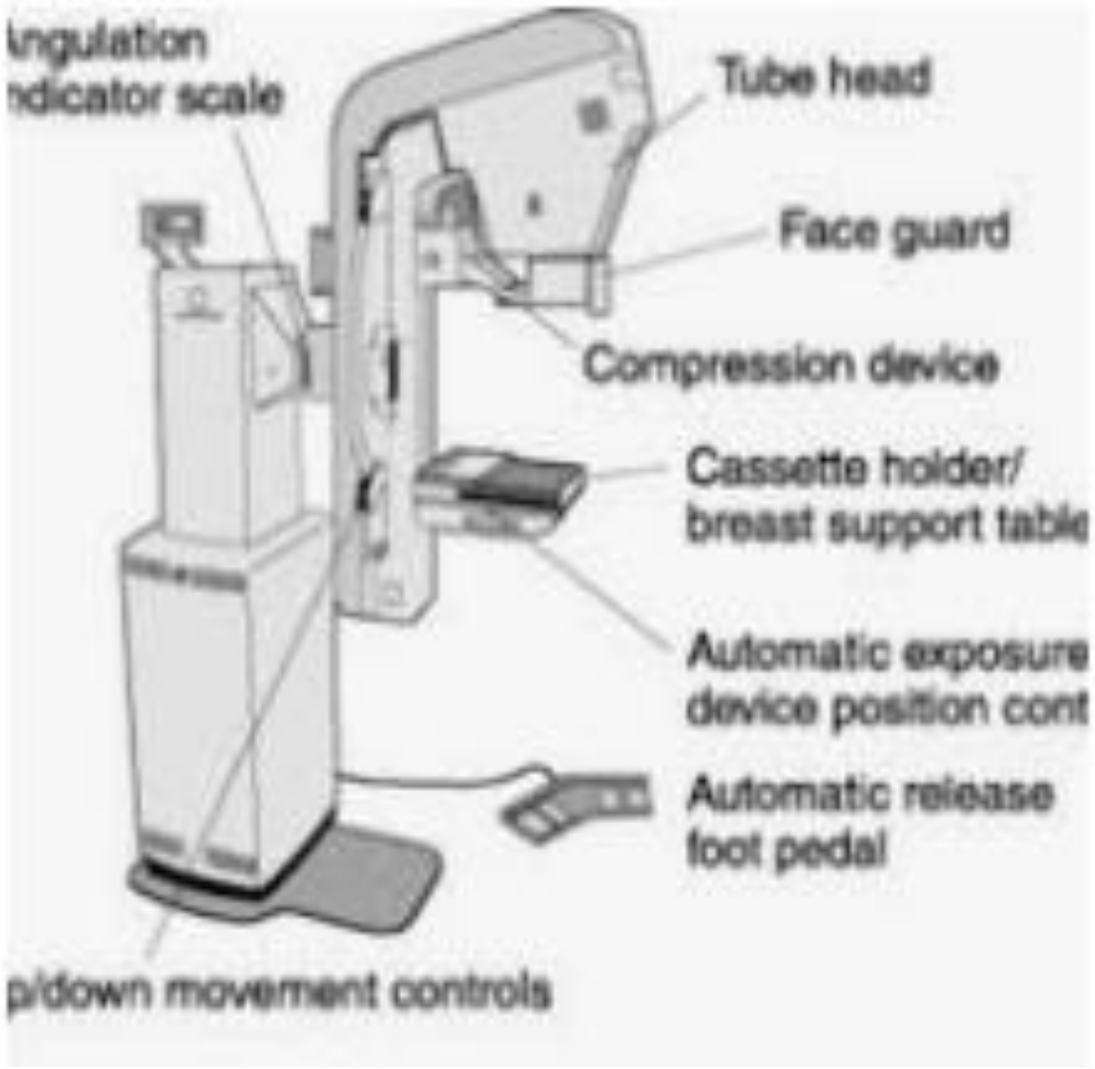




Mammograhy Technics



Mammography equipment

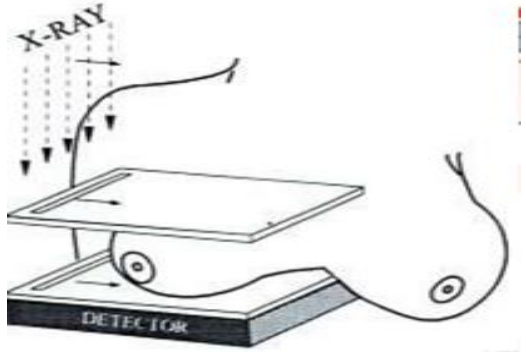


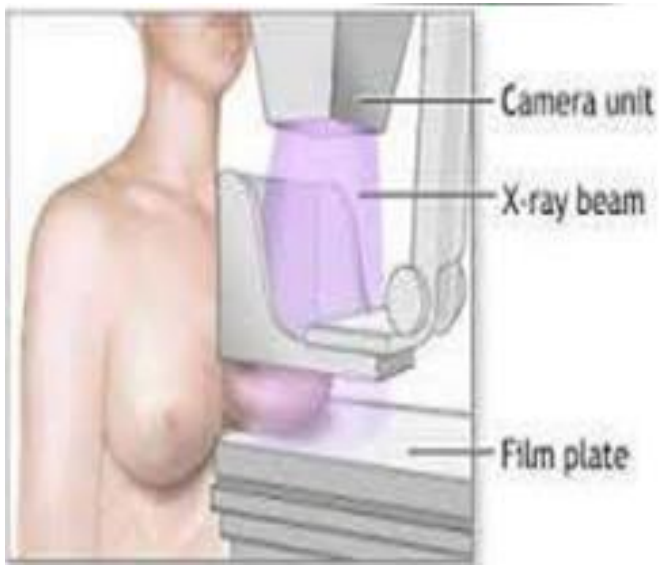
Mammography equipment

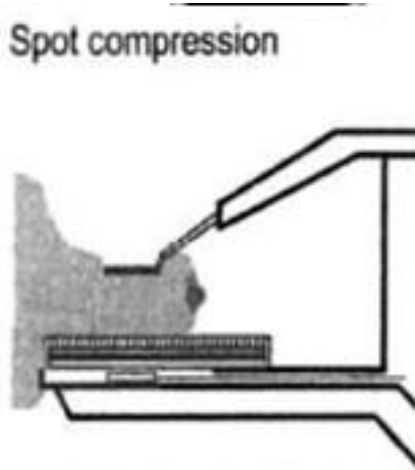
- ✓ **Generator**
- ✓ **X ray tube**
- ✓ **Target:** molybdenum and rhodium
- ✓ **Berylium window**, minimises absorption of radiation within the tube
- ✓ **Molybdenum filter**, by transmitting only characteristic radiation, absorbs unwanted radiation and forms a mooenergetic beam
- ✓ **Grids**
- ✓ **Compression device**: 1- 4mm thick plastic plate

Compression peddle

- Decrease the thickness of the breast, thus reduces the scattered radiation improves contrast
- Reduces geometric unshapness by homogenously bringing the object close to the film
- Makes breast thickness uniform in film density
- Separates the super imposed breast lesions
- **Reduces radiation dose the breast tissues**





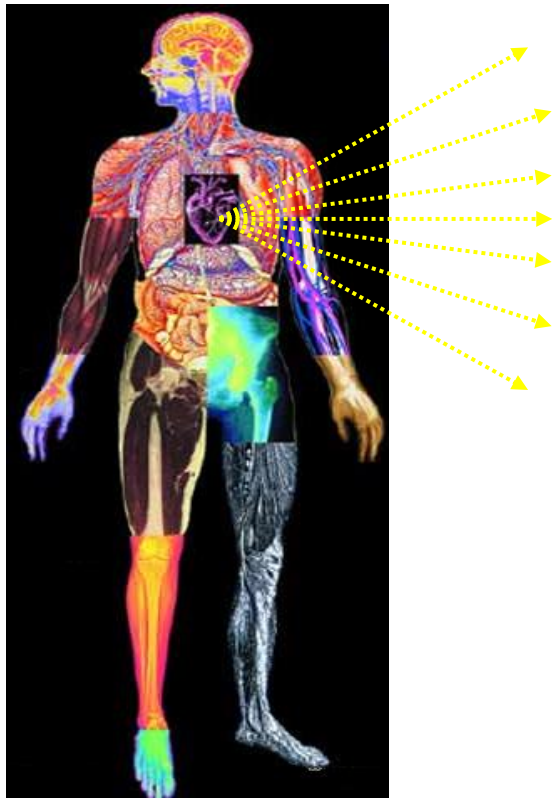


Spot compression paddle:
Better compression over small a

References

Books:

- **Textbook of Radiology and Imaging** , by David Sutton MD FRCP FRCR DMRD MCA Ror
- **Medical Imaging Signals and Systems**, by Jerry L. Prince
- **Radiation Physics for Medical Physicists**, by Ervin B. Podgorsak



Nuclear medicine devices

Objectives:

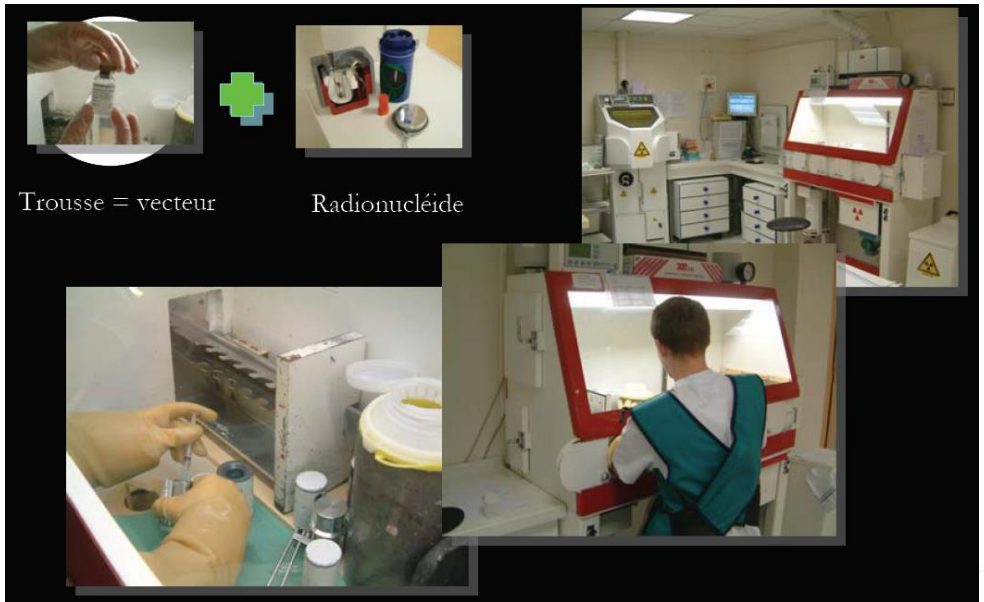
- **Nuclear medicine activities**
- **Gamma camera**
    - -Collimator
    - -Scintillator
    - -Photmultiplier
- **PET CT**
    - -Crystals used in PET
    - -Principle of annhilation coincidence detection
    - -Protocole of exam
- **Calibrator dose**

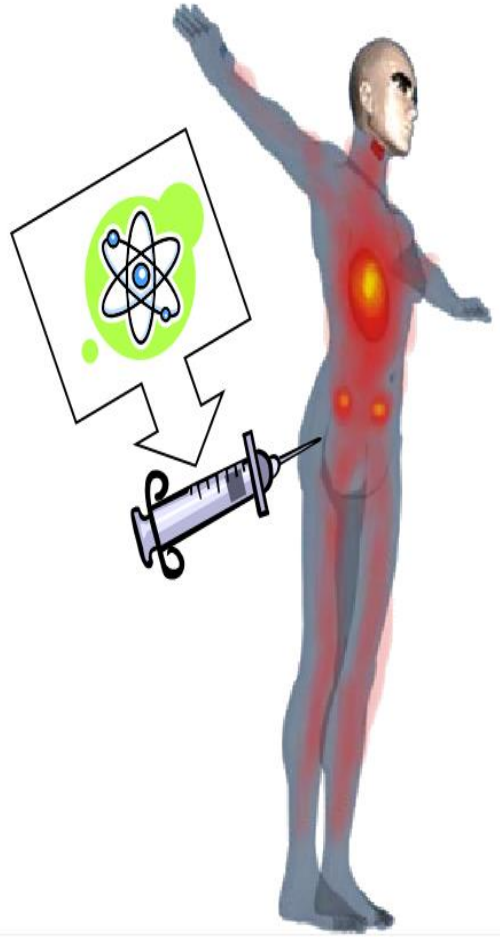
What is radiopharmaceutical?

- The radioactive matrials administered to patients are known as radiopharmaceuticals
- These consists of:
- **A chimical molecule** which determines the behaviors of the radiopharmaceutical in the body
- **A radionuclide:** the radiation emitted by radionuclide may be detected from outside the body by a radionuclide imaging device (gamma camera) or may be detected in a sample of a body fluid (plasma)

The ideal radionucleide for diagnostic

- Emit gamma ray with the right energy (120 Kev-300) to allows detection by a gamma camera
- Have a short half life
- Be cheap
- Be readily available





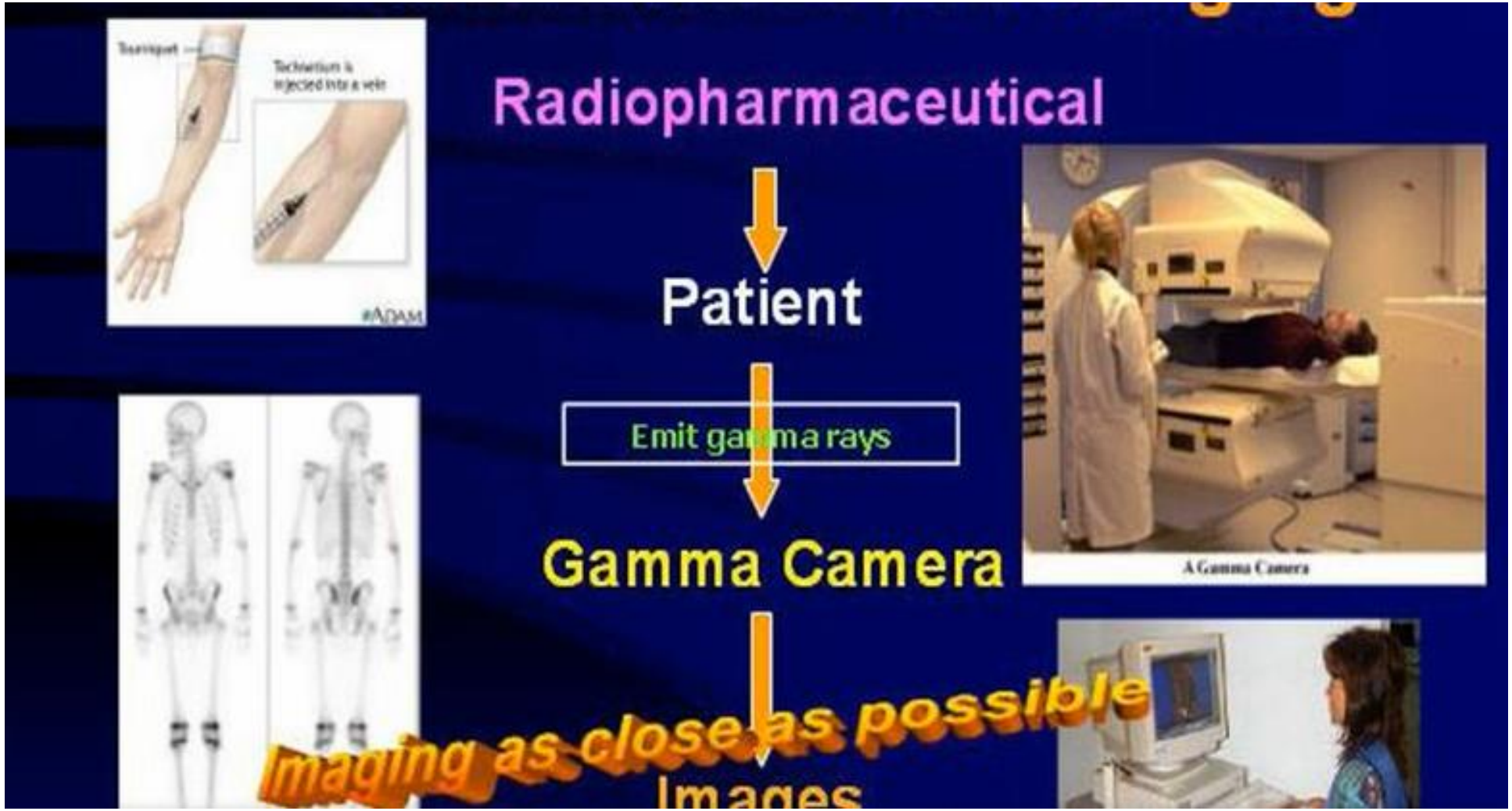
Administration of radioactivity

- In large departments, producton is done in house in what is know as **« Hot Lab »**
- The routes of administration for radioactive substances include:

✓ **Intravenous injection**: the radioactive substances is injected into a vein

✓ **Inhalation:** Some radioactive substances and radioisotopes are inhaled by the patient

✓ **Ingestion**: radioactive substances can be ingested as well


Tourniquet
Technetium is injected into a vein
A.D.A.M.
Radiopharmaceutical
Patient
Emit gamma rays
Gamma Camera
A Gamma Camera
Imaging as close as possible
Images

Major imaging systems categories

Positron emission tomography systems

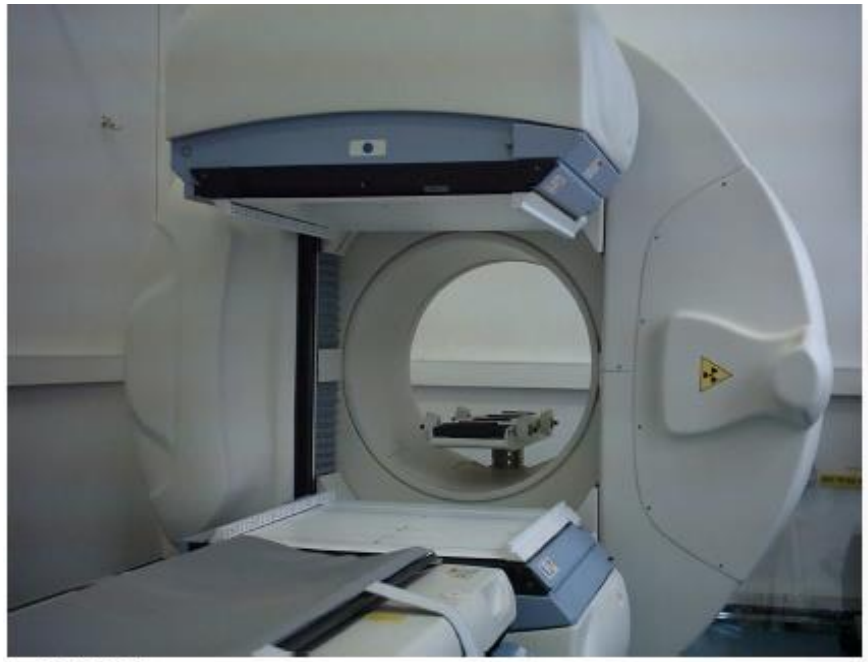
- Tomographic systems
  - PET (3-D images)

Gamma camera systems

- Planar gamma cameras (2-D images)
- Single photon emission computed tomographic systems
  - SPECT (3-D images)

Major imaging systems categories

SPECT/CT



PET/CT

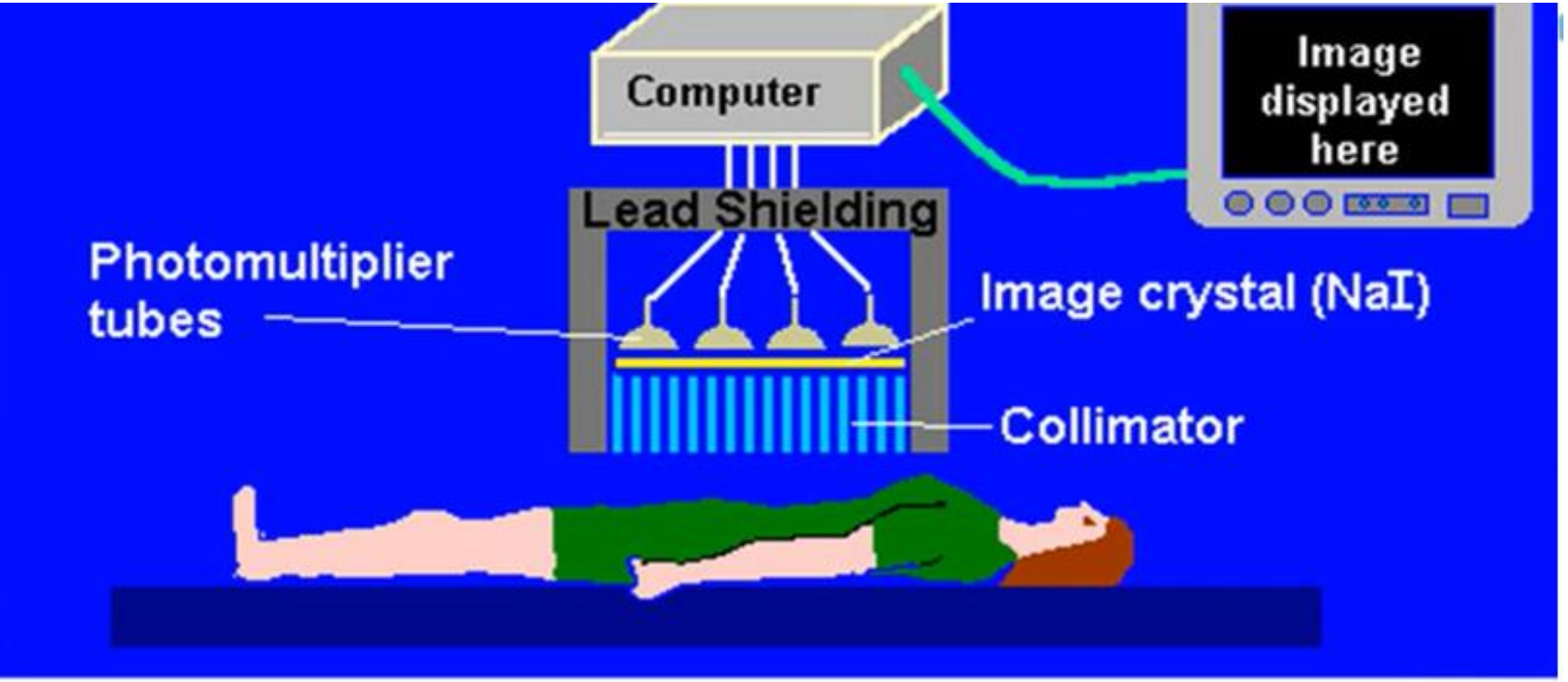
- The CT images provide an anatomical reference frame for the functionnal images and allow for attenuation correction

Gamma camera systems

Gamma camera

- Device used to image gamma radiation radioisotopes. This technics is called also the scintillation camera.
- Gamma camera is used to view and analyse images of the human body or the distribution of the medically ingested, injected or inhaled radionuclides

Gamma camera



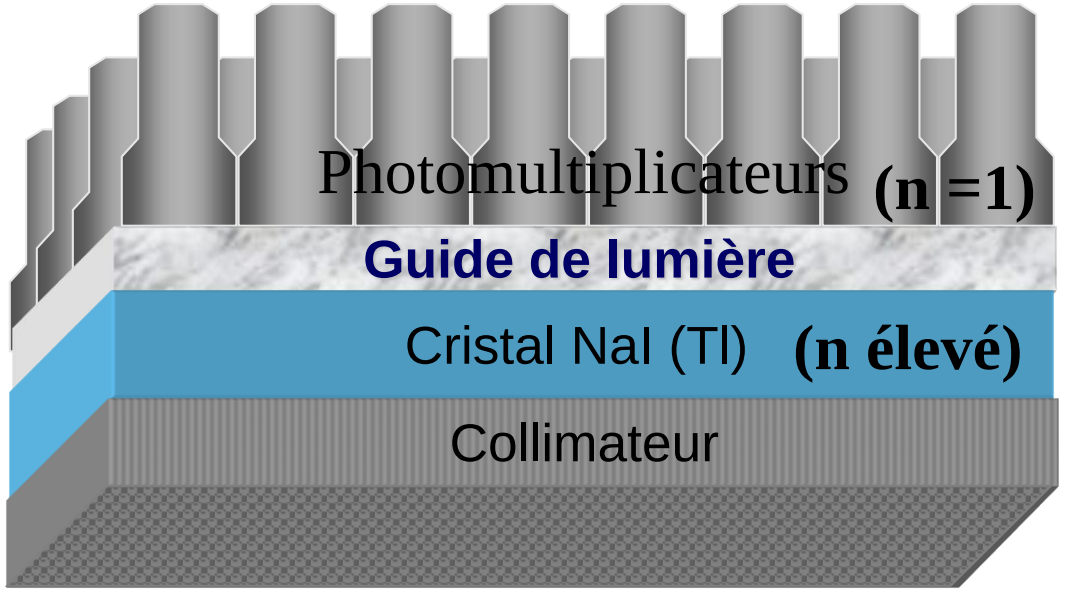
Gamma Electromagnetic Energy (The gamma ray has been emitted from the patient) → Light Electromagnetic Energy (The image crystal produces flashes of light) → Electrical Energy (To display the image)

Basic elements of gamma camera system

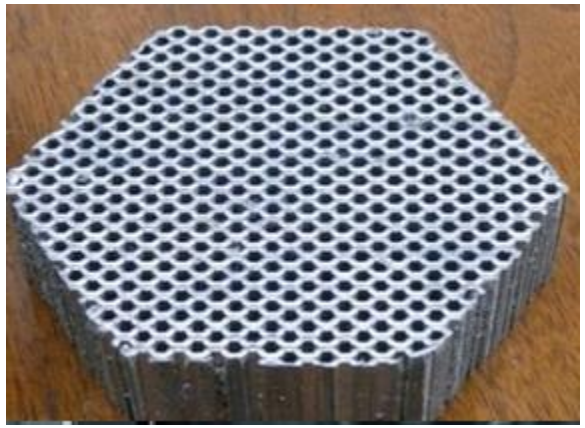
- **Collimator**
  - ✓ Defines lines response
- **Radiation detector (crystal)**
  - ✓ Counts the incident gamma photon
- **Photomultiplier Tube (PMT)**
- **Computer system**
  - ✓ Creates2 D images from detector data
- **Gantry system**

✓ supports and moves gamma camera and patient

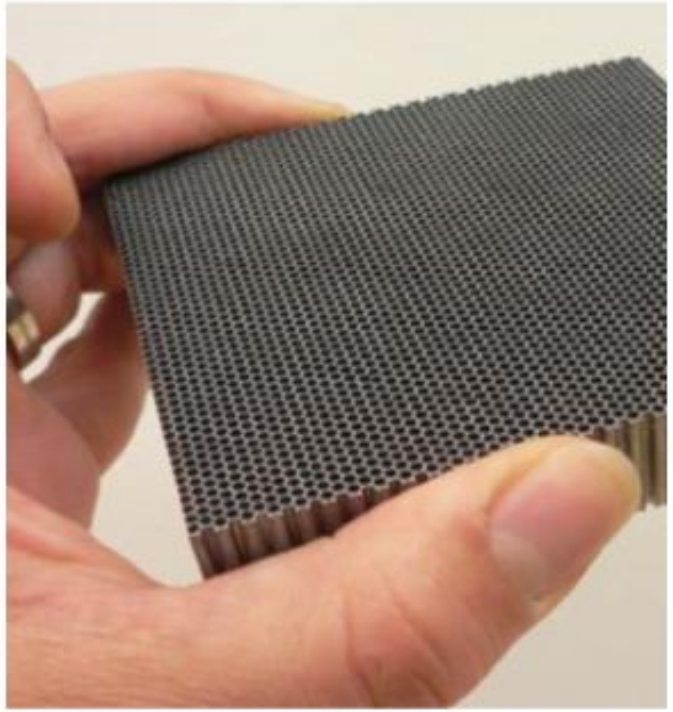
Basic elements of gamma camera system:



Collimator



- Collimator is made from lead
- Maintains the quality of the image
- Spaces between holes are known as **septa**
- Collimator consisting of **series of holes in a lead plate** can be used to select the direction of the rays falling on the cristal.
- The collimator provides an interface between the patient and the scintillation cristal by **allowing only those photons travelling in an appropriate direction**



Collimator

- Collimator is made from lead
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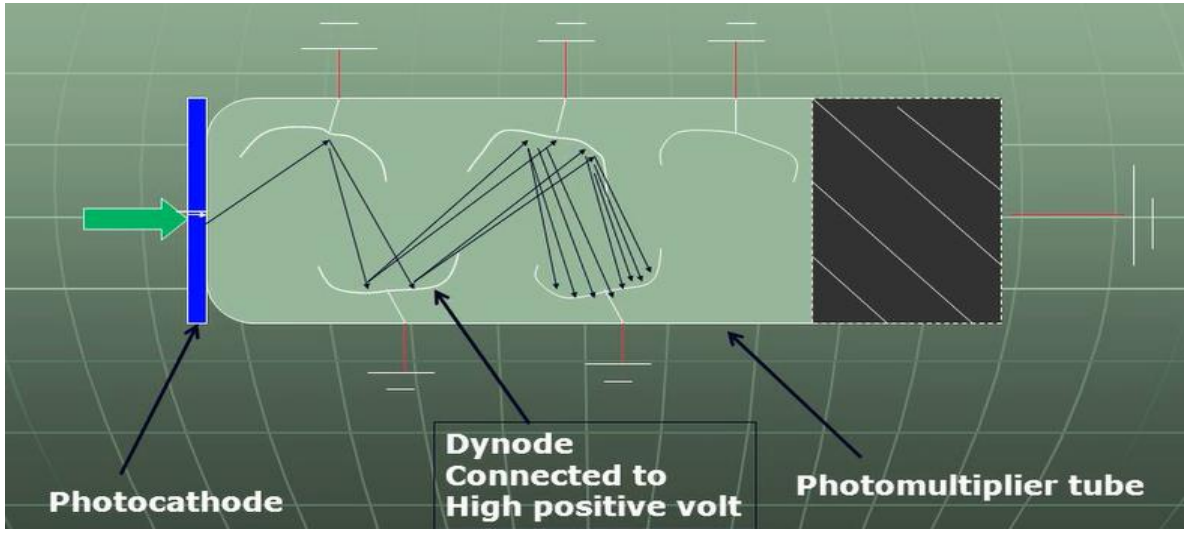
Scintillator (crystal)

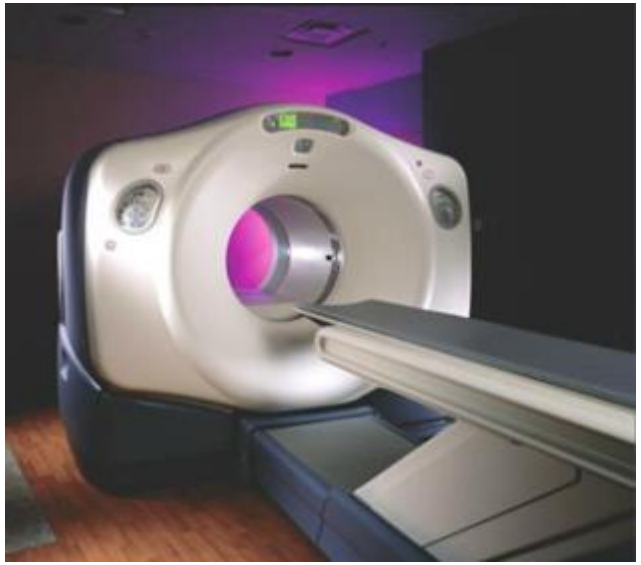
- The chosen material for the crystal is Sodium iodide with thalium
- The main function of crystal is to convert gamma rays to photons of visible light this process is called **scintillation**
- Amount of light is proportionel to the deposited energy

Photomultiplier Tube (PMT)

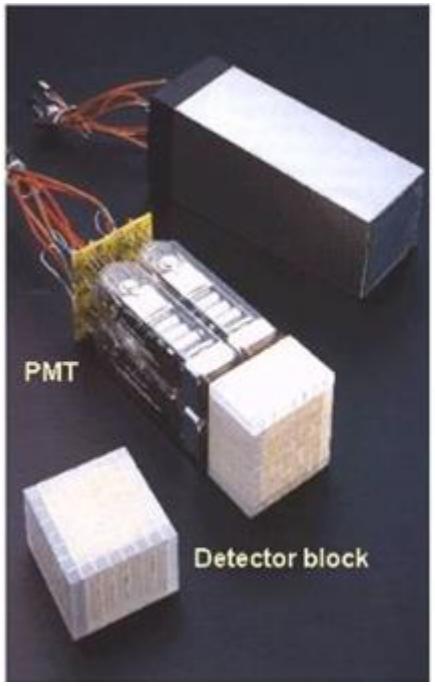
- A photomultiplier tube is an evacuated glass envelope
- It consists of
  - ✓ A photocathode
  - ✓ An anode
  - ✓ 10 dynodes

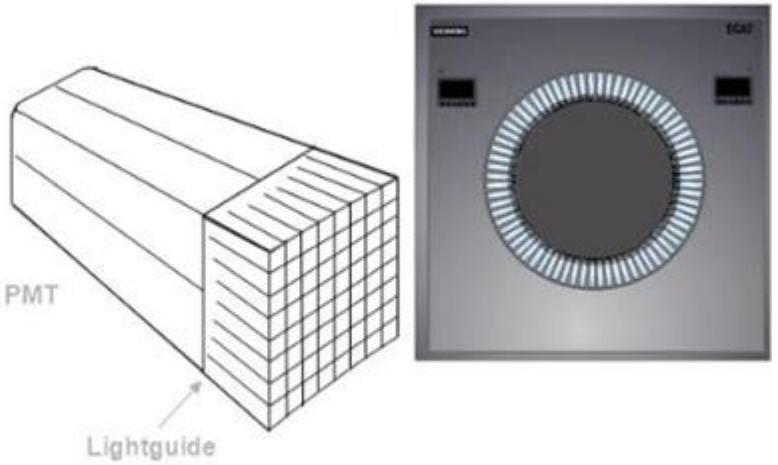


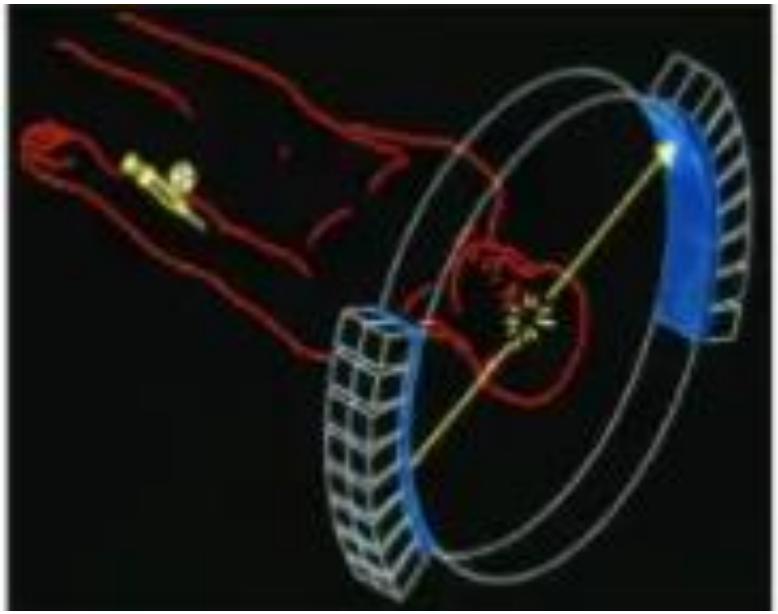
PET CT (positron emission tomography)



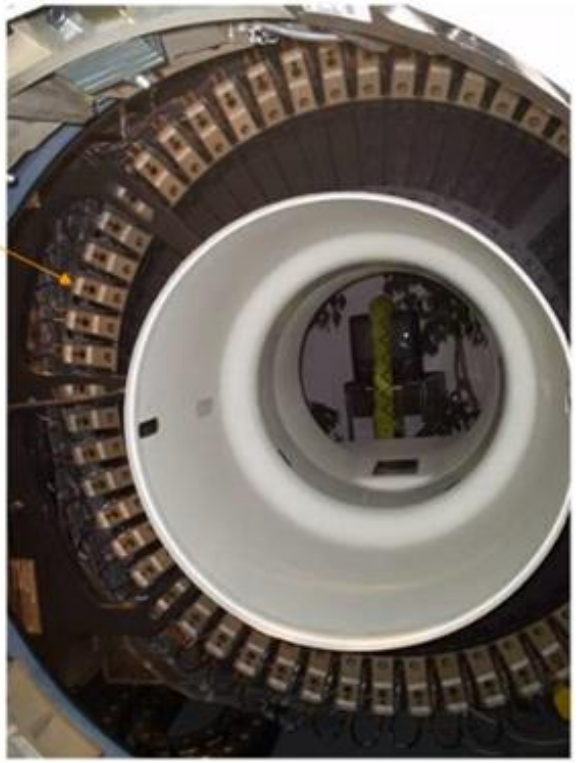
Full ring system





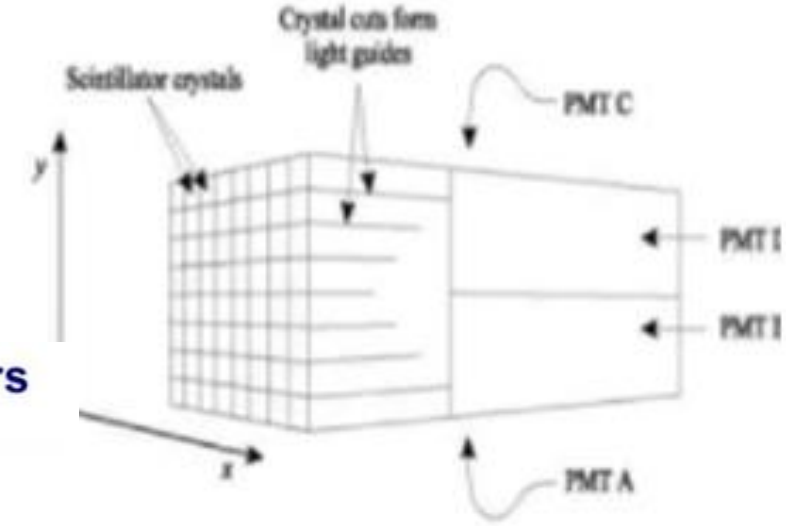


Block
detectors

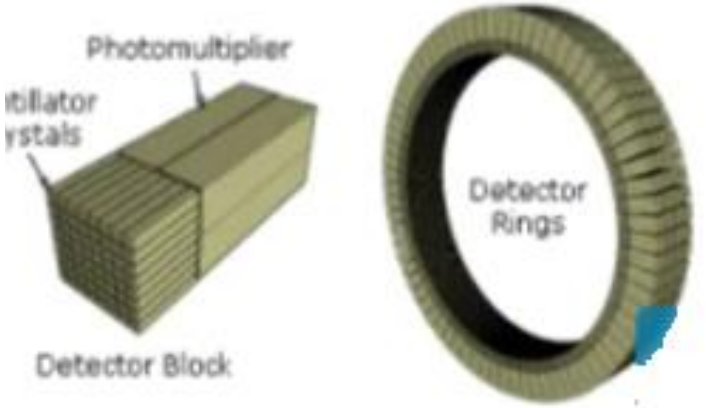


Crystals used in PET

- BGO, LSO and LYSO are common scintillators used in PET scanners

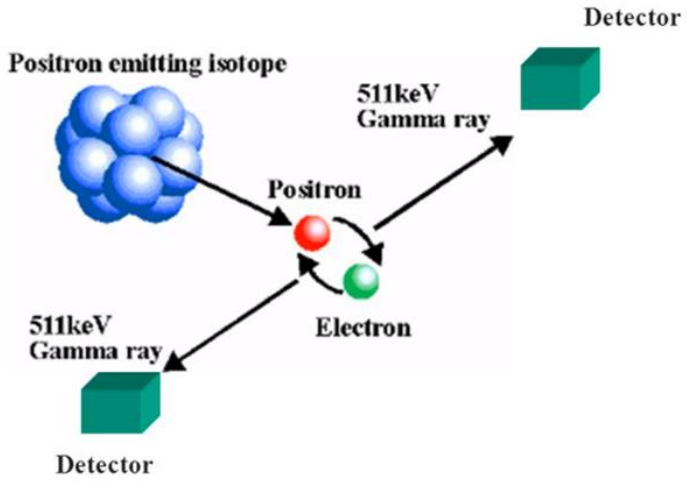


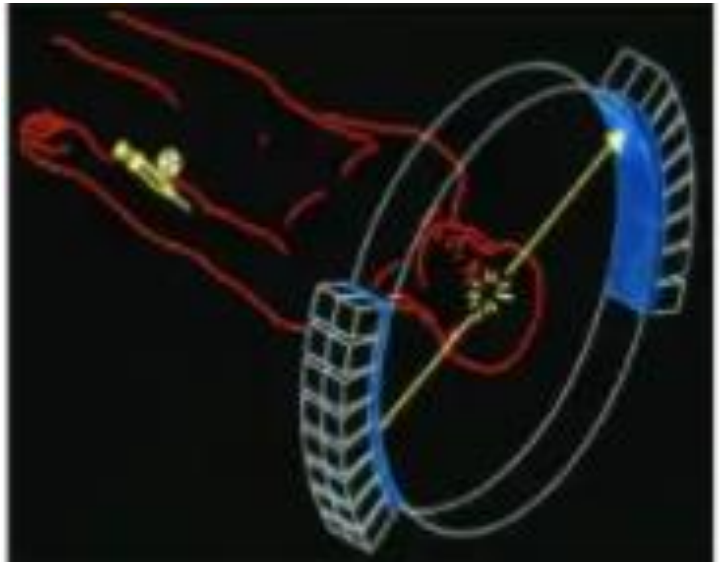
- Na(TI) I works well at 140 keV. Poor efficiency at 511 keV



How PET CT works?

- PET does **not require a collimator** and, therefore, eliminates the weakest link in the SPECT image formation process.
- **Coincidence detection** is used to distinguish photons arising from positron annihilation, based on temporal discrimination
- These facts makes PET more advantageous than SPECT, in terms of spatial **resolution**, statistical quality and quantitative accuracy





Calibrator dose

Dose calibrator

- Dose calibrators designed to verify clinically administred radioactivity are just one type of radiation detector

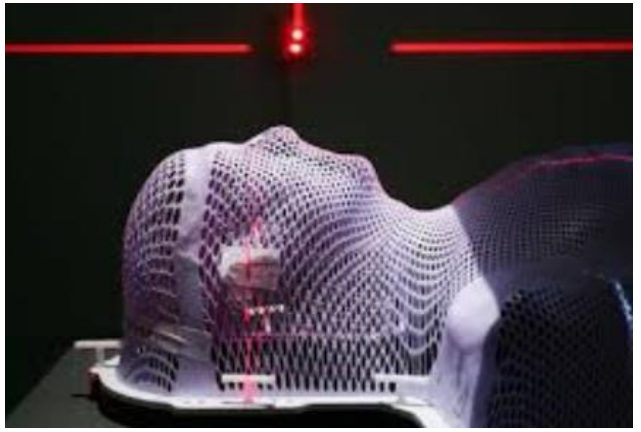
Books:

- **Essentials of Nuclear Medicine Imaging**, Sixth Edition, Fred A. Mettler, Jr. and Milton J. Guiberteau

- **Handbook of Nuclear Medicine and Molecular Imaging for Physicist**, *By Michael Ljungberg*

- **Nuclear Medicine and Molecular Imaging**, by Lilia B Solnes MD MBA, Harvey A. Ziessman

Radiotherapy & Brachytherapy

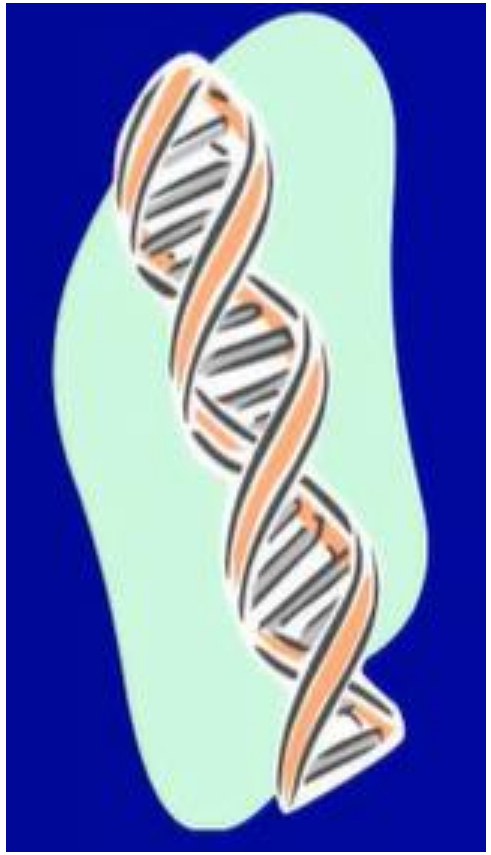


Treatment of cancer

- **Surgery** – cut it out
- **Chemotherapy** – through whole body
- **Radiation** – On targeted area

Radiation effects on cells

- Radiation damages ALL cells healthy and diseased
- This causes side effects but **ONLY** in the area we are treating
- Healthy cells can repair themselves while diseased cells die off



What is radiation therapy?

- Radiation therapy works by damaging the DNA within cancer cells and destroying their ability to reproduce.
- When the damaged cancer cells are destroyed by radiation, the body naturally eliminates them.
- Sometimes radiation therapy is the only treatment a patient needs
- Other times, it is combined with other treatment, like surgery and chemotherapy

- Radiation therapy is used:

✓ To cure cancer (radical RT):

✓ Destroy tumors that have not spread to other body parts

✓ Reduce the risk that cancer will return after surgery or chemotherapy

✓ To reduce symptoms (palliative RT)

✓ Shrink tumors affecting quality of life, like a lung causing shortness of breath.

✓ Alleviate pain by reducing the size

Types of radiation therapy

- Radiation therapy can be delivered two ways : **externally and internally:**
- The type of treatment used will depend on the location, size and type of cancer

✓ **External beam radiation therapy** delivers radiation using a linear accelerator

✓ **Internal radiation therapy**, called brachytherapy or seed implants, involves placing radioactive sources inside the patient

Types of radiation therapy

- **Proton beam therapy**: uses protons rather than X rays to treat certain types of cancer.
- **Steriotactic radiotherapy**: sometimes called steriotactic radio surgery, this technique allows the radiation oncologist to precisely focus beams of radiation to destroy certain tumors
- **Neutron beam therapy**: a specialized form of radiation therapy that can be used to treat certain tumors that are very difficult to kill using conventional radiation therapy

Meet the radiation oncology team

- **Radiation oncologist**: the doctor who oversees the radiation therapy treatment
- **Medical radiation physicist**: ensure that complex treatment plans are proporly tailored for each patient
- **Dosimetrist** : works with the radiation oncologist and medical physicist to calculate the proper dose of radiation given to the tumor
- **Radiation therapist**: administers the daily radiation under the doctor’s prescription and supervision
- **Radiation oncology nurse**: cares for the patient and family by providing education, emotional support

External Beam radiotherapy (EBRT)

External beam radiotherapy

- **The primary goal of radiation therapy:**
- To treat the tumour to the highest dose possible while minimising the effects on normal tissues

External beam radiotherapy

Other goals of treatment

- **Cure**
  - ✓ Eradicate cancer and live a normal life span
- **Control**
  - ✓ Conrol growth or spread of cancer, live for a time without symptoms
- **Palliation**
  - ✓ Relieve or diminish symptoms, improve quality of life
- **Prophylactic or anticipatory**
  - ✓ Prevention of complications or symptoms

Basic principles

- Treatment with beam of ionizing radiation produced from a **source external (**linear accelerators) to the patient.
- **Superficial tumors** are often treated with X rays **of low energy**, The beam size is selected by using metal cone shaped applicators of different sizes
- Use of **megavoltage X** rays :

✓ Energies in the range 4-20 MV,

✓ Higher penetration, higher dose rate

Steps involved with radiation therapy

Radiation therapy process

- ✓ Diagnosis
- ✓ Consultation
- ✓ Simulation and treatment planning
- ✓ Treatment
- ✓ Patient follow -up

1- Simulation / Planning

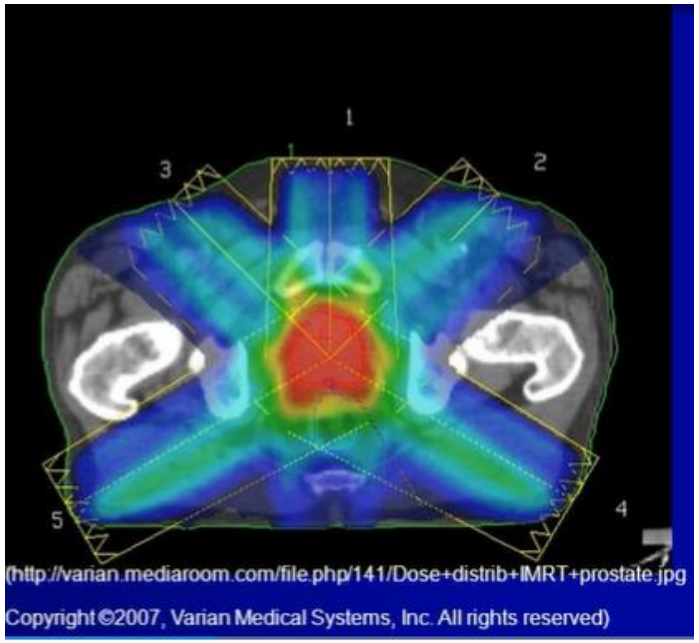
- Ct Scanners are used to **localize the treatment volume as per the prescription.**
- These machines are exactly the same as diagnostics scanners with a few minor changes; the addition of external laser positionning systems, and a flat table top

1- CT Simulation

- ✓ Operate CT machine
- ✓ Create relation between patient and beam coordinates
- ✓ Place isocenter
- ✓ Patient marking/Tattoo
- ✓ Transfer of plan

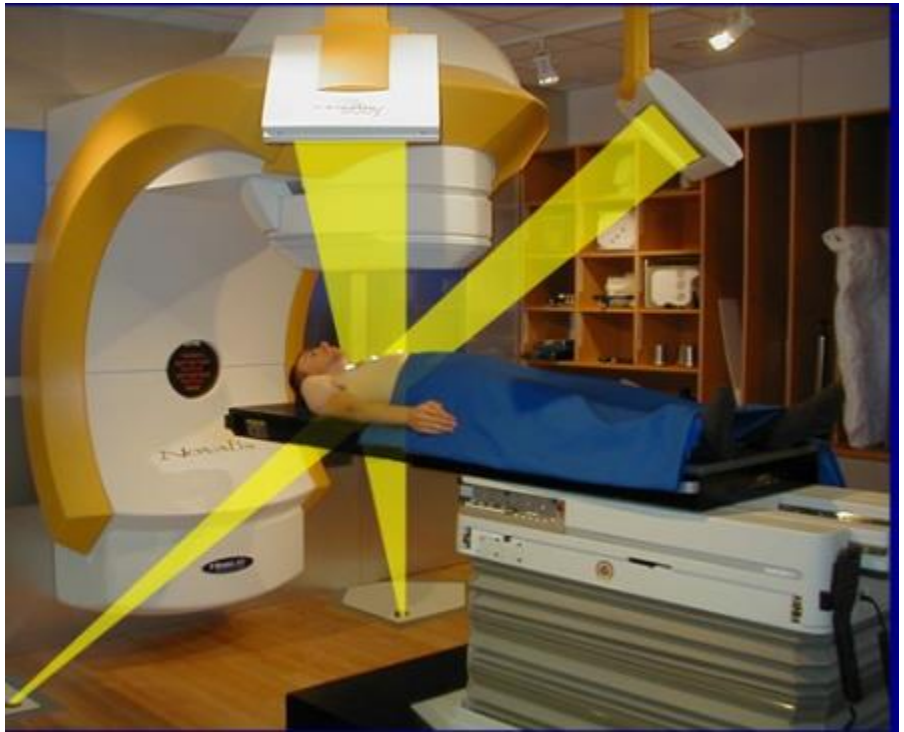
2- Traitment Planning/ Dosimetry guidelines

- Typical prescribed doses
  - ✓ Breast 50 Gy in 25 treatments
  - ✓ Prostate 70 Gy in 35 treatments
  - ✓ Palliative 20 Gy in 5 treaments
  - ✓ **Objectif of fractionation:** to achieve the required level of effect on the tumor with the minimal effect to surrounding normal tissues.



3- Treatment

- Linear accelerators are the standard treatment machine
- Electrically produce beams of X rays which are shaped (collimated) to the precise size and energy required for treatment
- Machines can rotate 360 degrees around a patient to deliver treatment from any angle.



Stereotactic radiosurgery

Stereotactic radiosurgery

- Alternative names:

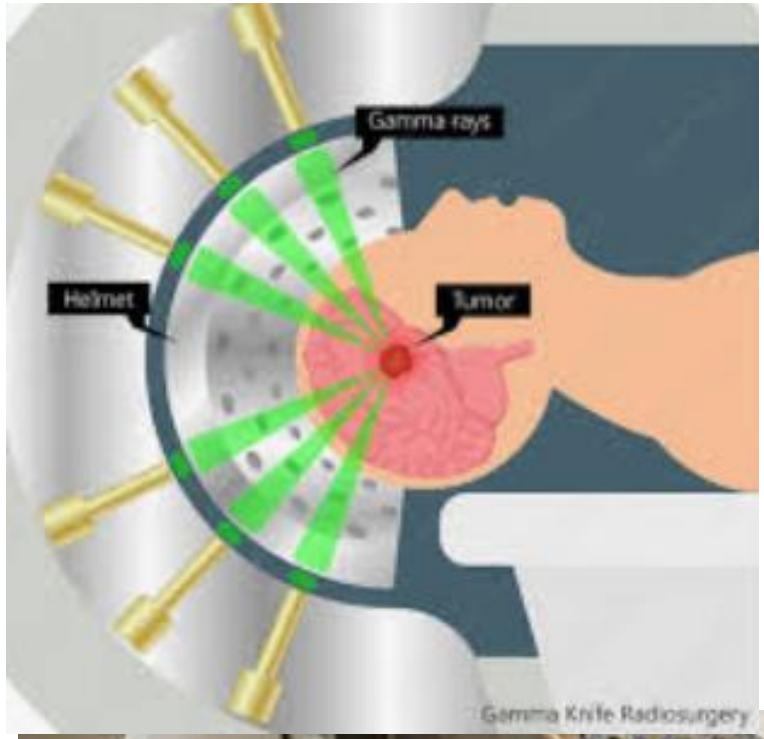
✓ Gamma knife

✓ Cyberknife

✓ Stereotactic radiotherapy

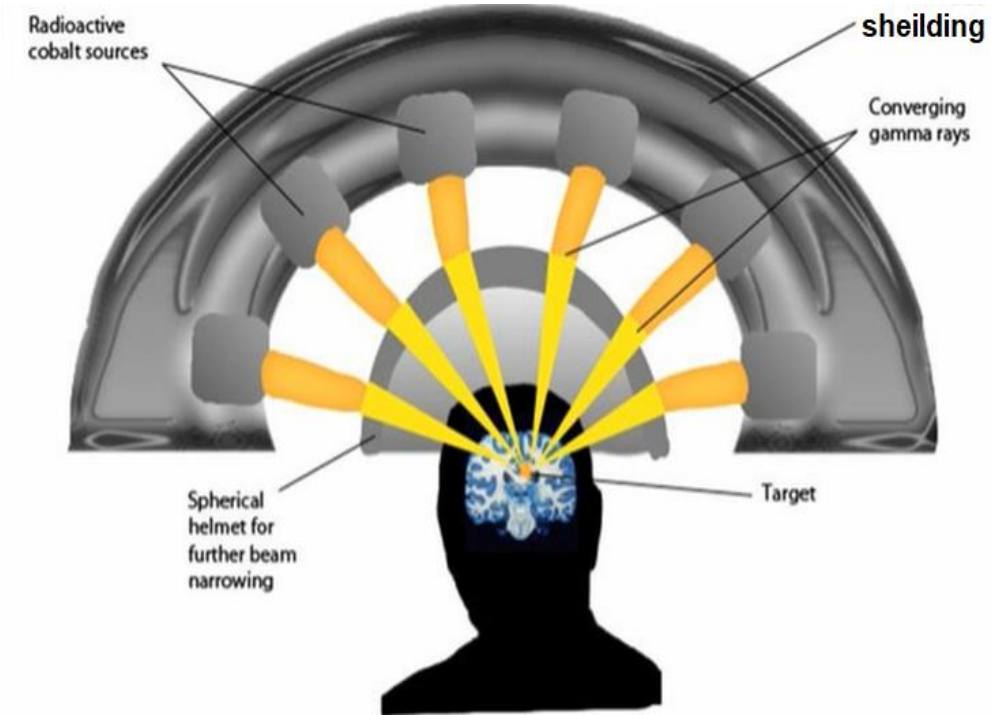
- Stereotactic radiosurgery is a form of radiation therapy that focuses **high-powered X rays** on a small area of the body
- Other types of radiation therapy can affect nearby healthy tissue, stereotactic radiosurgery **better targets the abnormal area.**

Gamma knife



Stereotaxic radiosurgery- Gamma Knife concept:

- Multiple radiation beams converge on target tumor, delivering high dose radiation to the tumor, but little to surrounding tissues
- We should ensure proper patient positionning frame is secured to the patient's skull, then attached to the radiation source.
- Treatment lasts 45 to 60 minutes
- It is a **single treatment.**



Stereotaxic radiosurgery- Cyber Knife

Brachytherapy

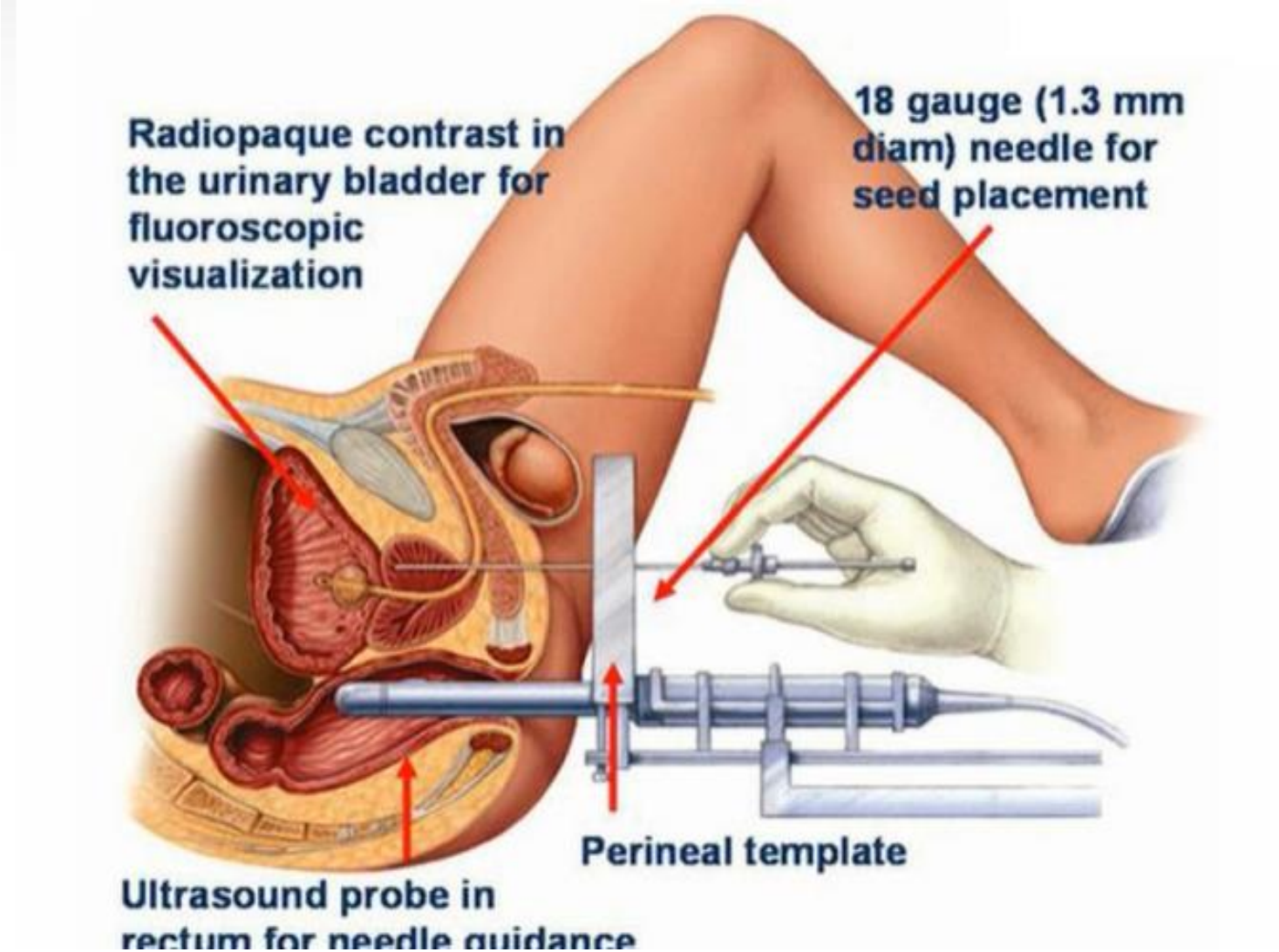
Brachytherapy (internal radiation therapy)

- A form of radiation treatment **where the radiation sources are placed within or close to the target volume** i.e. the sources are placed at the heart of the tumor. It allows minimal dose to normal tissue.
- **Radioactive sources** used are thin wires, rods, capsules or seeds.
- These can be either permanently or temporarily placed in the body.
- **Indication:** The site should be accessible for both inserting and removing source

Brachytherapy

- Treats mostly breast cancer, locallized prostate cancer, cervical cancer and cancers of head and cancers of neck
- Permanent brachytherapy is often performed for prostate cancer using « seeds » small radioactive rods implanted directly into the organ

Brachytherapy (prostate)



Brachytherapy

Brachytherapy

- **Advantages:**
  - Allows the delivery of a localized high radiation dose
  - Low radiation risk
- **Disadvantages**
  - Staff (nursing and medical staff) exposure to radiation
  - Large tumors are usually unsuitable
  - Accurate positioning of sources requires special skills.