# Imaging of Cancer

# Imaging of Cancer:

Subtitle: What actually happens in a Radiology Department?

Peter L. Choyke, MD, FACR
Molecular Imaging Program, NCI

# Imaging of Cancer

- Imaging is a key element of:
  - Screening (e.g. lung cancer, breast cancer)
  - Staging (has it spread locally? Metastasized?)
  - Monitoring of treatment (Better or worse?)
  - Recurrence (Has it come back?)
  - Prognosis (What will happen?)

# The Main Imaging Devices

- Computed Tomography  (CT)
- Magnetic Resonance Imaging  (MRI)
- Ultrasound  (US)
- Single Photon Emission Computed Tomography  (SPECT)
- Positron Emission Tomography (PET)
- Optical Imaging

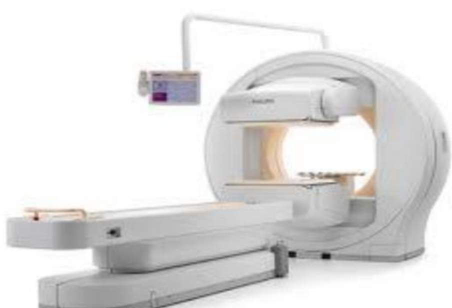
# The Main Imaging Devices

## Quiz: Name that Scanner

CT

MRI

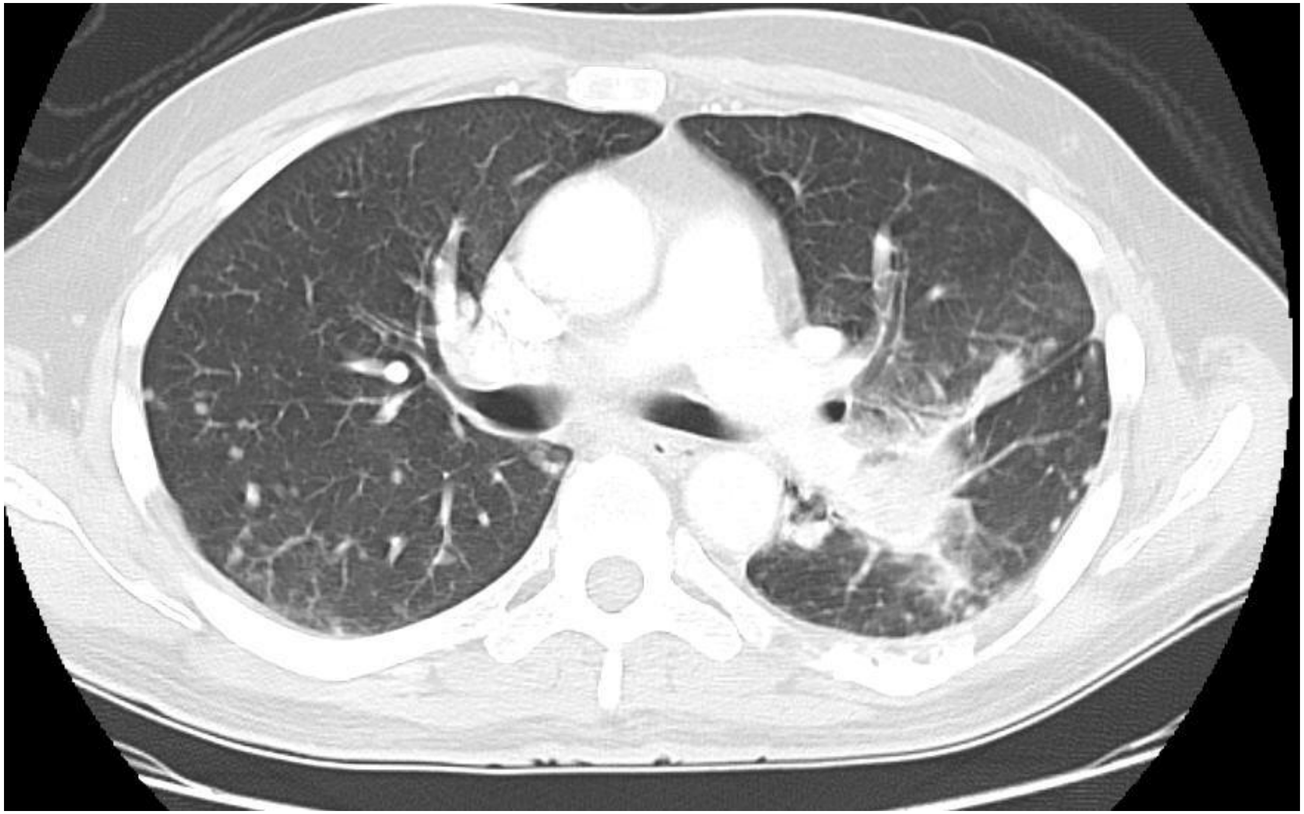
US



SPECT

PET

# Computed Tomography



# Advantages of CT

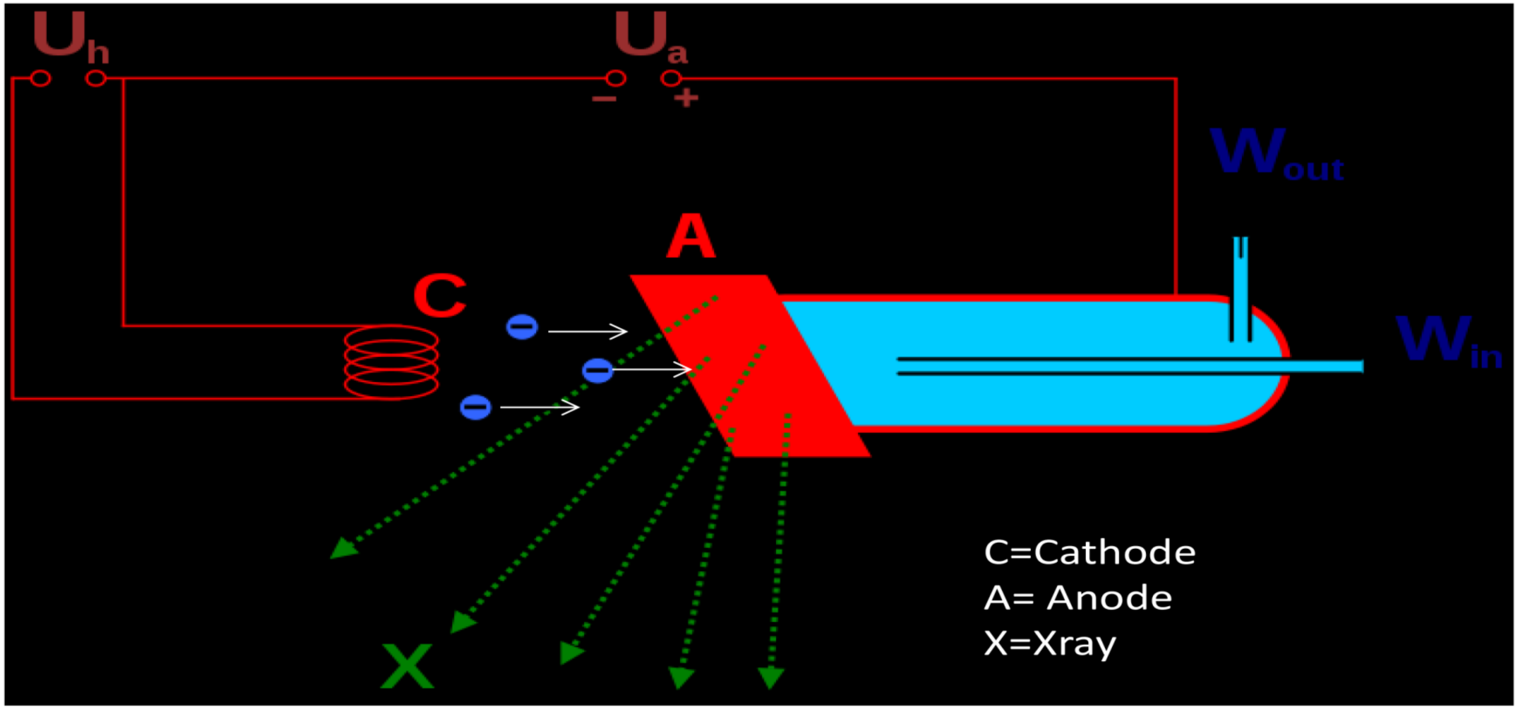
- Widely available
- Minimal prep (NPO, drink contrast)
- Very rapid (2-3 seconds neck to pelvis)
- High resolution
- Relatively inexpensive

# Disadvantages

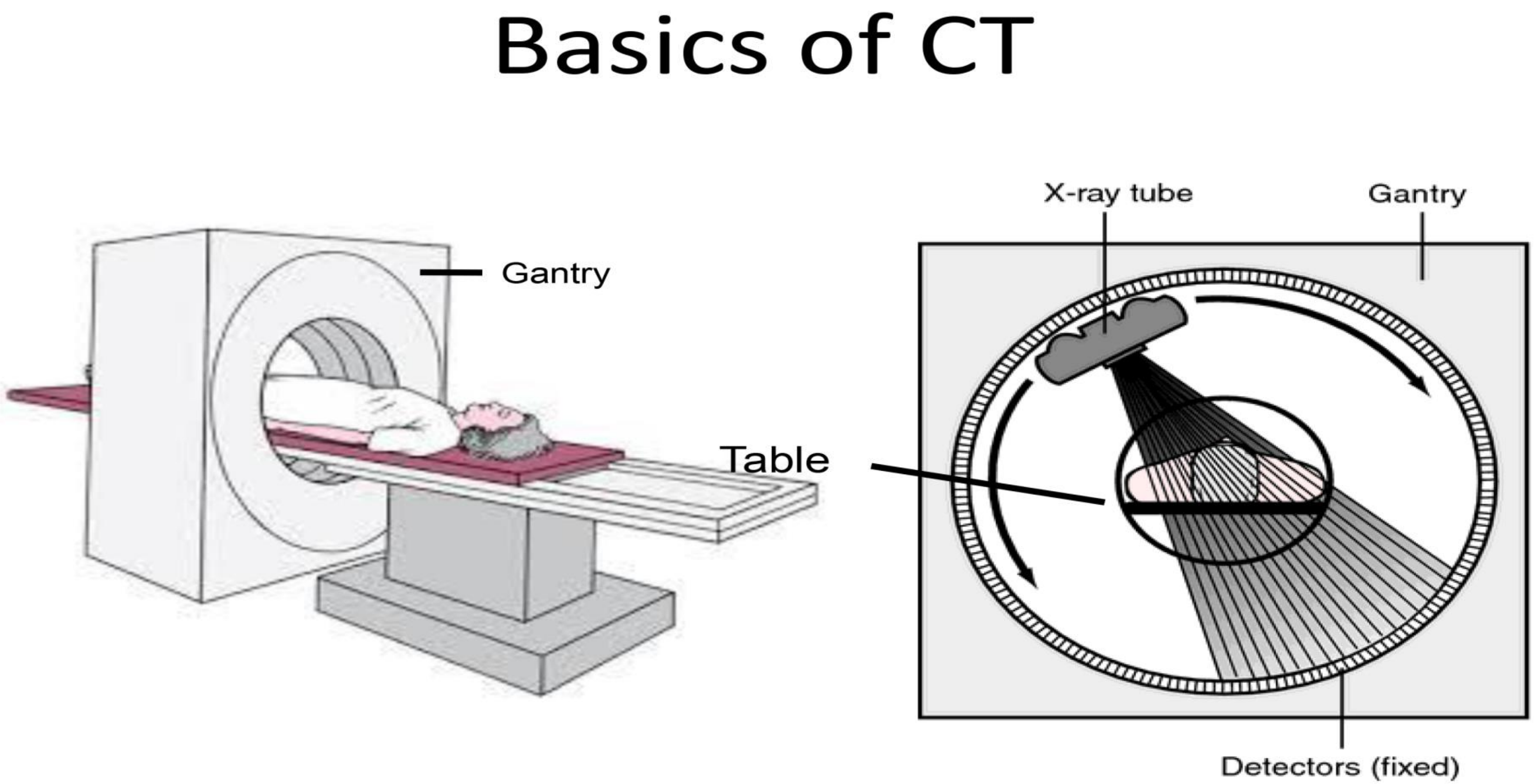
- **Radiation**
- Often requires iv contrast media
  - Allergic reactions (minimal)
  - Kidney damage (only in high risk patients)
- Anatomic information only

# X-ray production

## X-ray production: cathode ray tube

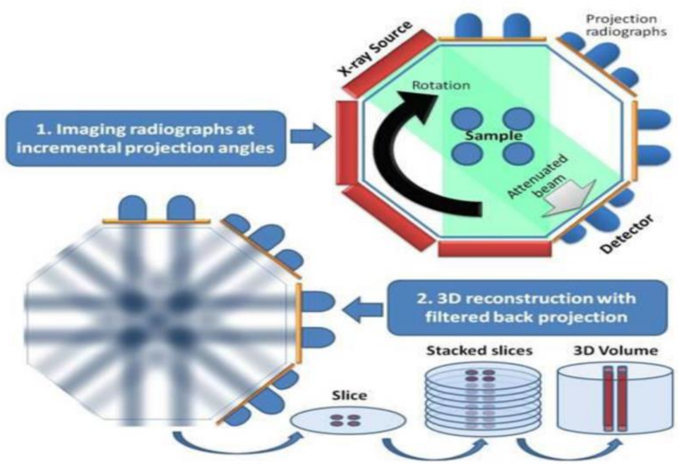


# Basics of CT



# CT projection

## Filtered Back Projection



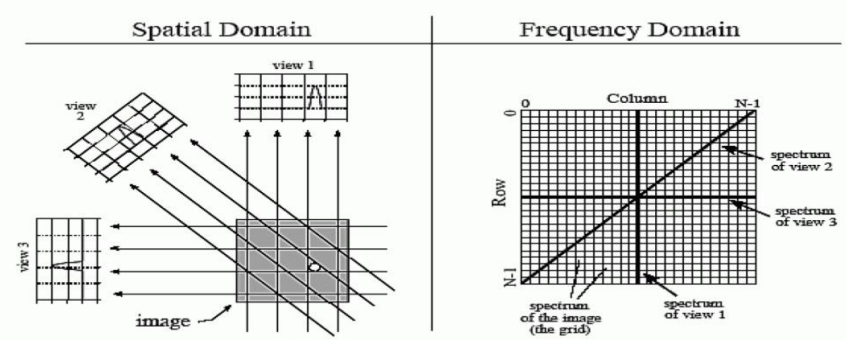
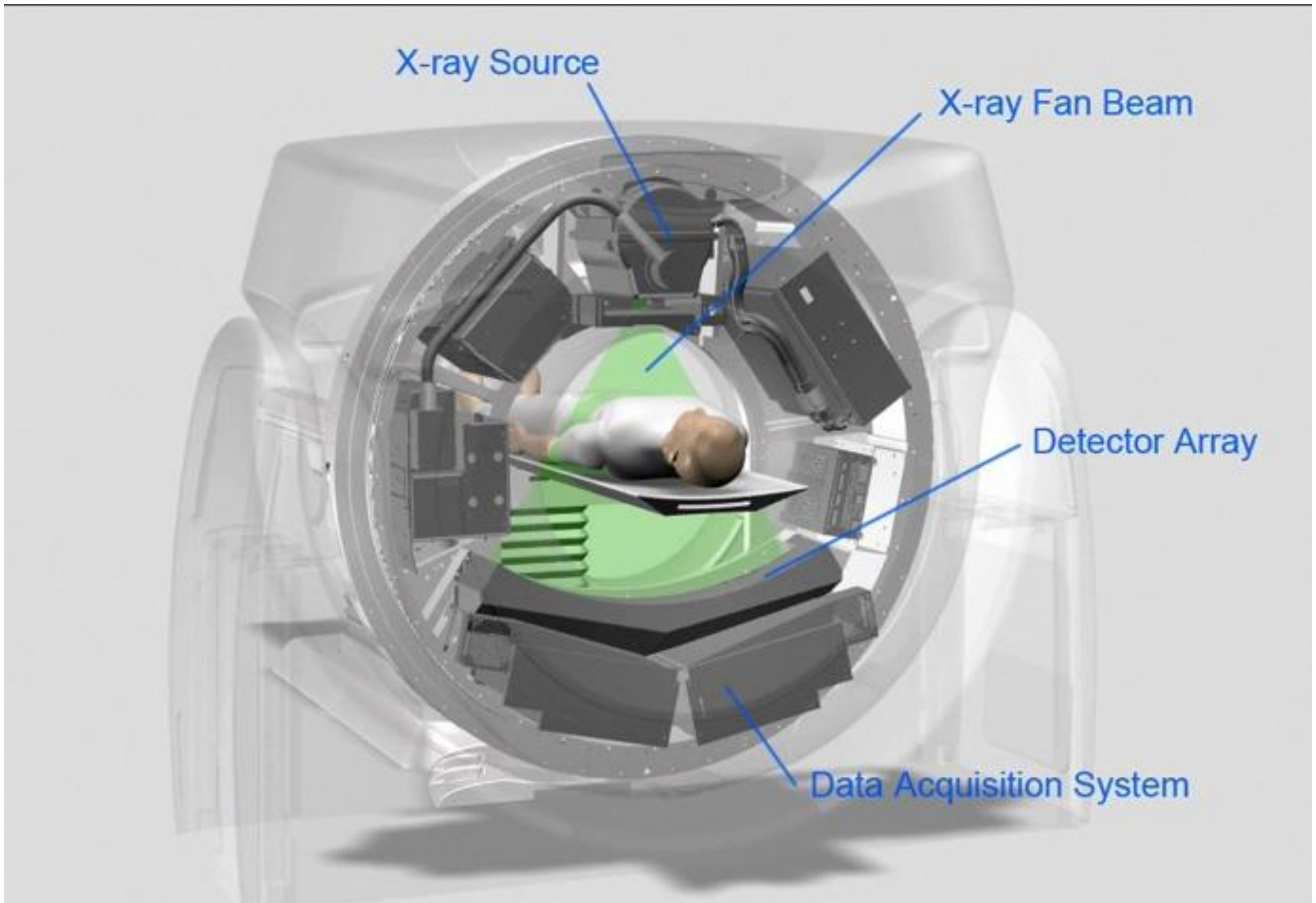
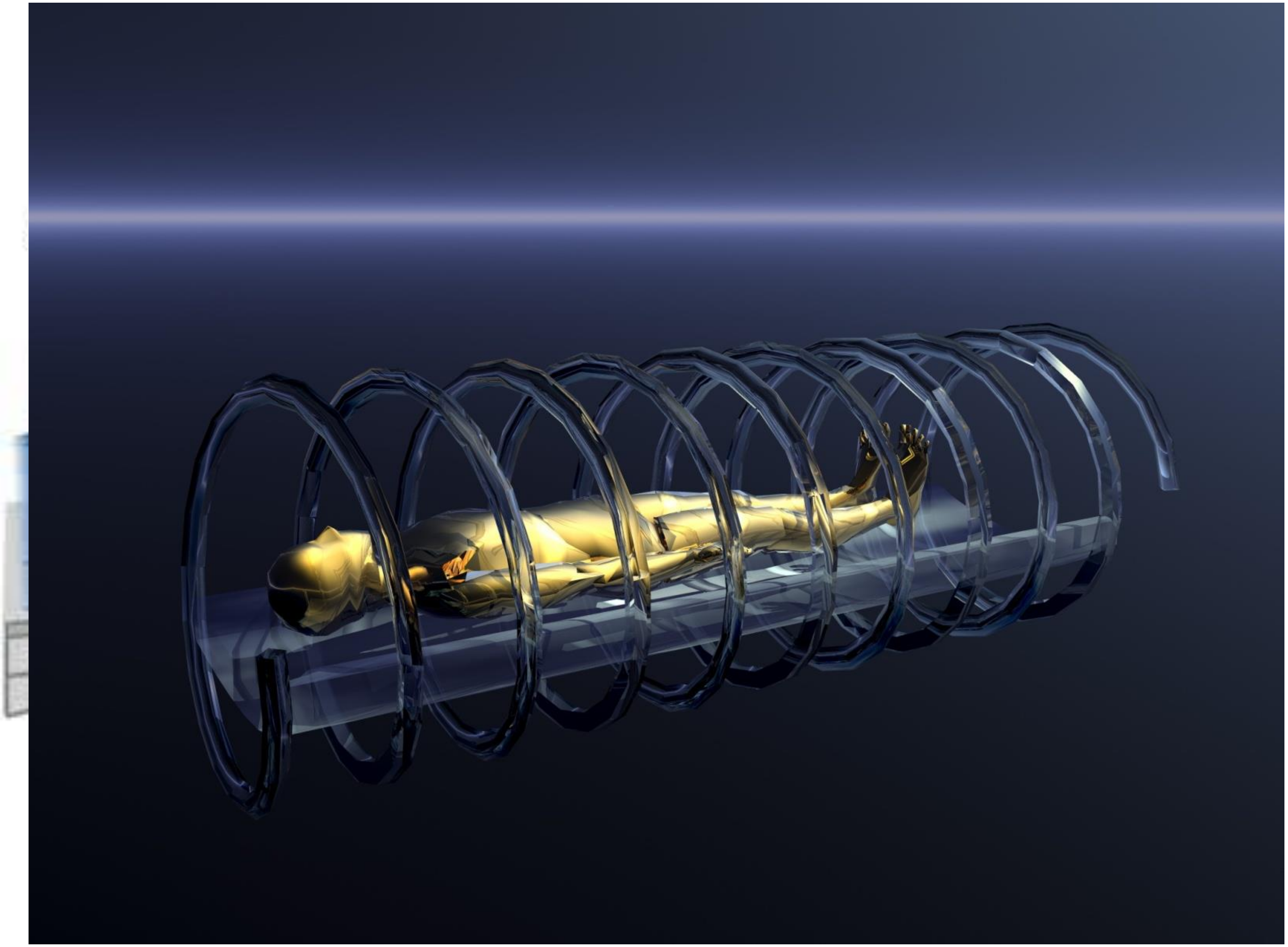




FIGURE 25-18
The Fourier Slice Theorem. The Fourier Slice Theorem describes the relationship between an image and its views in the frequency domain. In the spatial domain, each view is found by integrating the image along rays at a particular angle. In the frequency domain, the spectrum of each view is a one-dimensional "slice" of the two-dimensional image spectrum.

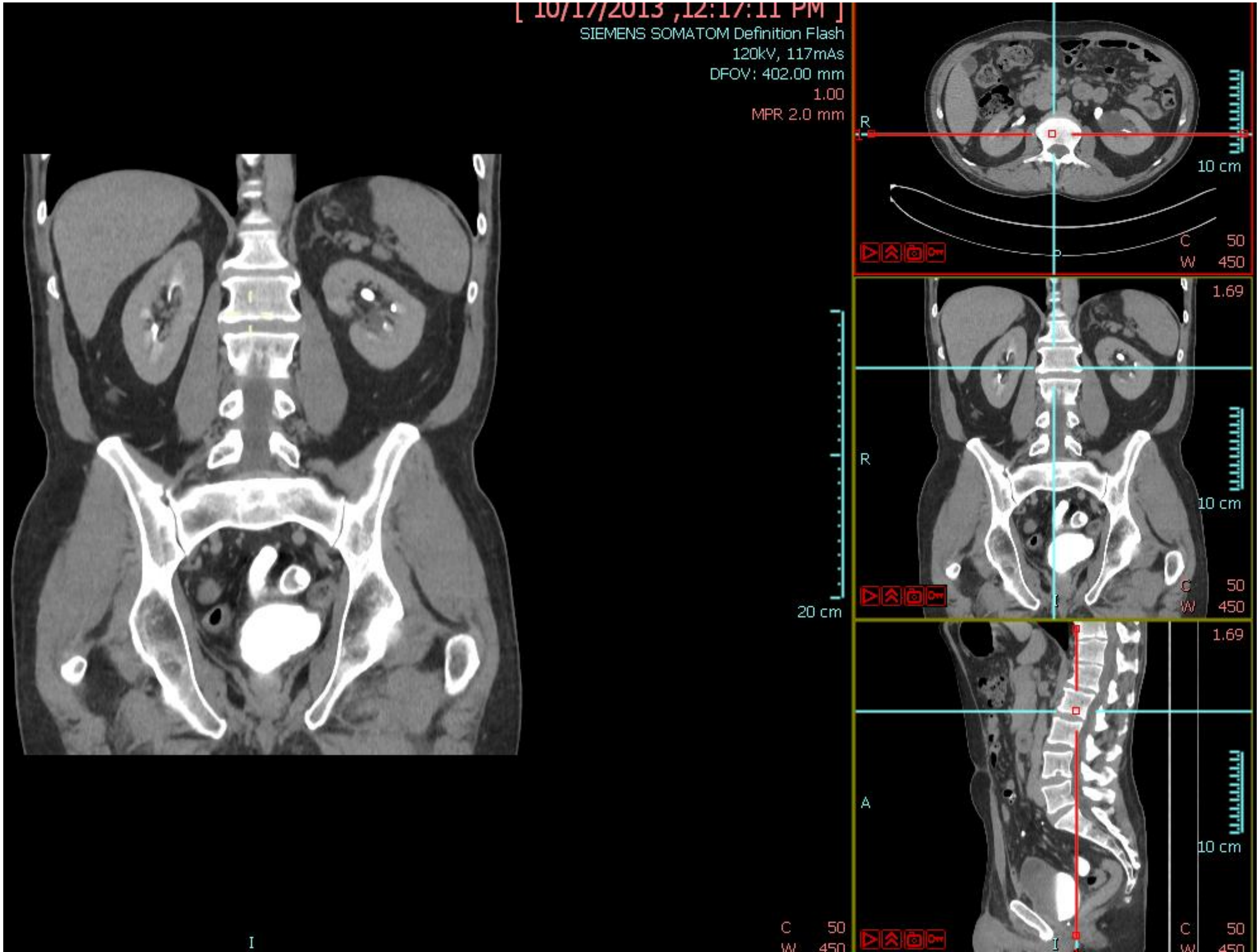
# Cross section of a CT Scanner



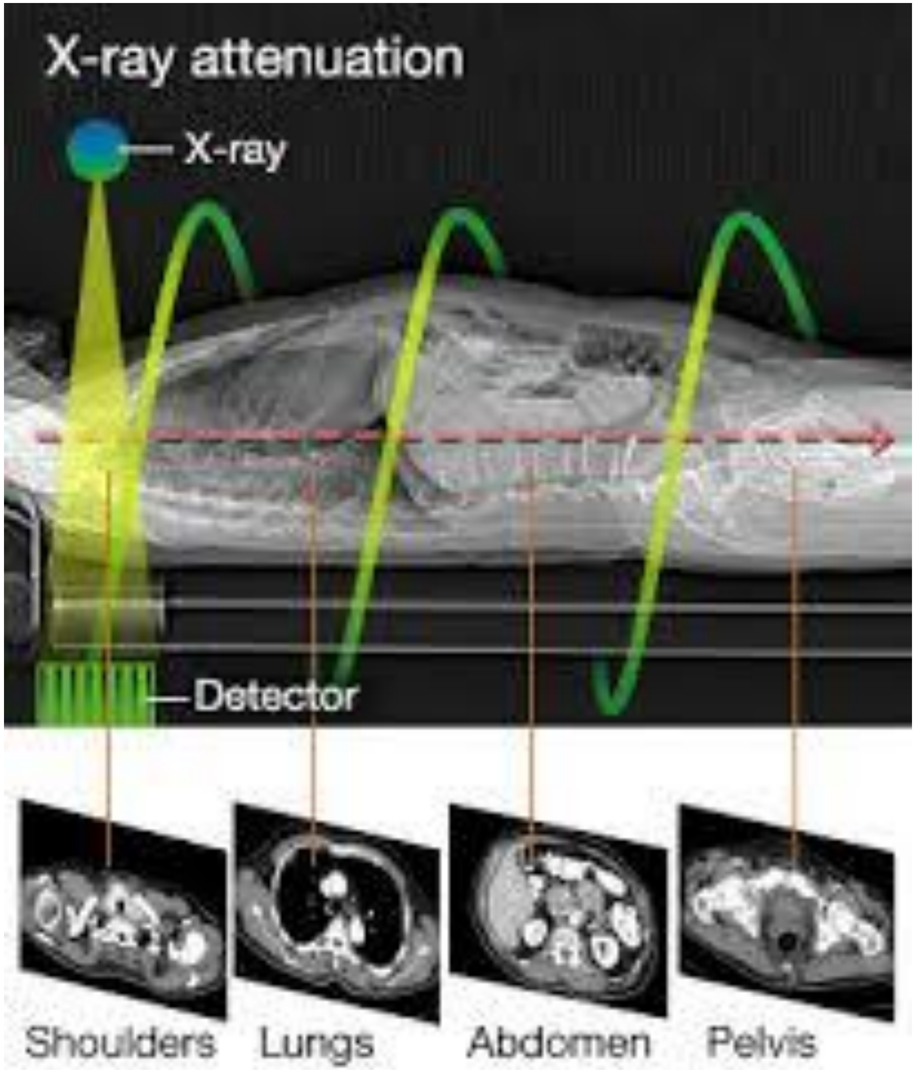
# “Spiral” CT



# “Volume” CT imaging



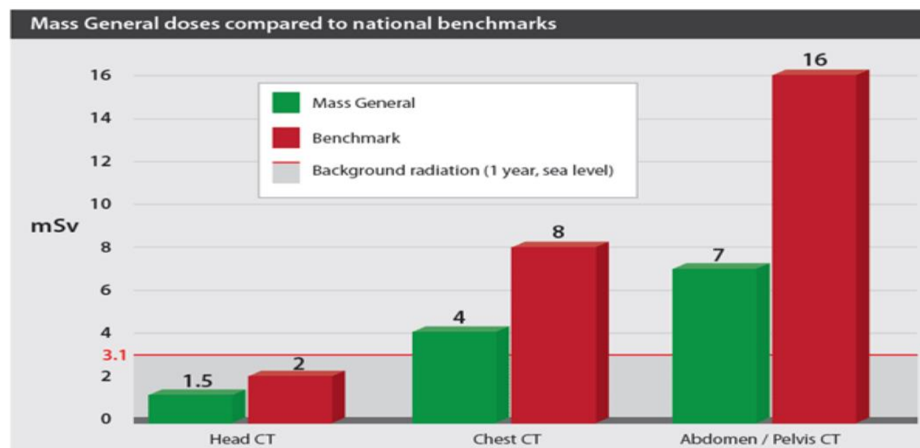
# Attenuation differences thru the body



# Radiation

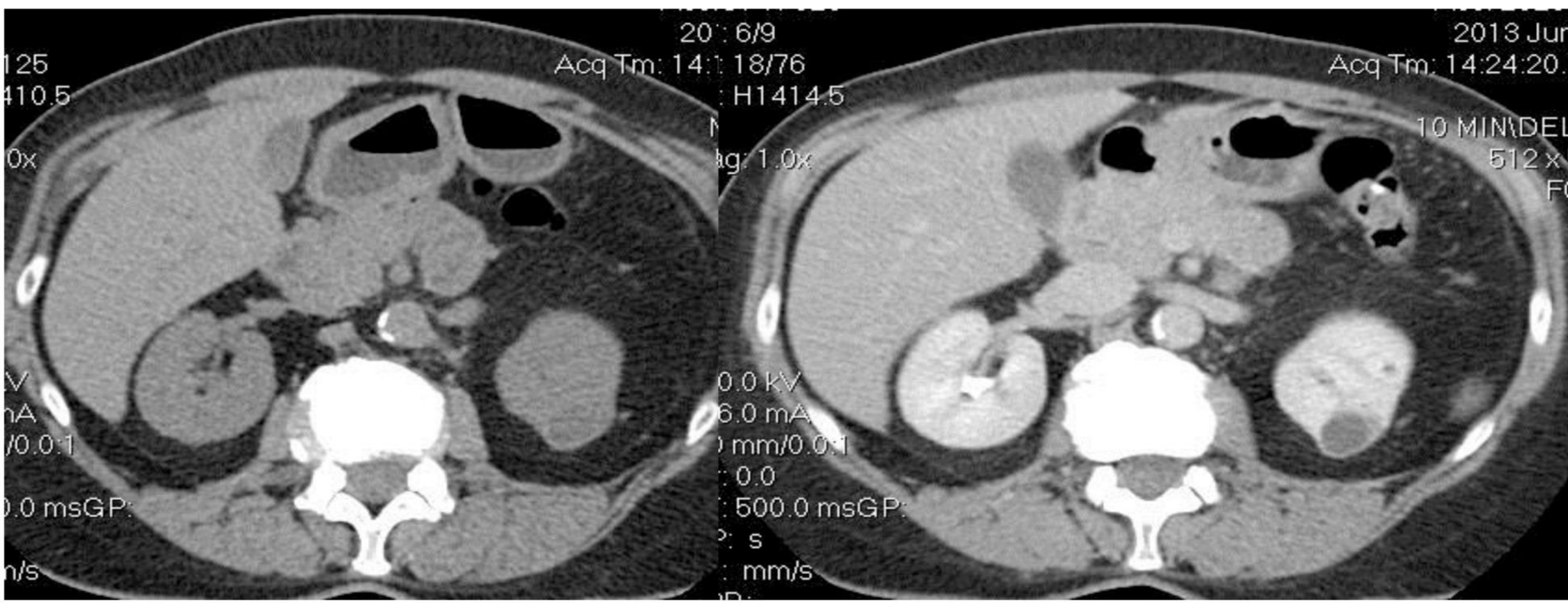
Radiation

Lower kV (energy) x-rays
More sensitive detectors
Better reconstruction algorithms
“Synthetic” images

# Contrast Media

## Iodinated Contrast Media

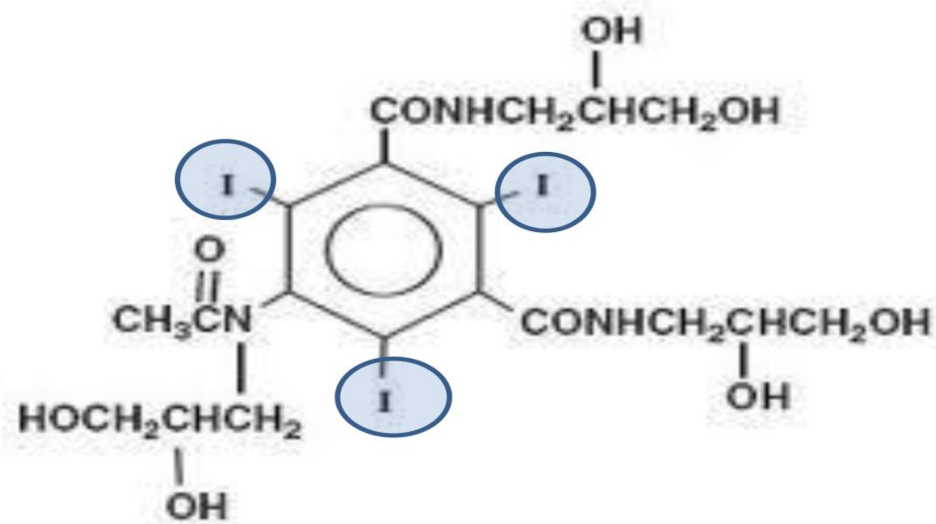


# Iodinated Contrast

Iodinated Contrast


# Non ionic iodinated contrast

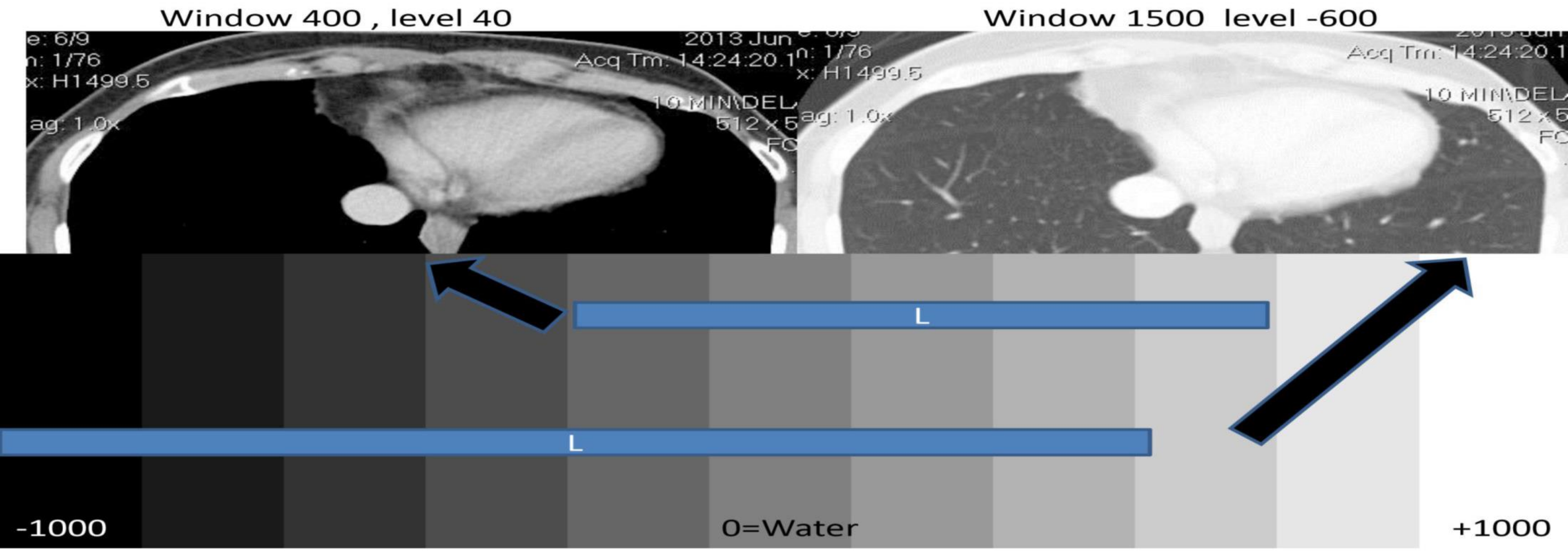
## Non ionic Iodinated Contrast



# CT

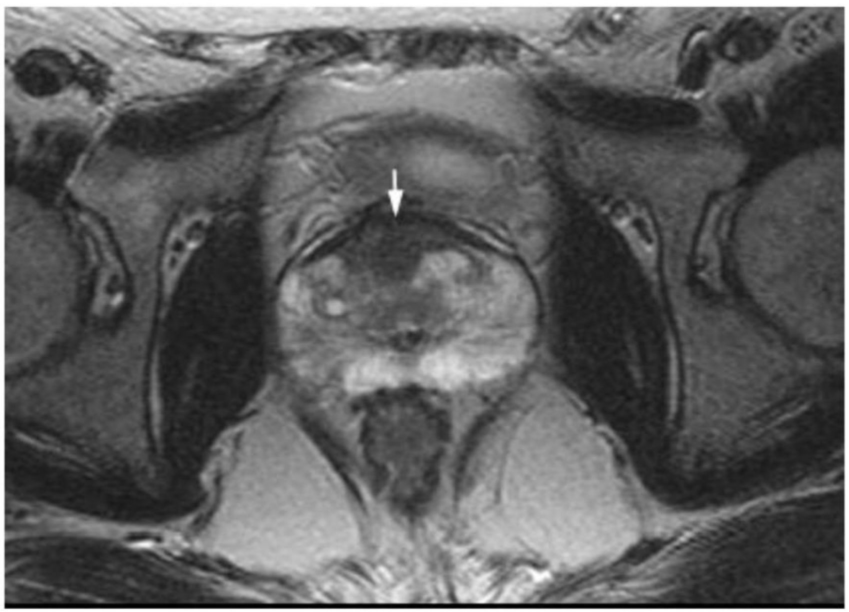
# Windowing a CT

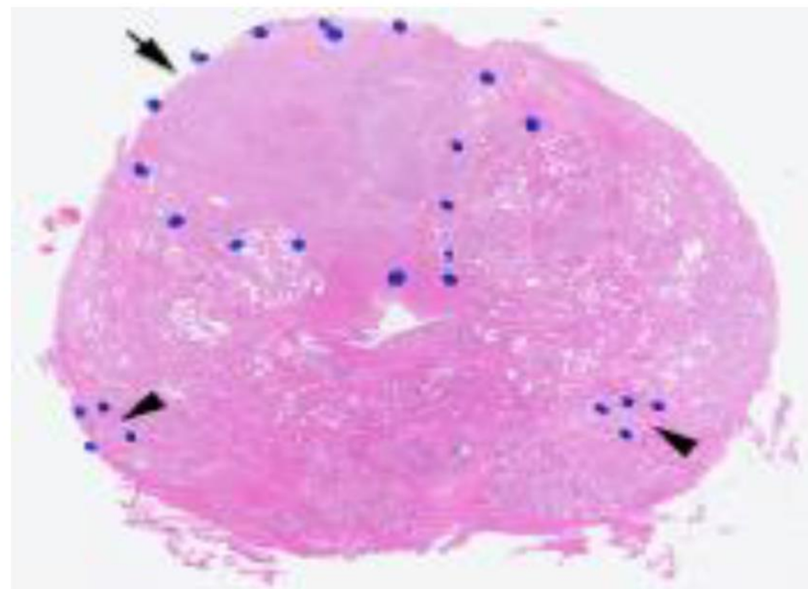
## “Windowing” a CT



# MRI

## Magnetic Resonance Imaging





Prostate Cancer on MRI and Pathology

# MRI Advantages

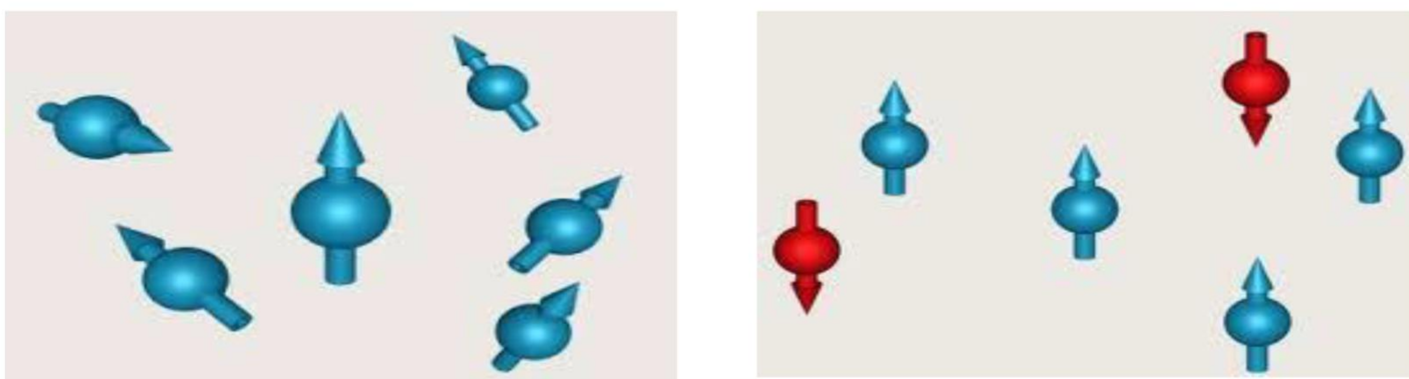
- No radiation
- Multiplanar
- Multiple contrast types:
  - T1 weighting, T2 weighting
  - Diffusion weighting
  - Contrast enhanced MRI
  - Spectroscopy

# MR Disadvantages

- Slower than CT
- More expensive
- Does not depict calcifications
- Safety issues
  - Metallic objects become projectiles
  - Incompatible with metallic implanted devices
    - Pacemakers
    - Cochlear implants

# MRI physics

## MRI Physics 101

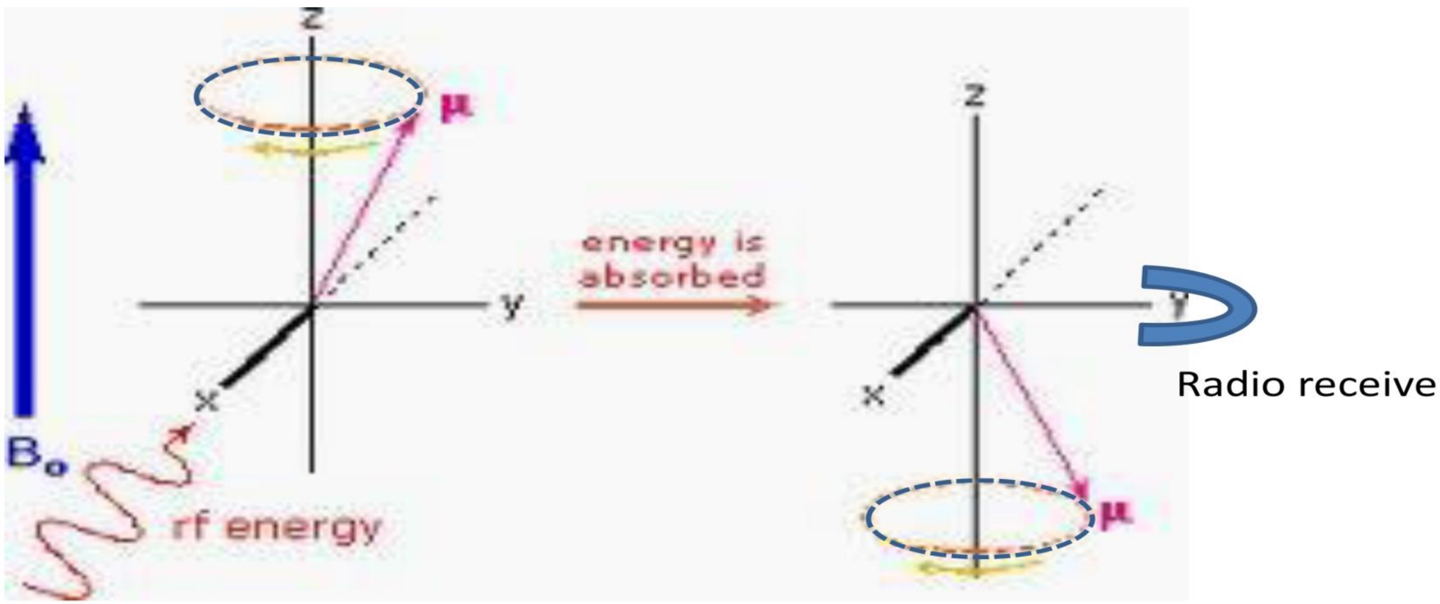


Protons in space: no field

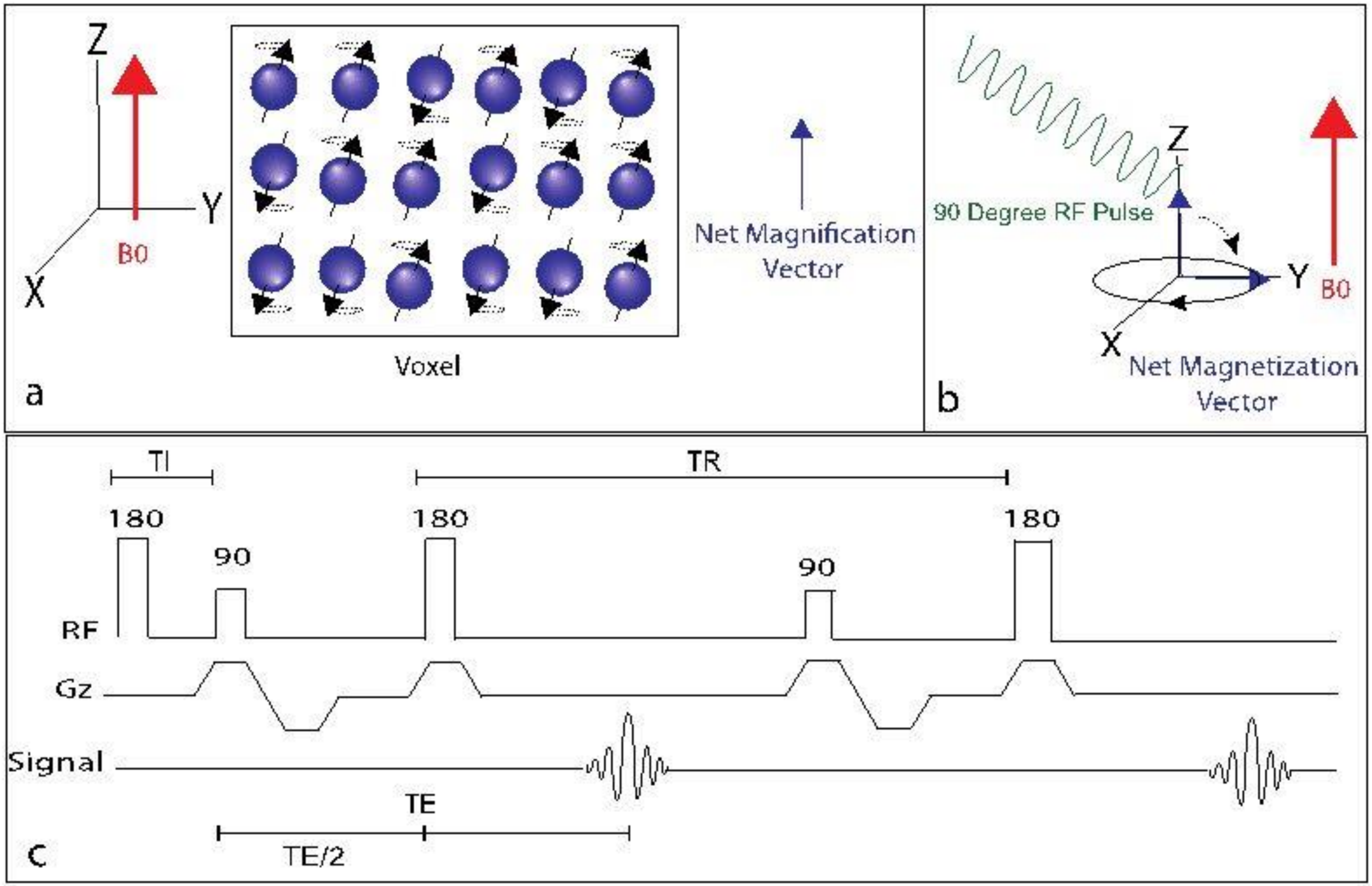
Protons in magnetic field

# MR physics

## MR Physics

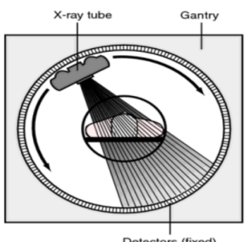


# Summary

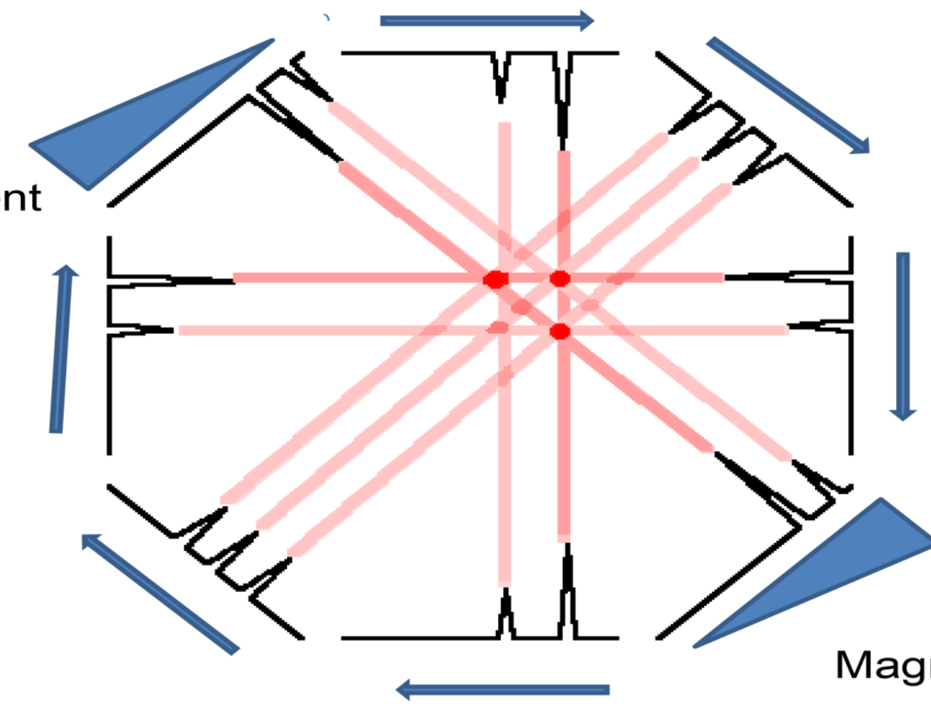

Z
Y
X
B0
Voxel
Net Magnification
Vector
a
90 Degree RF Pulse
Z
Y
X
B0
Net Magnetization
Vector
b
TI
TR
180
90
180
90
180
RF
Gz
Signal
TE
TE/2
c

# Creating a MR Image

## Creating an MR Image:
## No detectors! Just antennas (coils)

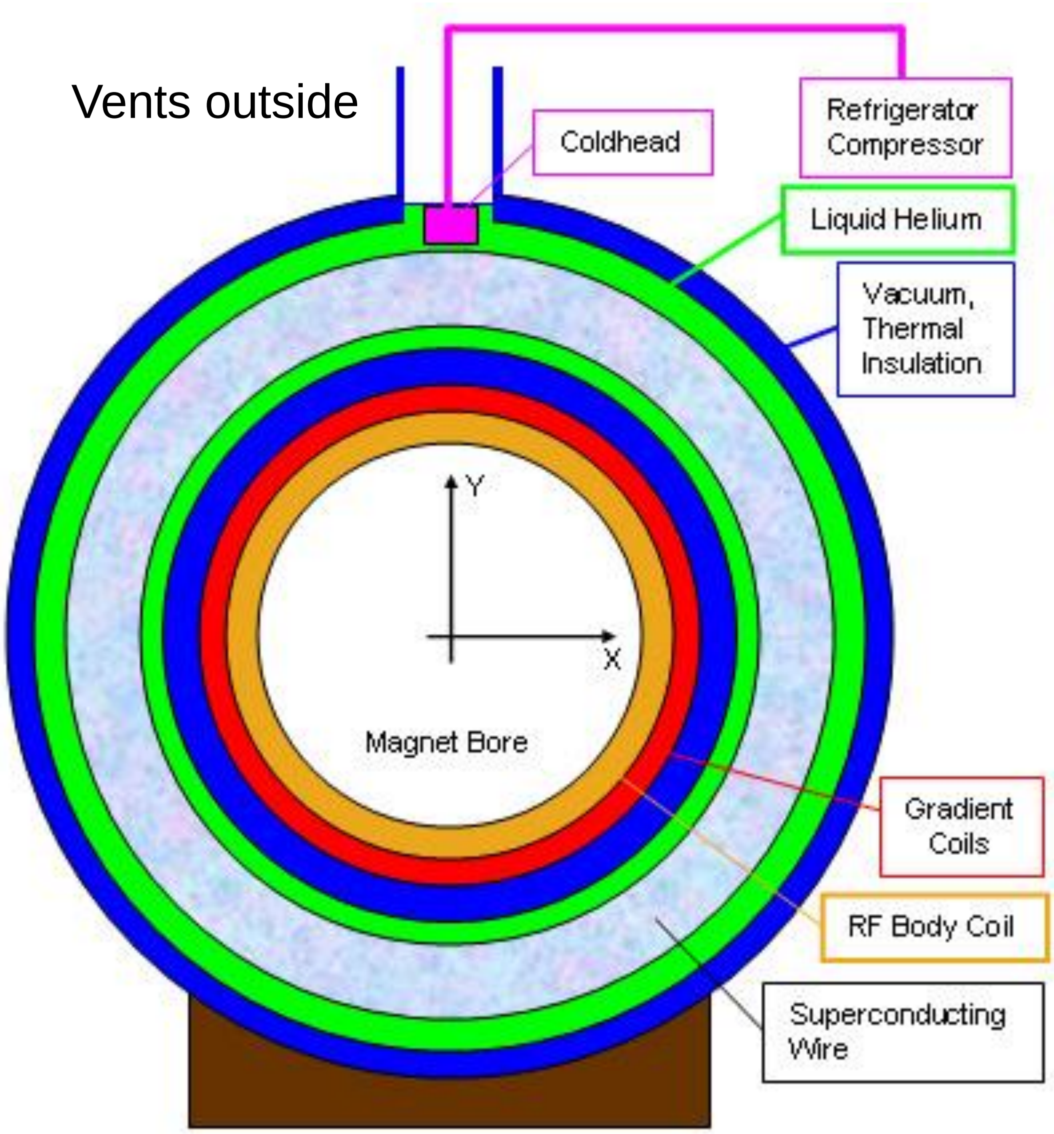



Magnetic Gradient



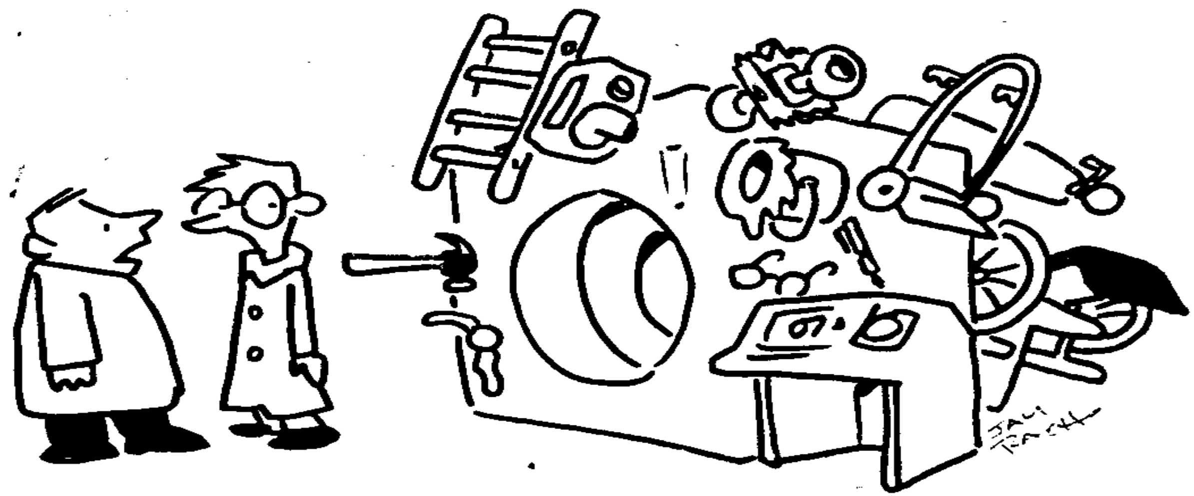
Magnetic Gradient

# Anatomy of an MRI



# Safety issues in MRI

# The Importance of MR Safety

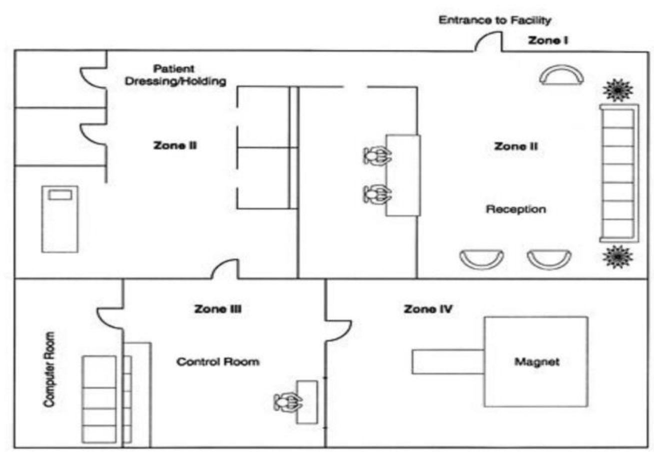


*"Maybe it is time for us to review the magnet safety instructions."*

# MRI Safety

## MRI SAFETY

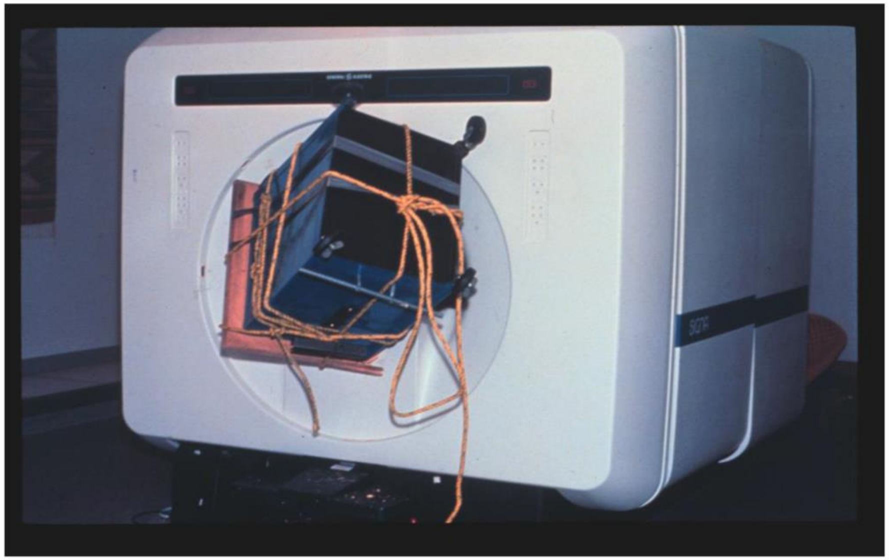
- MRI scanners are extremely powerful
- Objects that are attracted by the MRI magnetic field can reach 60 miles per hour.
- A sharp or heavy object can be deadly to anyone standing in its path.
- Metal objects used everyday (scissors, oxygen tanks, infusion pumps, etc) become projectiles
- This can causepotential injury to patients or hospital staff.
- MRI departments are divided into Zones for Safety



# MRI Safety

## **MRI SAFETY**

•



# Oxygen tank

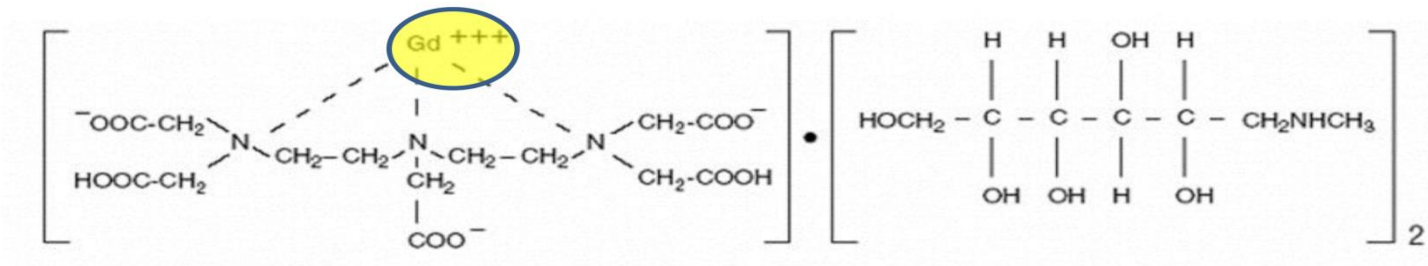
## <u>O2 Tank, "Missile"</u>

An Oxygen tank can become an Airborne torpedo in an MRI

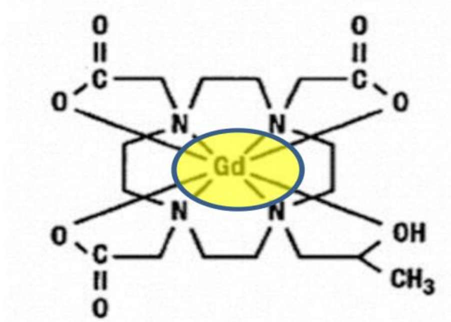

- ed
- en

# Value of Contrast Media

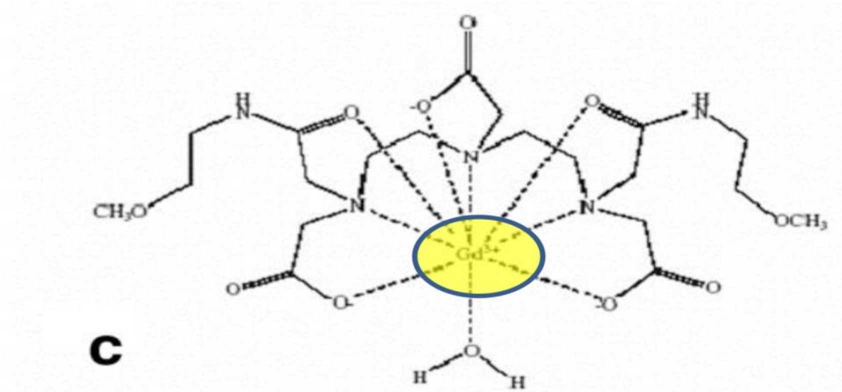
# Gd reagents



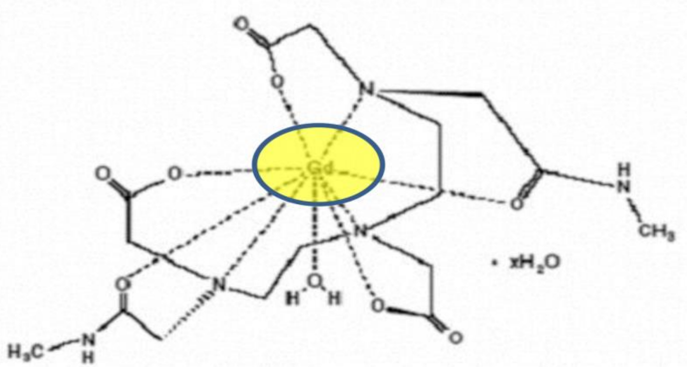
a



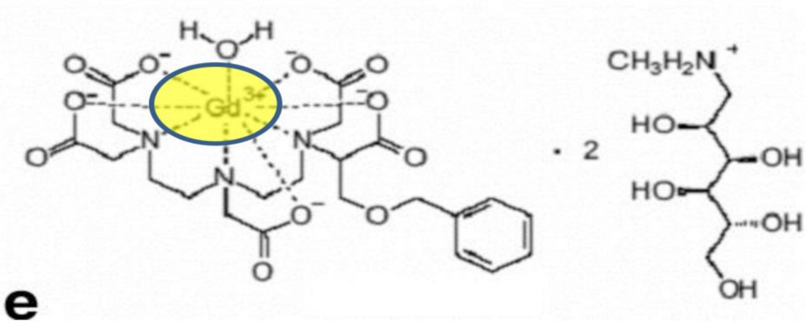
b



c



d



e

# GD reagents

## GD Reagents

| Extracellular Gd-CM | Type | Thermodynamic stability constant | Conditional Stability | Amount of excess chelate (mg $ml^{-1}$) | Kinetic stability (dissociation half-life at pH 1.0) |
|---|---|---|---|---|---|
| Gadoversetamide, Gd-DTPA-BMEA (OptiMark, Tyco, St. Louis, MO) | Non-ionic linear | 16.6 | 15 | 28.4 | Not available |
| Gadodiamide, Gd-DTPA-BMA (Omniscan, GE, Waukesha, WI) | Non-ionic linear | 16.9 | 14.9 | 12 | 35 s |
| Gadobutrol, Gd-BT-DO3A (Gadovist, Schering, Berlin, Germany) | Non-ionic cyclic | 21.8 | Not available | Not available | 5 min |
| Gadoteridol, Gd-HP-DO3A (Prohance, Bracco, Italy) | Non-ionic cyclic | 23.8 | 17.1 | 0.23 | 3 h |
| Gadopentetate Gd-DTPA (Magnavist, Schering, Berlin, Germany) | Ionic linear | 22.1 | 18.1 | 0.4 | 10 min |
| Gadobenate, Gd-BOPTA, (Multihance, Bracco, Italy) | Ionic linear | 22.6 | 18.4 | None | Not available |
| Gadoterate, Gd-DOTA (Dotarem, Guerbet, France) | Ionic cyclic | 25.8 | 18.8 | None | >1 month |

# Nephrogenic systemic sclerosis

## Examples: nephrogenic systemic sclerosis

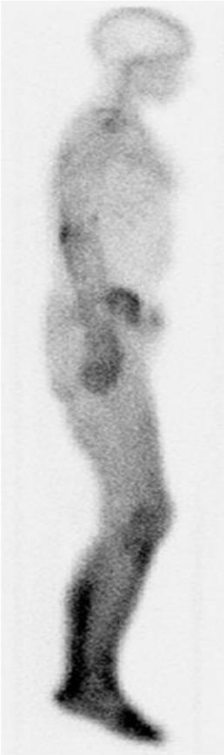
AJR 188 Feb 2007

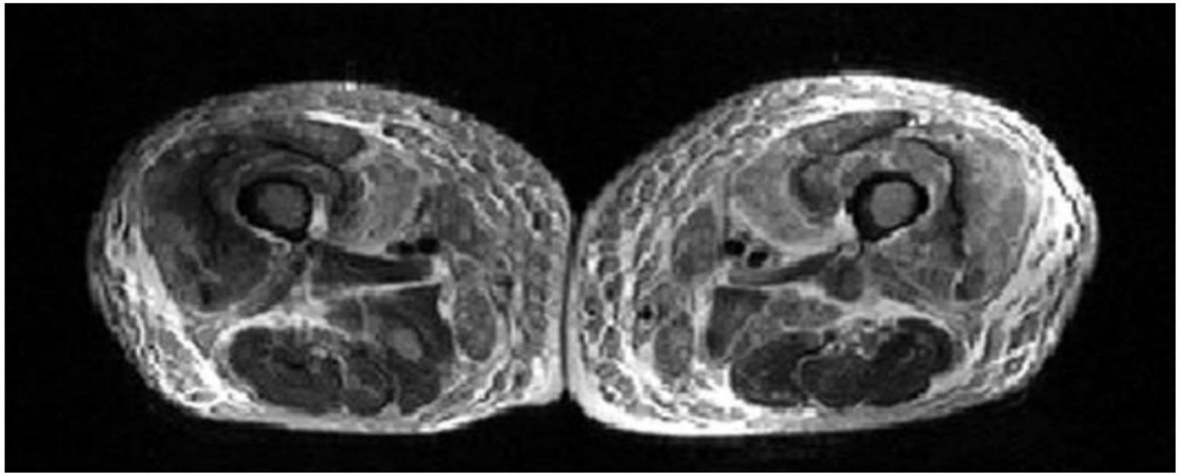
# Nephrogenic Systemic Fibrosis (NSF)

- May 2006 Danish Medicine Agency reported 25 cases of NSF in patients in renal failure who received gadodiamide (~2m)
- Nov 2006  Loma Linda reported 12 (8 on dialysis) NSF patients receiving 0.2mmol/Kg gadodiamide within 2-8 weeks of injection
- Since then over 200 cases have been reported with all of the available contrast agents but mostly Omniscan and Optimark
- By 2013 almost no cases are reported

# Case of NSF

Case of NSF





AJR 188 Feb 2007

# Mechanism

- Gadolinium is highly toxic
- Patients with normal renal function excrete Gd-chelates within 24-48h
- Patients with abnormal renal function may take weeks to excrete the agent
- Dissociation of Gd from the chelate could deposit in soft tissues (documented)
  - Hugh et al. Tissue Gd conc .14-24 ng/mL
- Fibrosis is an inflammatory response to toxic Gd ion.

# Risk Factors

- Renal failure:
  - Dialysis
  - Chronic renal failure (GFR <30cc/min)
- Dose
  - Double, triple (vs. half dose)
- Contrast agent
  - Omniscan>Optimark>Magnevist>Prohance>
- Alternative imaging?
  - Non con MRI
  - CT, US, PET

# Imaging of cancer

# Imaging of Cancer:

# Ultrasound

# US advantages

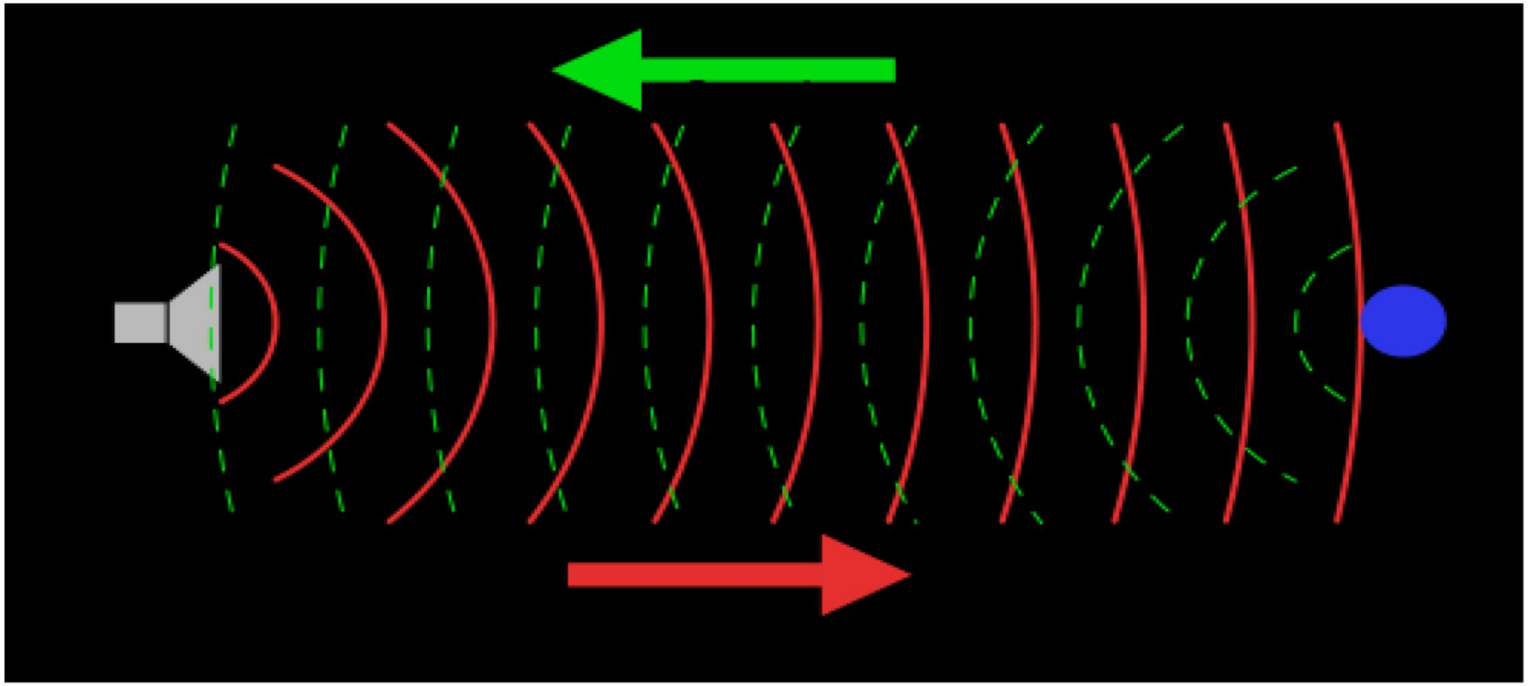
- No radiation
- Real time
- Inexpensive
- Quick,  little prep
- No injection

# US disadvantages

- Operator dependent
- What you see is all there is
- Difficult to quantify
- Limited access (lungs, brain, bone etc.)

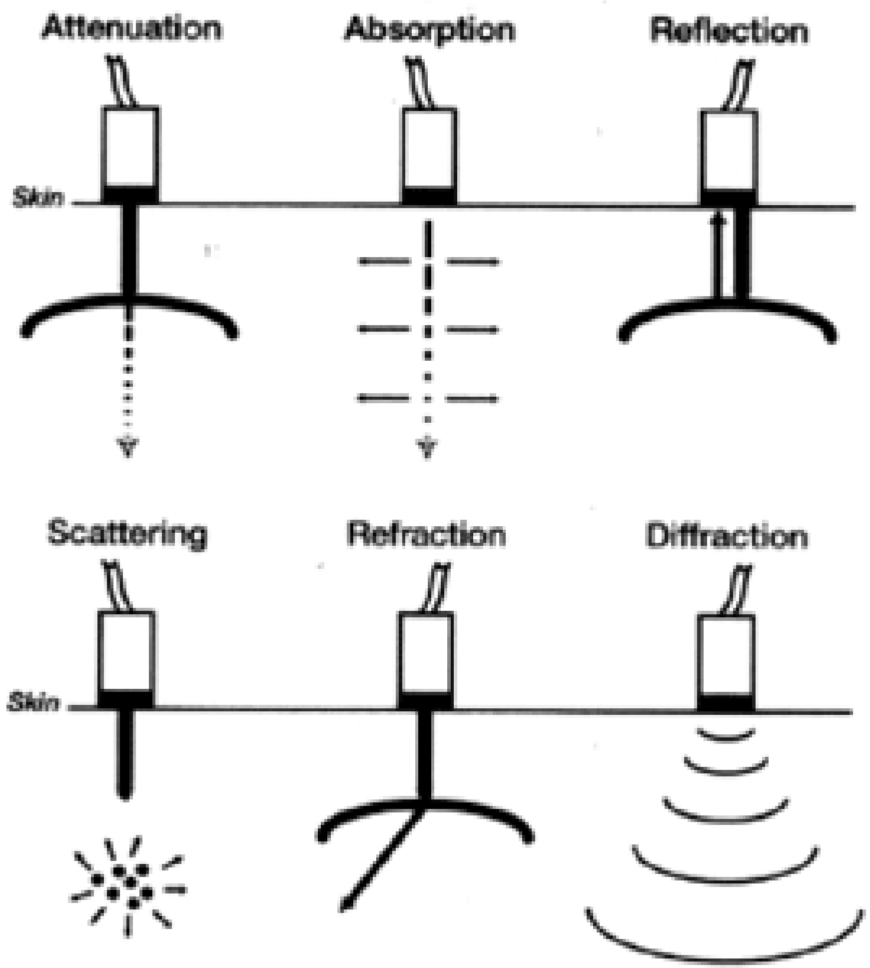
# Ultrasound basics

## US basics



Imaging dependent on the speed of sound
In tissue

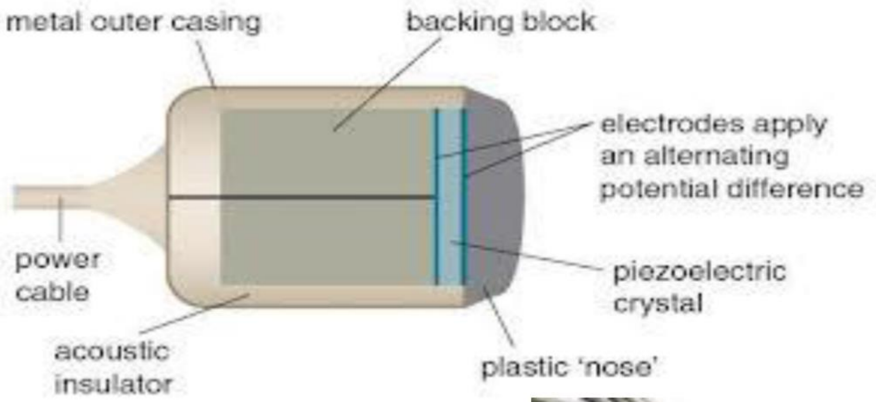
# Fate of sound waves in body



# Liver metastases

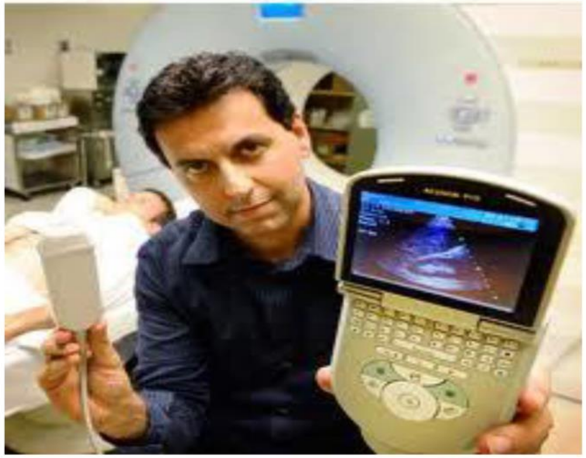
# Ultrasound probes

## US Probes



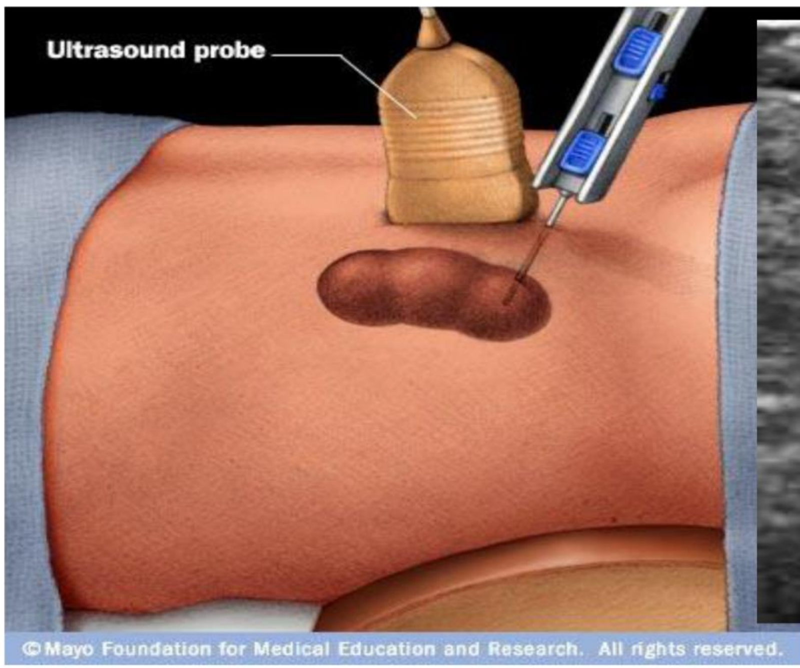

# Ultrasound devices

## Evolution of US devices

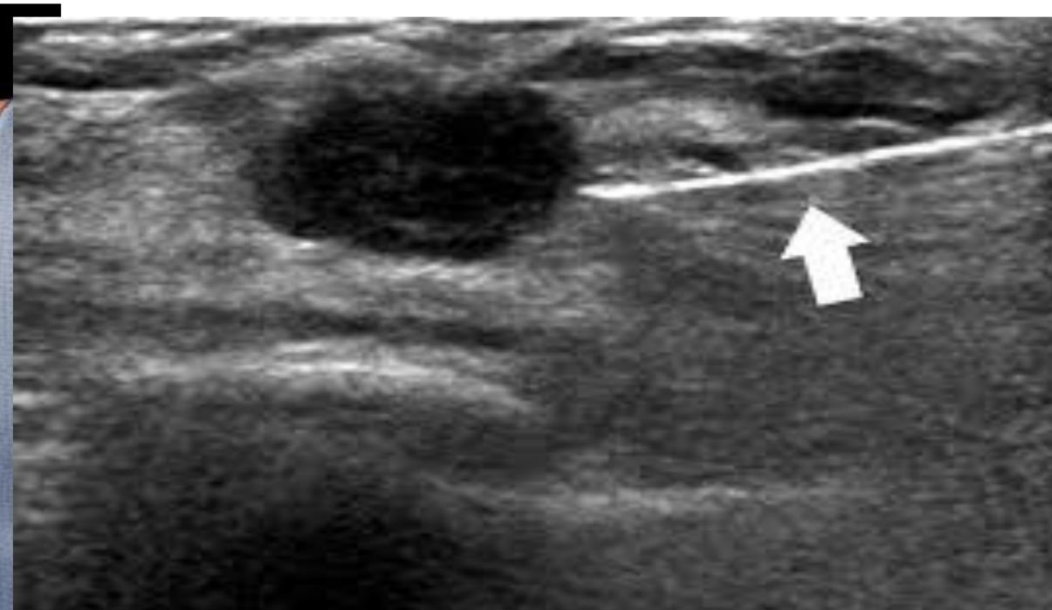


# Ultrasound guided biopsy

## US guided biopsy-real time

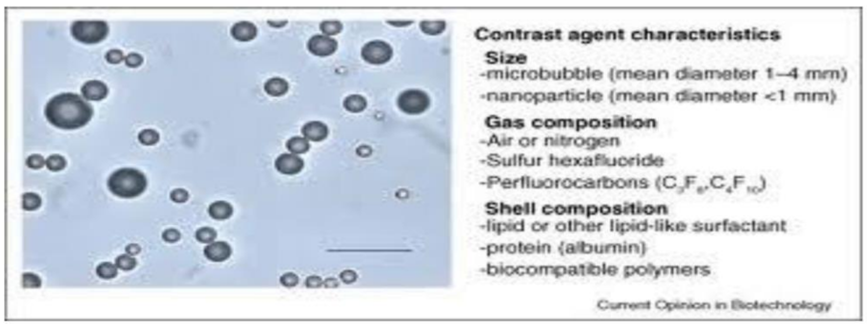


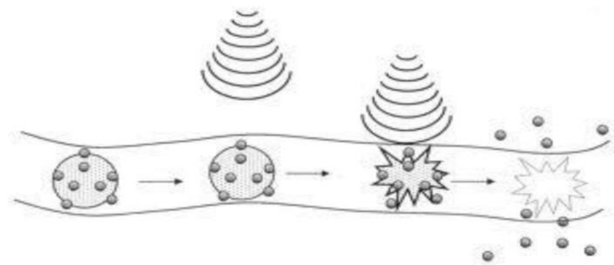


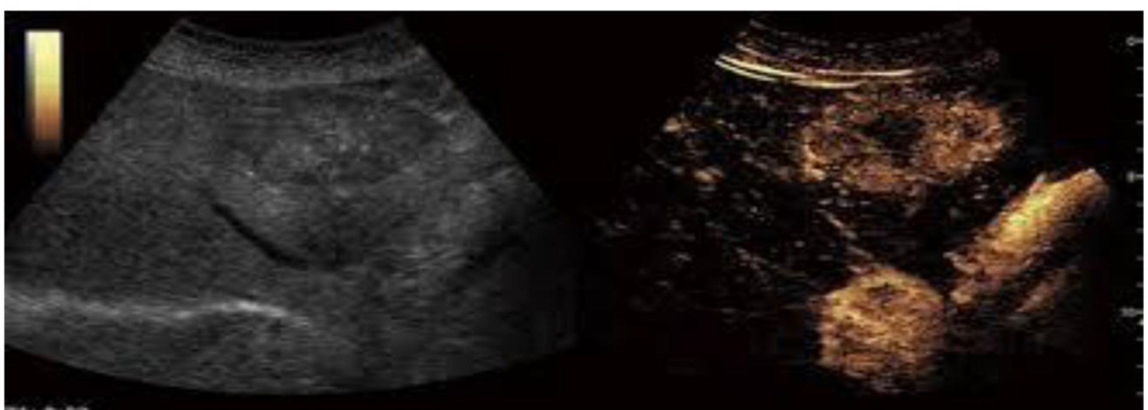


# Ultrasound

## US Microbubble contrast



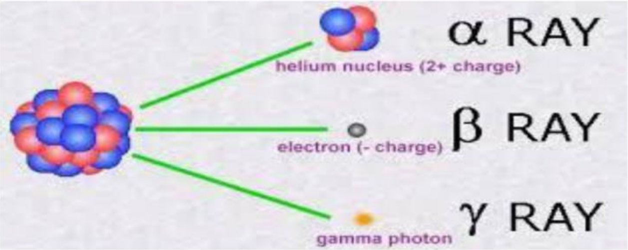





# SPECT

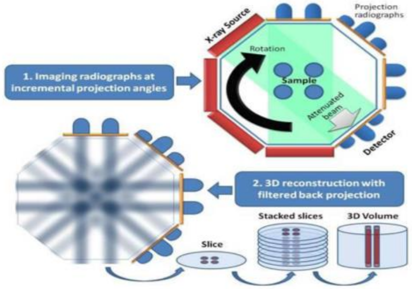
## Single Photon Emission Computed Tomography-SPECT

- Single Photon Emission




+

- Computed Tomography



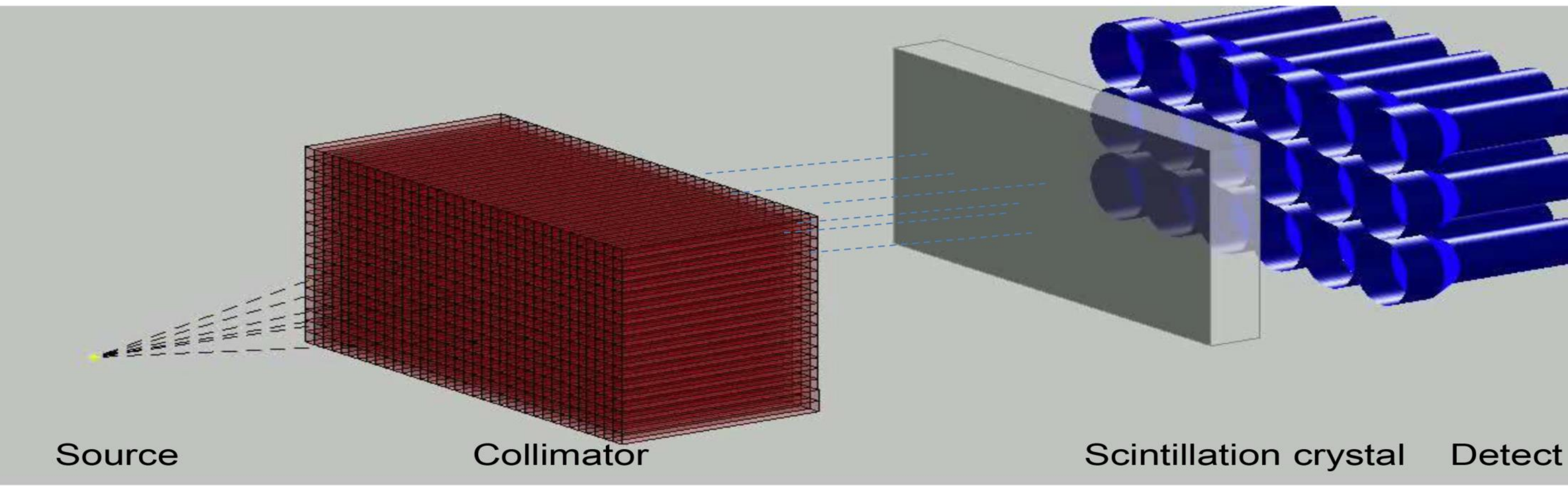
# SPECT Advantages/Disadvantages

- Relatively inexpensive
- Broad experience

- Disadvantages
  - Radiation exposure
  - Preparation of imaging agent
  - Nuclear Regulatory
  - Scanning is slow, low resolution

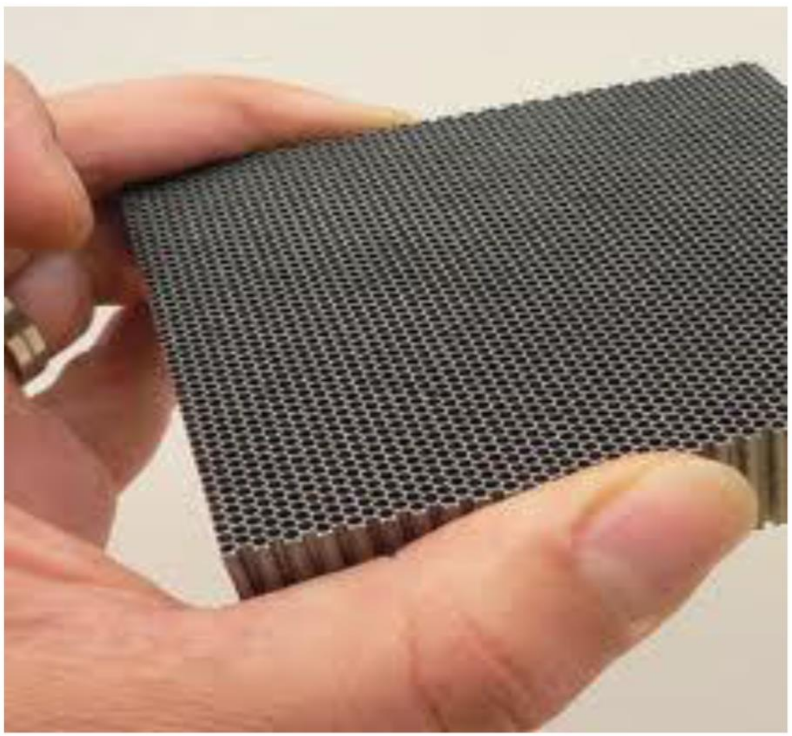
# SPECT detectors

SPECT detectors



# Collimation

## Collimation cont'd

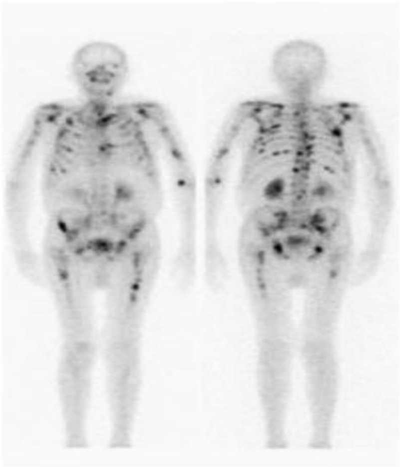



Collimation reduces the sensitivity and resolution of SPECT by rejecting the majority of events

# SPECT imaging

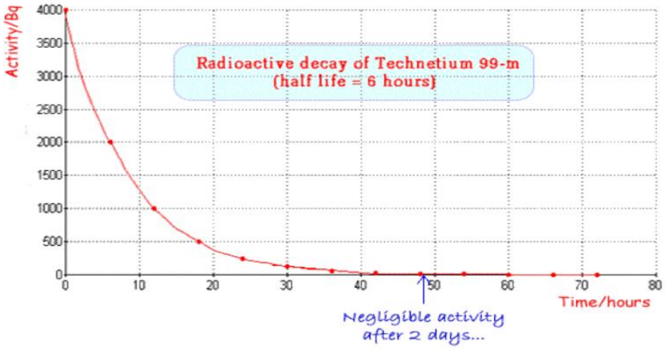
## SPECT Imaging

- Requires conjugation of a radioactive isotope to a compound of interest which is injected into the patient:



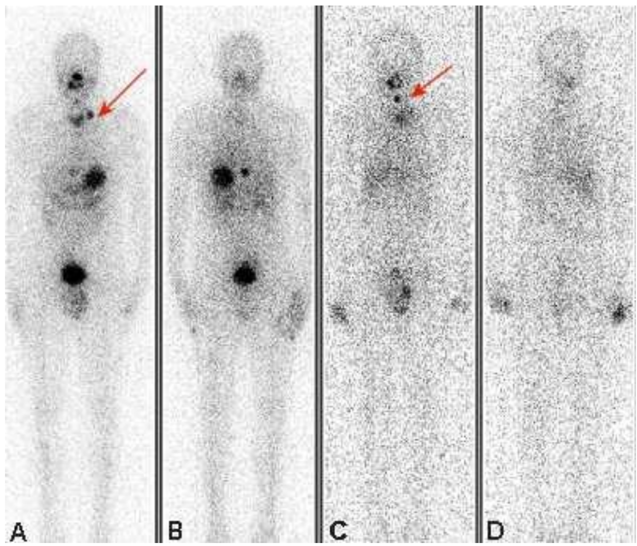
The bone scan:

$^{99m}$Technetium-methyl diphosphonate



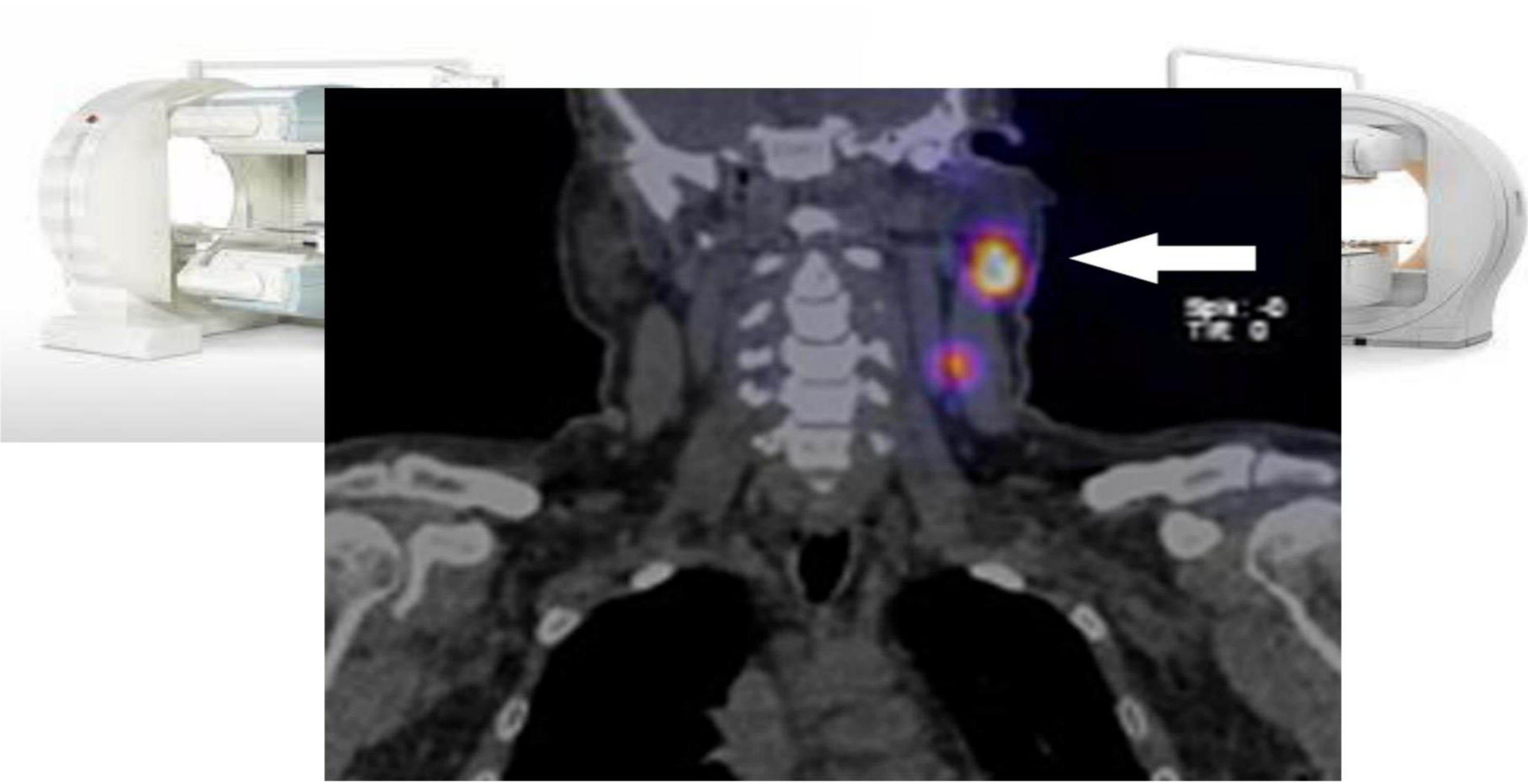
# SPECT agents for cancer

- $^{99m}$Tc  MDP   Bone Scan
- $^{99m}$Tc Pertechnetate   (thyroid, salivary gland)
- $^{201}$Thallium Chloride (parathyroid)
- $^{111}$Indium  oxine  (WBC labelling)
- $^{131}$Iodine  (thyroid)



# Hybrid Imaging

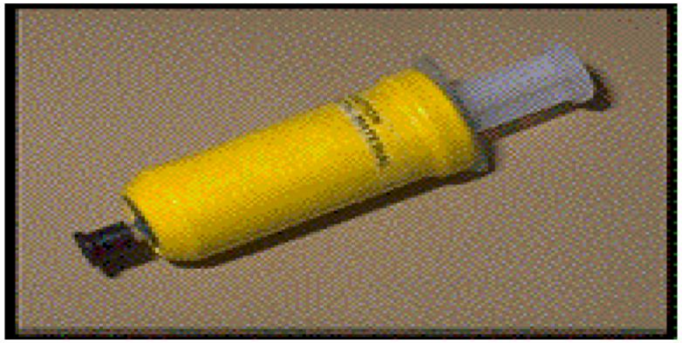
Hybrid Imaging

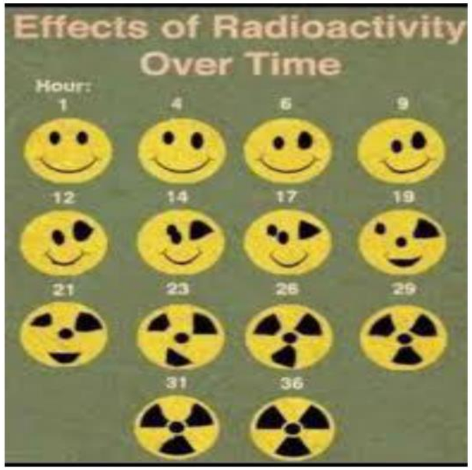


# Safety

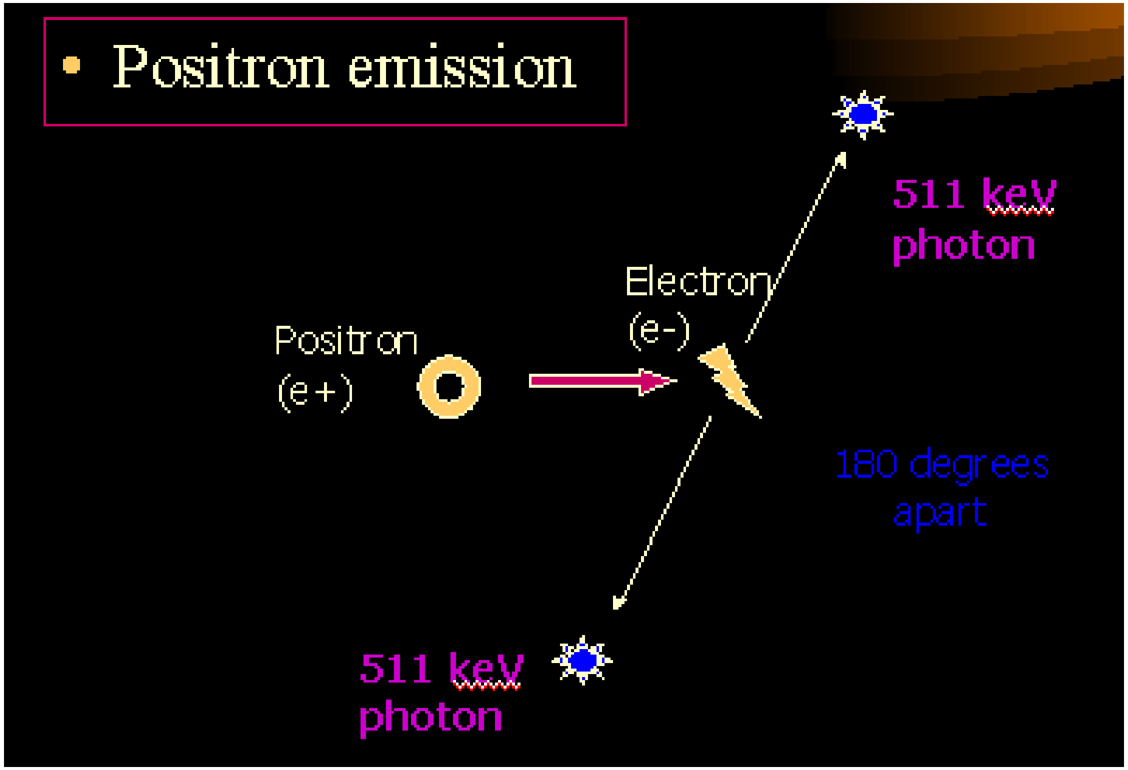
Safety

- Operator
- Patient





# Positron Emission Tomography

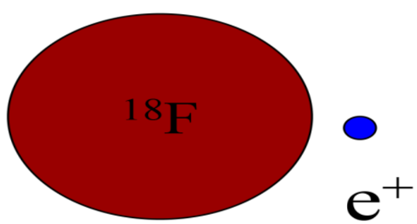


# PET:Advantages and Disadvantages

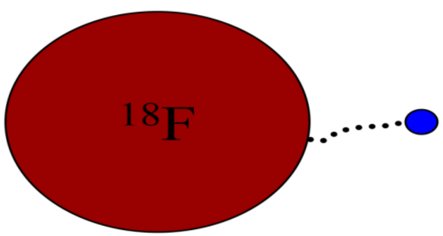
- Highly sensitive
- Metabolic information
- Better spatial resolution than SPECT
- Combined with CT
- ________________________________________
- Expense
- Regulatory
- Short half life

# PET

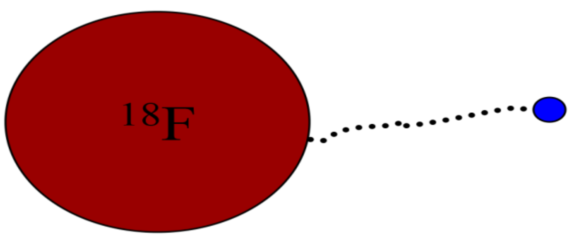
Positron Emission Tomography



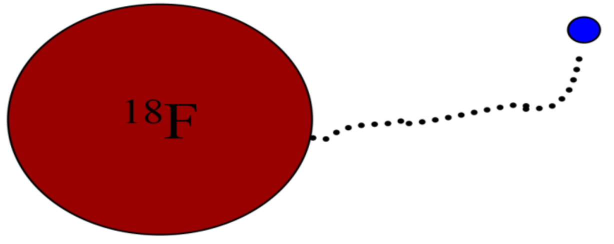
# Positron travel



# Positron travel



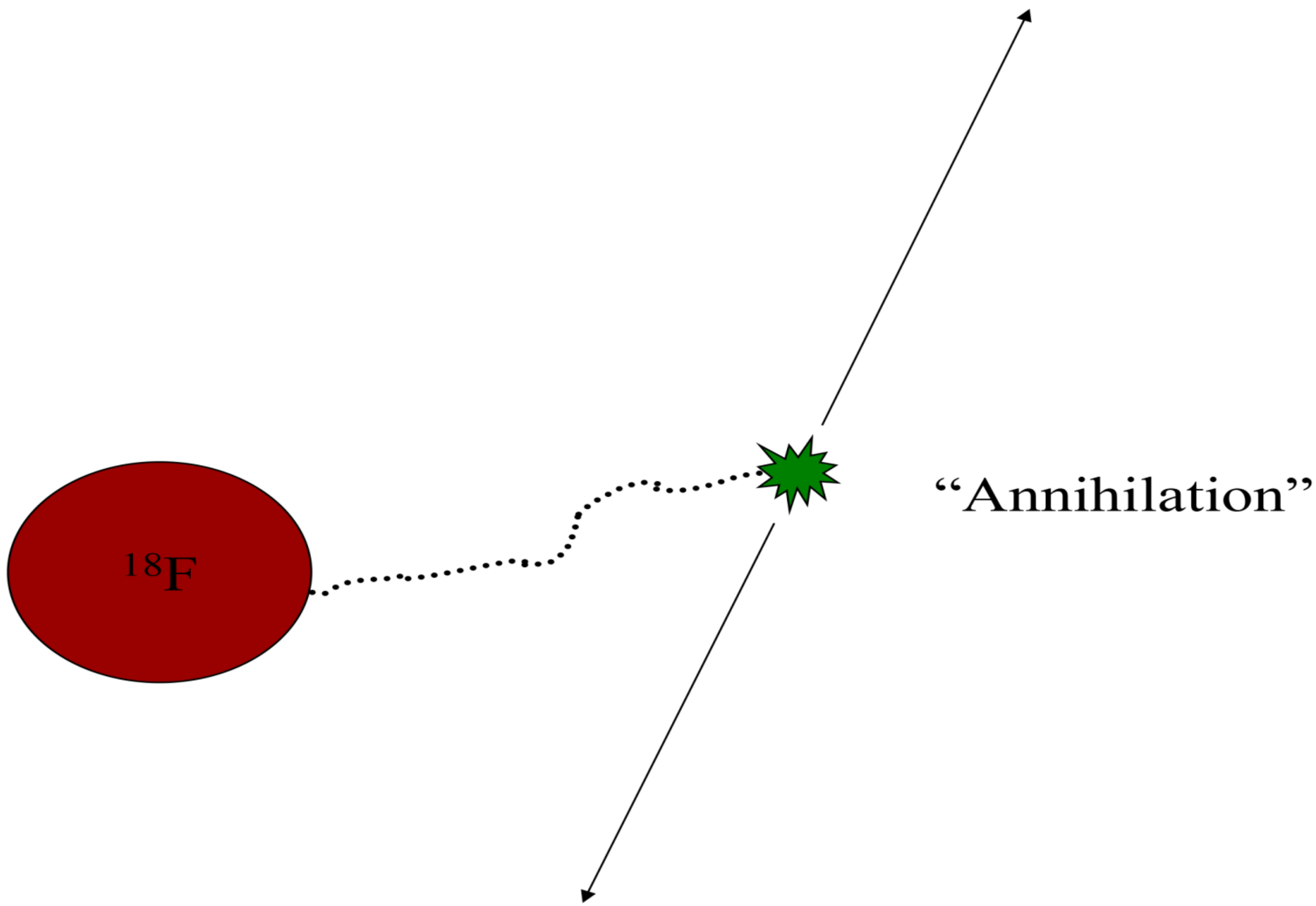
# Positron travel



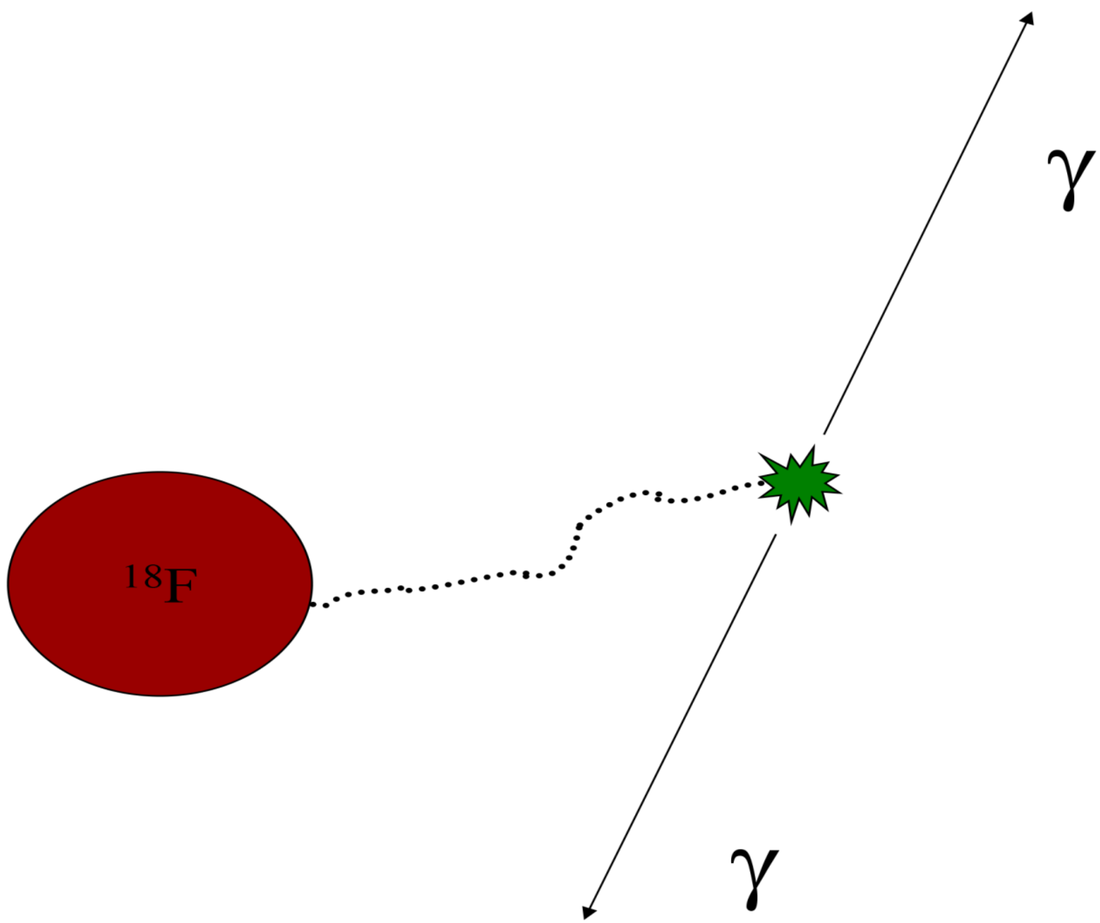
# Positron travel

# Positron and Electron

# Annihilation

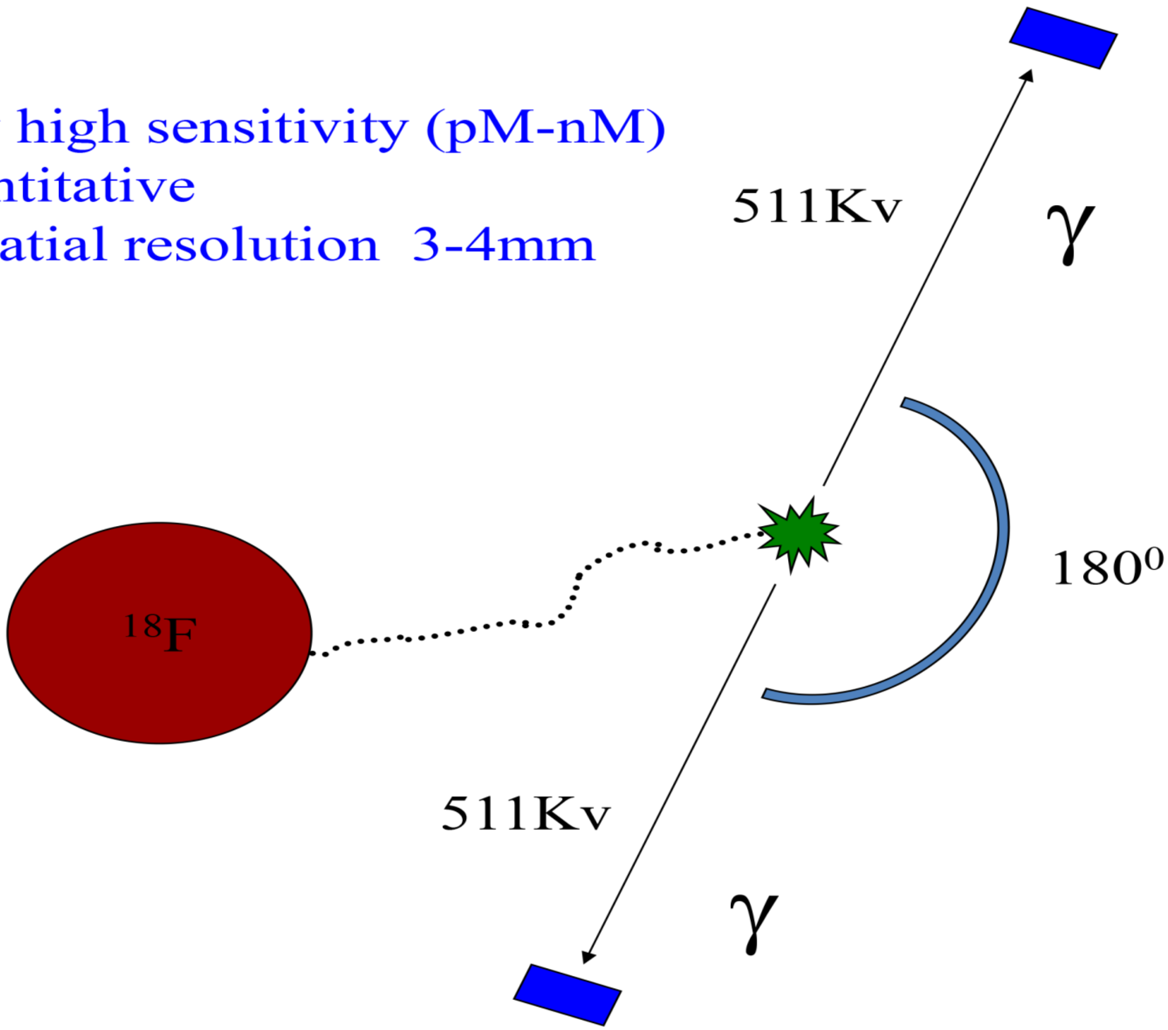


# Gamma rays



# Gamma ray orientation

Very high sensitivity (pM-nM)
Quantitative
± Spatial resolution 3-4mm

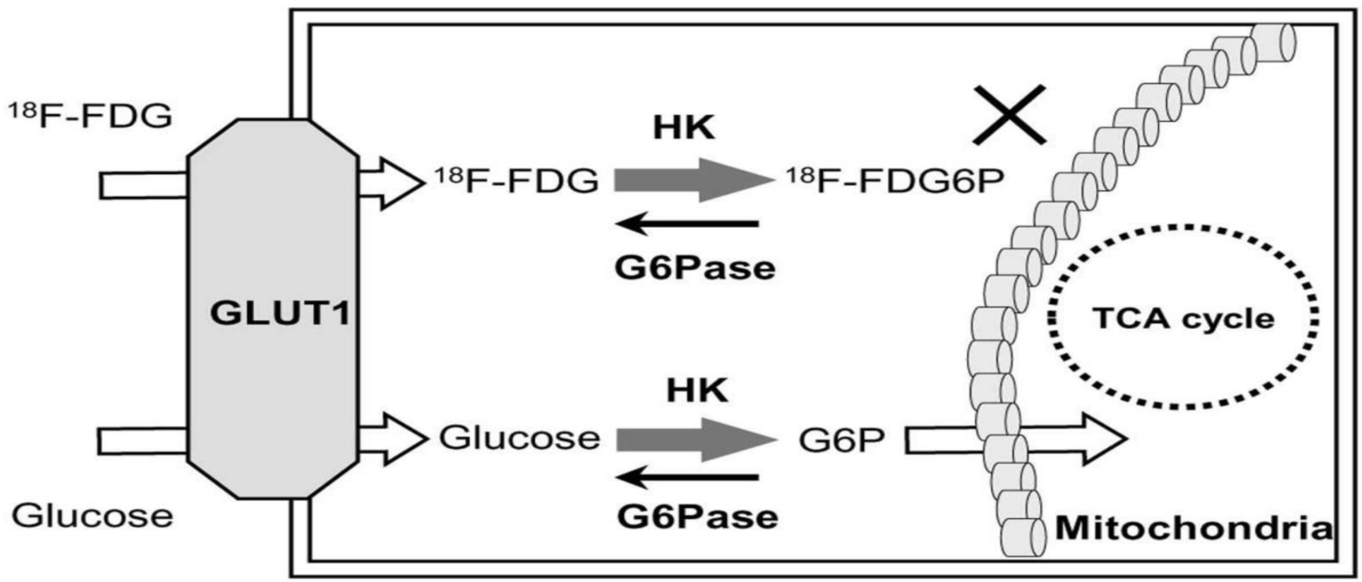


# F-18 Deoxyglucose

F-18 Deoxyglucose

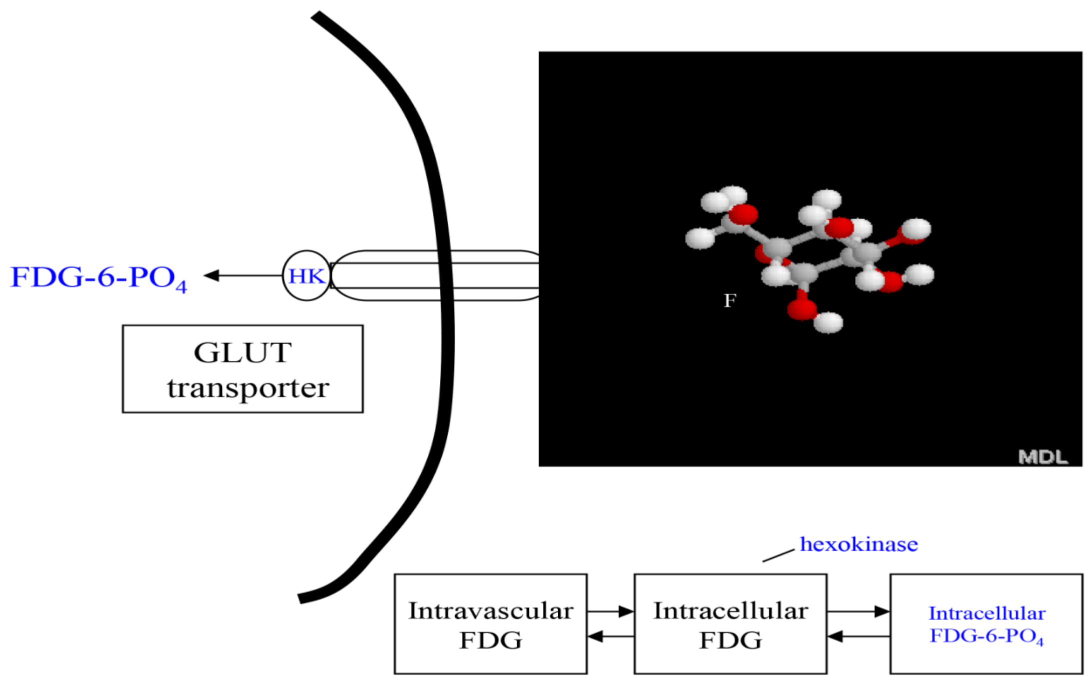
Otto Warburg

Lou Sokoloff



# PET imaging

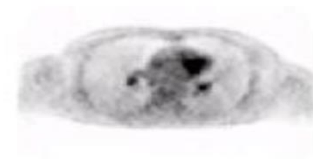
## $^{18}$FDG PET Imaging



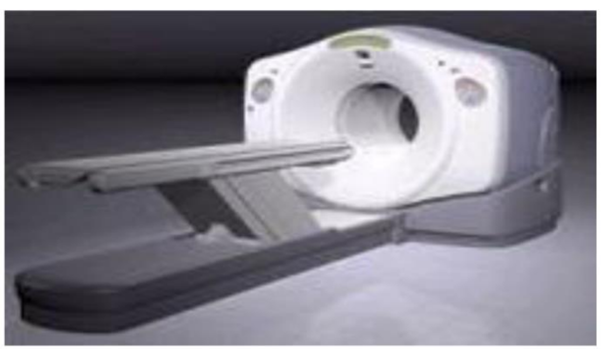
# PET-CT device

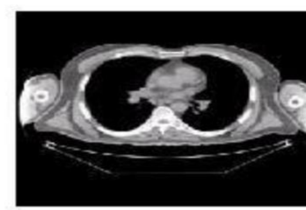
Facilitate Advanced Imaging Technology

- Positron Emission Tomography
  - PET-CT Device

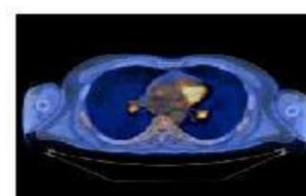


PET Image





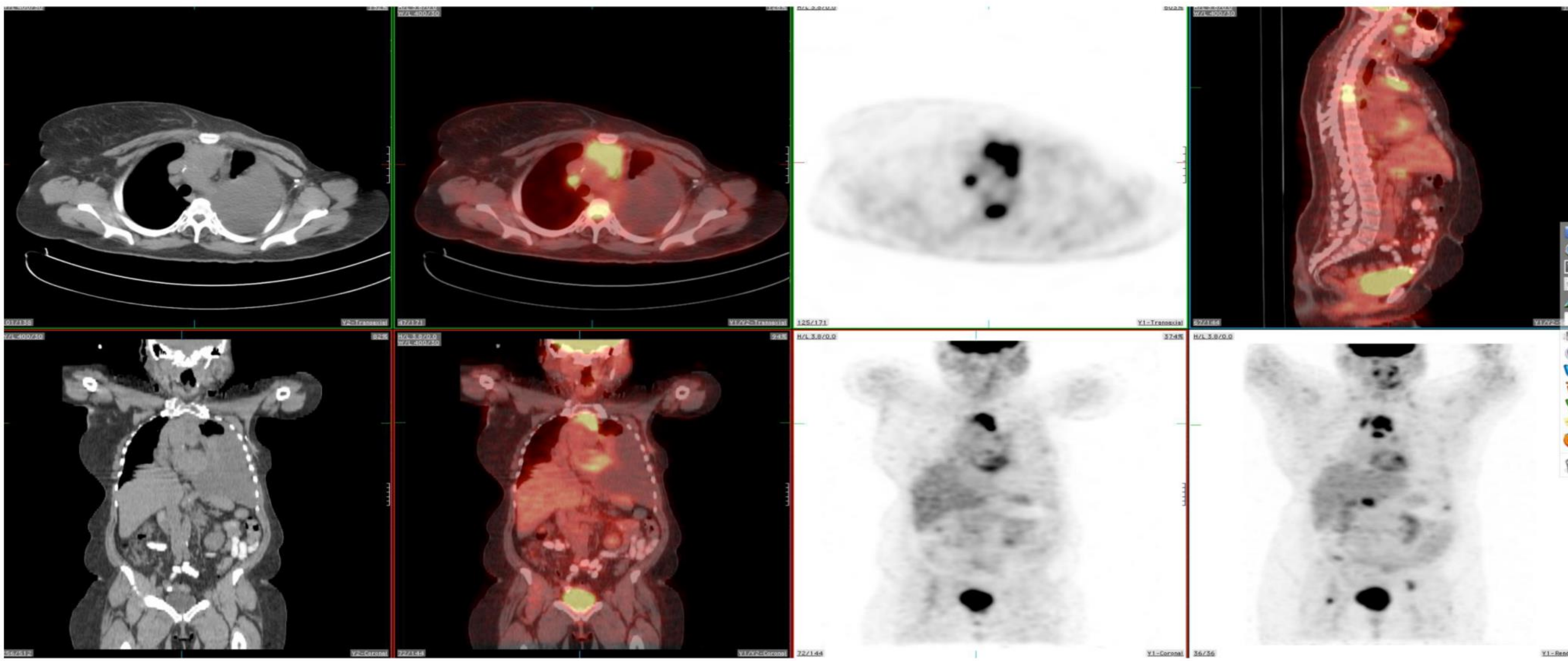
CT Image



Discovery™ LS

# Metastatic Breast Cancer

## Mediastinal and spine metastases (breast)



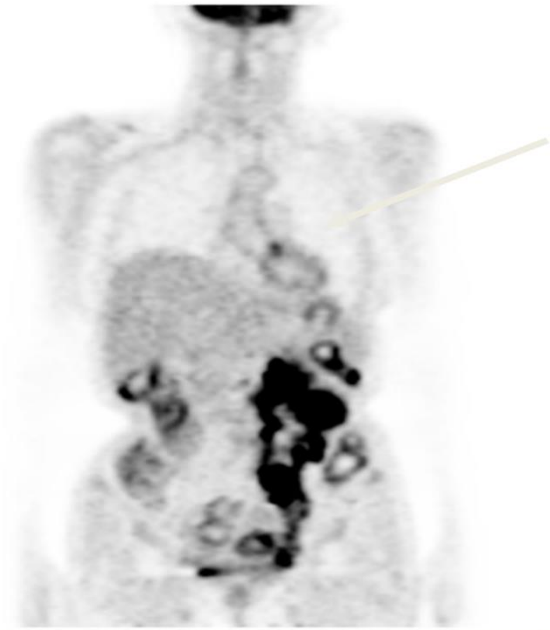
Metastatic Breast Cancer

# Notable PET Agents

- Sodium Fluoride:  Bone target
- Fluorothymidine:  Cellular Proliferation
- Fluoroestadiol:  Estrogen receptor
- Fluorocholine: Membrane Turnover
- Fluoromiso:  Hypoxia
- Florbetaben: Amyloid (Alzheimers)
- Zirconium Herceptin:  labeled antibody
- Zirconium Oxine:  Cell labeling

# Image Correction

Non-attenuation corrected



Attenuation corrected

# PET Imaging

- Positron emission tomography (PET) has the advantages of :
  - **High energy photon imaging**
  - **High Sensitivity, Moderate Specificity**
  - **The ability to correct for attenuation**
  - **No need for collimation**
  - **Resolution is still limited**

# Summary

## Summary of Cancer Imaging

| Presentation | Resolution | Sensitivity | Cost (low-hi) |
|---|---|---|---|
| CT | CT | PET | US |
| MRI | MRI | SPECT | CT |
| US | US | US (microbubble) | SPECT |
| SPECT | PET | MRI | MRI |
| PET | SPECT | CT | PET |

# Cancer Imaging

## Summary of Cancer Imaging

| Presentation | Resolution | Sensitivity | Cost (low-hi) |
|---|---|---|---|
| CT | CT | PET | US |
| MRI | MRI | SPECT | CT |
| US | US | US (microbubble) | SPECT |
| SPECT | PET | MRI | MRI |
| PET | SPECT | CT | PET |

# Cancer Imaging

## Summary of Cancer Imaging

| Presentation | Resolution | Sensitivity | Cost (low-hi) |
|---|---|---|---|
| CT | CT | PET | US |
| MRI | MRI | SPECT | CT |
| US | US | US (microbubble) | SPECT |
| SPECT | PET | MRI | MRI |
| PET | SPECT | CT | PET |

# Cancer Imaging

## Summary of Cancer Imaging

| Presentation | Resolution | Sensitivity | Cost (low-hi) |
|---|---|---|---|
| CT | CT | PET | US |
| MRI | MRI | SPECT | CT |
| US | US | US (microbubble) | SPECT |
| SPECT | PET | MRI | MRI |
| PET | SPECT | CT | PET |

# General Guidelines

- Overall “workhorse” for oncology: CT
- Specialty cancers: brain, liver, prostate:  MRI
- Problem solving (e.g cyst vs. solid): US
- Bone mets:  SPECT
- Metabolic activity:  PET

# Imaging of cancer

Imaging of cancer

Imaging of Cancer: