Imaging using ionizing radiations

III- Quantification in SPECT

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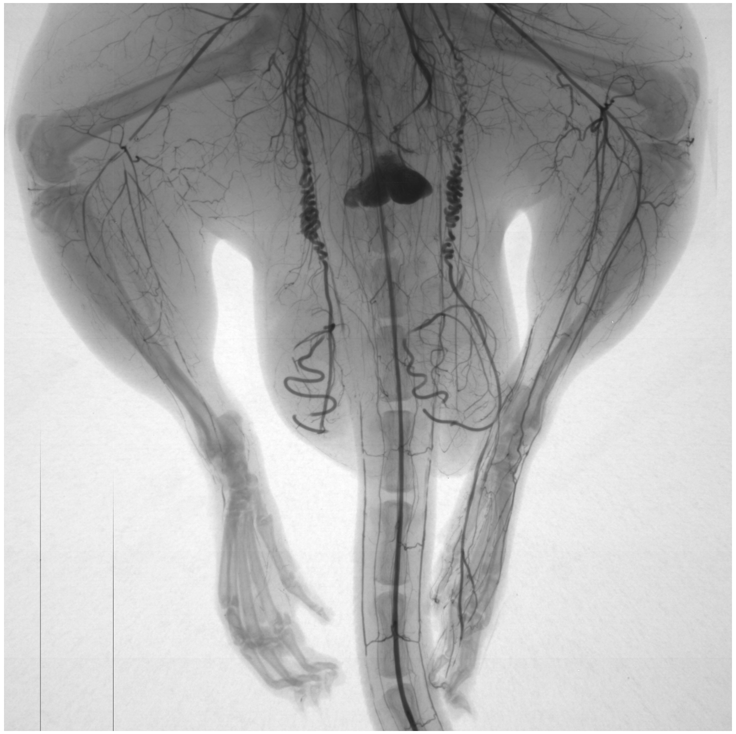
Slides are courtesy of David Brasse

Introduction



This is a « nice » image
There is more black than grey
We can distinguish the arteries
The pixel x,y is more dense than its neighbor
Its value is: *XXX niveau de gris*
XXX UH
XXX cm^{-1}
XXX quantité de produit

The quantification is the measurement of the numerical value extracted of the image and informing about the studied physiological process

Two types of quantification

- Relative quantification
  - No dimension
  - Comparing two numerical values with each other
- Absolute quantification
  - With dimension
  - Measurement of the molecule concentration injected in the organ or a region
  - Measurement of a constant characterising the observed physiological phenomena

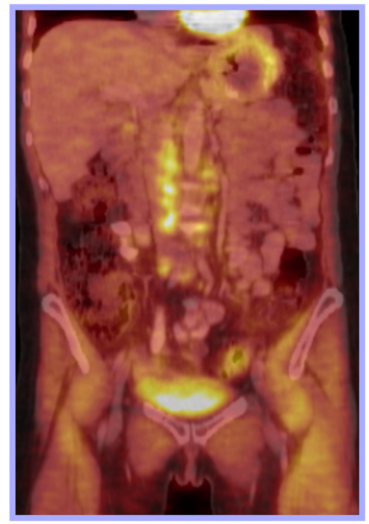
Challenges

- Cognitive
  - Detect, characterize and understand the functional processes
    - Localization of cerebral functional sites corresponding to the realization of specific task
    - Predict the pharmalogical effects of a substance by characterizing its specificity for a taret
- Diagnosis
  - Objective characterization of observed anomalies « pathologies »
    - Better orientation of the therapy
    - Therapy follow-up

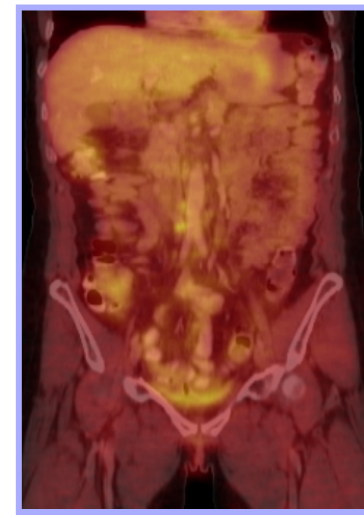
Challenges

Pronostic challenges

Pre-treatment



post-treatment



Therapeutical challenges

Quantification obstacles

Intrinsic due to imaging technique

Interaction radiation/matter

Attenuation of photons in tissues
Compton scatter

Imaging system limits

Spatial/energy resolution
Measurement noise
Image reconstruction

Potential obstacles

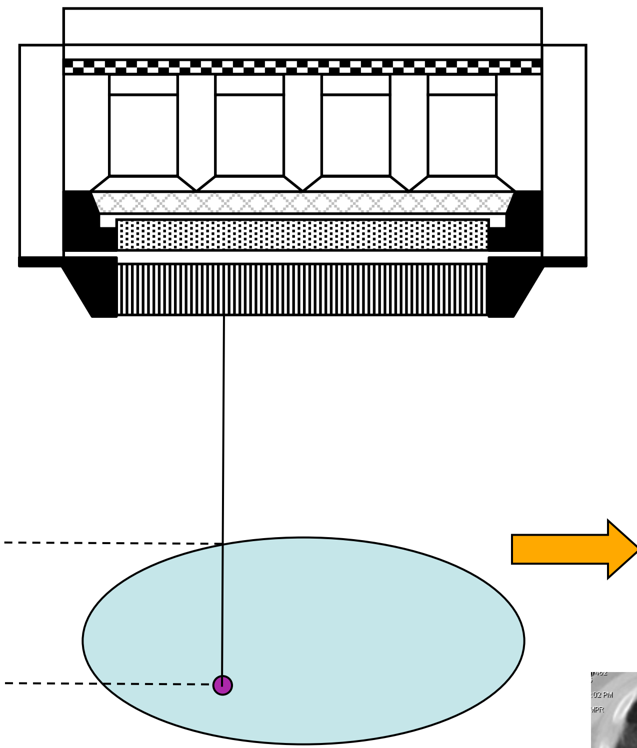
Patient motion

Physiological (respiratory and cardiac)
Random patient motions

Detection system default

Uniformity, linéarity, dead time, mechanic

Attenuation in SPECT

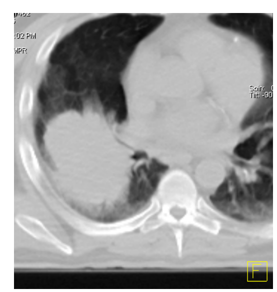


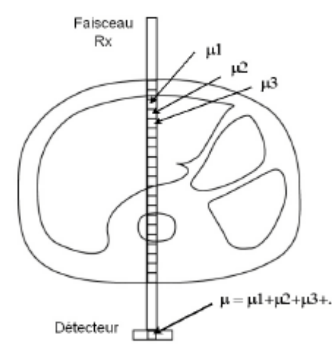
$$N_0 e^{-\mu d}$$

$$d$$

$$N_0$$

$$N_0 e^{-\int_0^d \mu_E(t)\,\mathrm{d}t}$$





Attenuation in SPECT

$$N = N_0 e^{-\int_0^d \mu_E(t)\,\mathrm{d}t}$$

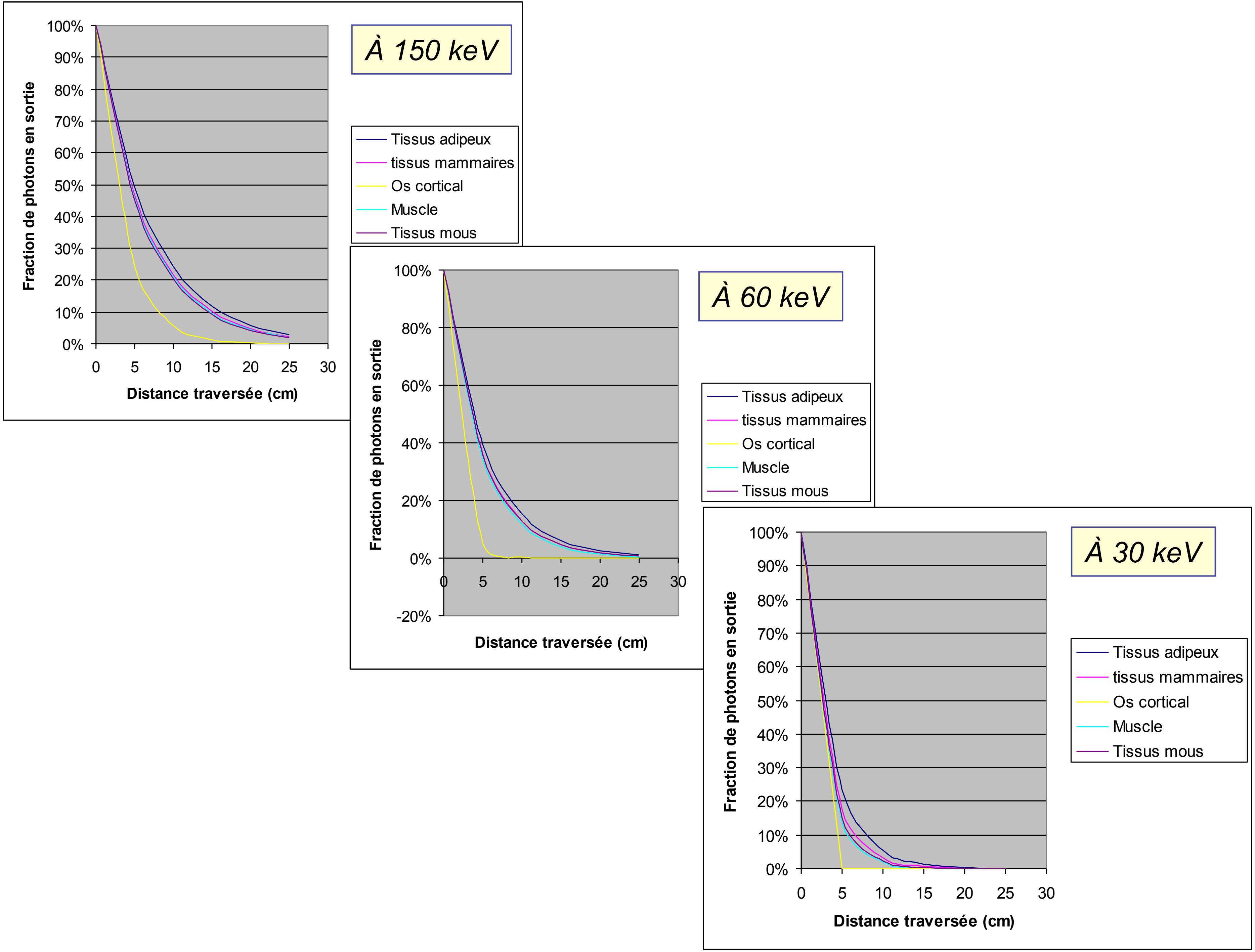
The number of photons N depends:

On the scintillation localisation(d)

Crossed tissue(μ)

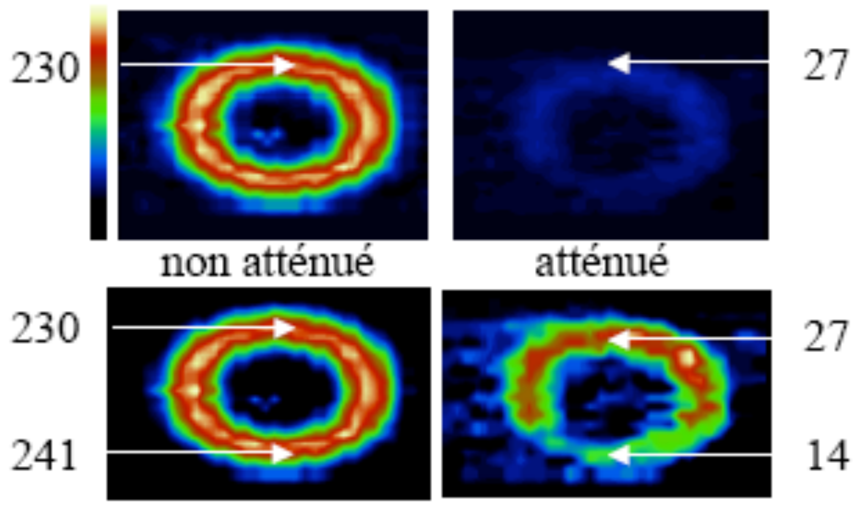
Photons energy (μ_E)

Tissues	Density (g/cm^3)	@ 150 keV µ (cm^{-1})	@ 60 keV	@ 30 keV
Adipose tissues	0,95	0,142	0,187	0,291
Mammary tissues	1,02	0,152	0,204	0,347
Cortical bone	1,92	0,284	0,605	2,555
Muscle	1,05	0,156	0,215	0,397
Soft tissues	1,00	0,149	0,205	0,379

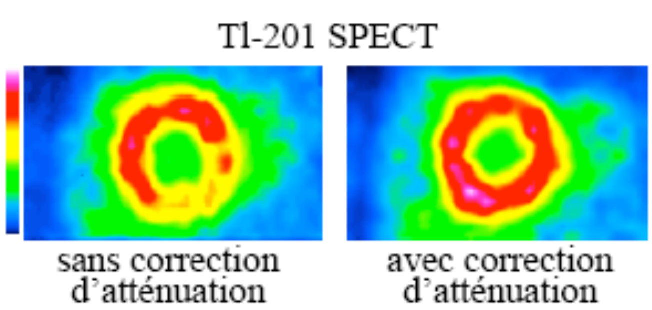


À 150 keV
Fraction de photons en sortie
Distance traversée (cm)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
5
10
15
20
25
30
Tissus adipeux
tissus mammaires
Os cortical
Muscle
Tissus mous
À 60 keV
Fraction de photons en sortie
Distance traversée (cm)
100%
80%
60%
40%
20%
0%
-20%
0
5
10
15
20
25
30
Tissus adipeux
tissus mammaires
Os cortical
Muscle
Tissus mous
À 30 keV
Fraction de photons en sortie
Distance traversée (cm)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
5
10
15
20
25
30
Tissus adipeux
tissus mammaires
Os cortical
Muscle
Tissus mous

False quantification



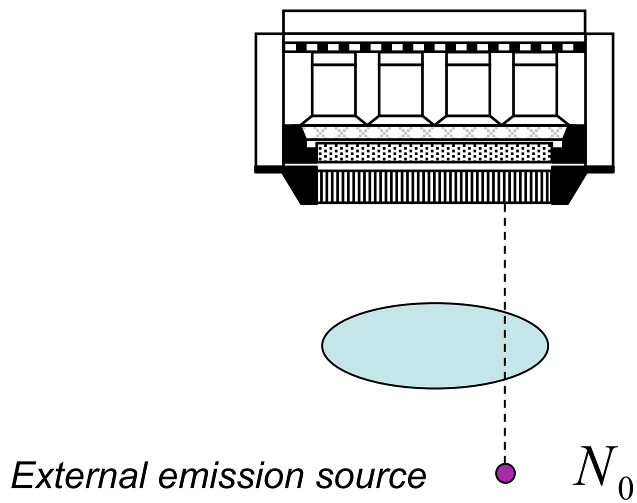
Depth-dependent attenuation



Attenuation correction

Determine the distribution of the linear attenuation coefficients

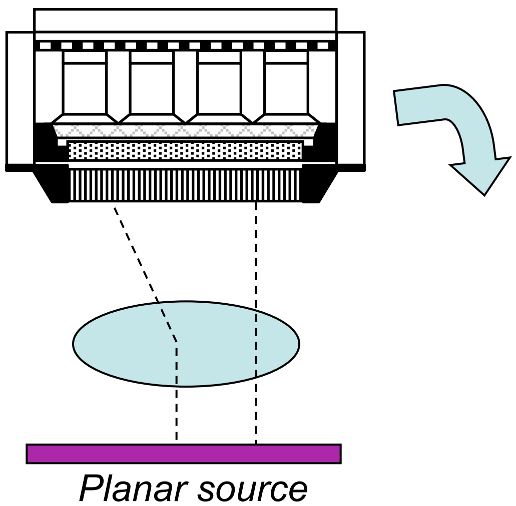
By mean of transmission imaging system



$$N = N_0 e^{-\int_0^d \mu_E(t)\,\mathrm{d}t}$$

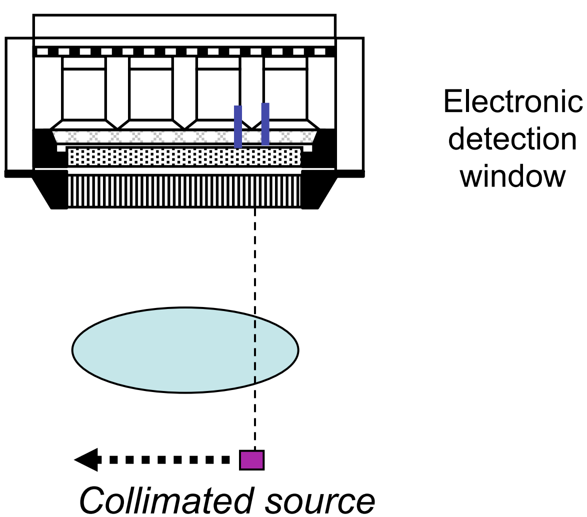
$$\boxed{\ln\left(\frac{N_0}{N}\right) = \int_0^d \mu_E(t)\,\mathrm{d}t} \Rightarrow \boxed{\mu_E(x, y, z)}$$

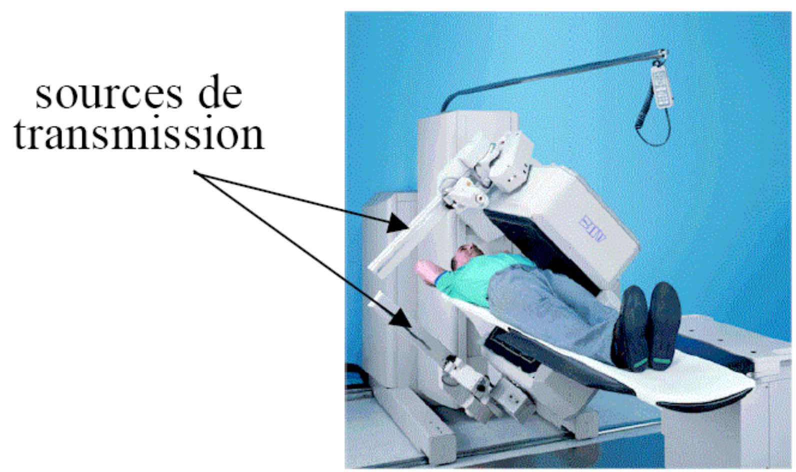
Attenuation correction



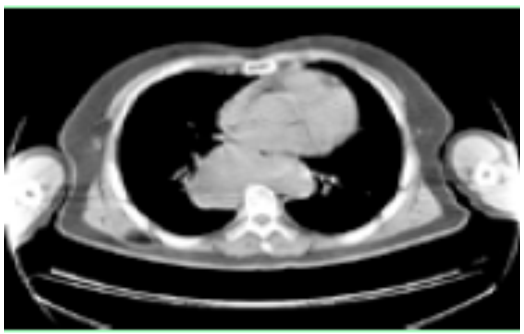
2D projections acquisition by transmission
With different angles
Tomographic reconstruction
Obtain the attenuation map

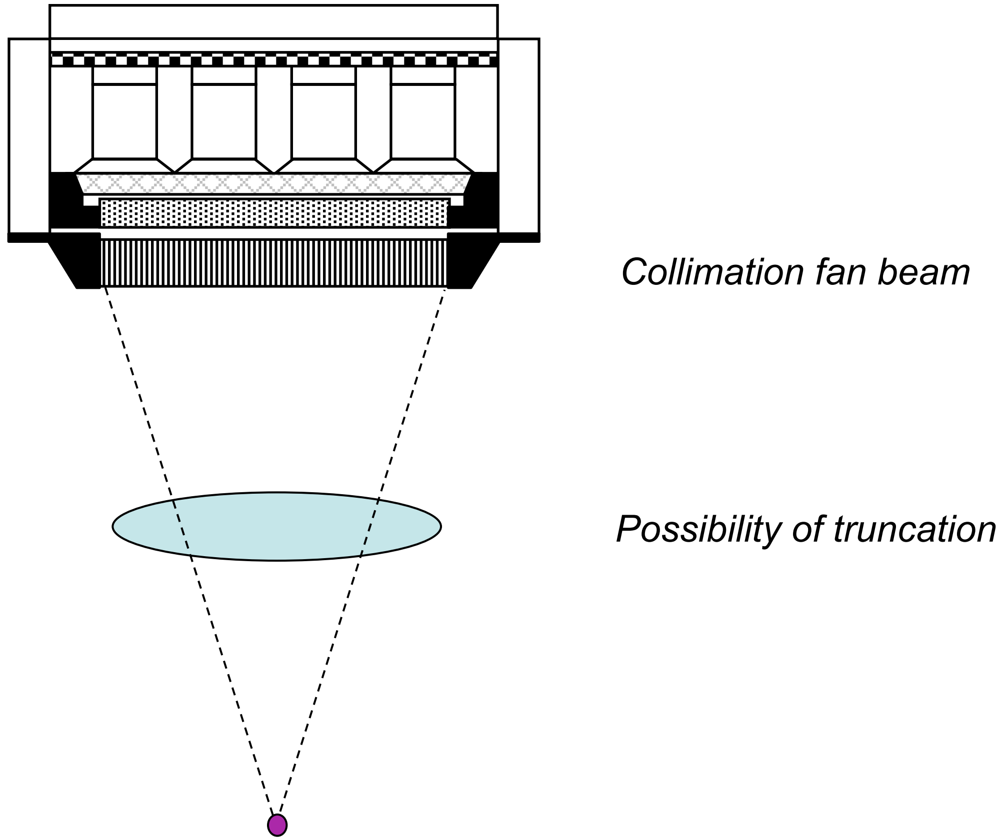
Problem: Scattering
Under-estimation of coefficients



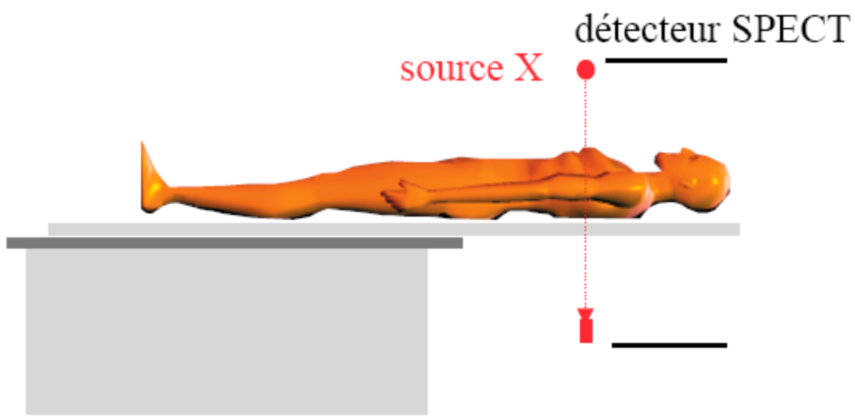


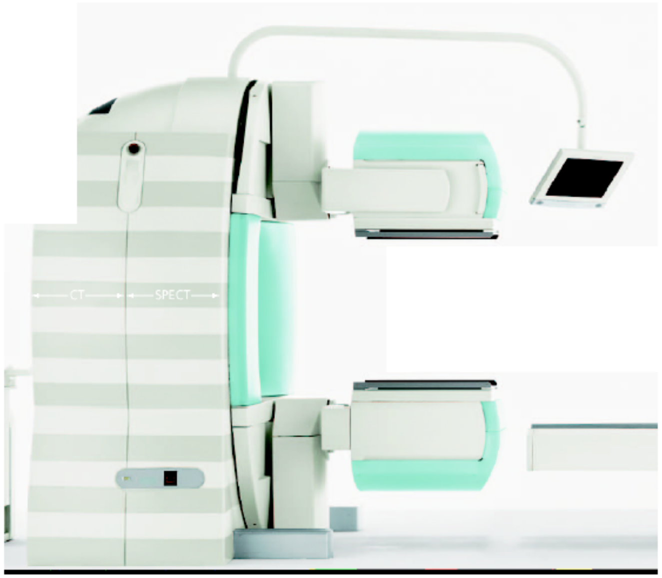
Attenuation correction





Multi-modality approach





2D acquisition
Tomographic reconstruction
Obtention of linear attenuation coefficients

Problems:
Spatial and temporal resolution of CT: no blurr caused by patient motion
Energy scaling

Correction methods

Before tomographic reconstruction

Multiplication of projections/sinograms by approximated correction factors

During the reconstruction

Modeling the attenuation in the reconstruction algorithm

After the tomographic reconstruction

Multiplication of the images by approximative coefficients (Chang algorithm)

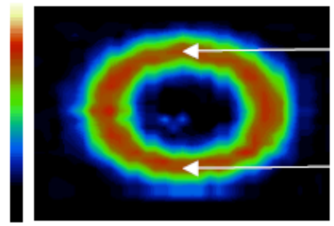
Problems

Motion between emission and transmission

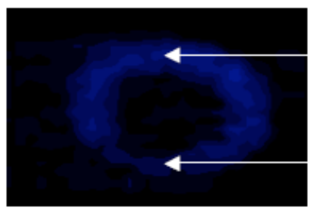
Noise propagation of transmission projections in the reconstructed images

Example

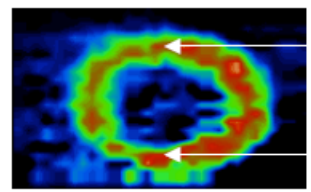
Coupe ventriculaire gauche petit axe



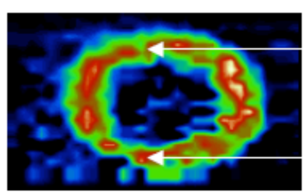
non atténué
$A_{ant}/A_{inf}=1$



atténué
$A_{ant}/A_{inf}=2,1$

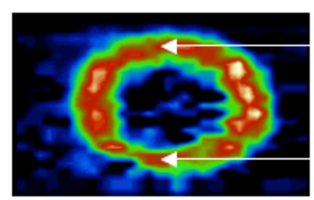


correction de Chang
$A_{ant}/A_{inf}=1,1$



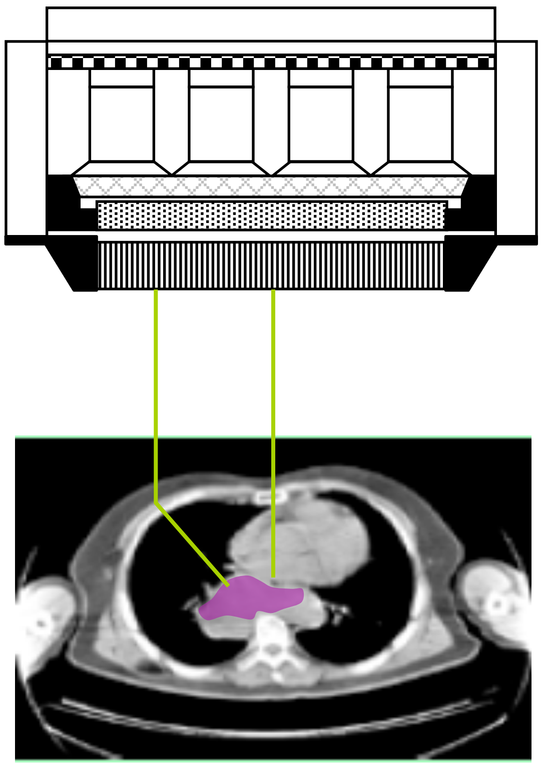
Chang itératif

$A_{ant}/A_{inf}=1,1$



correction lors de la reconstruction
$A_{ant}/A_{inf}=1,1$

Compton scatter



Possible Compton scatter

in the patient,
in the collimateur
in the crystal

Photon mispositioned in the projections

Energy loss

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

Blurr
Loss in contrast
Quantitative bias

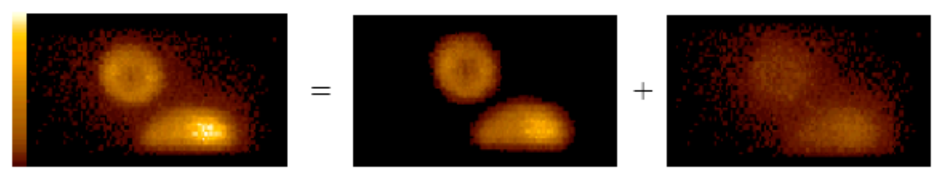
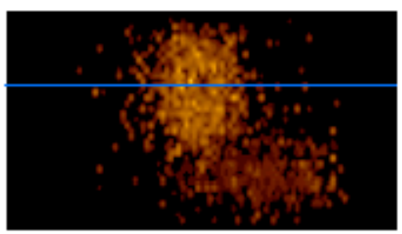


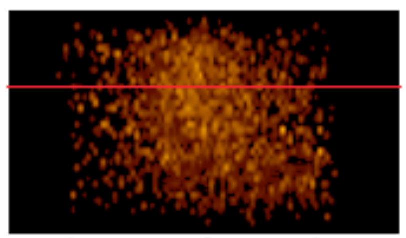
image fenêtre spectrométrique d'acquisition Tc99m (126-154 keV) | photons primaires | photons diffusés (37%)

Scatter is important in soft tissues
Compton cross sections increase when the energy decreases

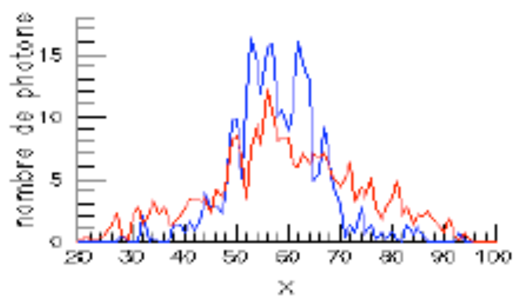
More loss of energy for high scatter angles



haute énergie
137-140 keV



basse énergie
74-77 keV



Scatter correction

Eliminate scattered photons

During the acqusition

Requires a good energy resolution

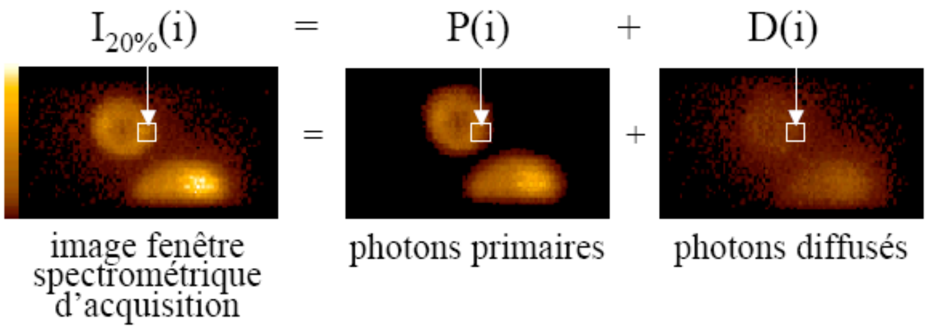
Post treatment

By substraction (previous scatter estimation)

Consider for scatter in the reconstruction algorithm

Correction example

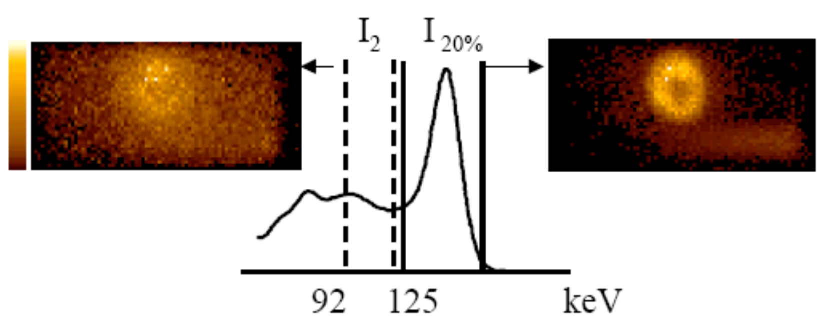
Method proposed by Jaszczack



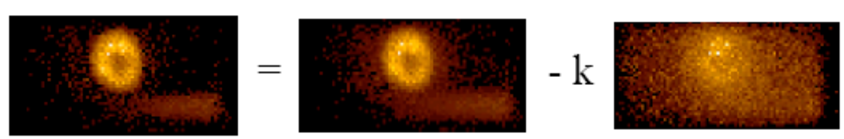
$$\hat{P}(i) = I_{20\%}(i) - \hat{D}(i)$$

- Hypothèse

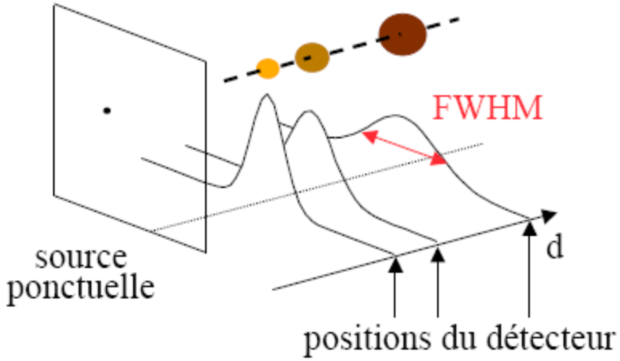
$$\hat{D}(i) = k.I_2(i)$$



- Correction



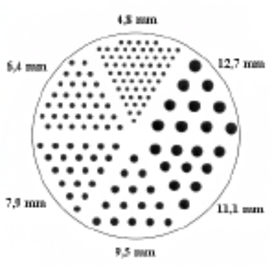
Non stationary spatial resolution

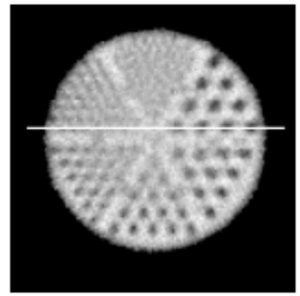


Distorsion in the reconstructed images
Excentred sphere-> ellipsoïd

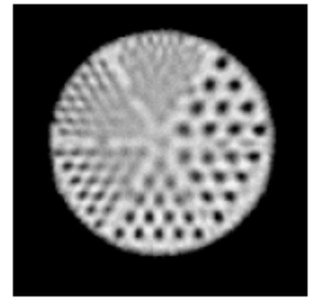
Projections correction
Consider for the impulse function in the reconstruction algorithm

Illustration

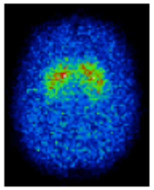




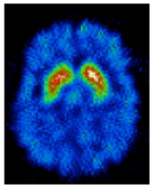
sans correction



avec correction

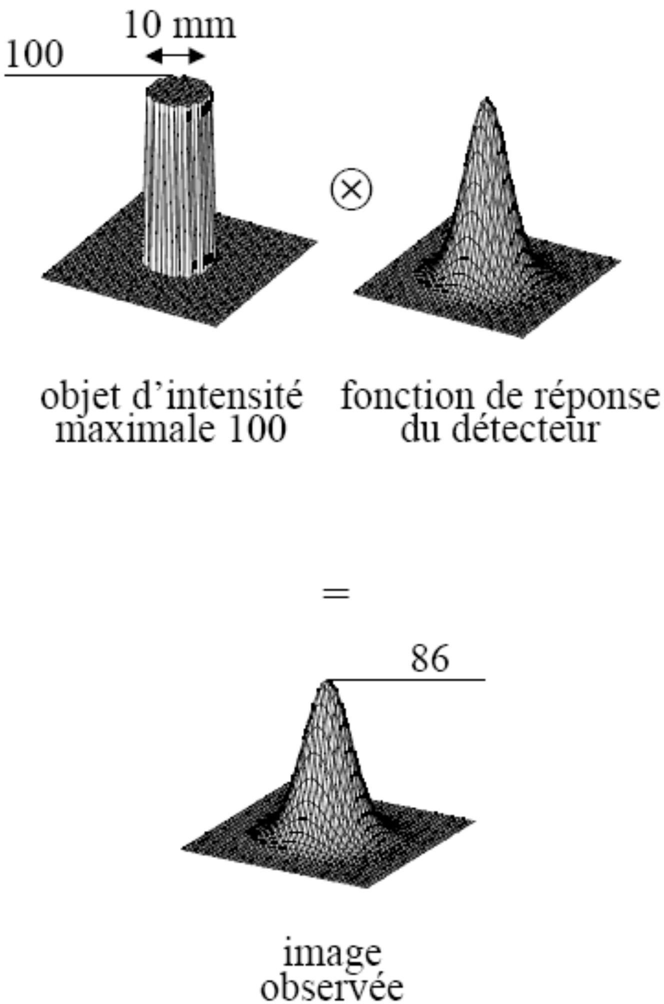


sans correction



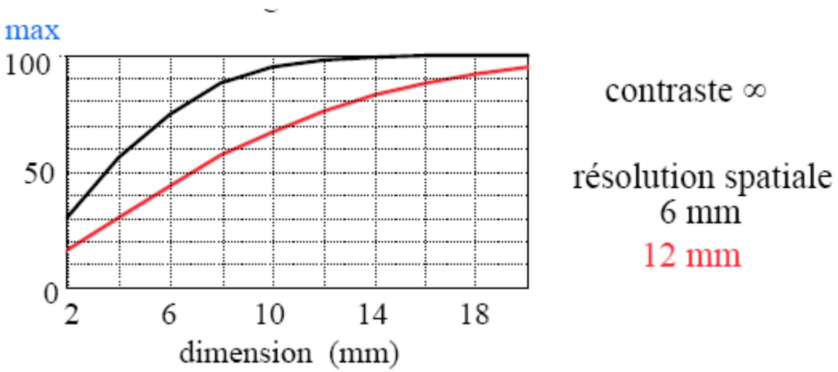
avec correction

Partial volume effect



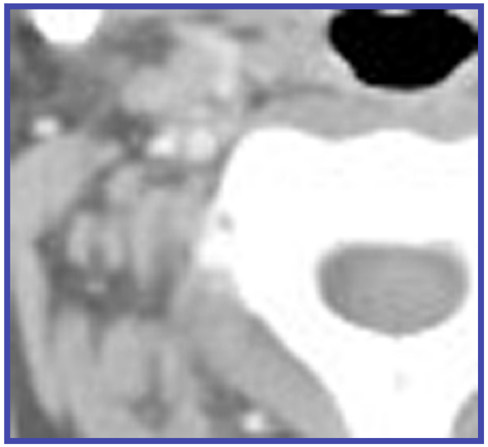
Under estimation of activity in small size structure
Depends

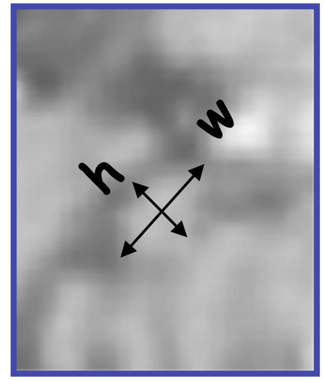
- on object/background contract
- on object dimension
- on system spatial resolution
- on the spatial sampling (pixel size?)
- on the considered Region of Interest (ROI)



⇨ affecte les structures de taille <2-3 FWHM

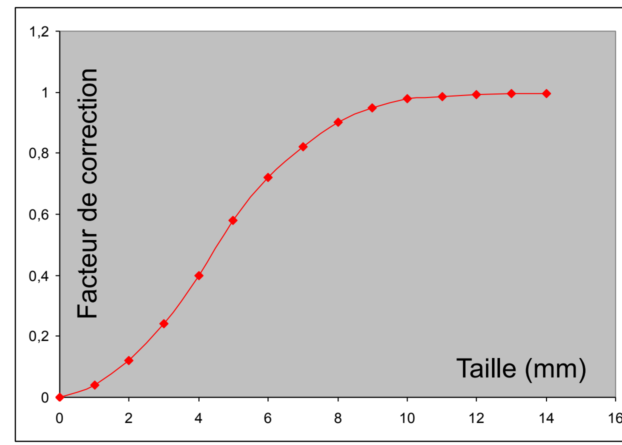
Illustration (PET)

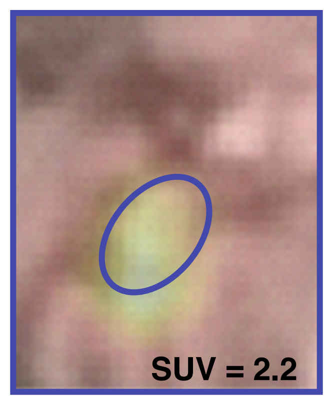




dimensions: w x h

SUV = 2,2





Nodule dimension= 6mm
Coefficient = 70%

SUV (corrected) = 3,2

Calibration

Required for absolute quantification

$$\text{X counts/s/pixel} \xrightarrow{\text{Scaling factor}} \text{Y kBq/ml}$$

Quantification en Tomographie d'Emission Monophotonique (SPECT)

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