Quantification in nuclear medicine: SPECT

Hind Saikouk[1,2]

[1]:Faculty of science of Rabat, Mohammed V University, Morocco

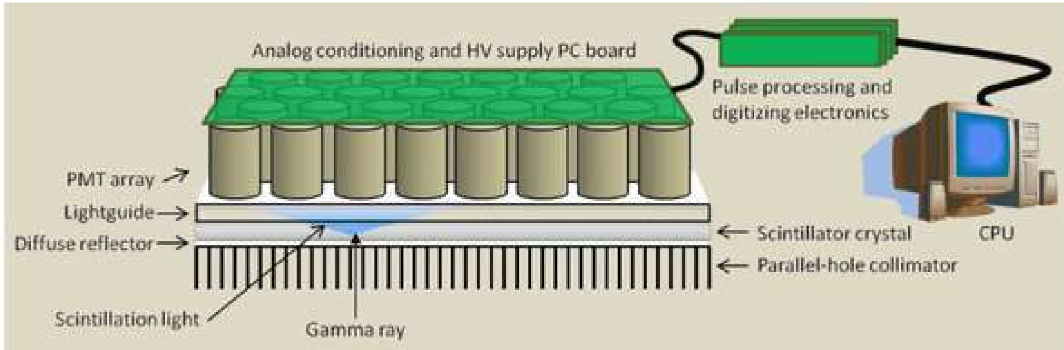
[2]: Medical physicist, Nuclear medicine department, Hematology and oncology hospital, Mohammed VI University Hospital, Marrakesh

Email: saik.hind@gmail.com

Introduction

SPECT

- SPECT: **S**ingle **P**hoton **E**mission **C**omputed **T**omography
- Collimator
  - Selection of photons
  - Definition of the lines of response
- Crystal
  - Conversion of photons to scintillations
- Light guide: Optical coupling Crystal-PMT
- Photomultiplier tubes (PMTs)
  - Conversion of scintillation to a signal
- Electronics
- Creation of 2D images

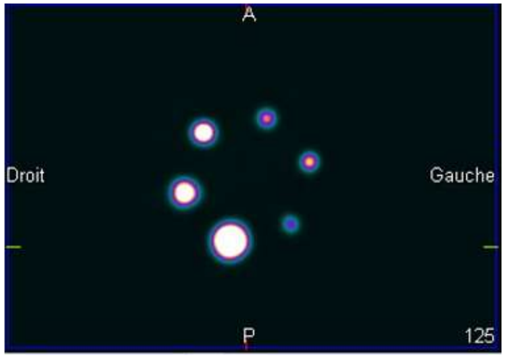


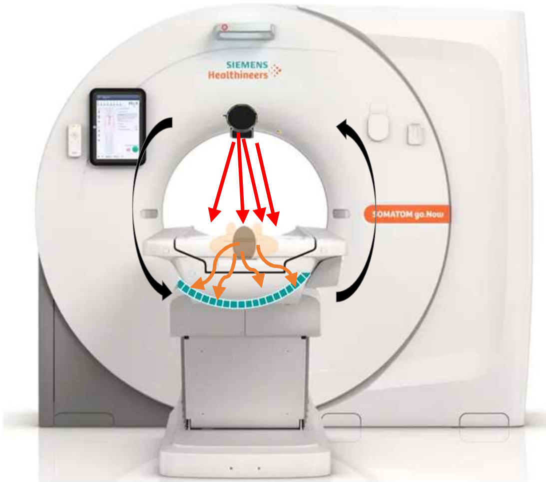
Composition of the gamma camera head *

*: Peterson TE, Furenlid LR. SPECT detectors: the Anger Camera and beyond. Phys Med Biol. 2011 Sep 7;56(17):R145-82. doi: 10.1088/0031-9155/56/17/R01

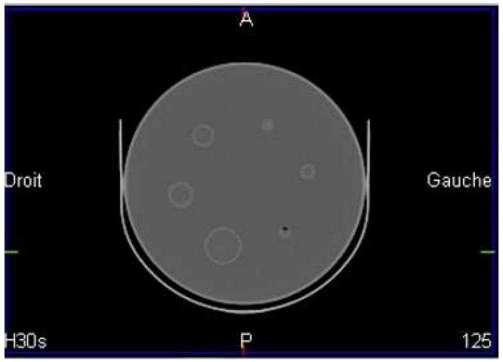
SPECT vs CT

SPECT

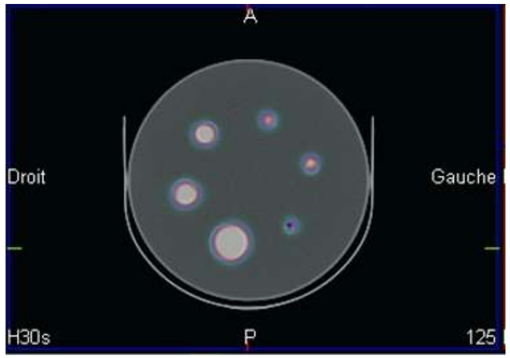




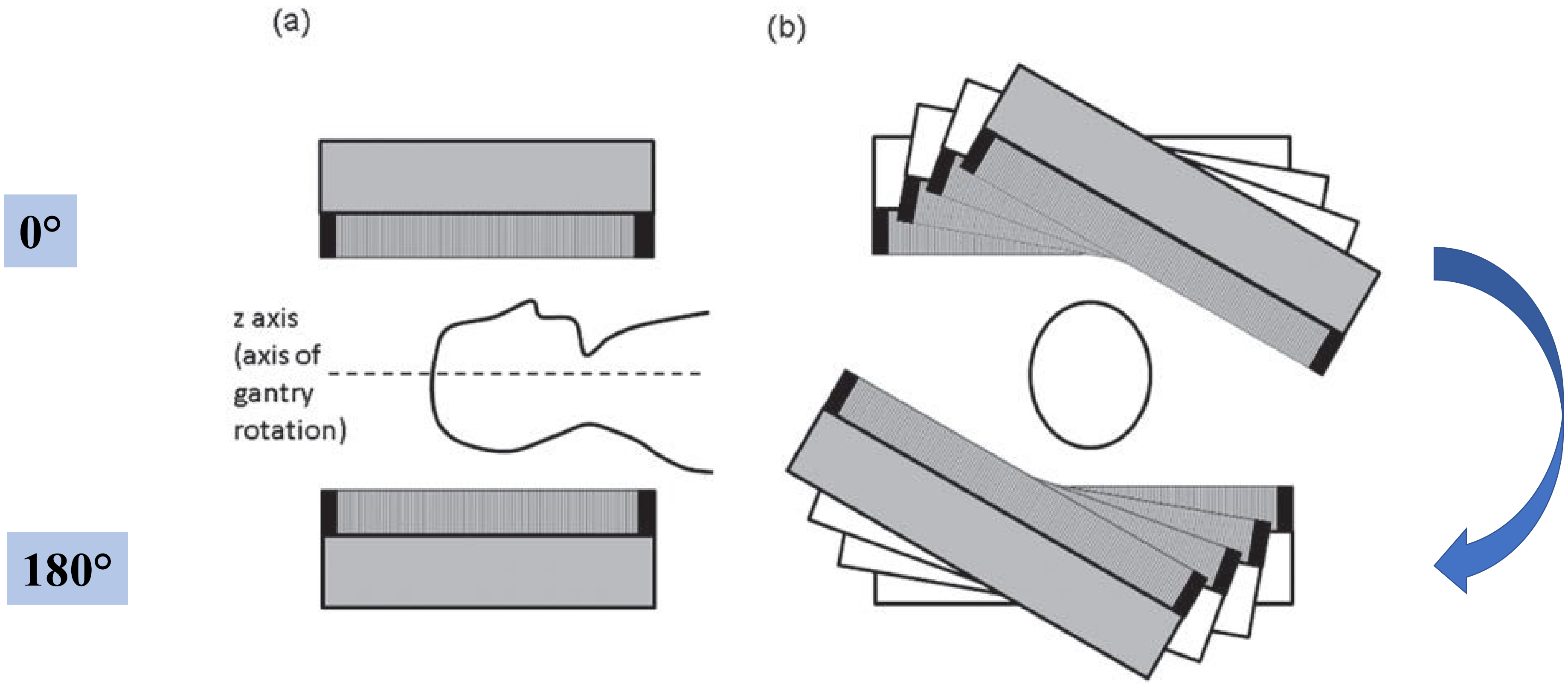
CT



SPECT-CT

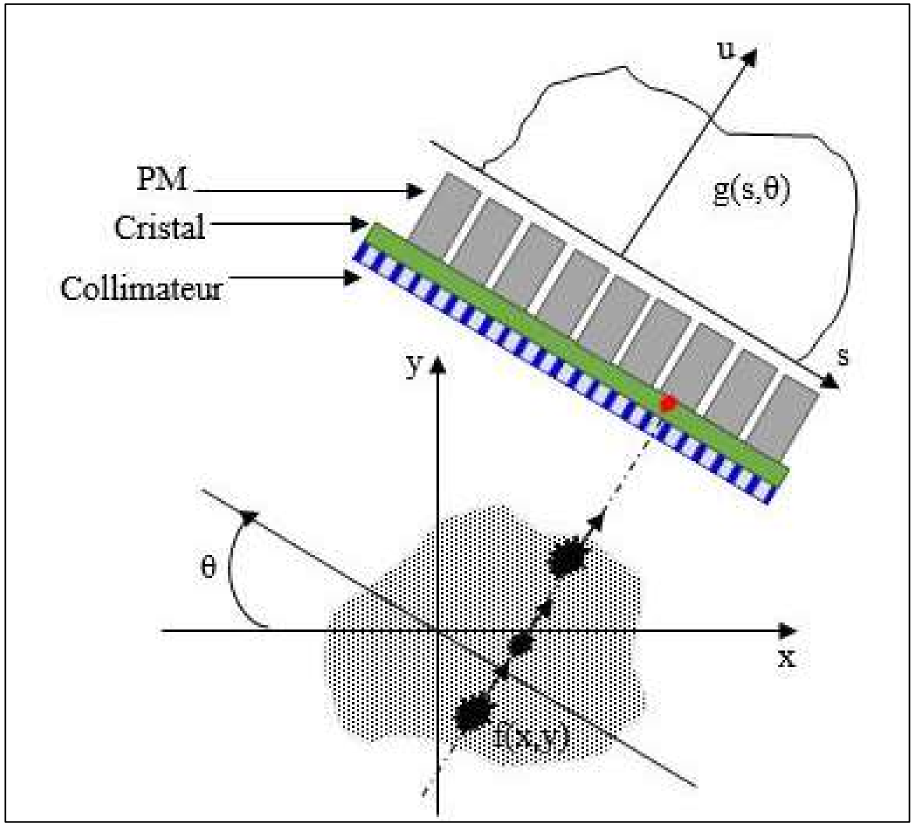


SPECT principle



Projection profile

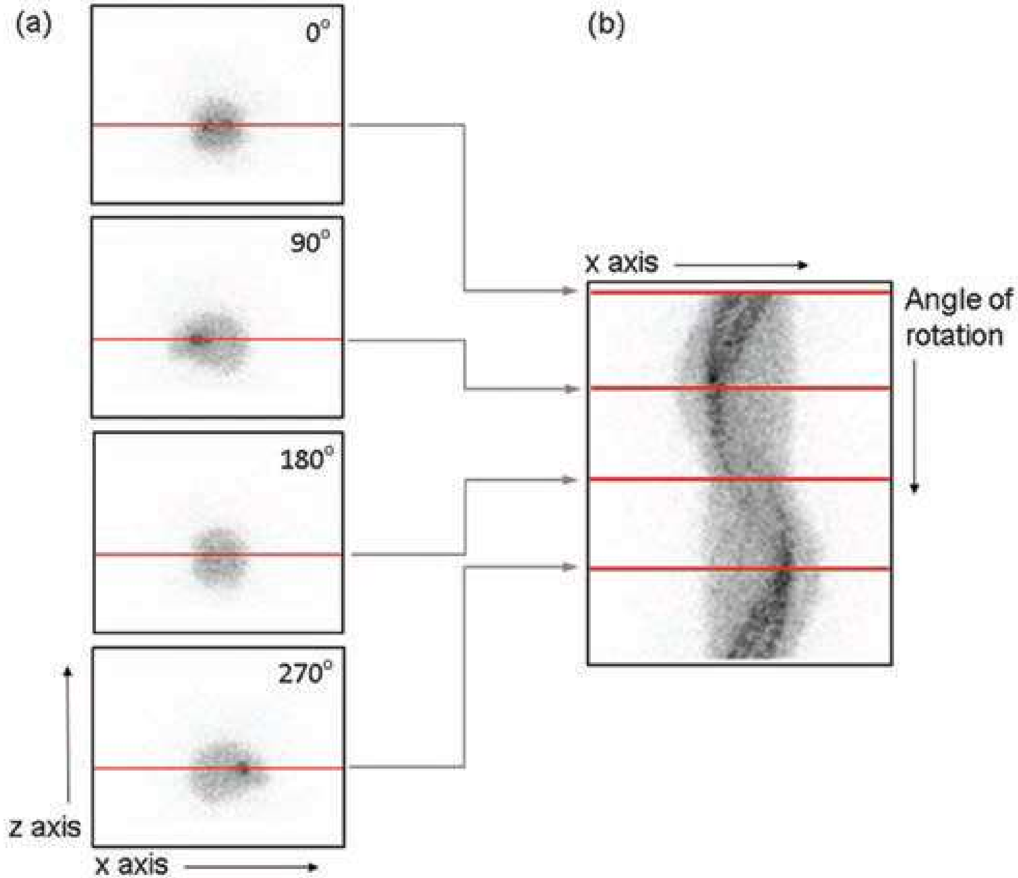
Object



Projection profile

Sinogram

- A sinogram is an array of all geometrically valid lines integral



Reconstruction

- Back projection
  - Projection profiles acquired at multiple angles
  - Forward projection: Counts summed along each projection element to get a "sum" value
  - Back projection: Counts are redistributed along each projection element with sum values
  - An approximation of the distribution of radioactivity within the scanned slice is obtained
  - Corrections are not included

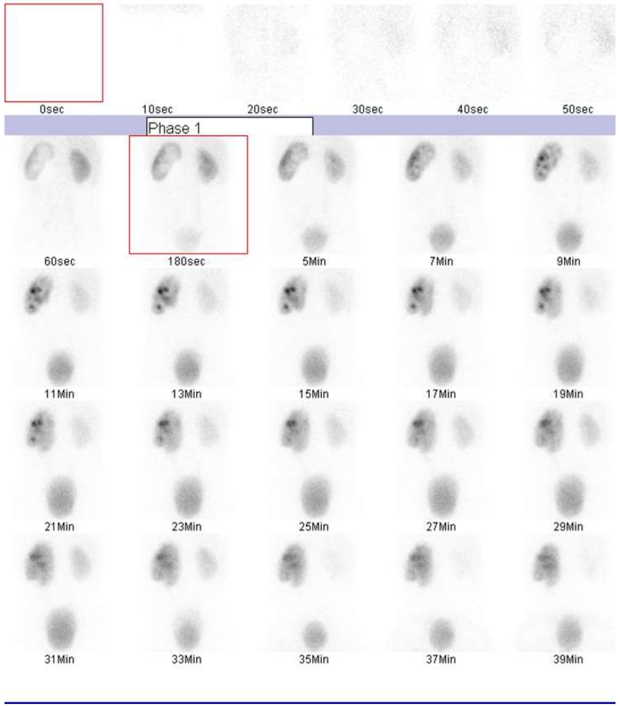
Reconstruction

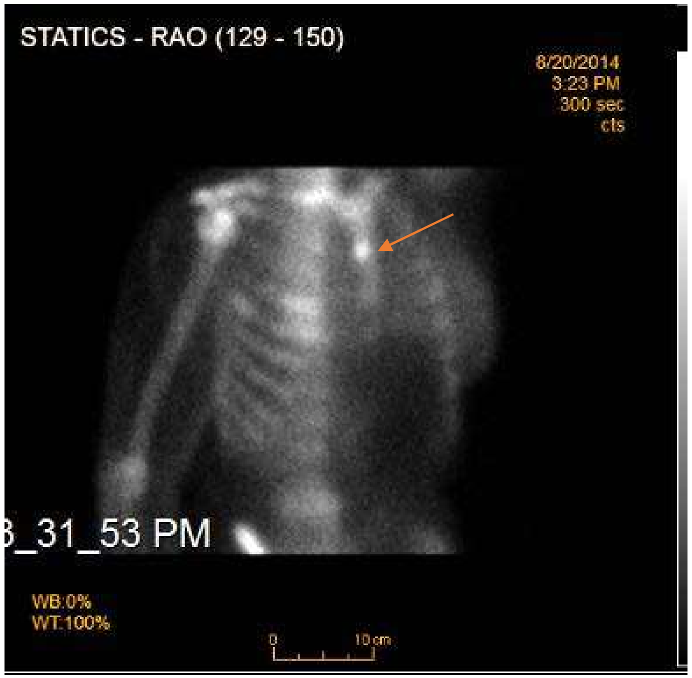
- Iterative methods
  - Successive estimations, **iterations**, are used to obtain the image of the radionuclide distribution in the organ of interest
  - A first estimation can be a uniform image with starting value of 1
  - The projections are calculated then compared to the measured projections
  - If any discrepancies are noted corrections are made and a new iteration is started
  - Corrections for degrading effects can be included in the reconstruction

Qualitative and quantitative image interpretation

Qualitative analysis

- The **visual interpretation** of images by a professional:
  - Rendering of disease is present or absent
    - Normal, mild, severe, absent ….
  - Subjective





Quantitative analysis

➢Results are reported in term of **values measured** in a quantitatively calibrated SPECT

- Time curve activity, radiopharmaceutical uptake, Bq/ml…
- Thresholds
- Objective

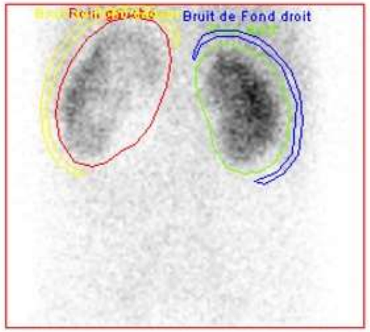


Tableau sommaire des résultats

Paramètres	Gauche	Droite	Total
Fonction séparée (%)	36,7	63,3	
Comptage reins (cpm)	6471,8	11140	17612
Durée de Max (min)	32,0	2,334	
Durée de 1/2 Max (min)		7,589	
Durée de Max à 1/2 Max (min)		5,254	
Durée de 2/3 Max (min)		5,677	

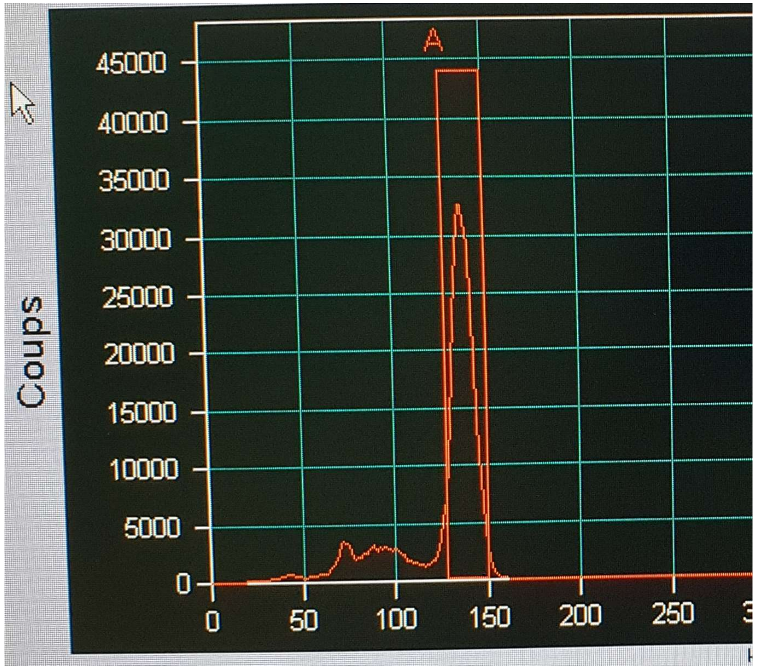
Quantitative analysis

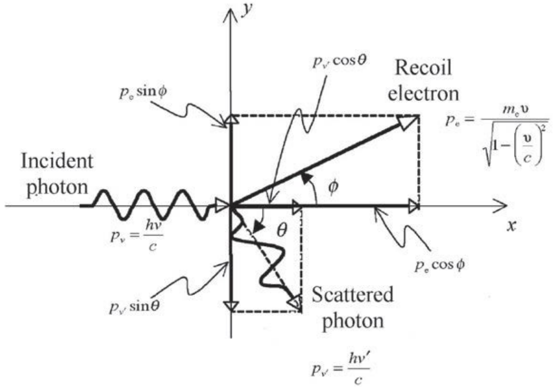
- Quantification in SPECT depends on:
  - Image acquisition conditions
    - Administered activity:
    - Matrix size
    - Pixel size
    - Number of projections
    - Acquisition duration: Time per projection, total counts
  - Image reconstruction
    - Reconstruction algorithm
      - Back projection: filter, parameters of the filter…
      - Iterative methods: number of iterations, subsets, post filter, parameters of post-filter…
    - Correction of degrading effects:
      - **Attenuation and scatter**
      - Collimator effect
      - Partial volume effect
      - ….

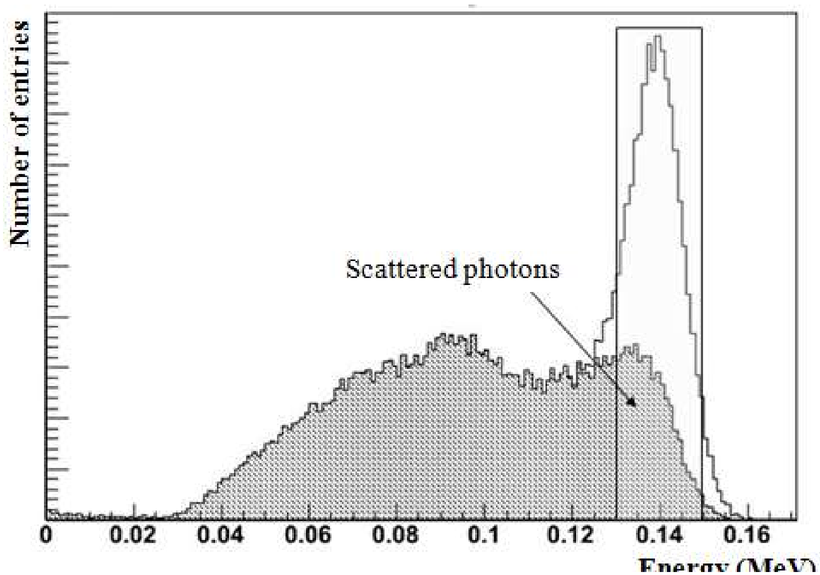
Scatter correction

Scatter

- Represents one of the major sources of spatial resolution deterioration
- Contribution in the energy window
- Different methods are used for the compensation of the scatter in images
  - Energy window based methods +++
  - Monte Carlo



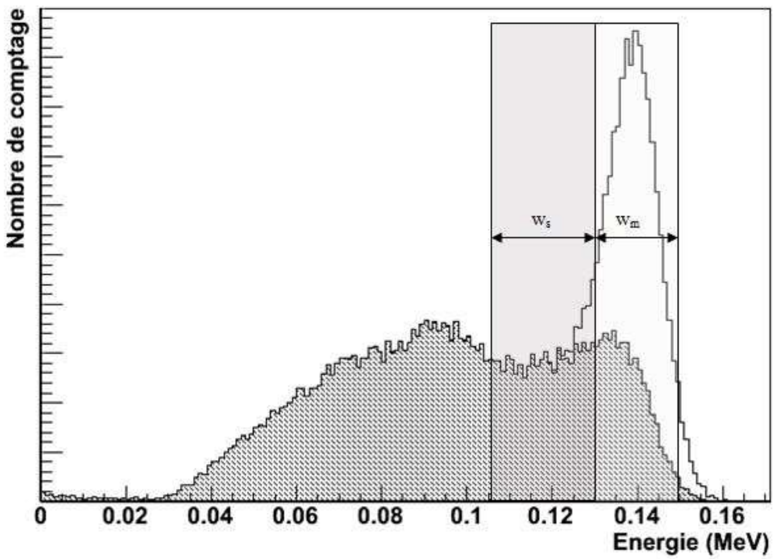




Double energy window

- Spatial distribution of the scattered photons SC_S in a secondary large energy window is considered as equal to the scattered photons SC_M under the photopeak

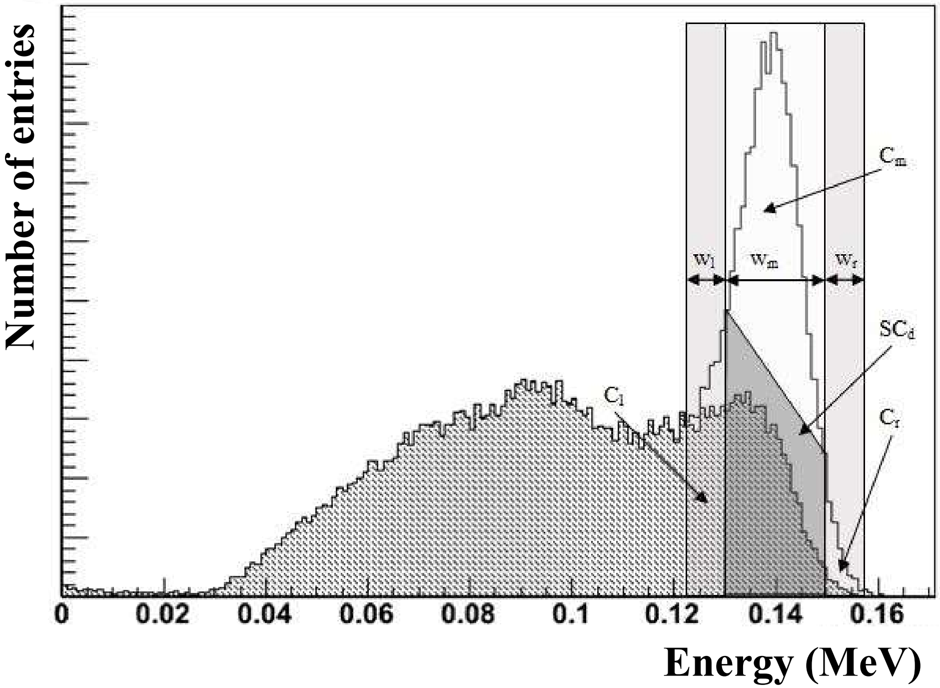
$$SC_M(i, j) = kSC_S(i, j)$$

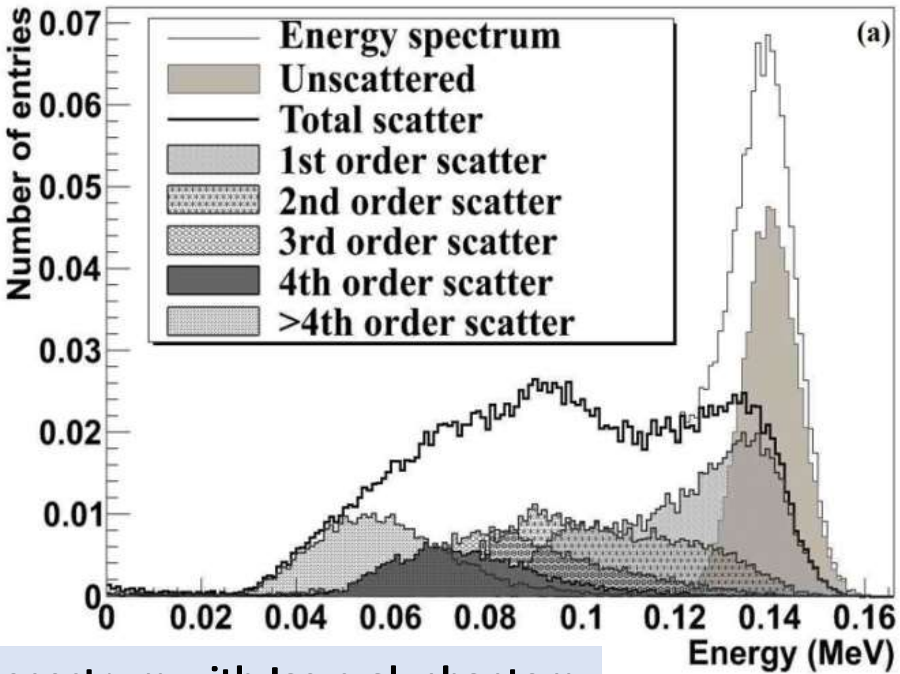


Triple energy window

- ➢Easy implementation and good results
- ➢Based on a pixel by pixel estimation of scatter counts, SC, by a trapezoidal rule

$$SC = \left[\frac{C_l}{w_l} + \frac{C_r}{w_r}\right] \times \frac{w_m}{2}$$





Tc99m energy spectrum with Jaszczak phantom

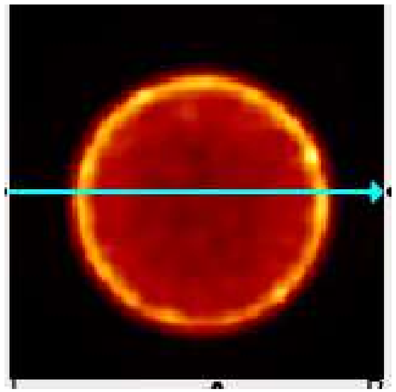
Attenuation correction

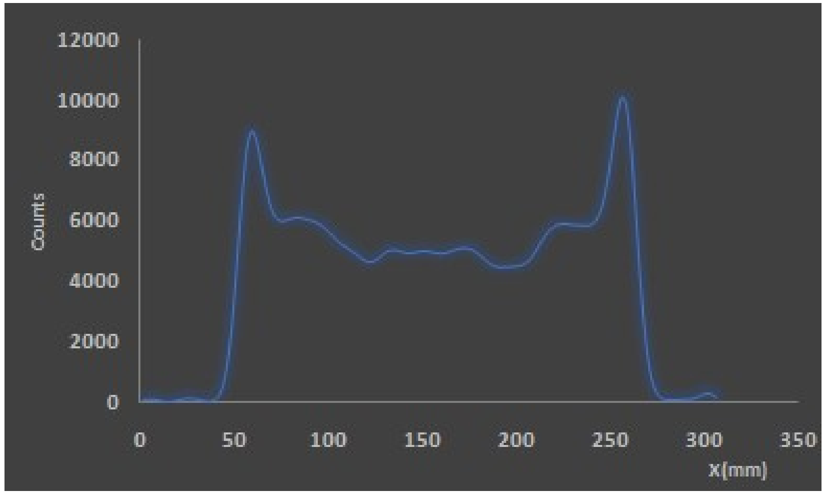
Attenuation

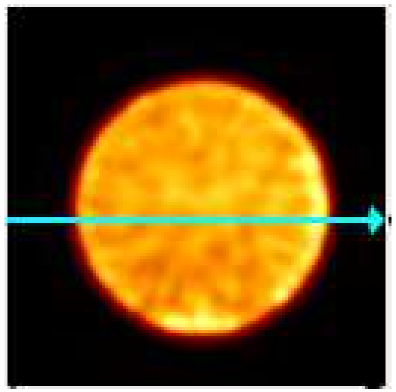
- One of the biggest factors degrading quantification in SPECT
- Underestimation of the absolute estimates of activity: factors of 5-20
- Greater effect for **low energy photons** and for **larger and denser regions of the body**

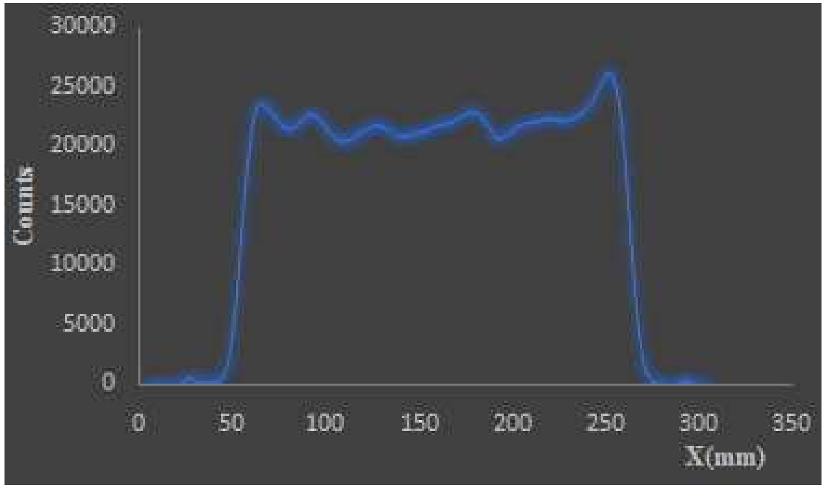
→ Compensation of the attenuation effect

Compensation of the attenuation effect





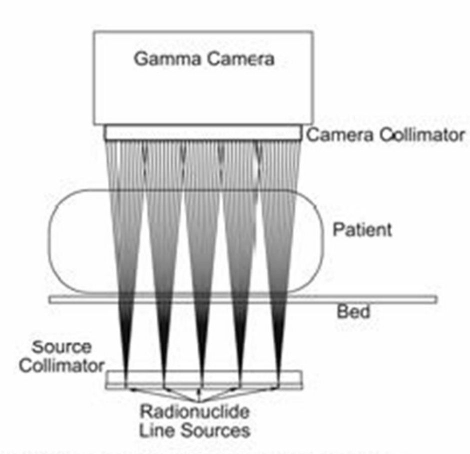




Compensation of the attenuation effect

- ➢ Reconstruction of the **attenuation distribution**
  - Determination **of linear attenuation coefficient, μ, map,** corresponding to the radiotracer used in emission (ex: Tc99m) for each patient
- ➢ Acquirement of transmission data sets for various angles
  - External radionuclide sources
  - X-ray tube: SPECT-CT
    - It can be a non-diagnostic CT, **low-dose**

SPECT-CT



Transmission line sources

Compensation of the attenuation effect

- Accurate μ-map obtained for each projection using CT
  - μ is not assumed to be constant
- μ values used in Chang's algorithm to correct pixel-by-pixel
  - Correction factors, CF, calculated for each pixel of the reconstructed image
  - Multiplication of the current reconstructed image by CF

- Current SPECT/CT systems use this method

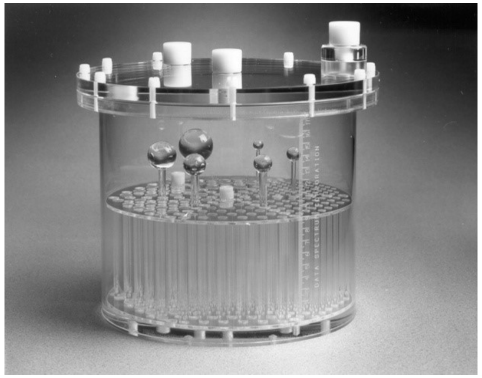
SPECT quantitative performance test

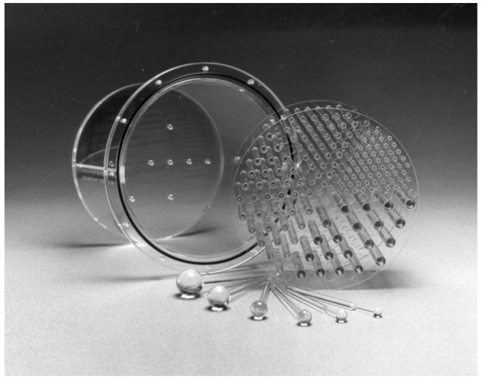
Aim

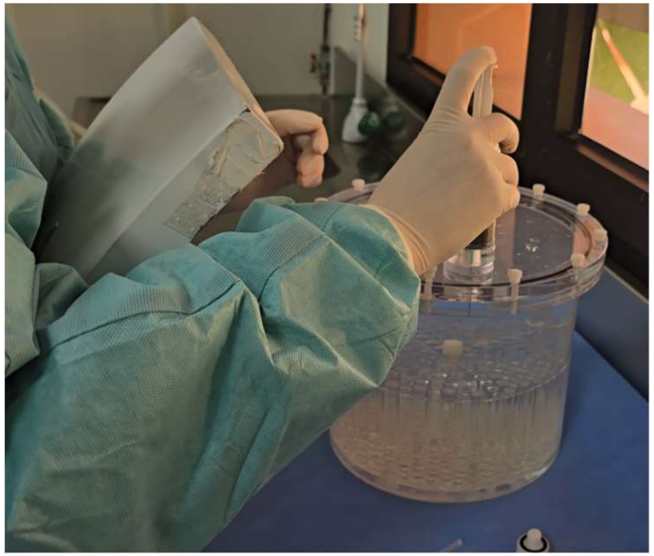
- ➢Evaluation of the correct functioning of the SPECT system
- ➢Verification of the image quality characteristics
  - Contrast
  - Tomographic uniformity
  - SNR

Phantom and sources

- Jaszczak phantom
  - Fill the phantom with water
  - Add15 mCi of ^{99m}Tc
  - Respect **radiation protection** rules
  - Mix for about 10 minutes
  - Let it sit for 45 minutes to 1 hour

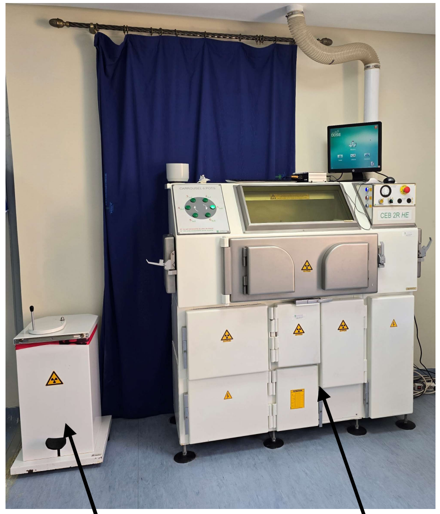






Radiation protection

- ➢ Source should be prepared inside the hot lab, inside the hot cell
- ➢ Use of surgical gown and gloves (should be changed frequently)
- ➢ Dosimeters: Passive and electronic
  - If a lead apron is used the dosimeters should be putted **under** it, at chest level
- ➢ Use of lead screen
- ➢ Use of syringe shielding during the injection of Tc99m in the phantom
- ➢ Contamination monitoring should be performed after each step of the manipulation of the phantom and source, and at the end of the testing
- ➢ Radioactive waste should be managed following the procedure adopted in the department

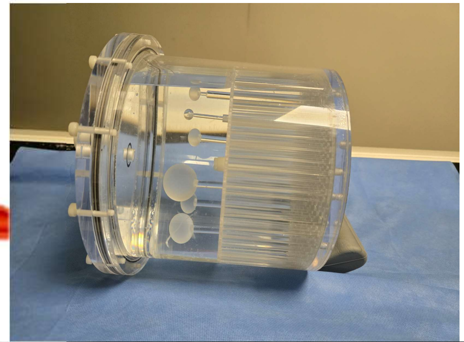


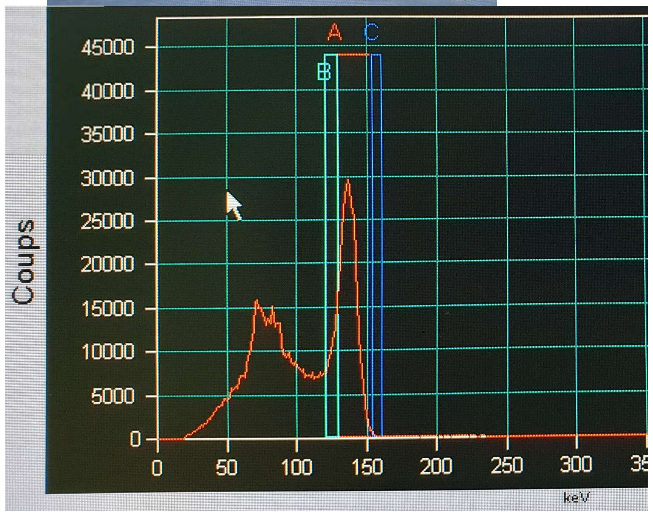
Shielded waste bin

Hot cell

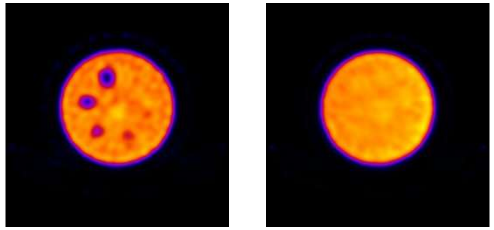
Acquisition parameters

➢Tomographic acquisition
- Center the phantom at the FOV of the detectors
  - Positioned at 22 cm away from each head
- 64 projections per head
- Rotation in 180° per head
- Energy window centered on the photopeak
  - Scatter correction
- 128 x 128 matrix, 3.3 mm pixel size
- Circular orbit
  - Very the rotation of the SPECT heads without colliding with the patient's table
- Time acquisition: 20 seconds per view or 400 kcts/view

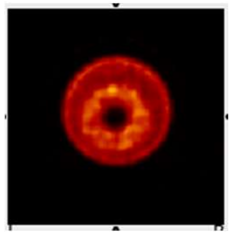


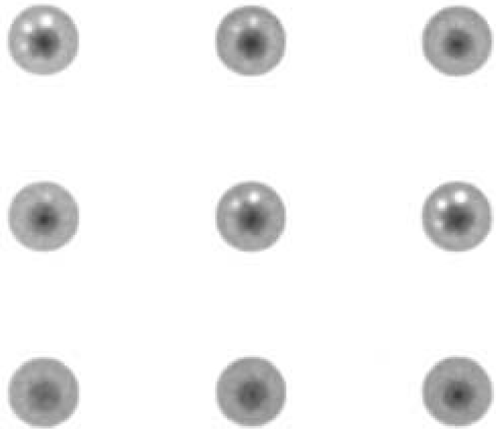


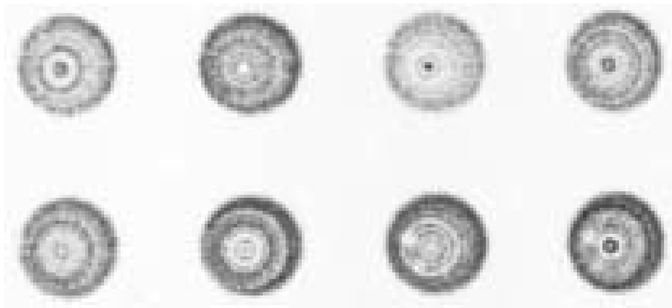
Reconstruction



- ➢ Reconstruction with the methods used in the department
- ➢ For iterative reconstruction
  - 18 iterations/8 subsets (OSEM Method)
  - Gaussian filter with FWHM of 10 mm
- ➢ Use of CT for attenuation correction
- ➢ Verification of the image qualitatively
  - Artefacts
- ➢ Image analysis
  - AMIDE: Medical Imaging Data Examiner
  - ImageJ
    - **IAEA NMQC toolkit**



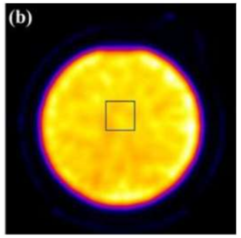




Tomographic uniformity

➢Uniformity: the capacity of the SPECT to restitute a uniform image for a uniform source

$$IU(\%) = \frac{Maximum\ pixel\ counts - Minumum\ pixel\ counts}{Maximum\ pixel\ counts + Minumum\ pixel\ counts} \times 100$$



$$RNB(\%) = \frac{SD}{Mean\ pixel\ value} \times 100$$

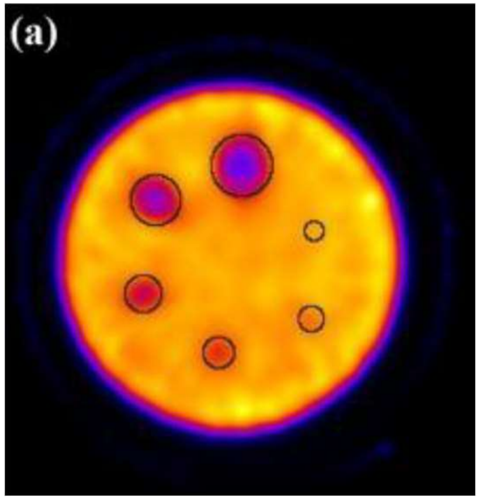
- Uniform section: Square ROI of 15x15 pixels

- Recommendation of AAPM, report N° 52
  - Uniformity: 10.7%-18.8%
  - rms noise: 3.6%-7.2%

Contrast

➢Fractional difference in the signal or brightness between the structure of interest and its surroundings

$$Contrast = \frac{Average\ pixel\ cts\ from\ uniform\ section - \min pixel\ count\ per\ cold\ sphere}{Average\ pixel\ cts\ from\ uniform\ section}$$



- Cold sphere section: Circular ROI for each visible sphere

Contrast

- Recommendation of AAPM, report N° 52

Sphere size (mm)	Minimum	Maximum
31.8	0.53	0.73
25.4	0.35	0.56
19.1	0.21	0.38
15.4	0.11	0.27

Signal-to-noise ratio

- SNR: The real measured signal to noise
- Calculate the SNR for each visible sphere

$$\mathbf{SNR} = \frac{\left|\bar{\mathbf{N}}_{sphere} - \bar{\mathbf{N}}_{\mathbf{bkg}}\right|}{\boldsymbol{\delta}_{\mathbf{bkg}}}$$

Let’s calculate!

References

- https://amide.sourceforge.net/
- https://humanhealth.iaea.org/HHW/MedicalPhysics/NuclearMedicine/QualityAssurance/NMQC-Plugins/index.html