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The (R)EVOLUTION of Hybrid Devices in MEDICAL IMAGING

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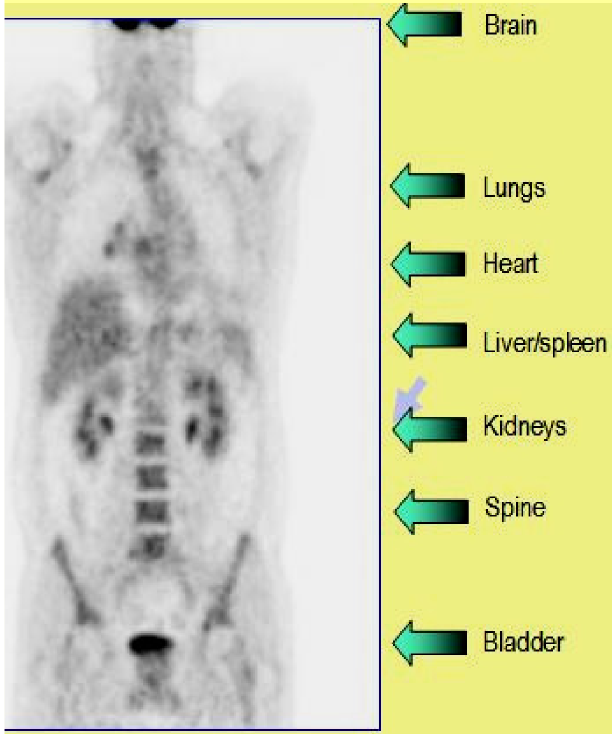
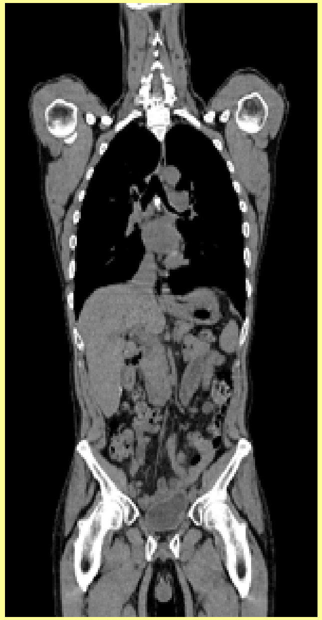


PET

1. Intro to Medical Imaging
2. CT-scanner (with X-Rays)
3. MRI
4. SPECT
5. PET
6. Quantification
7. Uses in Hospital
8. Improvements
9. Conclusion



CT

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1.INTRODUCTION

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Imaging modalities today

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Hardware combination ➡ Evolution / Revolution

Imaging Modality	Spatial Resolution (mm)	Acquisition time per frame(s)	Molecular probe mass required (ng)	Molecular sensitivity (mol/L)	Tissue penetration depth (mm)	Signal quantification capabilities
PET	1-2 (animal) 6-10 (clinical)	1-300	1-100	10^{-11}-10^{-12}	>300	High
SPECT	0.5-2 (animal) 7-15 (clinical)	60-2000	1-100	10^{-10}-10^{-11}	>300	Medium-High
Optical	2-5 (visible to IR)	10-2000	10^{3}-10^{6}	10^{-9}-10^{-11}	1-20	Low
MRI	0.025-0.1 (animal) 0.2 (clinical)	0.1-100	10^{3}-10^{6}	10^{-3}-10^{-5}	>300	High
US	0.05-0.5 (animal) 0.1-1 (clinical)	0.1-100	10^{3}-10^{6}	Not well characterized	1-300	Low
CT	0.03-0.4 (animal) 0.5-1 (clinical)	1-300	NA	Not well characterized	>300	Medium-High

From Craig S Levin. Eur J Nucl Med & Mol Imag. 2005, 32(14), S-325-45

(Thru D. Townsend and modifiied by YL)

EVOLUTION in MEDICAL IMAGING (combination of existing equipment)

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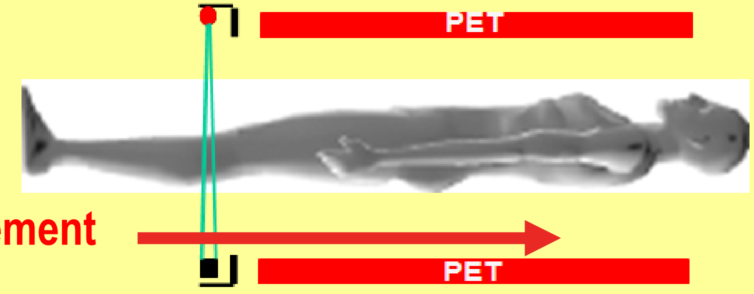
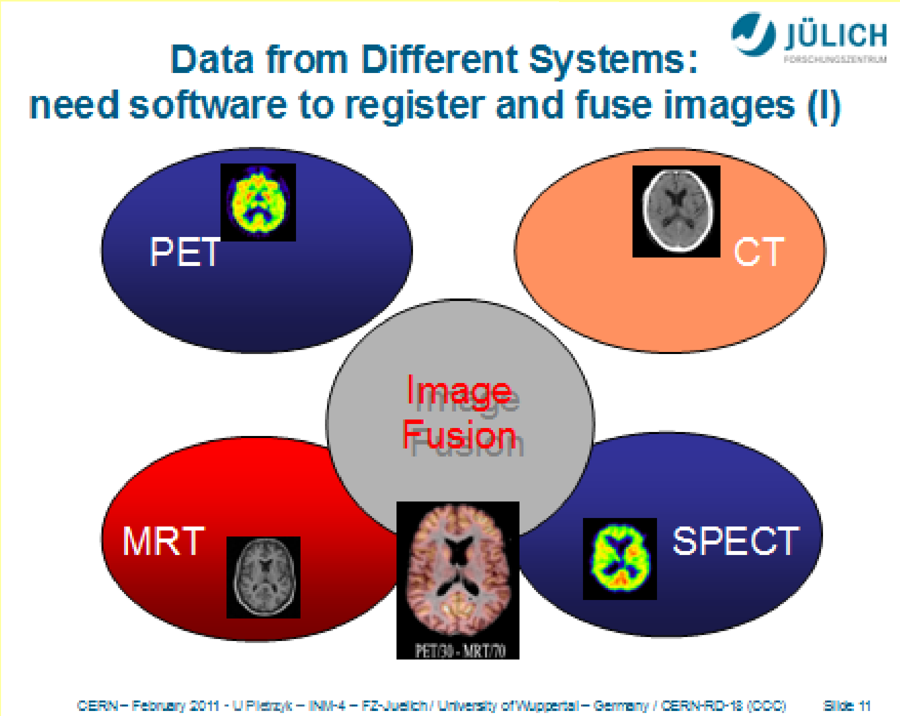
Example: **CT** **PET**

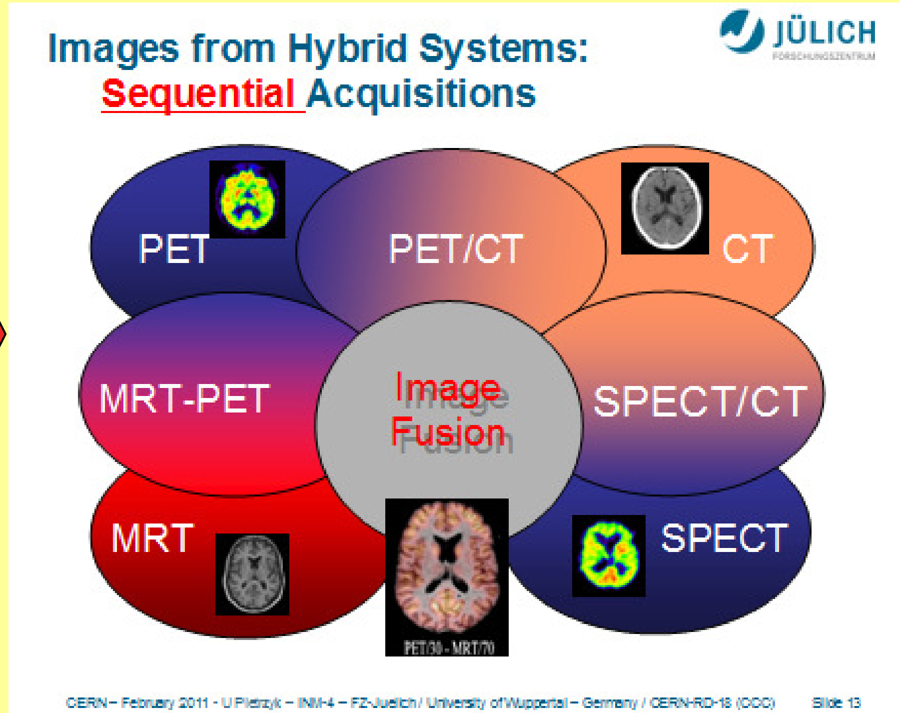


movement

MDCT

(Tfrom D. Townsend and modifiied by YL)





Data taken at different time / in different configuration / in different places…

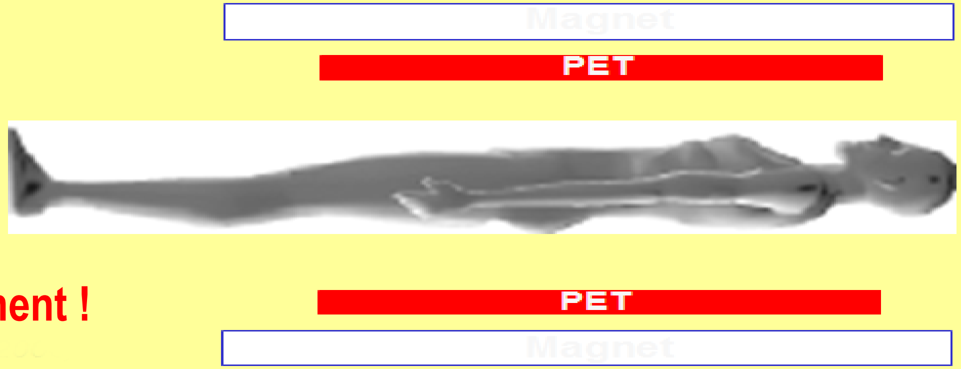
Fusion only by software

Data taken at sequential time / with minimal movement of patient

Fusion by software

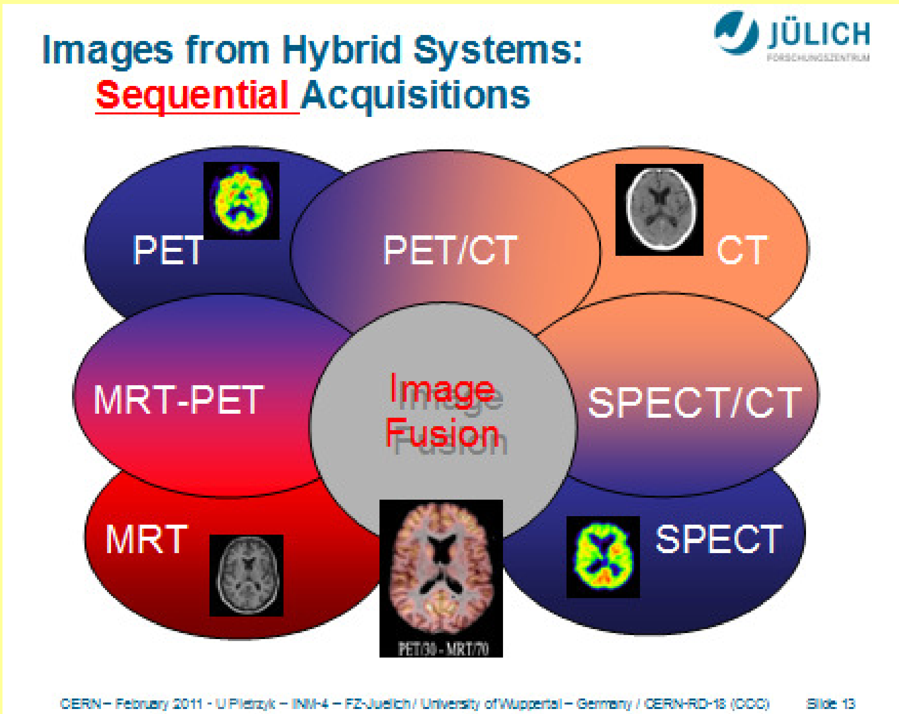
REVOLUTION in MEDICAL IMAGING
(Integrated devices from technical developments)

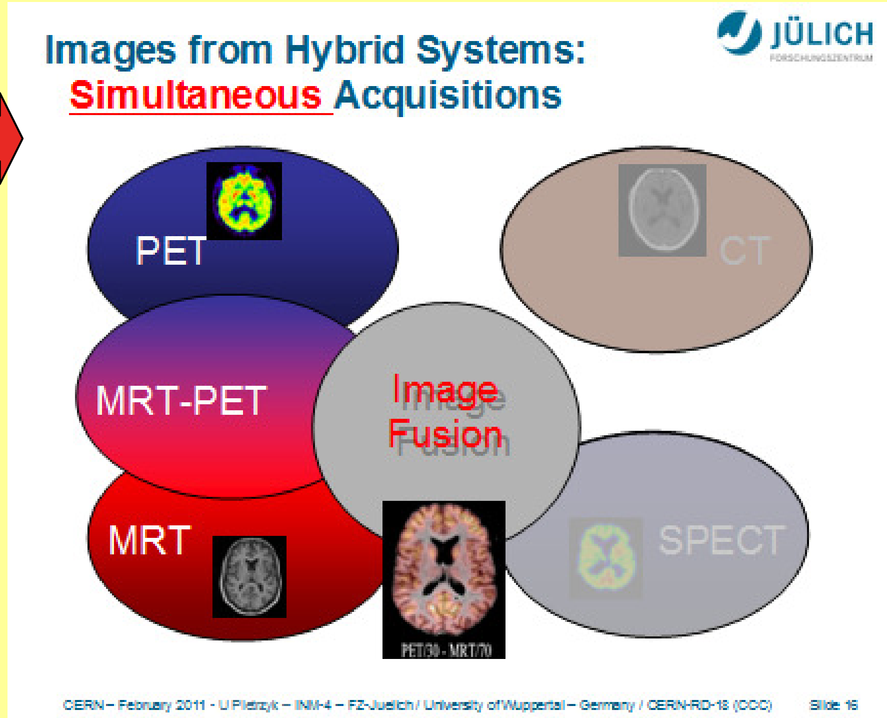
Example: **MRT** **PET**



No movement ! **(same hardware)**

(Thru D. Townsend and modifiied by YL)





REVOLUTION is simultaneous Acquisitions without patient deplacement !!

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EUROPEAN SCIENTIFIC INSTITUTE (ESI) ARCHAMPS, FRANCE
EUROPEAN SCHOOL OF MEDICAL PHYSICS (ESMP)

HOW PHYSICS HELPS IN ESTABLISHING DIAGNOSIS

Physics has made it possible to create sophisticated devices to "explore" the human body from different perspectives:
- anatomical, to see "inside" the human body at a certain moment;
- functional, to see how the body functions during a given period of time.

"In-Vivo" Imaging: Complementary devices

Domain of use: Help to patient treatment; Biology / Medical Research / New drugs

	Anatomy	Physiology	Metabolic level	Mole level
Special applications		PET (PET-Scan)		
		SPECT (Gamma camera)		
Common applications	X - Rays Scanner			
	MRI (magnetic resonance)			
		functional MRI		
	Ultrasound			

Research

"SCANNER" - TDM

CT

"PET-SCAN"

Each technique has its own specificity and thus a particular area of application:

- Scanner: TDM with a good space-resolution; ionising X-rays.

- PET-SCAN: functional analysis can be VERY sensitive; limited space-resolution. Uses ionising rays (radiotracers).

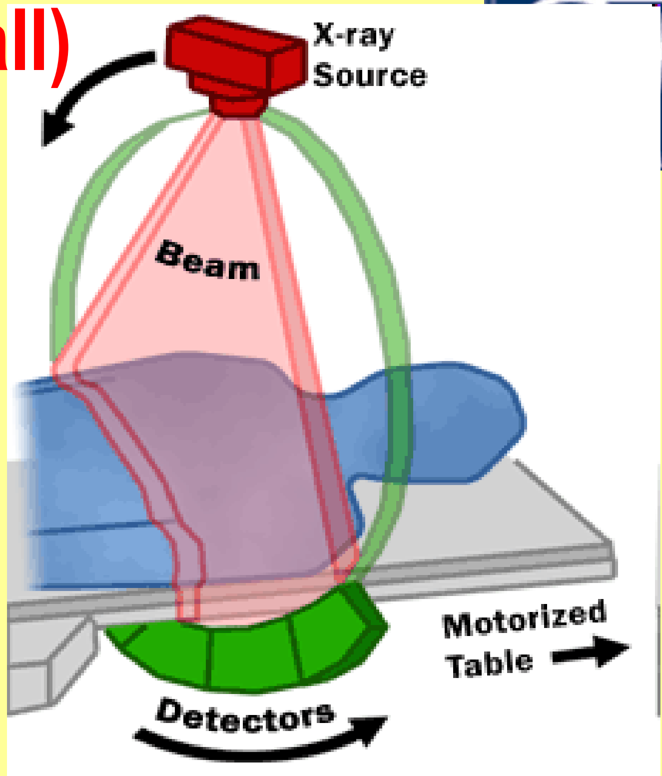
2. X-Rays CT

2 - CT Principle (recall)

Description

Computed tomography (CT) scanning is a medical imaging procedure that uses x-rays to show cross-sectional images of the body.

These cross-sectional images are used for a variety of diagnostic and therapeutic preparation purposes.

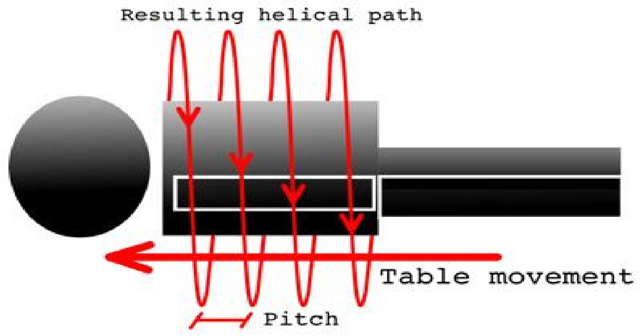


How a CT system works:

A motorized table moves the patient through a circular opening in the CT system. While the patient is inside the CT, a x-ray source and detector within the housing rotate around the patient. The x-ray source produces a narrow beam of x-rays that passes through a section of the patient's body.

A detector opposite from the x-ray source records the x-rays passing thru the patient's body as a "snapshot" image. Many different "snapshots" (at many angles through the patient) are collected during one complete rotation and are sent to a computer to reconstruct all individual "snapshots" into one or multiple cross-sectional images (slices) of the internal organs and tissues. (3-D Imaging)

CT Utility & Definitions



X-Rays-CT has become recognized as a valuable medical tool, for:

1. Diagnosis of disease, trauma, or abnormality (Anatomy imaging)
2. Planning, guiding, and monitoring therapy (Ex: Treatment Planning preparation)

Beer's Law for one material: $I = I_0 \exp[-\mu x]$

where I_0 and I are the initial and final X-ray intensity, μ is the material's linear attenuation coefficient (units 1/length) and x is the length of the X-ray path. With multiple materials i, the equation becomes: $I = I_0 \exp\left[\sum_i (-\mu_i x_i)\right]$

But:

Non-negligeable x-ray radiation exposure:

- Typical dose, Computed Tomography (CT)-Body : 10 mSv (=3 years of natural dose)
- Classical Chest Radiography: 0.1 mSv (10 days of natural dose)

$$Hounsfield\ unit = \frac{\mu_{tissue/material} - \mu_{water}}{\mu_{water}} \times 1000$$

An important issue within CT radiology today is how to reduce the radiation dose during CT examinations without compromising the image quality (Target CTA protocol, Adaptive Iterative Dose Reduction …) in some case hopefully 1 mSv can be reached…

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Typical CT Doses :

ExaminationTypical	Effective dose (mSv)
Chest X-ray	0.110
Head CT	1.5
Abdomen CT	5.3
Chest CT	5.8
Chest, abdomen and pelvis CT	9.9

The annual per capita exposure to medical radiation in the U.S. increased from 0.54 mSv in 1980 to 3.2 mSv in 2006 !!.

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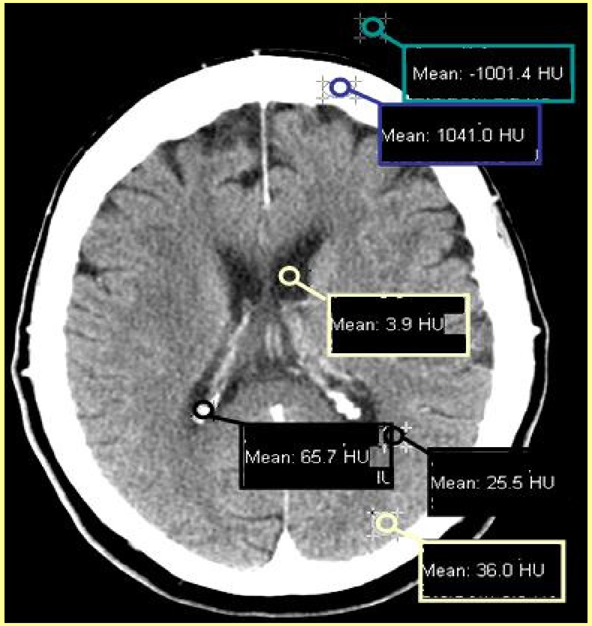
Low-dose CT scan :

- Aim is : Reduce the radiation dose during CT examinations without compromising image quality.
- Higher radiation doses => higher-resolution images,
- Lower doses => higher image noise => unsharp images.
- An abdominal CT gives = 300 chest x-rays (for dose).
- Several methods exist to reduce exposure dose :



1- New software technologies: some filters reduce random noise and enhance structures => to get higher quality images and at the same time lower the dose by 30% to 70 %.

2. Individualize the examination and adjust the radiation dose to the body type and body organ examined. Different body types and organs require different amounts of radiation.

3. Prior to every CT examination, evaluate the appropriateness of the exam whether it is motivated or if another type of examination is more suitable. Higher resolution is not always suitable for any given scenario, such as detection of small pulmonary masses.

3. MAGNETIC RESONANCE IMAGING

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MRI : Overall picture of how it works…

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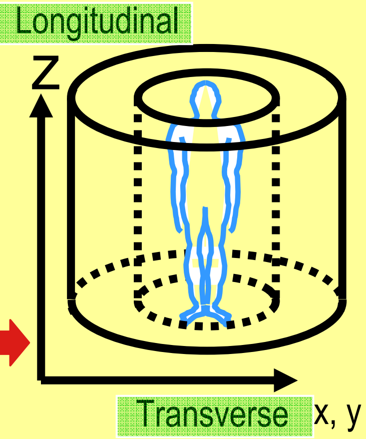
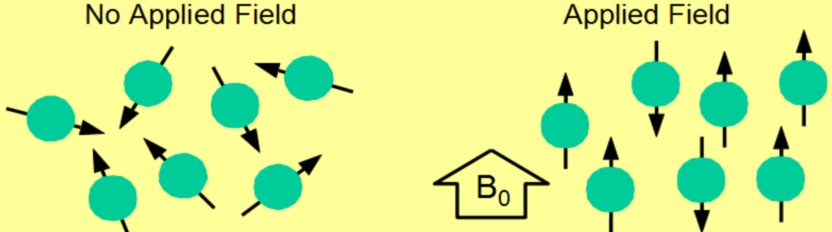
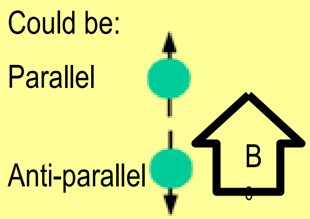
- Our bodies are made up of roughly 63% water
- MRI machines use hydrogen atoms
- The hydrogen atoms act like little magnets, which have a north and south pole (“Spin”).
- The atoms inside our body are aligned in all different directions



- The MRI is basically a large magnet
- Patient lies within scanner where magnetic field is created
- Magnetic force causes nuclei with hydrogen (proton) to line with the field-referred to as parallel, there is also antiparallel
- Electromagnetic radiation (radio waves) are emitted from machine



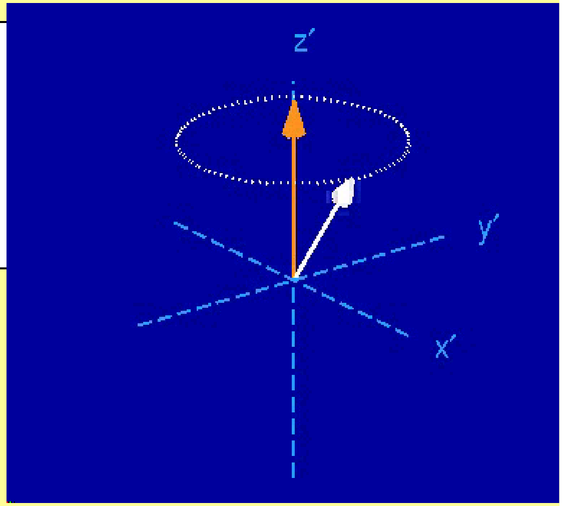


Anti-Parallel have higher Energy than Parallel ones → Radio waves are emitted when coming back to equilibrium

Precession

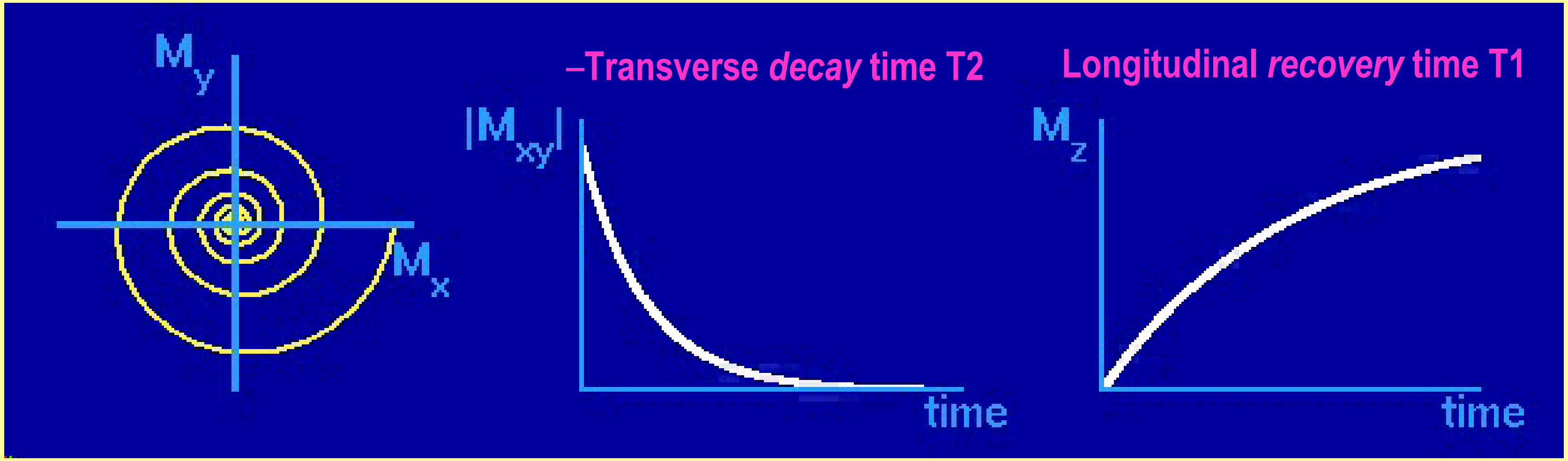
- Spins precess about applied magnetic field, B_0, that is along z axis.
- The frequency of this precession is proportional to the applied field.

Larmor law: $\omega = \gamma B$



- Magnetization returns exponentially to equilibrium:
  - Longitudinal *recovery* time constant is T_1
  - Transverse *decay* time constant is T_2
- Relaxation and precession are independent.

Relaxation



Precession Decay Recovery

MRI : how it works (Cont'd)…

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An MRI consists of:

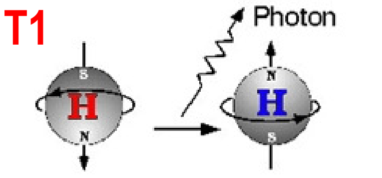
- a big magnet creates the magnetic field by coiling electrical wire and running a current through the wire
- gradient magnets: to alter precisely the magnetic field and allow image slices of the body to be created.
- a coil: emits the radiofrequency pulse allowing disturbence of the alignment of the protons / also Receiver

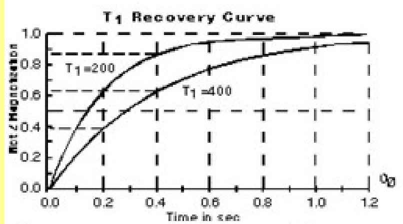
Larmor Equation $\omega_o = \gamma.\beta_o$ **For H[1] :** $\gamma = 2.675x10^8$ $\beta_0 = 1.5T$ $\omega_0 = 63.864MHz$

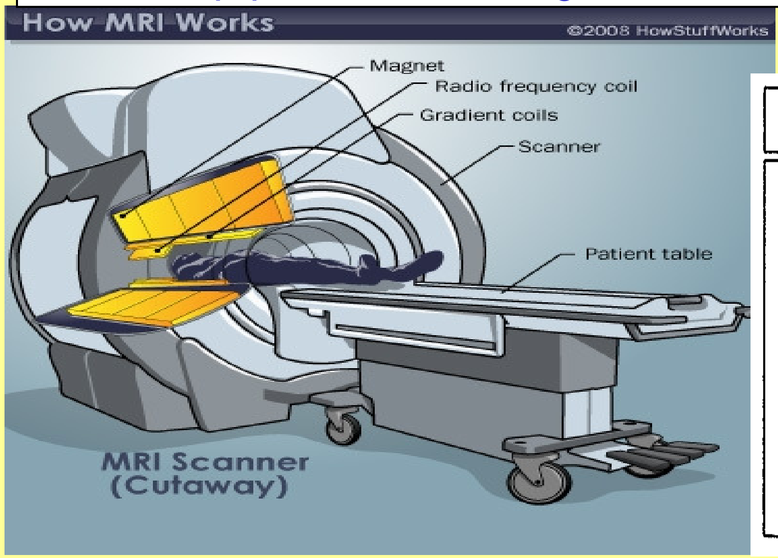
Relaxation:

- Protons align parallel or anti-parallel to the magnetic field generated
- Larmor Frequency: magnetic moment of proton within external field
- Protons that are parallel=lower energy
- Protons can oscillate back and forth between states, but majority line up parallel with magnetic field

T1

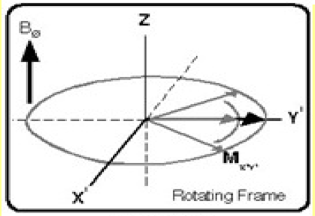




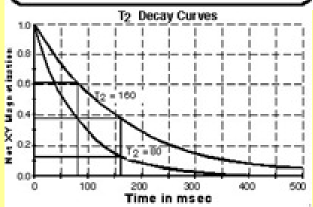


Different relaxation times T1 & T2 help to recognize different matters

Tissue	T_1 (ms)	T_2 (ms)
gray matter (GM)	950	100
white matter (WM)	600	80
muscle	900	50
cerebrospinal fluid (CSF)	4500	2200
fat	250	60
blood	1200	100-200[3]



T2



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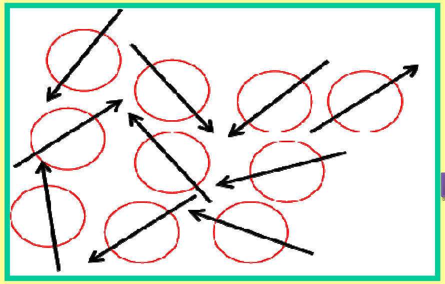
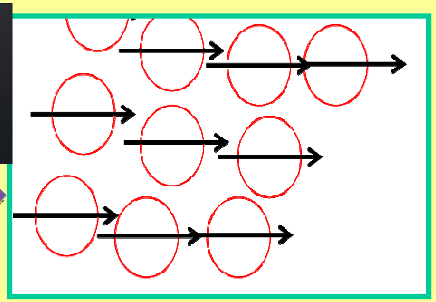
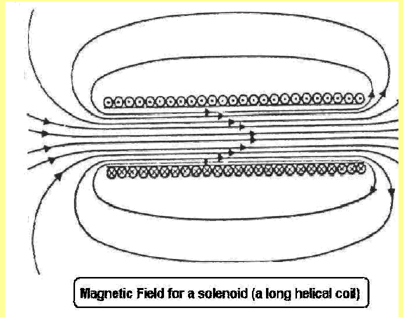
MRI and Radio Frequencies

the magnetic moments of protons within a person are not cohesive. They are pointing and moving in all different directions.



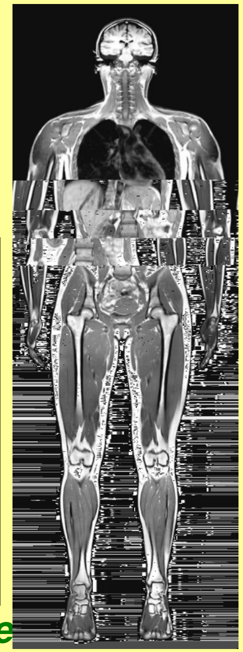




The radio frequency pulse manipulates the fact that you are now magnetized making your net magnetic moment flip in a particular area. This generates an electric current in a receiver of the MRI.

The MRI is a giant solenoid magnet providing a magnetic field which aligns the protons magnetic moments.

The MRI scanners extend the frequency along a plane creating a slice that can be imaged.



-The RF coil produces a radio frequency simultaneously to the magnetic field
-This radio frequency vibrates at the perfect frequency (resonance frequency) which helps align the atoms in the same direction
-The radio frequency coil sent out a signal that resonates with the protons.
-The radiowaves are then shut off. The protons continue to vibrate sending signals back to the radio frequency coils that receive these signals.

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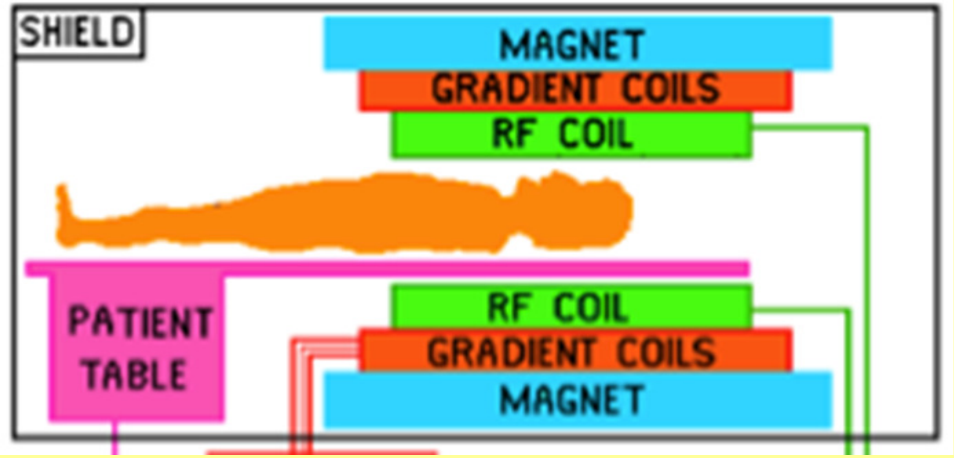
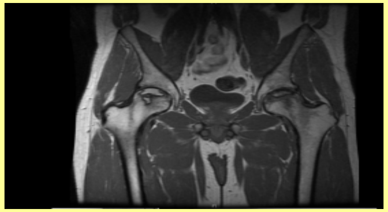
Uses for an MRI

- The signals are then ran through a computer and go through a Fourier equation to produce an image.
- Tissues can be distinguished in function of nature (atoms) and densities.

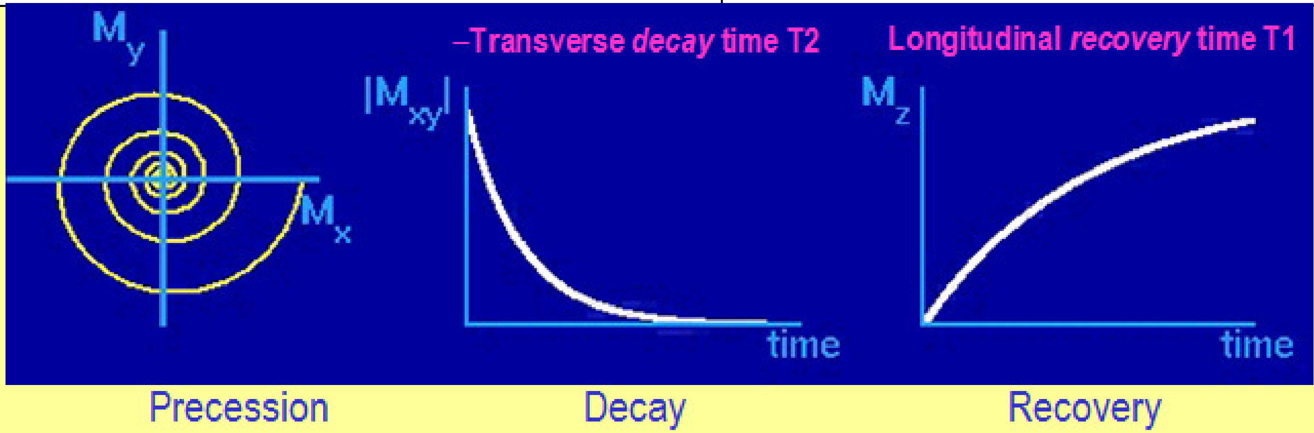




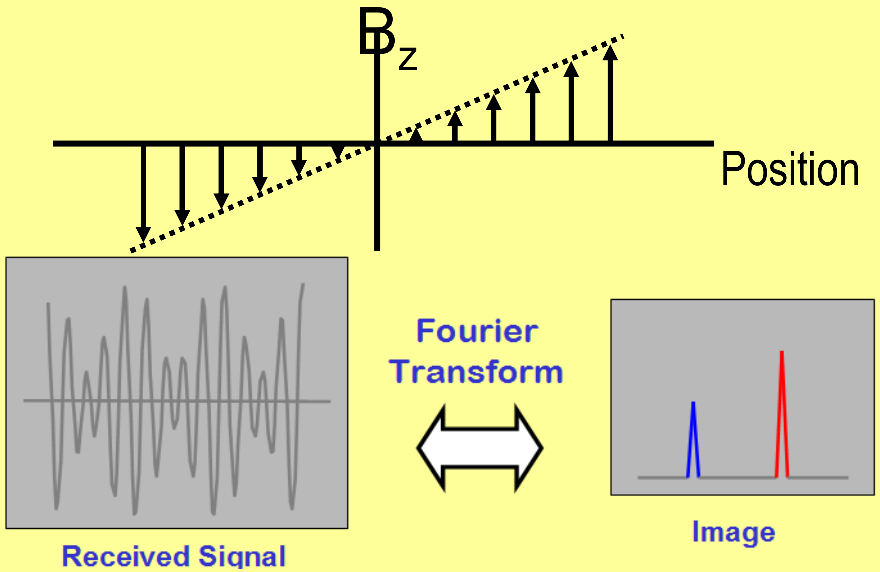
Used to image a large variety of tissues and substances.
- Brain imaging: to define anatomy, identify bleeding, swelling, tumors, or the presence of a stroke
- To locate glands, organs, joint structures, muscles and bone
- Some diseases manifest themselves in having an increase in water content
- The MRI can detect inflammation (tumors) in many tissues
- Helpful in diagnosing problems with eyes, ears, heart, circulatory system, lungs, pelvis, spinal cord, etc.

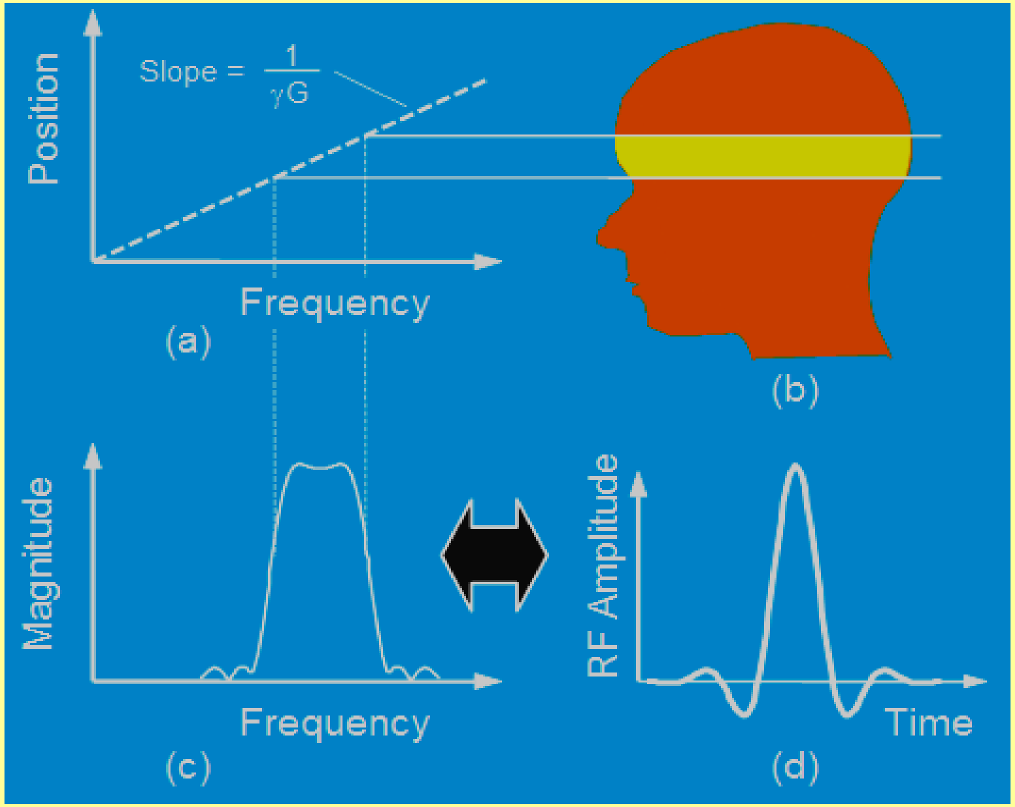
Creates a 2D (3D) image that comes from the information of the radio waves of the protons

MR Image Formation | Selective Excitation



- Gradient coils provide a linear variation in B_z with position.
- Result is a resonant frequency variation with position.





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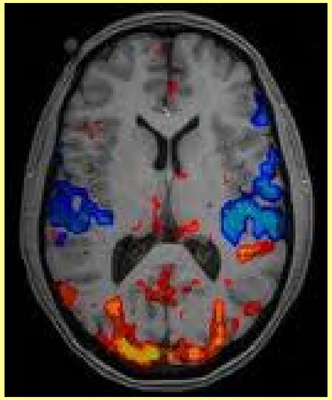
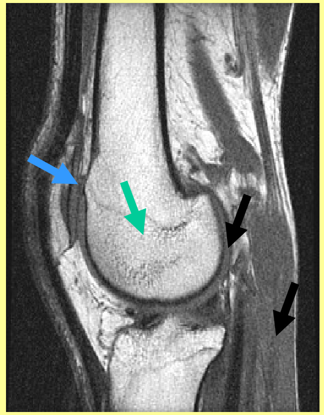
Different types of MRI

Advantages:
- Excellent / flexible contrast
- Non-invasive
- No ionizing radiation
- Arbitrary scan plane

Challenges:
- New contrast mechanisms
- Faster imaging

Advantages:
- Various acquisition sequences
- Large range of contrast
- Excellent space resolution:
  25 µm (animal research)
  200 µm (@clinic)





- Interventional MRI :

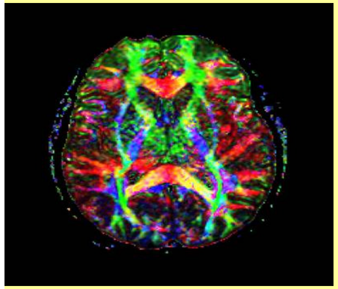
  Used to guide in some noninvasive procedures
- Real Time MRI

  Continuous filming/ monitoring of objects in real time
- Functional MRI (fMRI)

  Measures signal changes in the brain due to changing neural activity
- MRS (MR spectroscopy)

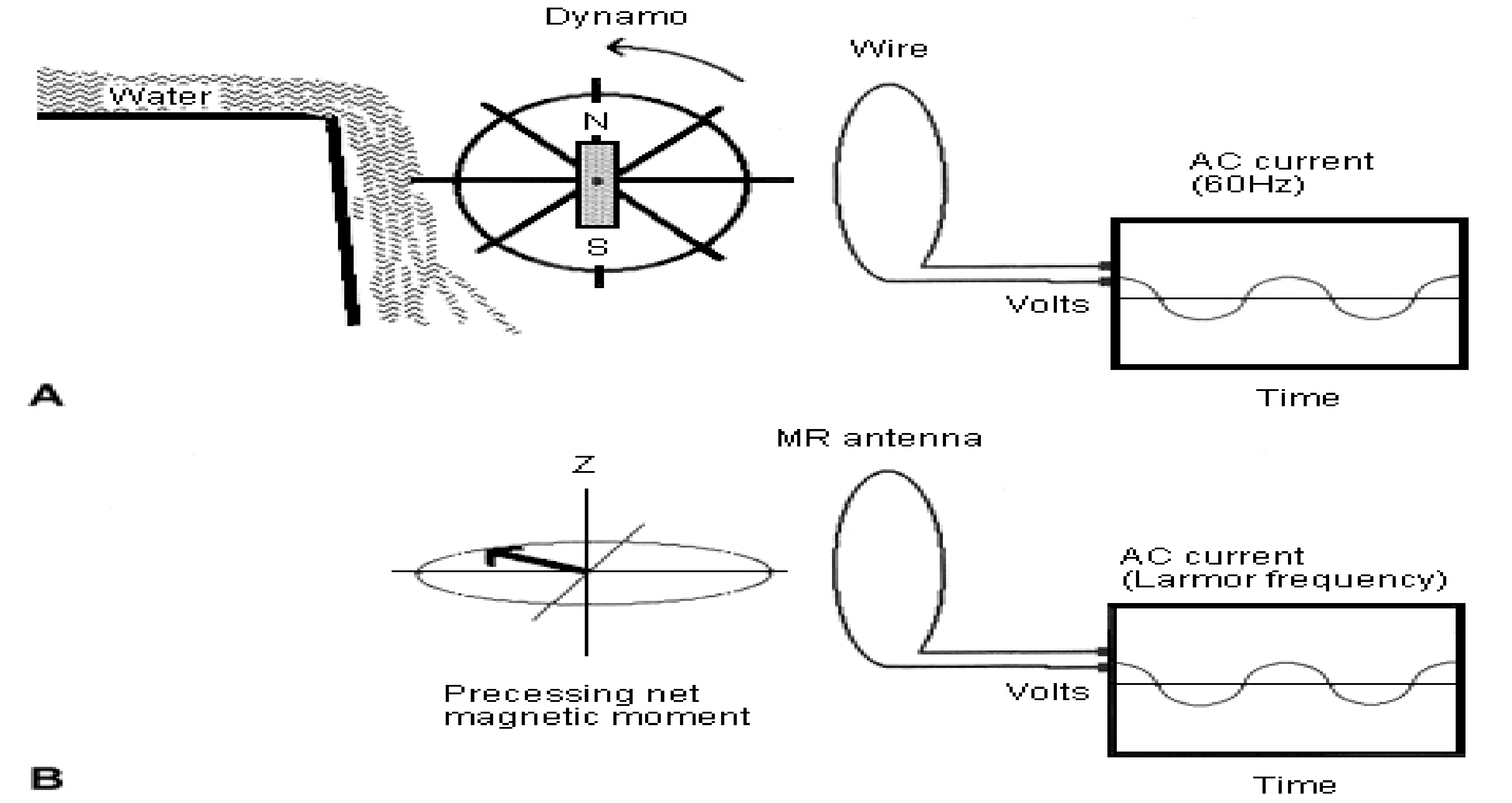
Resonance frequencies of common nuclei

Nucleus	Resonance Frequency (1.5Tesla) MHz
^{1}H	63.86
^{2}D	9.81
^{13}C	16.05
^{14}N	4.62
^{19}N	6.57
^{23}F	60.07
^{31}Na	16.89
^{31}P	25.86
^{35}Cl	6.27
^{39}K	2.97



MRI showing nerve connections inside the brain.

IMAGE (comparison is sometimes treason, but..)



- **. A)** The falling water rotates a wheel to which a magnet is attached. When this magnet rotates it induces an alternating current in a coil of wire which can be detected. **B)** A magnetic field (spin of a proton) rotating near a coil of MR antenna induces a similar current in the loop which can be detected.

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Remember if you forget you can always say this:

"Protons resonate or wobble at a certain frequency and when you excite them they relax and emit energy in the form of electromagnetic radiation. The body has different numbers and location of protons in various tissues. When you receive the emitted energy you can map the data onto a matrix. Then you can extrapolate using sine and cosine waves what the body looks like based on the mapped RF pulses emitted by different numbers of protons residing in various tissues (kind of like picturing the music arrangement by looking only at the sound signal on your audio receiver!)."

- **It is not simple to understand exactly how MRI works….**
- **But MRI has so many Possibilities (many acquisition modes for instance) that it is very exciting… It is worth working hard to master the MRI…**
- **MRI has a great future….**

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4. SPECT

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ISOTOPIC TRACERS AND THEIR USE WITHIN SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY

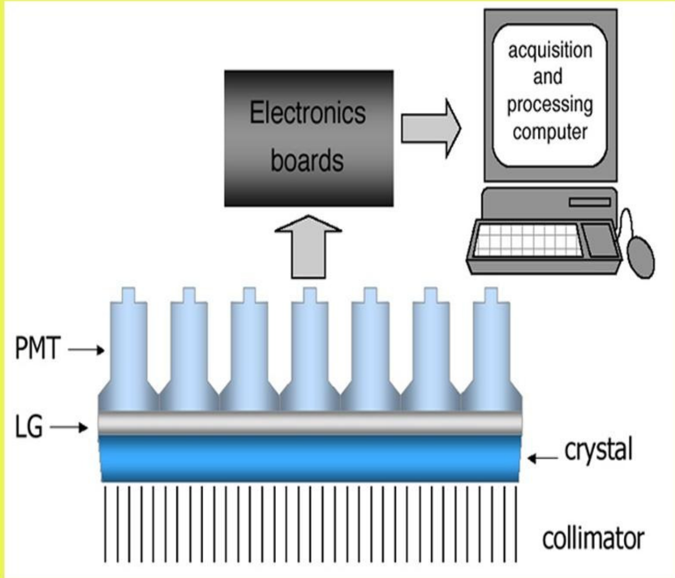
Isotope Half-life

In medicine it is necessary that the radioactivity should disappear quickly enough (short half-life) and that the quatity of tracer applied to the patient should be very small (measured in micro-moles and even in pico-moles). The sensivity of the apparatus used is thus crucial.

In monophotonic tomography, the patient receives marked molecul whose biological behaviour is known. The detectors will recognise t photons emitted and therefore they will allow to recognstitute one more images data processing (which is a complex process).

MONOPHOTONIC TOMOGRAPHS or GAMMA CAMERAS / SPECT

Very popular in Nuclear Medicine because they require only standard radiotracers.



A radiotracer (Technetium-99m, by example) is injected into the patient to depose into the target-organ.

The radiotracer emits gamma photons of 140 KeV energy which are detected by the crystals and the photomultipliers (PM).

The collimator removes the photons not directly emitted by the organ targeted.

The signals are collected by the electronic components and also by the computer to reconstitute the images.

Tools :

the device can use only two arms:

y specific to the detected photon (in this case, 140 KeV);

d by the collimator.

ws anyway to obtain images of the whole-body of the patient by the

the photo above.

To fight background noise,

- the selection on the energ

- the photon origin impose

The device shows here allo

succesive translation, as in

SI-Archamps

D. NEAMTU, Y. LE

Emission Computed Tomography

Aim: - to measure and display the concentration of a gamma ray-emitting radioisotope within individual slices of the body

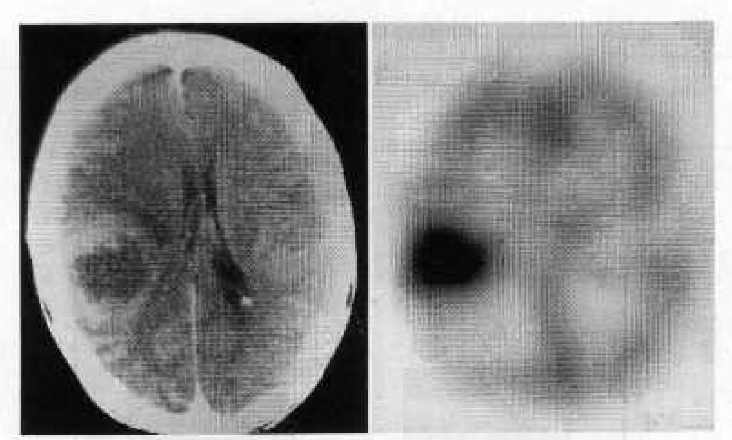
SPECT: Single photon emission computed tomography with tracers such as Tc-99m using either a rotating gamma camera or a dedicated ring camera

Advantages over planar imaging:

- improved image contrast
- better localisation
- improved detection rates
- quantification (see later)

Example

SPECT brain scan using a 99mTc labelled blood flow tracer showing high perfusion in the tumour



X-ray CT scan *SPECT blood flow scan*

SPECT Systems and Principles

Basic Method of ECT

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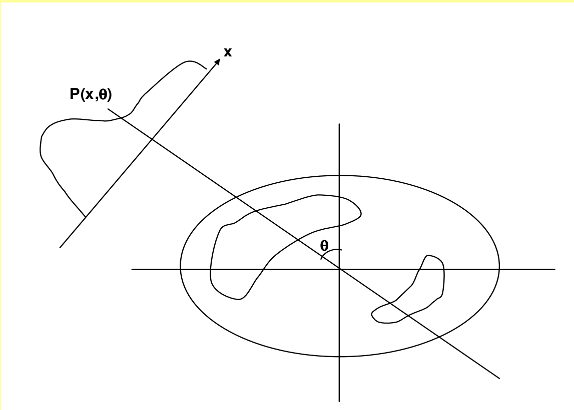
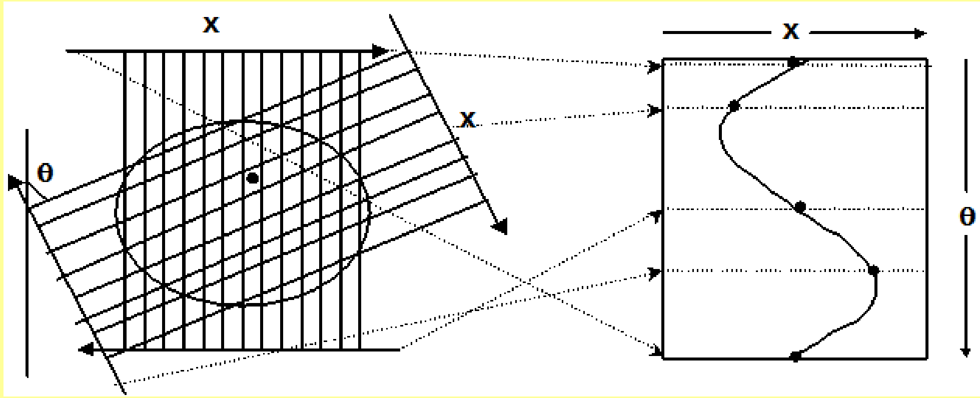
- Similar to X-ray CT : take 1D profiles or 2D projections at discrete angles around the object
- Assume that each profile/projection point = sum of activity elements along detector LOR

Raw data can be displayed as a **Sinogram**

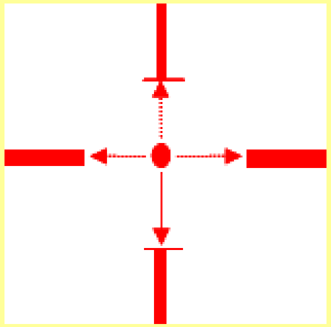




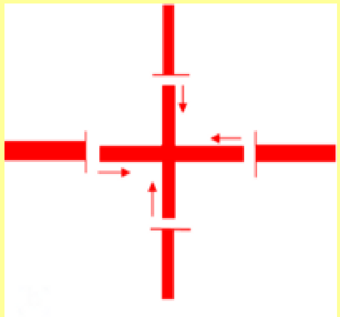
Parallel Projections

Sinogram

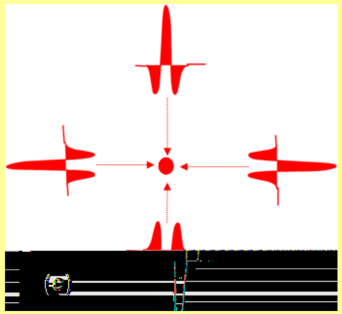
(See Yannick's Talk later)



Forward projection



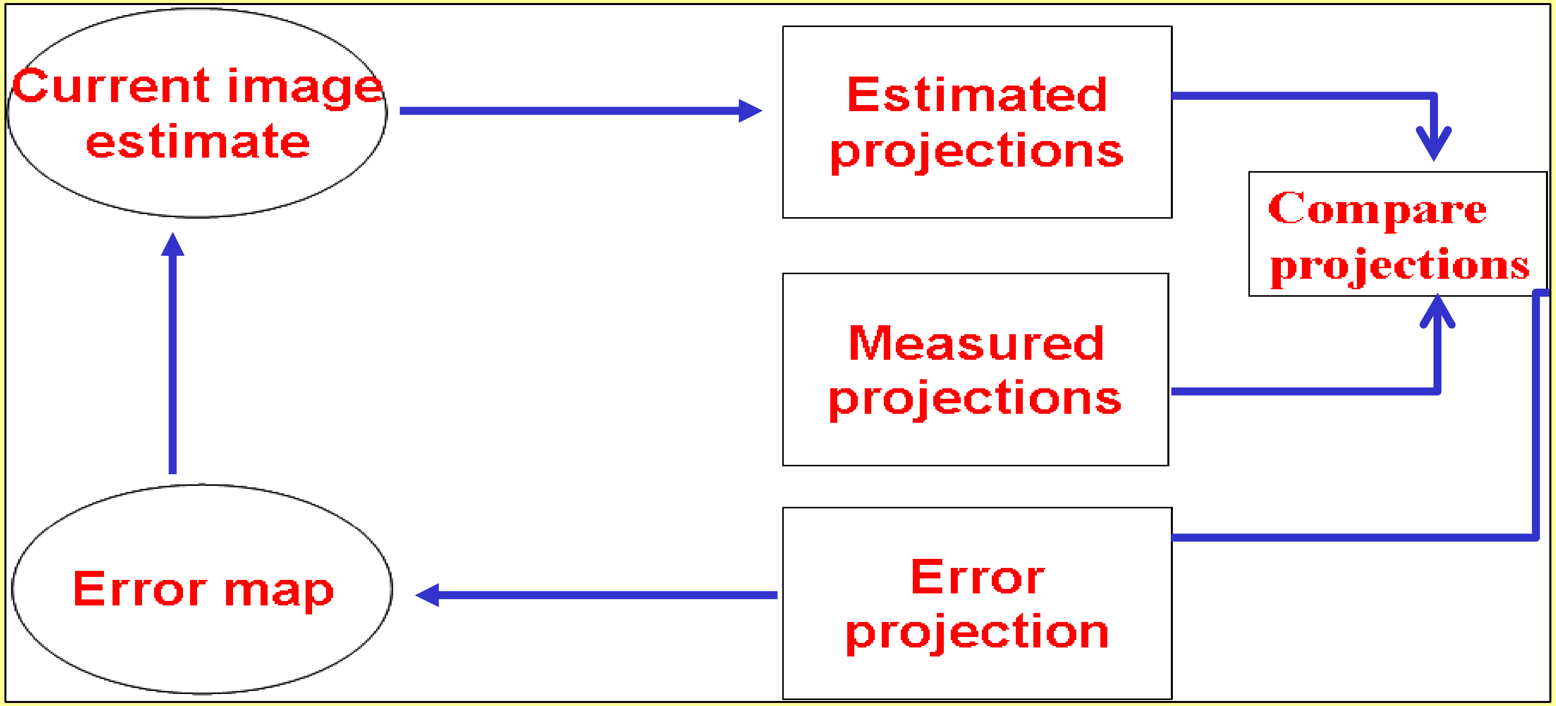
Backprojection



Filtered backprojection

Principles of iterative reconstruction

Image space　　　　Projection space



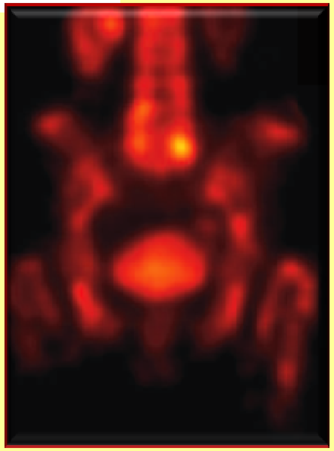
A very popular algorithm: Ordered Subset Expectation Maximisation (OSEM)

A fast variation of the ML-EM algorithm using subsets of the projections

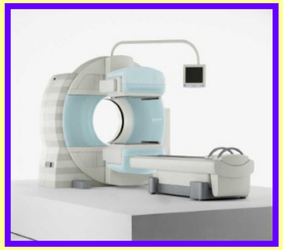
For example 64 projections used 8 at a time for 8 separate image production procedures (requires substantial data storage space). Thanks to Progress in Computers….

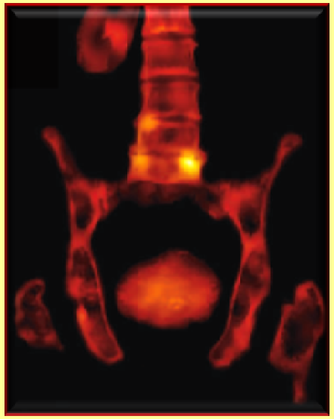
Now: SPECT/CT in the clinic

(From D. Townsend 2014)

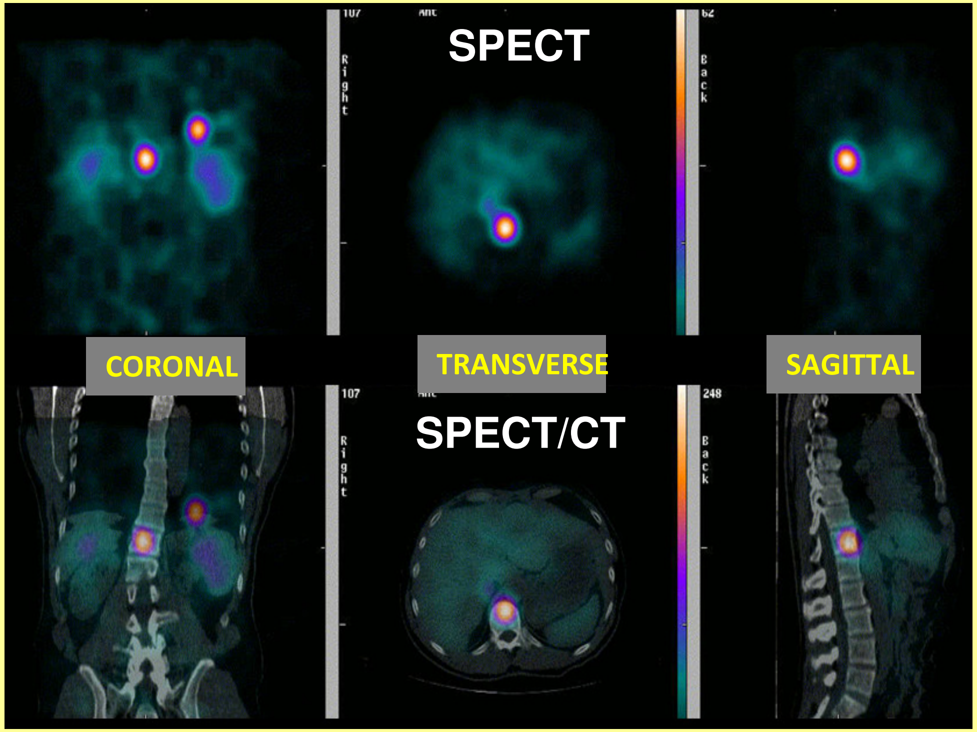


Conventional SPECT





SIEMENS xSPECT



Symbia TX

Discovery NM/CT 670

"CT is potentially more valuable for SPECT than for PET"

Bailey DL. Eur J Nuc Med & Mol Imag 2003; 30(7):1045-1046

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5. PET

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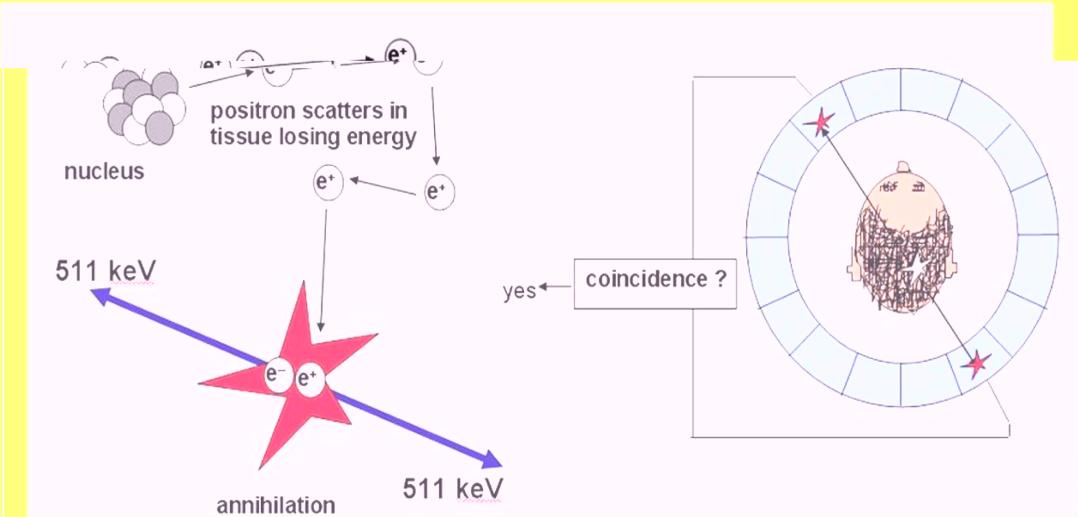
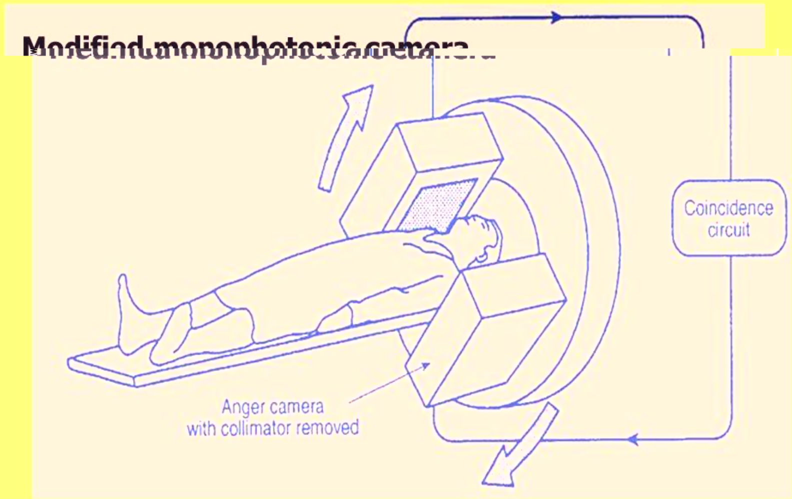
DIPHOTONIC TOMOGRAPH or PET CAMERA

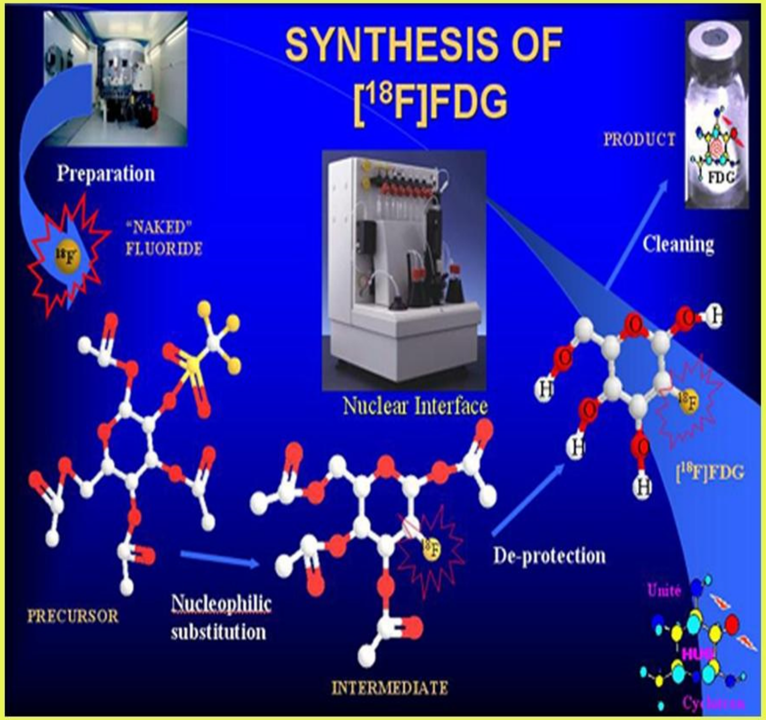
ANTI-MATTER ON CENTER STAGE!

Some isotopes desintegrate by emitting a positron (anti-electron) which, by successive collisions with the matter, will lose its energy and will produce matter-antimatter annihilation with an electron from one of the atoms encountered. This process results in two "back-to-back" photons of well-established energy (511 KeV) and emitted simultaneously. Consequently, we can suggest that two opposed detectors should emit two simultaneous signals (see the diagram). With all this constraints, the PET camera eliminates the background noise much better than the Gamma camera and thus reaches a higer sensitivity.

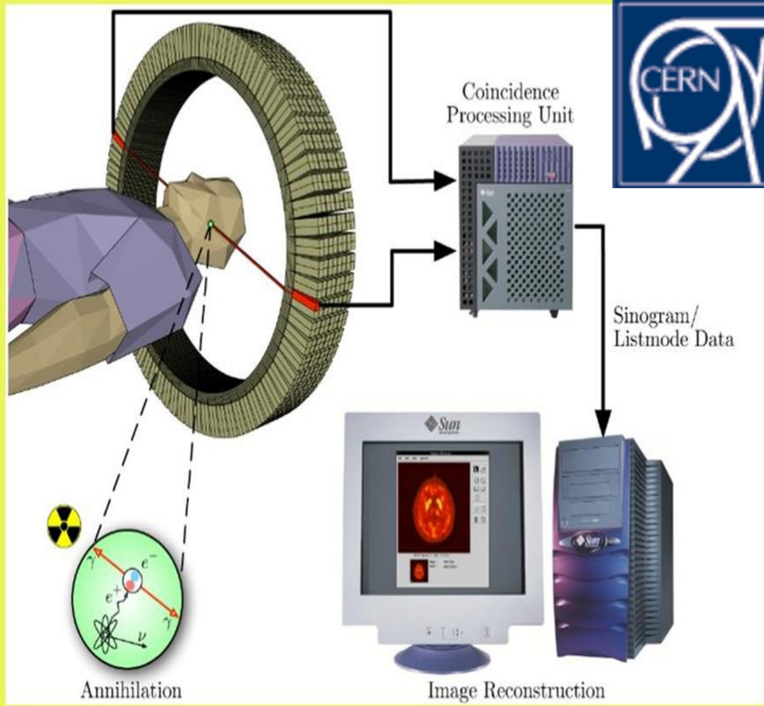




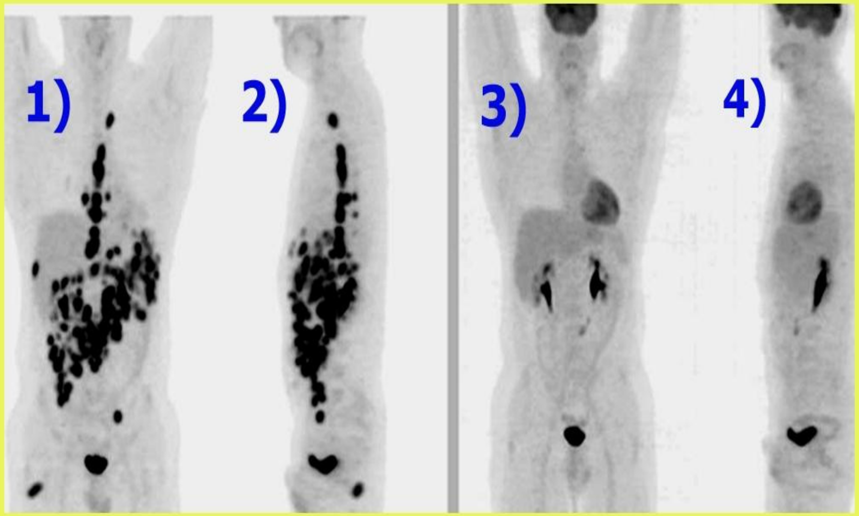
The first PET were simply Gamma cameras, from which the collimators had been removed and coincidence added between opposed detectors. Thereafter, better optimised PET equipments were built. For the human PET, several rings of detectors (crystals and PM) are assembled together.



The tracers for PET are more difficult to use because their half-life is shorter.
A cyclotron and a synthesis laboratory are necessary.



The most used isotopic tracer is FluoroDeoxyGlucose (FDG), which has the Fluor atom replaced by Fluor-18 which disintegrates by positron emision. The FDG accumulates in the cells with abnormal metabolism, i.e. cancer cells. It is phosphorylated (then trapped in cell) By hexokinase to FDG-6-PO_4 not metabolised further in the Glycolitic pathway

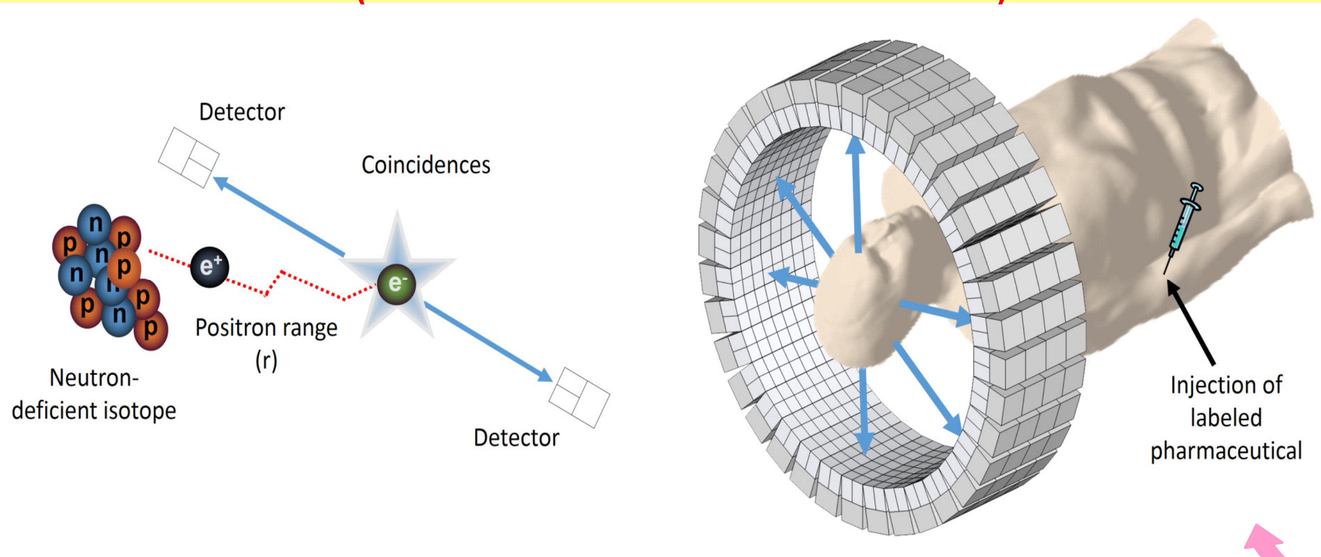


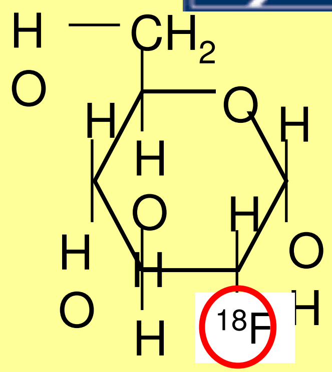
PET and cancer:

1) & 2): front and side view before treatment;
3) & 4): front and side view after chemotherapy.
FDG accumulates naturally in the brain, kidneys, bladder and the heart; in this case chemotherapy was very effective.
Only the PET can do that!

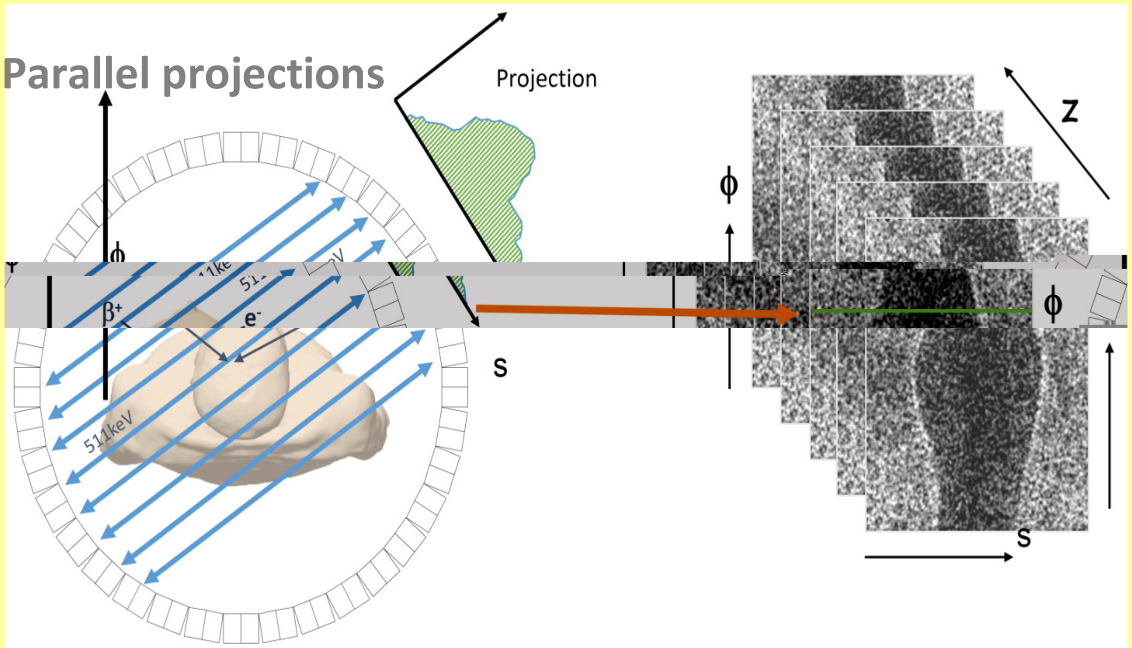
Positron Emission Tomography: how it works

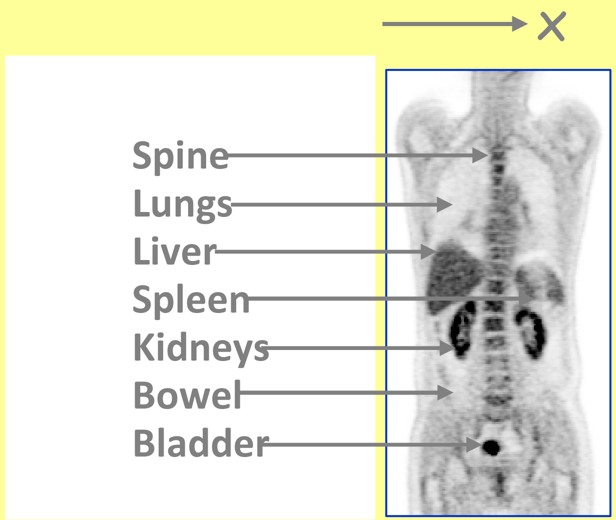
(see also Yannick Arnoud lectures)





^{18}FDG





PET images

Sinograms

From D. Townsend 2014

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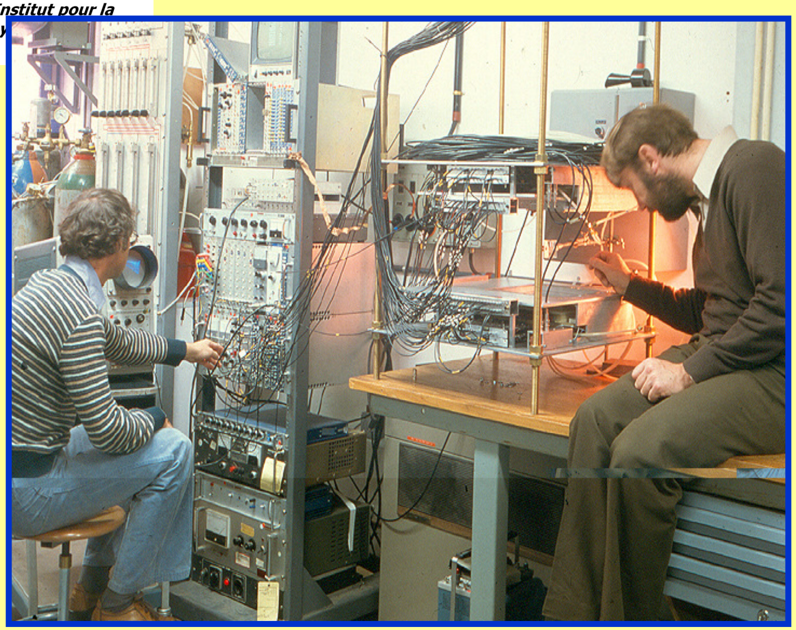
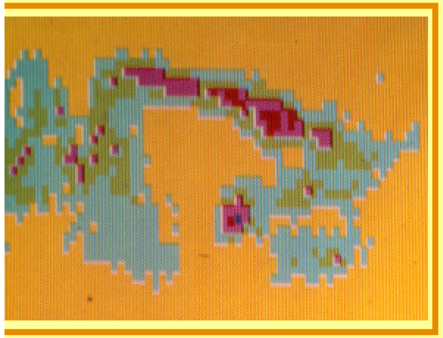
The HIDAC Camera Project, 1977-1988 CERN & HCU, Geneva



First mouse imaged at CERN with Na-^{18}F in 1978



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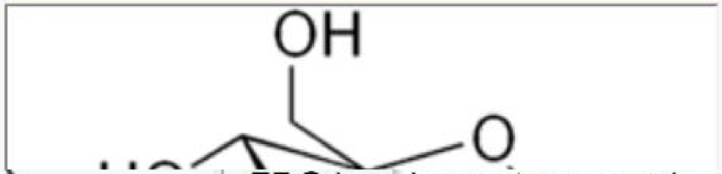
Why FDG Works So well?

$C_6H_{11}FO_5$

Fluorodeoxyglucose is a glucose analog. Its full chemical name is **2-fluoro-2-deoxy-D-glucose**, commonly abbreviated to FDG.

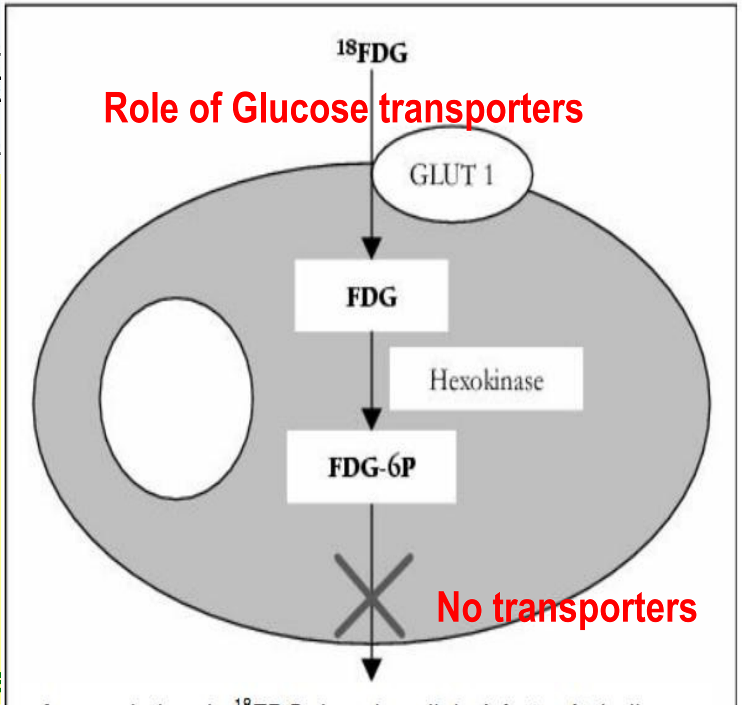
sed in the medical
emission
orine in the FDG
the positron-
e fluorine-18, to
DG is injected into
can form images of
ound the body. The
by a nuclear
iologist to provide

Fluorodeoxyglucose



Chemical name	2-Deoxy-2-fluoro-D-glucose
Other names	2-Fluoro-2-deoxy-D-glucose FDG
Chemical formula	$C_6H_{11}F$(

FDG is most commonly us
imaging modality positron
tomography (PET): the flu
molecule is chosen to be
emitting radioactive isotop
produce ^{18}F-FDG. After F
a patient, a PET scanner



Fusion imaging: from software to hardware

Why Imaging (SPECT, PET..)

is useful in Oncology for

- Help in Diagnosis
- Help in Treatment plannings
- Help Post-treatment survey

SPECT-CT & PET-CT are better than SPECT & PET alone….

disease progression SURVEY(ex: Breast cancer)

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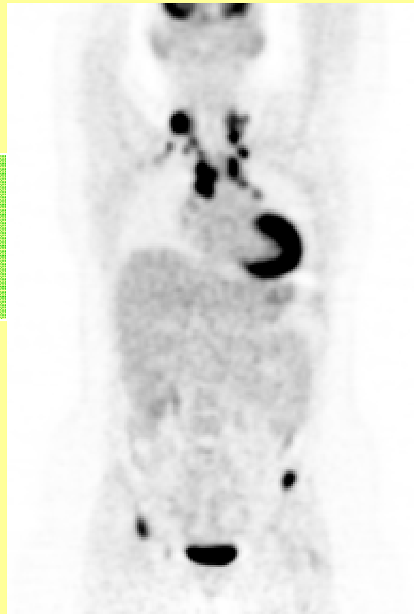
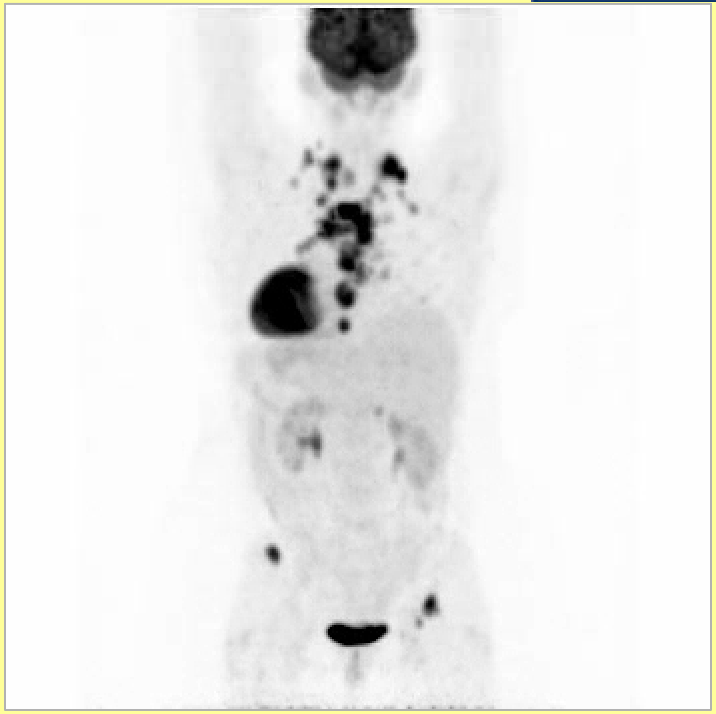
*

Two imagings at a 9 months interval :





28 min (8/05)

10.6 mCi, 115 min pi
4 min/bed, 7 beds
3i / 8s; 6f

15 min 9 months later (5/06)

10.5 mCi, 104 min pi
3 min/bed, 5 beds
3i / 8s; 6f

Scan duration: 15 min

Biograph

48 year-old female (200 lbs) with history of breast cancer. First PET showed intense uptake in bilateral supraclavicular, mediastinal and right parasternal nodes and the thyroid. 9 months later PET showed significant disease progression including sternum and pelvic region

(From D. Townsend)

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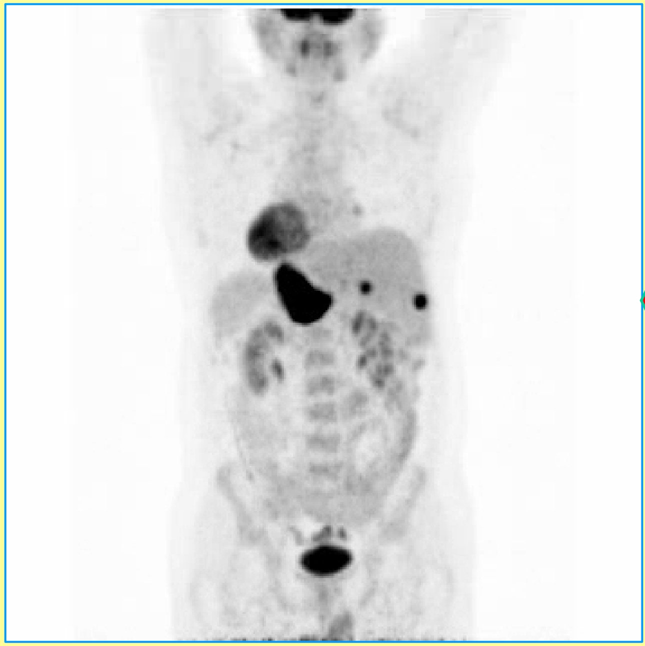
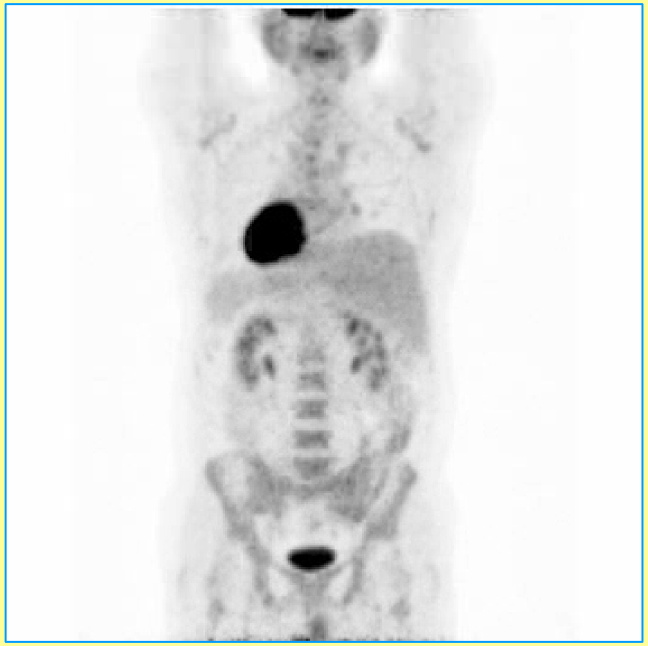
½ year Post / Pre treatment Survey

Restaging gastric cancer

*



*



Pre-therapy

Post-therapy

Pre-therapy (4/06) **With Biograph** **Post-therapy** (10/06)

6 months later

Pre-therapy	Post-therapy
Scan duration: 15 min	**Scan duration: 15 min**
5 beds; 3 min/bed; 8s/3i/6F	**5 beds; 3 min/bed; 8s/3i/6F**
10.6 mCi; 90 min post-injection	**9.8 mCi; 90 min post-injection**

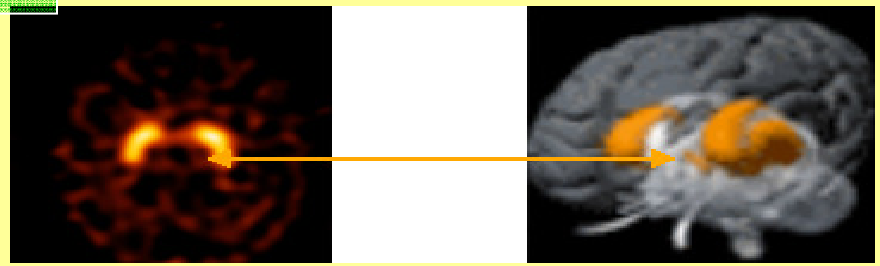
A 52 year-old male patient with history of gastric cancer imaged pre- and post-therapy (after ½ year)

6. QUANTIFICATION

(SPECT & PET)

Quantification in emission tomography :

- **Quantification is a measurement !**
  = numerical value extracted from an image, to get concentration of radiotracer (kBq / ml) = from signal strength in region (pixel value)
  ... Then estimate physiological parameters in Nuclear Medicine
- **Major problems affecting the quantification**
  in SPECT & PET: problem, consequences, methods, correction, results:
  - Attenuation
  - Scattering
  - Effect of partial volume
  - Movement
  - Variation of spatial resolution in SPECT

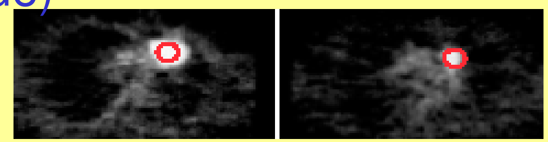


N : signal intensity in a region (pixel value)   *C concentration of radiotracer (kBq / ml) in the region*

- **Two types of quantification:** Absolute or Relative quantification:
  -1- Absolute quantification needs:
  a - Measurement of the concentration of radiotracer within an organ (kBq / ml) or of parameter derived from this concentration
  b - Measurement of a volume (Ex:glucose metabolism in mouse brain : µmol/100 g/ min). Ensure that N = k C then Determine k

  -2- Relative quantification
  - Concentration ratio between 2 regions (tumor/healthy tissue) or between two instants: Evolution of the tracer uptake
  The measured quantity is dimensionless

  Ensure N = k C Needless to know k **(only k constant over time)**



D-Day   *D-Day + 3 months*

Definition of SUV (Standardized Uptake Value):

Coeficient used in Oncology for semiquantitative analysis

The percent injected dose per gram of tissue:

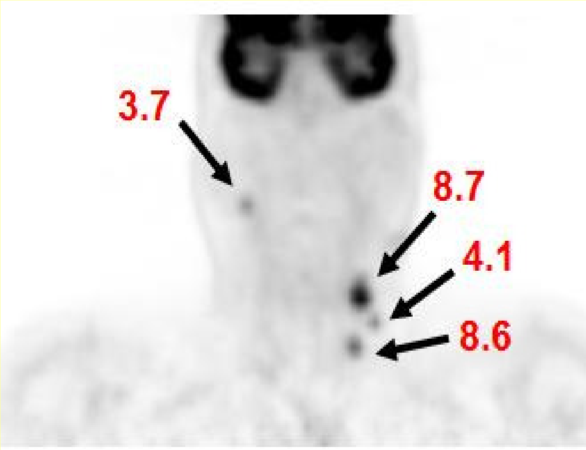
$$SUV = CT.Ws \,/\, d_T.Dinj$$

Where: C_T (in mCi/cc) is obtained from counts/pixel/time from PET ROI.
$d_T=W_T/V_T$ (weigth to volume of studied tissue) is the density in the region (often 1 g/cc)
D_{inj} being the injected dose

Ws is the total weight of the patient)

SUV=unitless parameter (from 1 to about 10)

Example of SUV



11.2 mCi; 90 min uptake

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Barriers to quantification

- **Intrinsic Barriers:**

  - Matter and radiation interactions in SPECT and PET
  . Attenuation ***
  . Compton scattering**
  To be studied carefully

  - Limits of the imaging device
  . limited and non-stationary spatial resolution **
  . random coincidences in PET
  . measurement noise

- **Potential Obstacles**

  - Patient movement
  . Physiological : heartbeat, breathing
  . fortuitous because relatively long exams

  - Defects in the detector
  . Non uniformity
  . dead time
  . mechanical stability

Attenuation in SPECT & PET

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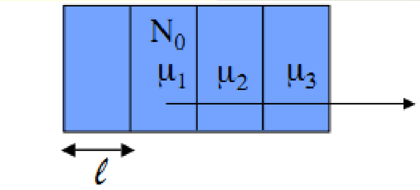
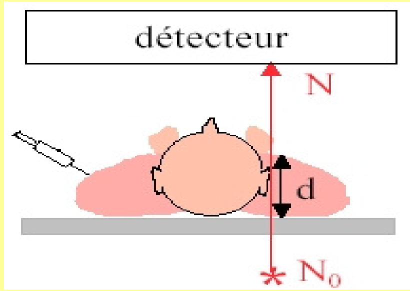


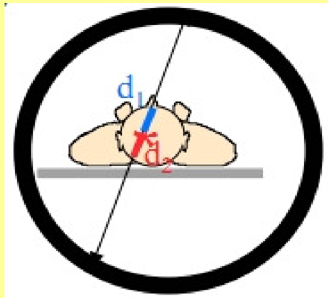
$N = N_0 \exp[-(\mu_1/2+\mu_2+\mu_3)]\,\ell$

- **In SPECT** Attenuation depends on the place of issue on the projection line. When an event is detected, it is not known how deep it comes: we do not know how much it has been attenuated making it difficult to correct the attenuation.

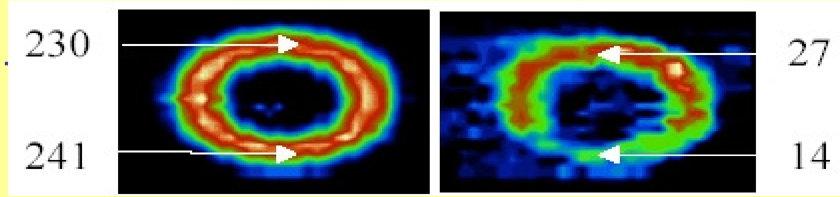
⇒Use medium density : μ for lungs=0.04 cm^{-1} μ for soft tissue=0.15 cm^{-1} μ for cortical bone=0.30 cm^{-1}. Attenuation is of course function of γ energy.



- In PET, attenuation do not depend on the place of emission on line projection. It depends only of the full attenuation d1 + d2 = D. When an event is detected on a line of response, suffered attenuation is known. We can therefore more easily compensate attenuation than in SPECT (identical for all radiotracer giving 511 Kev pair).

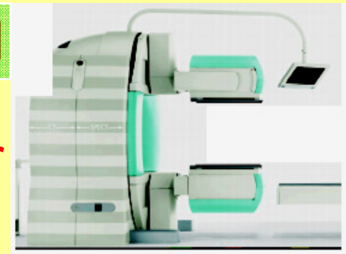


- In SPECT (and PET also), attenuation leads underestimates of activity generally greater than 70%. (Cardiac example)



No attenuation **With attenuation**

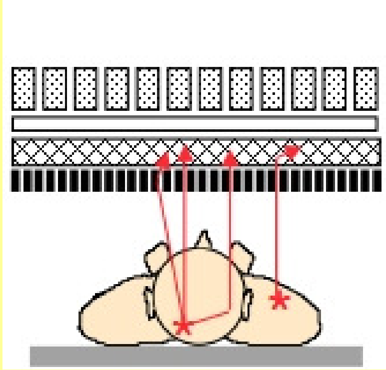
- Attenuation problem is **better solved now by SPECT/CT and PET/CT hybrid** machines. Fortunately acquisition in transmission is very fast.
If attenuation coefficients are measured at different energies than the radiotracer energy (Spect or PET), adaptation is necessary.

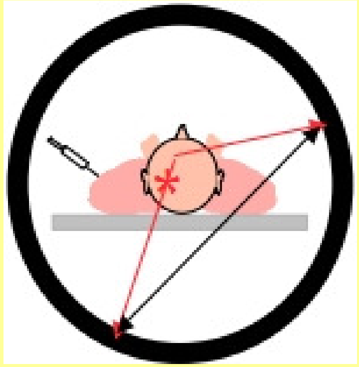


Compton scattering

Scattering can happen:

- In the patient
- In the collimator septa
- In Crystals



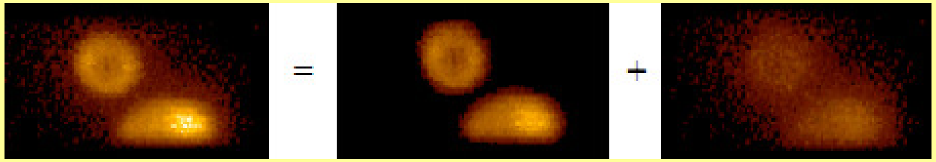


Consequences of Scattering:

- Photons lose energy
- Photons change direction so they will be poorly localized in images
- Bluring pictures
- Contrast decreases

SPECT

Importance of scattering in SPECT



acquisition picture window *primary photons* *scattered photons (37 %)*

With Tc- 99m , about 30% of detected photons in the conventional acquisition window are scattered photons (thus bad positioned in the image)

Scattering cross section Increases when energy decreases :

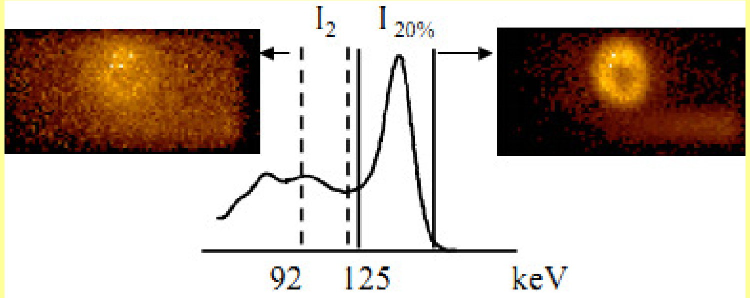
SPECT

images from Tl -201 (70 KeV) are more affected by scattering than Tc- 99m images (140 KeV)

Different correction methods in SPECT

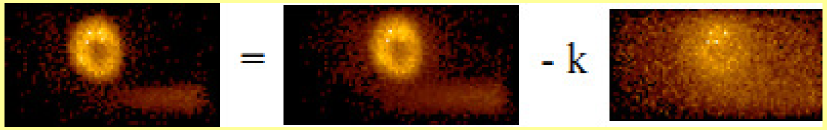
-1 From reduction of acquisition spectrometric windows : Reduction of scattered photons (Importance of having a good energy resolution tomograph)

-2 Jaszczak Subtraction in SPECT



$$\hat{D}(i) = k.I_2(i)$$

Correction very simple to implement (hence its success)



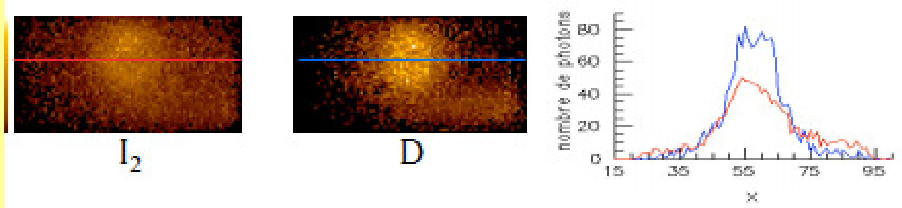
But neglects the dependence of angle deviation θ and wasted energy

• overcorrection if away from sources and undercorrection near sources.

• Artificial enhancement giving pleasant contrast for eye.

Approximate on quantitative point of view but overall performant

$$E' = \frac{E}{1 + E\,(1 - \cos\theta)/m_0c^2}$$



-3 Method 3 energy windows (TEW)

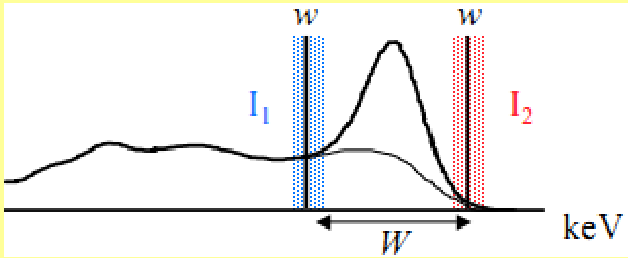
- Data acquisition in 3 windows I20 % , I1 and I2

- Estimation of D (i) for each pixel i :

$$\hat{D}(i) = W\,[I_1(i)+I_2(i)] \,/\, 2w$$

- Estimation of P

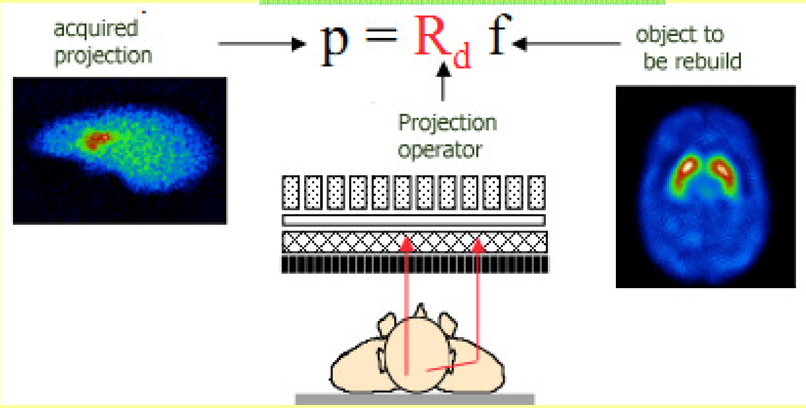
$$\hat{P}(i) = I_{20\%}(i) - \hat{D}(i)$$



Repositioning of scattered photons / Modeling of scattering

- Iterative Reconstruction with scattering modeling

Illustration in SPECT



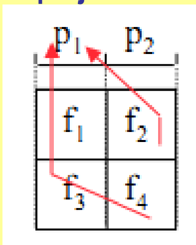
without modeling of scattering:

$p_1 = r_{11} f_1 + r_{13} f_3$

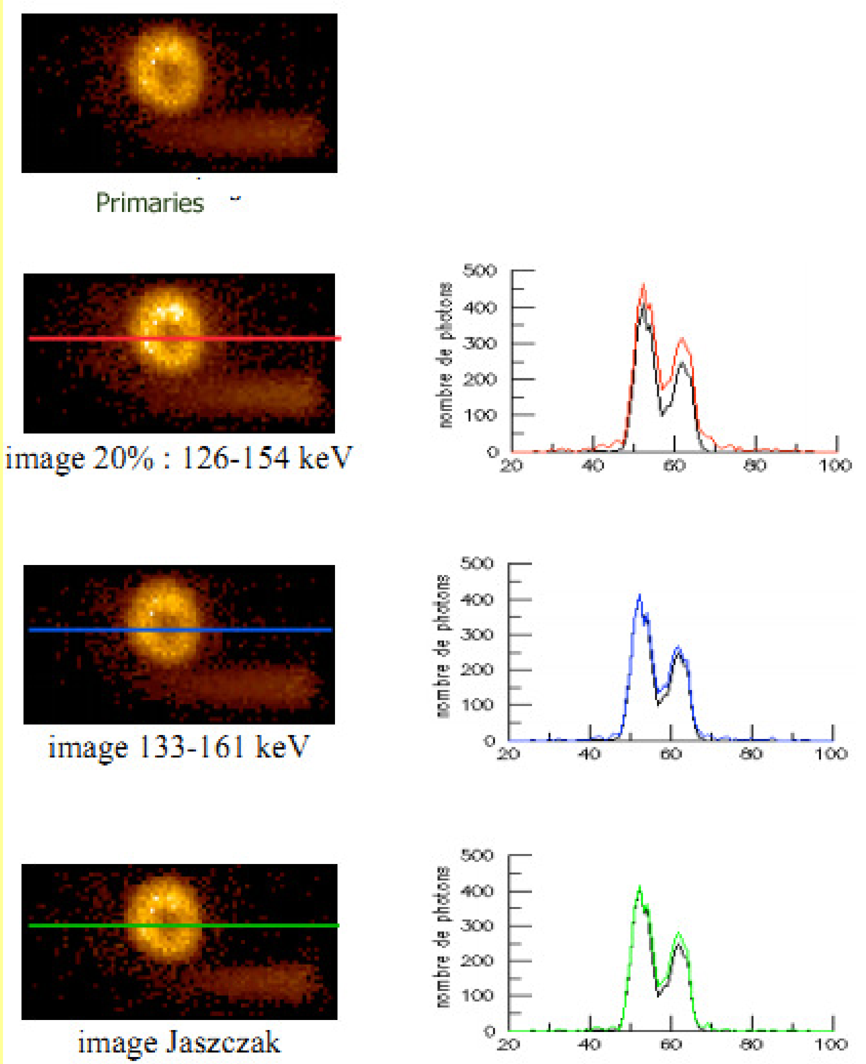
with modeling of scattering :

$p_1 = r_{11} f_1 + r_{12} f_2 + r_{13} f_3 + r_{14} f_4$

projections



- Approximate analytical modeling
- Monte Carlo modeling



- Iterative Reconstruction with scattering modeling

- very general approach suitable for all Iterative reconstruction algorithms
- expensive storage space and computing time

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7. EXAMPLES OF USES @ HOSPITAL

TREATMENT PLANNINGS

(Will be explained later by Alex Rijnders)

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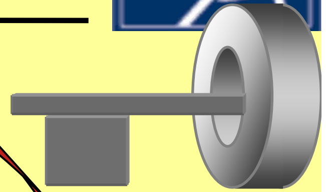


Treatment plannings are compulsory for correct treatment

The Software start from Images

CT-SCAN ↔ MRI or / and PET

- external contours
- densities
- anatomical structures
- beam data library

- anatomical structures

BEAM DEFINITION

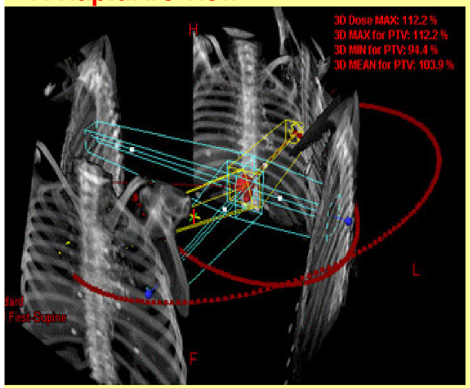
TREATMENT PLANNING SYSTEM

OPTIMISATION

Most Popular systems:

Pinnacle (Philips Medical systems)
ADAC -> Pinnacle3(Philips)
Monaco (CMS/Elekta)
Eclipse (Varian Medical Systems)
RapidArc: see(varian.com/us/oncology/treatments/treatment_techniques/rapidarc/resources.html
…..

A RapidArc view



- Dose distribution
- Dose-Volume Histograms
- Biological indices

- Reconstructed radiographs (DRR)

- Field shape
or
- Position of leaves

- Treatment parameters
- Treatment time (monitor units)

SIMULATOR and/or ELECTRONIC PORTAL IMAGING

BLOCK CUTTING DEVICE or MLC

ACCELERATOR

VERIFIY AND RECORD SYSTEM

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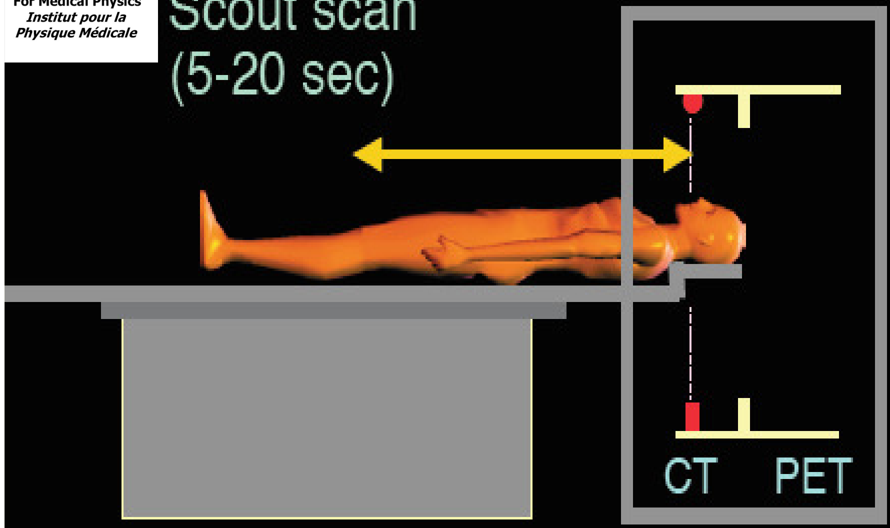
PET/CT (SPECT/CT) Scan protocol

(From D. Townsend)

Scout scan
(5-20 sec)

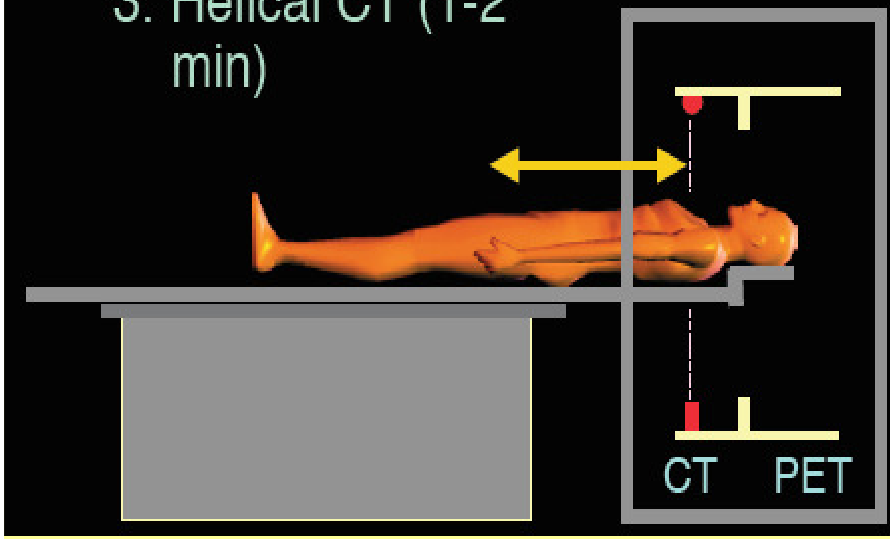


2. Selection of scan region (1-2 min)

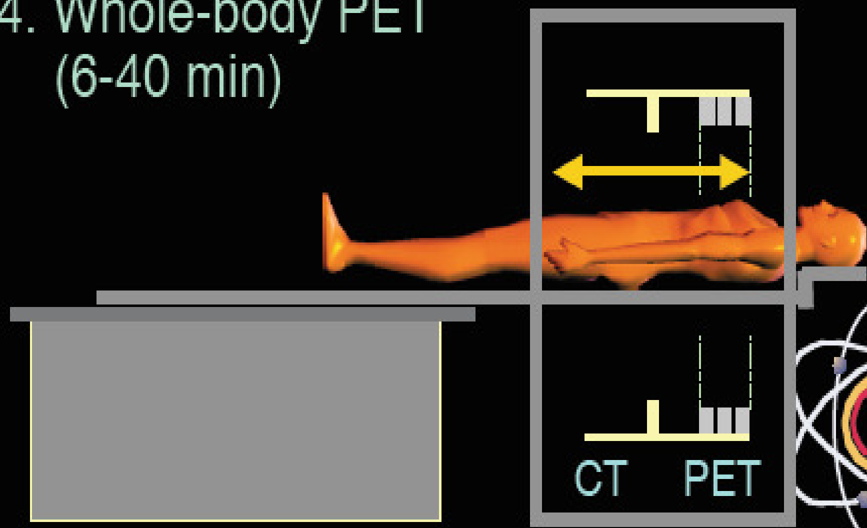
Scout scan image

4000 PET/CT scanners operational worldwide

3. Helical CT (1-2 min)



4. Whole-body PET (6-40 min)



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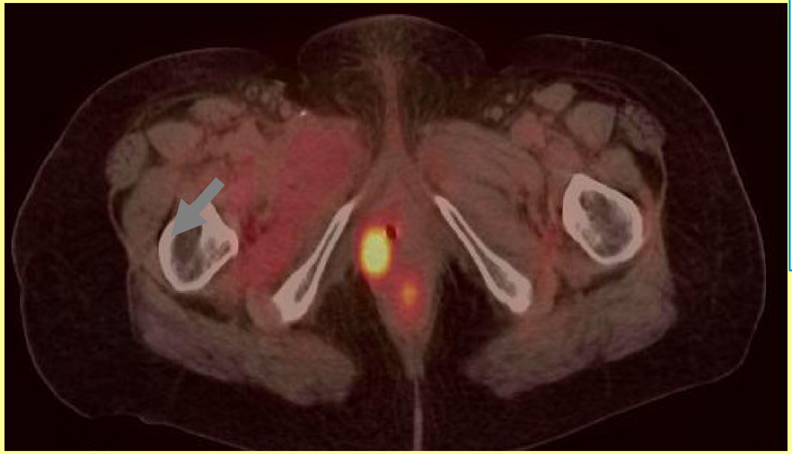
SURVEY : Vaginal cancer

PET-CT is more powerful than PET alone….

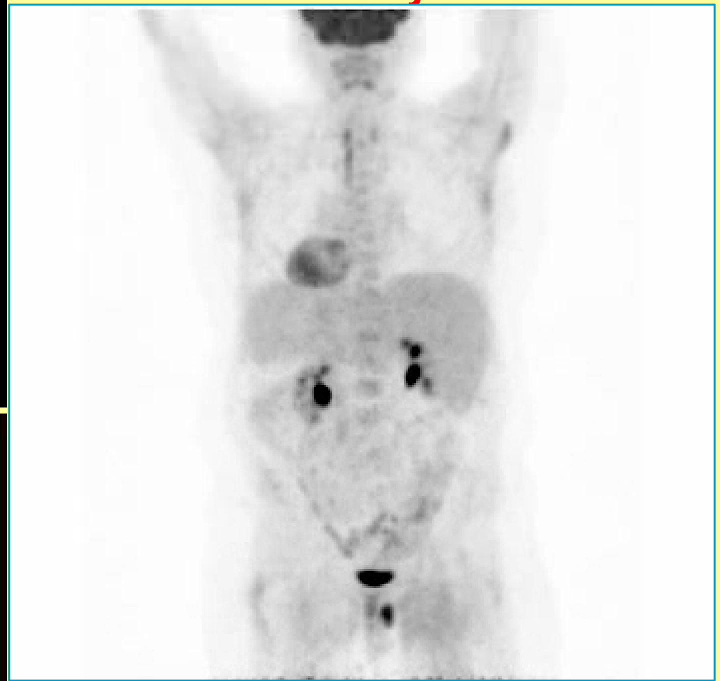
(From D. Townsend)

CT only

PET+CT



*** PET only**



Biograph Scan duration: 15 min

5 beds; 3 min/bed; 8s/3i/6F

10.6 mCi; 90 min post-injection

A 50 year-old female patient restaged for vulvar cancer with history of NHL (Non-Hodgkin lymphoma),. The PET/CT scan shows focal uptake in right aspect of the vulva (SUV: 10.3). Adjacent focal anorectal uptake (SUV: 5.5). CT is negative with no abnormality seen. Only combination of CT and PET can show that!

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8. IMPROVEMENTS

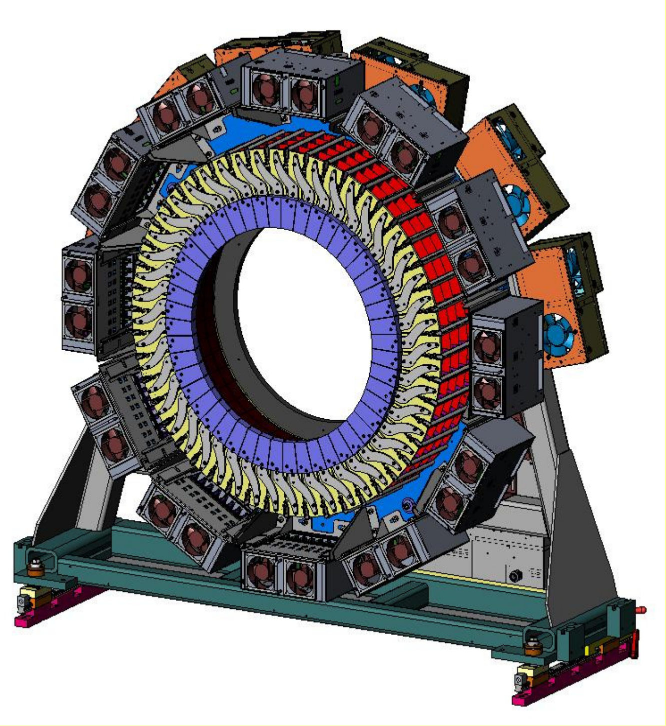
Last years Improvements in PET cameras

- **Better Crystals (Ex: more ph/MeV with LSO, LYSO, LuBr3…)**
- **Spatial resolution (Ex : Crystal size 4 x 4 mm or smaller)**
- **New reconstruction algorithms**
- **Efficiency (Septa removed in PET)**
- **Time-of-Flight (Tof)**
- **MRI-PET Devices:**

Complementary nature of MRI & PET

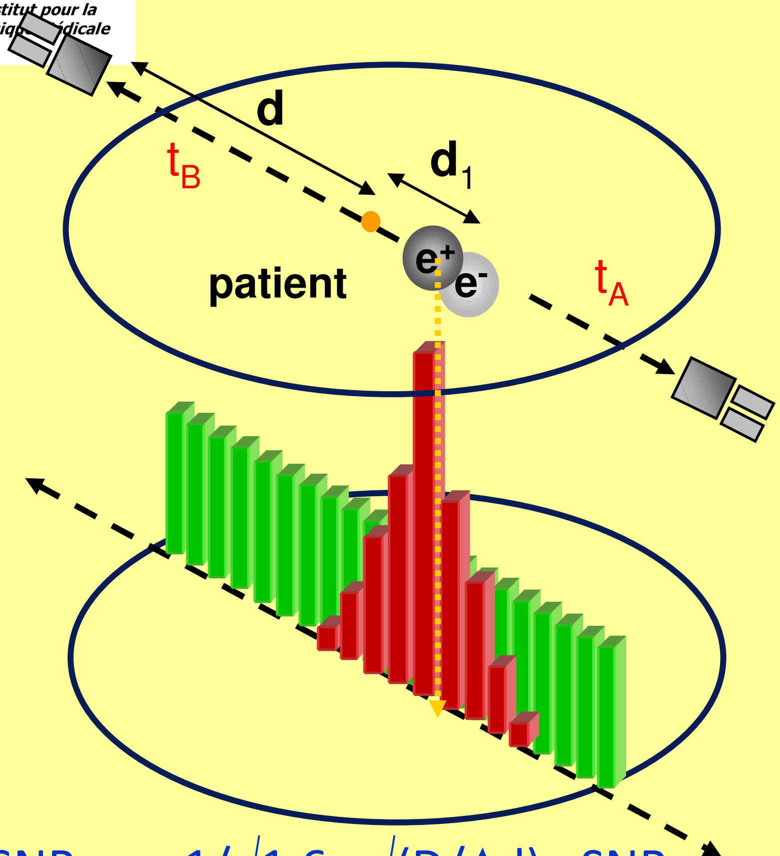
Parameter	MRI	PET
Anatomical Detail	Excellent	Poor
Spatial Resolution	Excellent	Compromised
Clinical Penetration	Excellent	Limited
Sensitivity	Poor	Excellent
Molecular imaging	Limited	Excellent

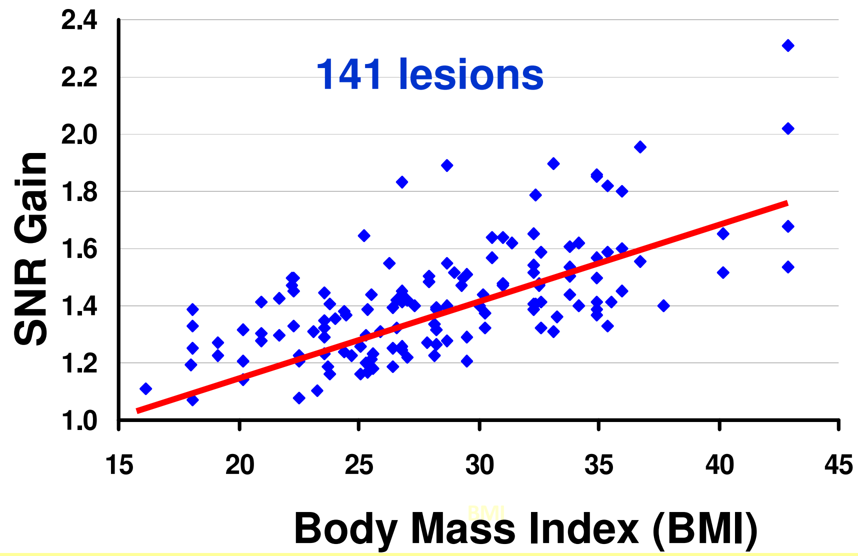
Hence: The Sum of PET and MRI should be excellent and even better **MRI + PET << MRI-PET**



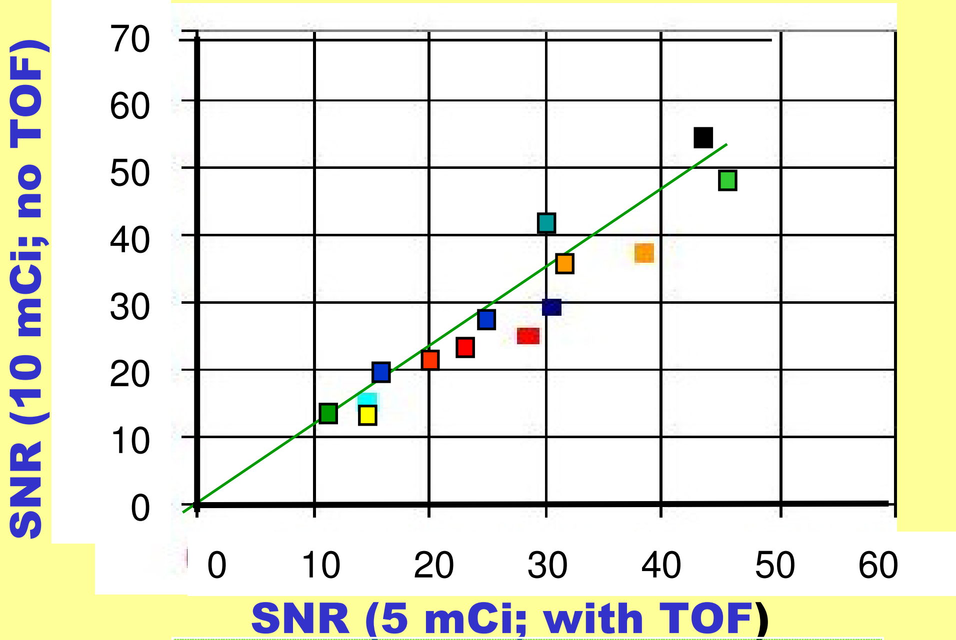
Ex: Biograph TruePoint PET•CT (Biograph TP)

Time-of-Flight (TOF)





✓ Improved signal-to-noise



✓ Reduced radiation dose

$$SNR_{TOF} = 1/\sqrt{1.6} \cdot \sqrt{(D/\Delta d)} \cdot SNR_{conv}$$

Ds (ps)	Dx (cm)	SNR gain
100	1.5	5.2
300	4.5	3.0
500	7.5	2.3
1200	18.0	1.5

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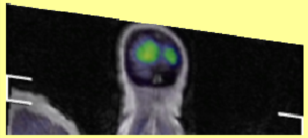
2010: PET/MR in the clinic



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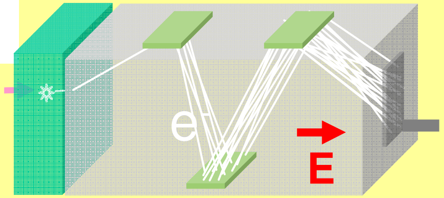
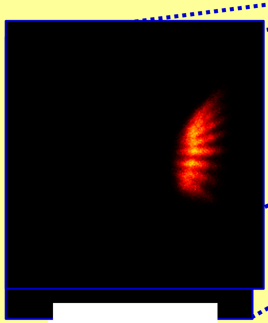
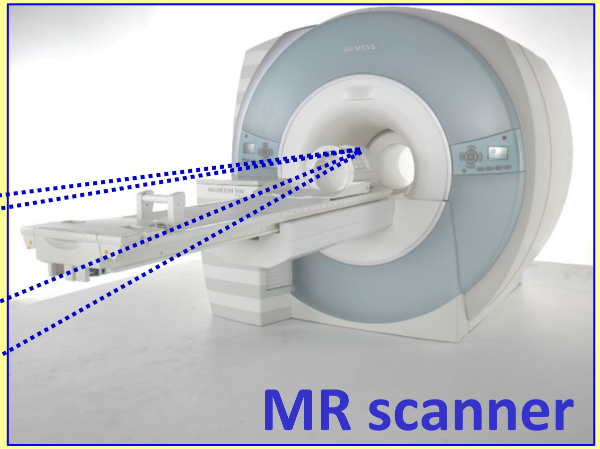
Solid state photodetectors for integrated PET/MR

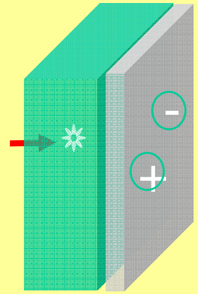


Block detector

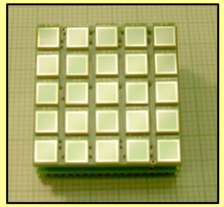


B = 1.5 T





APD-based
PET detector



SiPM-based
PET detector

Photodetectors

	PMT	APD	SiPM	dSiPM
MR compatible	No	Yes	Yes	Yes
TOF capability	Yes	No	Yes	Yes
Stability	Good	Good	Unknown	Unknown
Amplification	High (10^6)	Low (10^3)	High (10^6)	N/A
Compactness	Bulky	Compact	Compact	Very compact
Power Readout	HV, ASIC Analog	HV, ASIC Analog	LV, ASIC Analog	LV, simple Digital

PHILIPS VEREOS PET/CT

(From D. Townsend)

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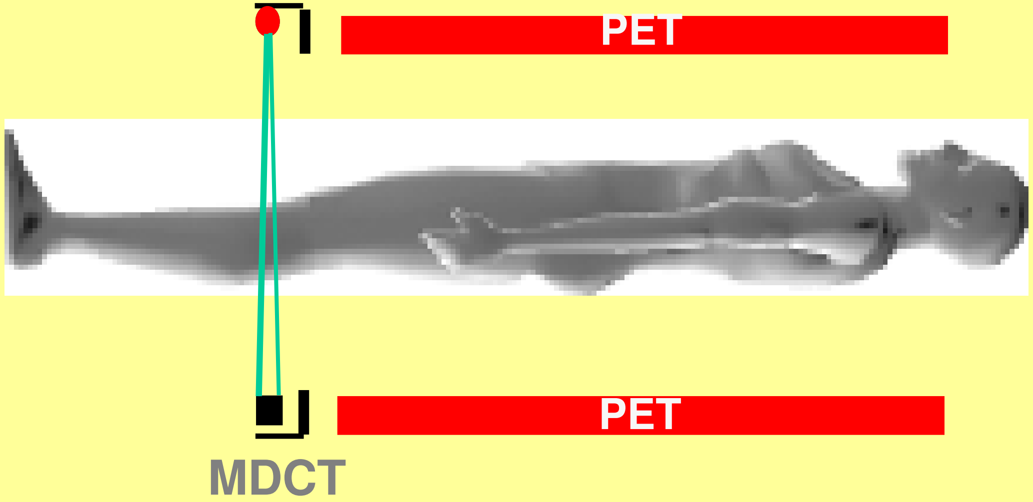
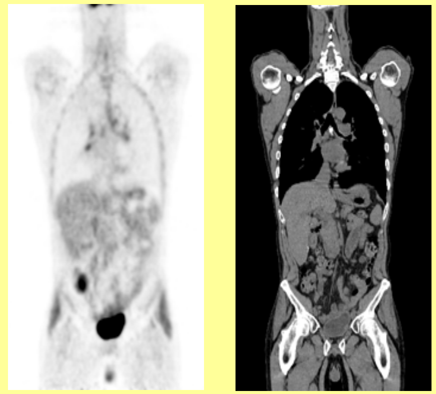
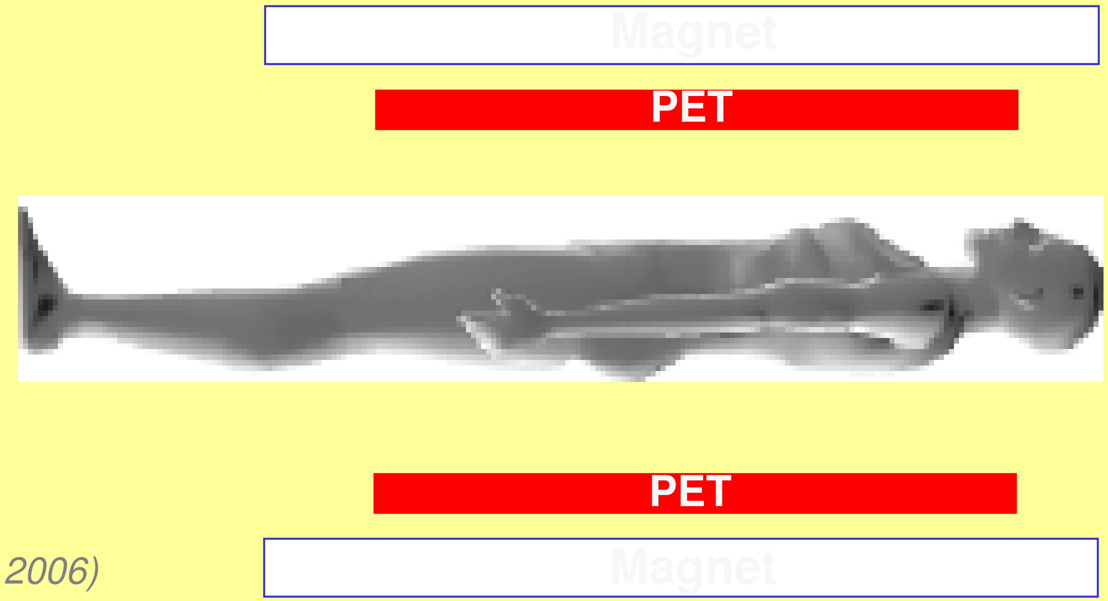
Combined whole-body PET/CT to PET/MR..

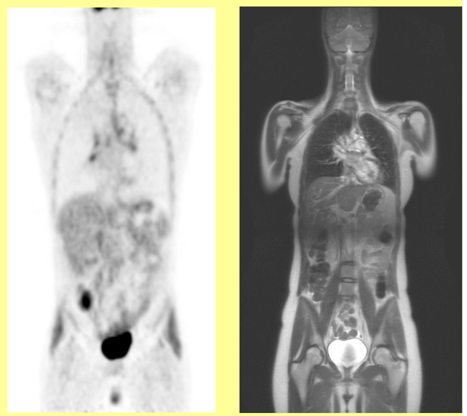
PET/CT





PET/MR





(S.R. Cherry, 2006)

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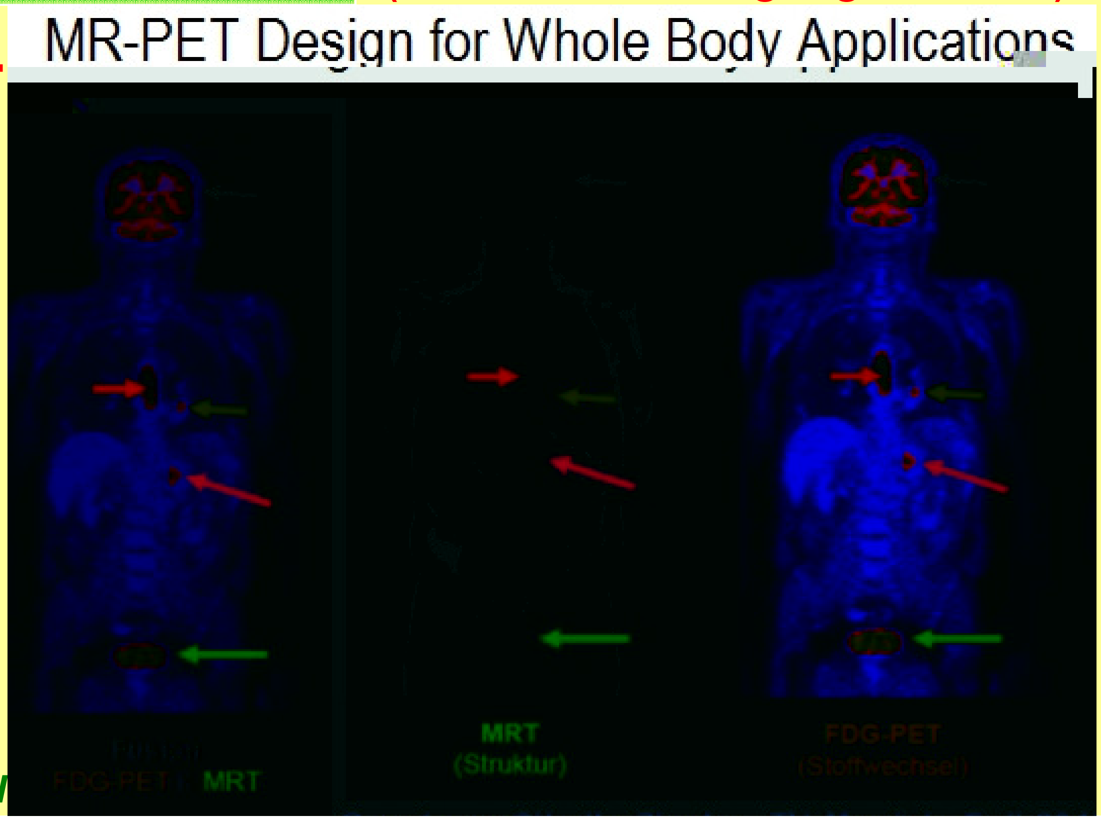
Challenges for PET/MR

- MR-compatible PET detectors from technics (APD,Si-PM..)
- PET attenuation correction factors from MR images
- role for simultaneous MR and PET acquisition?
- financial cost (eventually) of the PET/MR system
- Used routinely for Small Animal PET ("Medical Imaging Ideas")

In biomedical research…

But already exceptionnal images …



As conclusion:
Radiation doses for clinical imaging procedures

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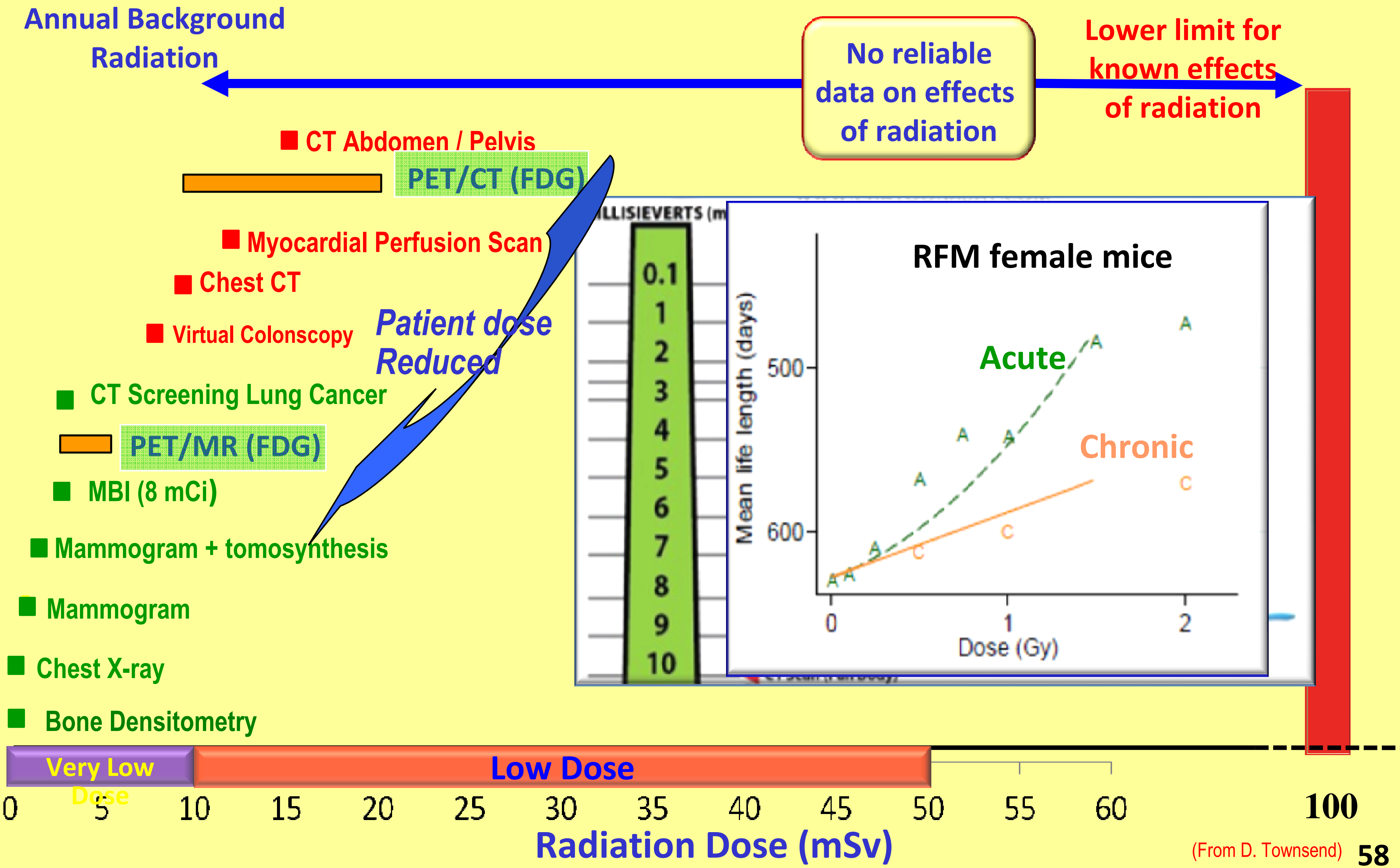

(From D. Townsend)

9. CONCLUSION

During last decade: Impressive progress in Medical Imaging

Due to enormous work on the technical front:

- New detectors
- Software
- Training
- Radiation Protection

About 4000 PET/CT scanners operational worldwide (start in 2000')

PET/MR scanners are beginning now (2014)

All that is for the main benefit of patients….

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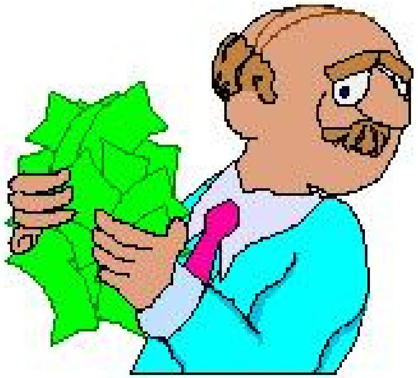

Thanks a lot for the gentle attention!