GATE activities at Lyon

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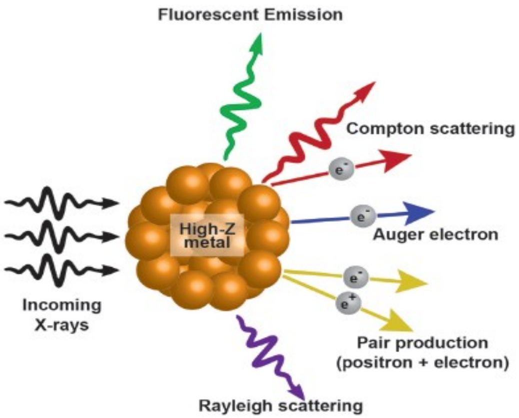
Outline

- Quantification of SPECT images
- Clinical SPECT simulations
- Simulation of preclinical SPECT with pinhole collimator

Why we need to quantify images?

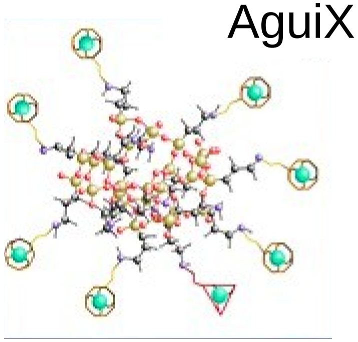
- Conventional radiotherapy is ineffective in case of certain type of cancer (ex. chondrosarcomas)

- Radiosensitization of tumors with high-Z nanoparticles
  → increase cross-section between X-ray and tumor tissue



- Gadolinium nanoparticles (AguiX)
  - functionalized with quaternary ammonium target proteoglycans
  - Intravenous or intra-tumor injection

AguiX



- Delivered radiotherapy dose is defined by nanoparticles concentration and localization

- Quantified imaging
  - **SPECT**
  - **Spectral CT (SPCCT)**
  - PET
  - MRI

Quantification of SPCCT images

- Spectral photon counting CT
- CT with several energy windows
- K-Edge imaging for selective and quantitative detection
- Direct concentration of Gd is measured
- High resolution but also high image noise
- Sensitivity

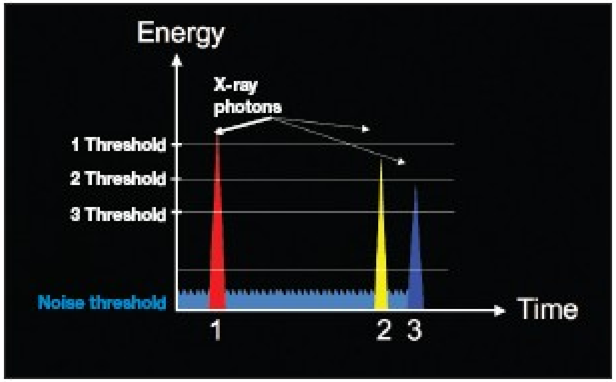
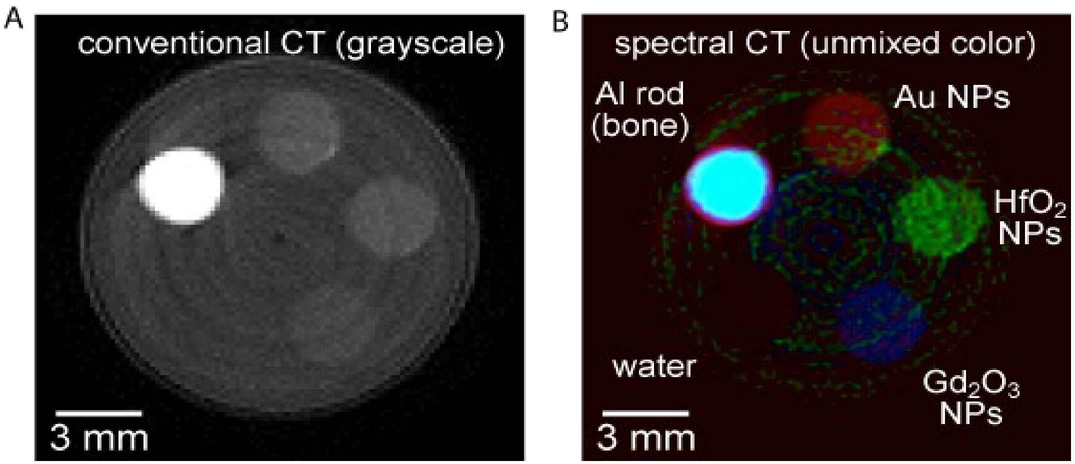
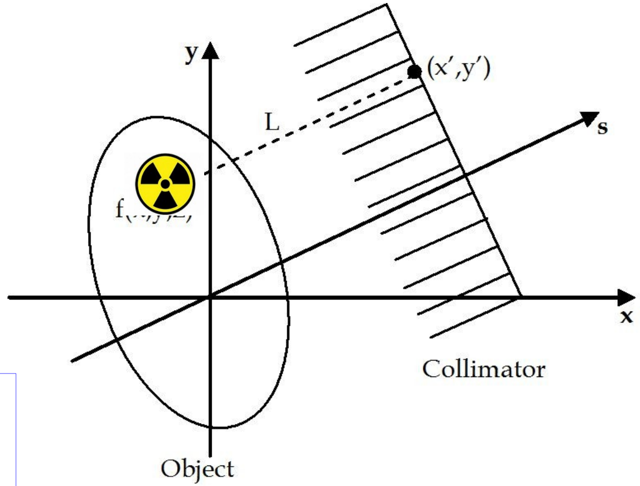


FIGURE 1. What does it mean to count photons? Observed pulse height from each x-ray provides an estimate of energy. This corresponds to the x-ray's "color." All electronic noise can be eliminated with a separate threshold, regardless of how small the pixel size or how low the radiation dose.

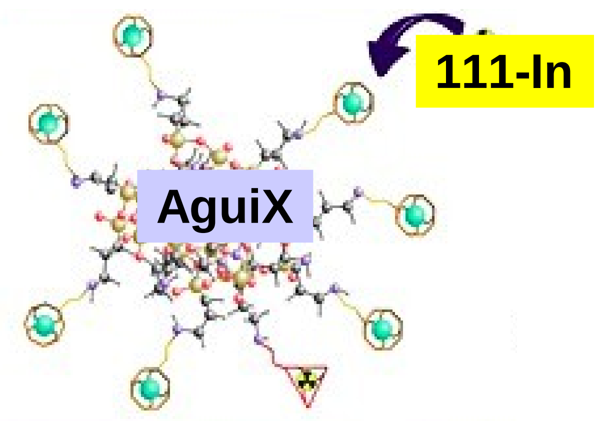


Quantification of SPECT images

- Single photon emission tomography: Direct emission of gamma
  $^{111}In \rightarrow {}^{111}Cd + \gamma_{171keV}/\gamma_{245keV}$
  $^{99m}Tc \rightarrow {}^{99}Tc + \gamma_{141keV}$
- Use collimator to detect the direction
- Save projections for a set of angles
- Tomographic reconstruction



In our case :
- Gd AguiX coupled in 111-In
- Aim: in vivo
- Development of protocols and proof of concept on Preclinical NanoSPECT/CT and SPCCT

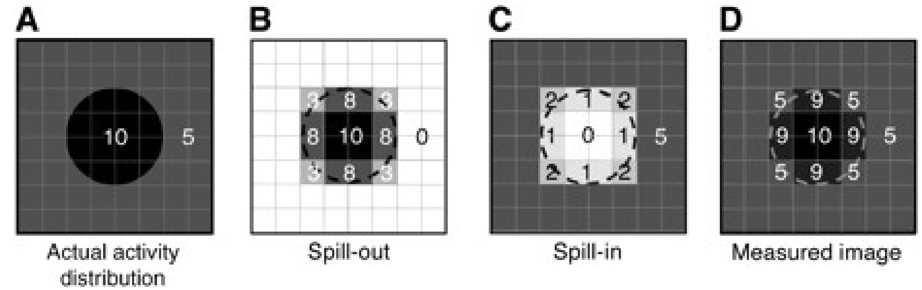


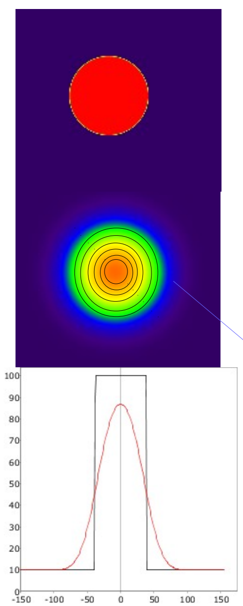
- Calibration is challenging
- Corrections (attenuation, scatter, dead time, kinetic of the activity distribution, partial volume effect etc)
- Use MC for some of them

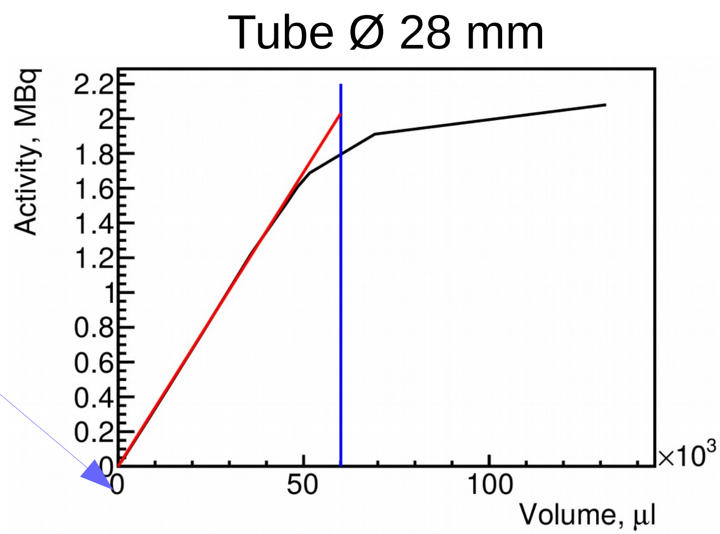
Partial Volume Effect in SPECT

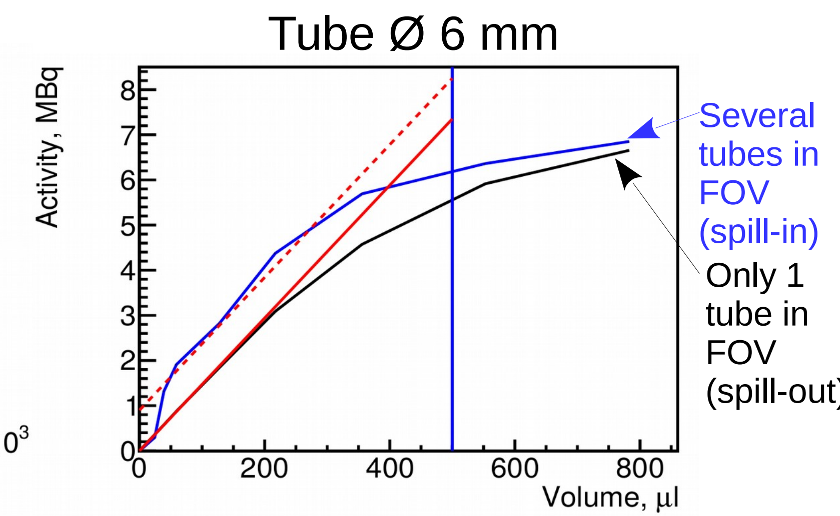
- Due to finite spatial resolution
  → Bias on the measured activity
  Spill-out and Spill-in

- Effect is more significant for small volumes









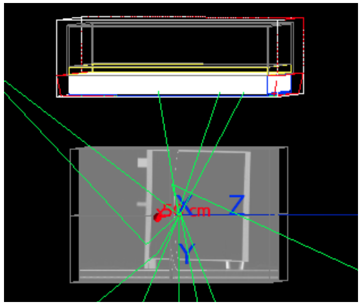
- **Partial Volume Effect is crucial for quantification measurement**
- **MC simulations for adequate corrections**

GATE simulations for SPECT quantification

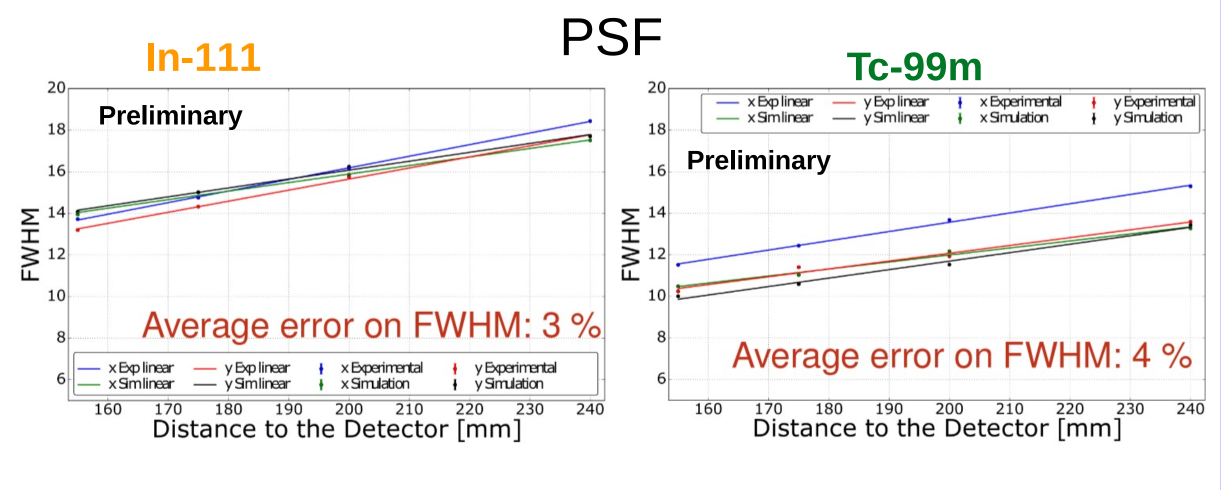
M. Jacquemin, A. Halty, D. Sarrut

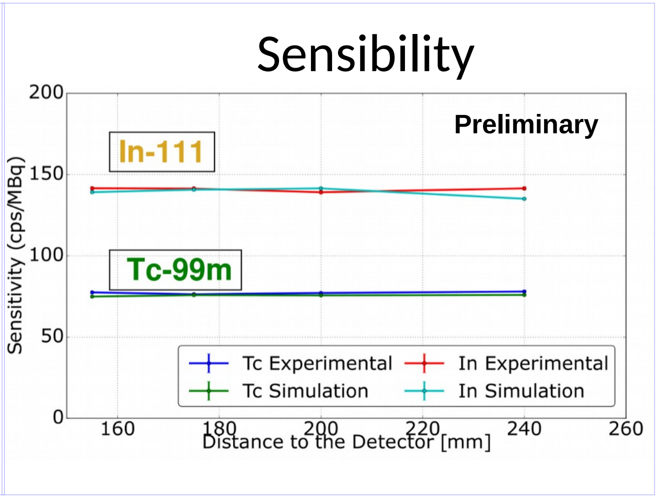
GATE: Clinical SPECT

- **Clinical SPECT/CT : GE Disco NM/CT 670**



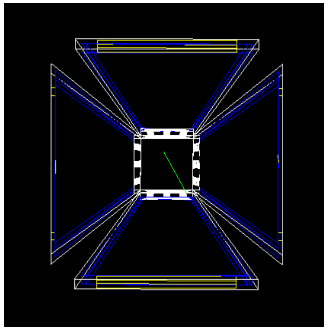
- Validations for two tracers Tc-99m and In-111 in progress:

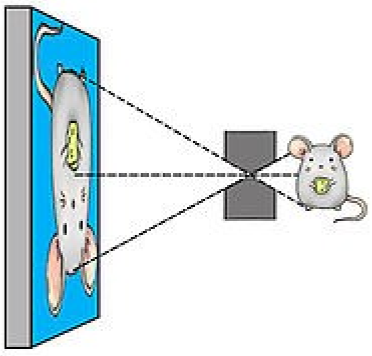




- Validation to be done
  - For energy spectrum
  - Complex shaped phantoms
  - Clinical data
  - Lu-177 tracer

GATE: NanoSPECT with pinhole collimator





- 4 detector heads
- Pinhole collimator
  - Cone-shaped holes
  - Angle between the cones and plate → focalization
- Reconstruction code by Jared Strydhorst

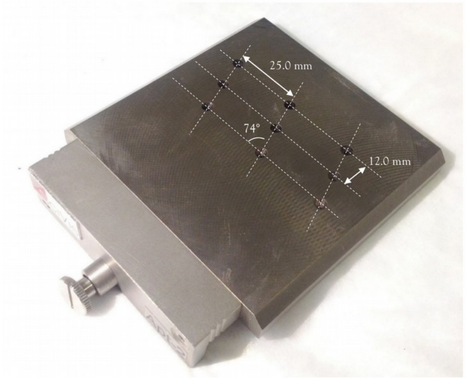
- The geometry is simulated already
  - New Class **GateParameterisedPinholeCollimator**

```
/gate/SPECThead/daughters/name colli
/gate/SPECThead/daughters/insert pinhole_collimator
/gate/colli/geometry/input mac/APT2.pin
```

APT2.pin
-(x,y) positions
-diameter
-cone opening angle
-(x,y) focal positions

- Preliminary results on sensitivity

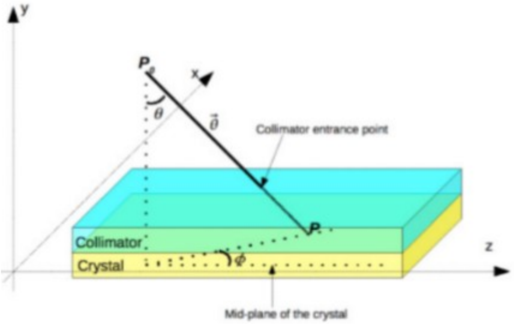
Tc-99m	Data	MC	Diff, %
Without collimator	(28.56±0.07)%	(29.17±0.05)%	2.1%
With collimator	(0.112±0.003)%	(0.109±0.002)%	2.7%



- Acceleration is essential!

Acceleration techniques: ARF

Implemented in GATE and validated for SPECT with parallel hole collimator



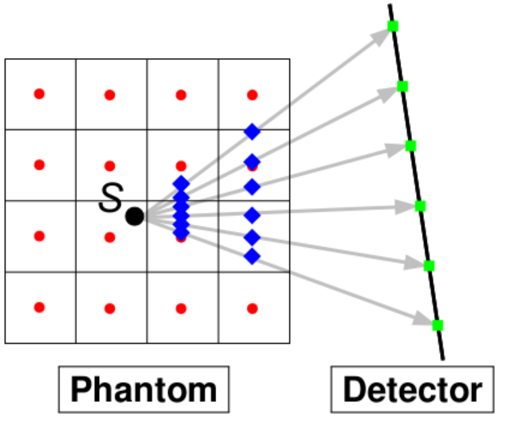
- **Angular Response Function (ARF)**
  - Replace collimator+detector response by tabulated modeling
  - Simulation of the detector response for a plane source
  - Computation of tables depending of the incident energy and the direction (θ, φ)
  - Couple of small bugs were fixed
  - Still unexplained bias in some cases

Implementation of Angular Response Function Modeling in SPECT Simulations With GATE - Descourt, Carlier, Du, Song, Buvat, Frey, Bardies, Tsui, Visvikis - 2010

Acceleration techniques: FFD

Implemented in GATE and validated for SPECT with parallel hole collimator

- **Fixed Forced Detection (FFD)**



  - Replace the tracking thought phantom toward detection plane
  - Deterministic response of every pixel at each Monte-Carlo interaction
  - Store probability for each MC interaction instead of events

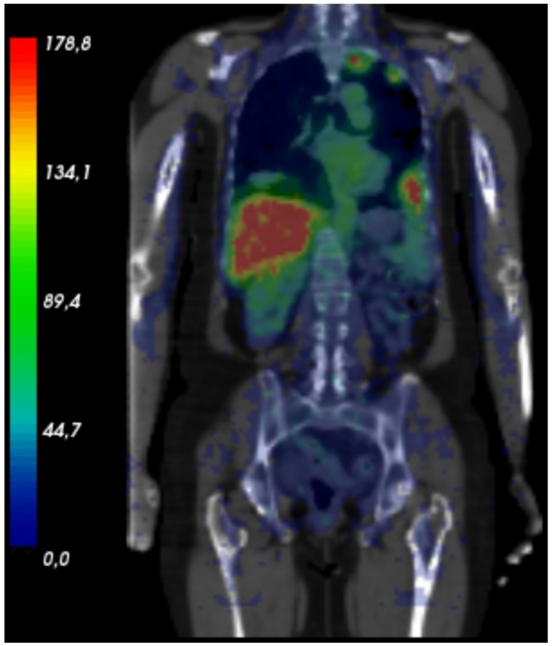
Gain in computation time
ARF+FFD vs. analog → 10^5
ARF+FFD vs. ARF only → 10^3

Fixed Forced Detection for fast SPECT Monte-Carlo simulation, Cajgfinger, Rit , Létang, Halty, Sarrut. Submitted to PMB
Fixed Forced Detection For X-Ray Imaging - Rit, Romero, Vila Oliva, Smekens, Arbor, Cajgfinger, Sarrut, Letang, Freud

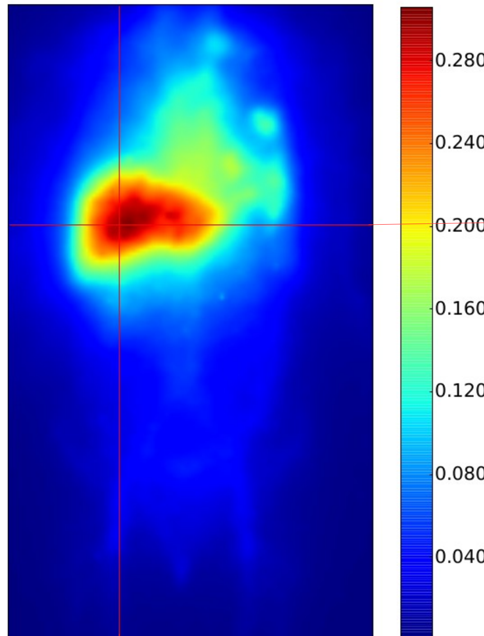
T. Cajgfinger, S. Rit, D. Sarrut

Acceleration techniques: FFD

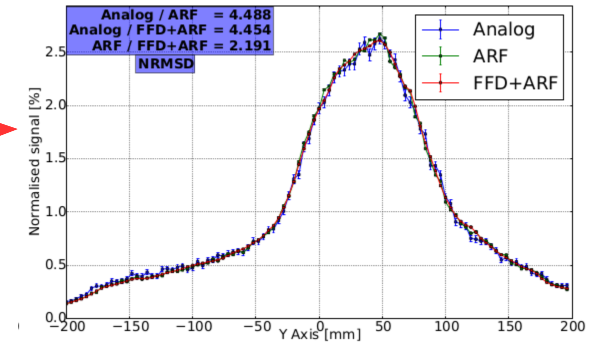
SPECT/CT data

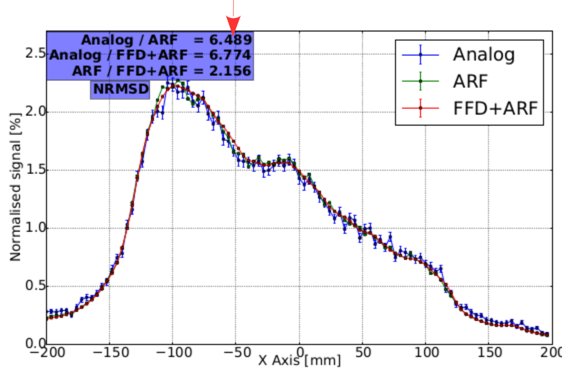


FFD+ARF projection



Comparison of Analog, ARF and FFD+ARF





$N_{primaries}$: 4×10^{10}, 10^{10} and 2×10^{6}

$t_{computation}$: 389 d, 87 d and 13 h

Intel Xeon CPU E5-1660 @ 3.30GHz

Fixed Forced Detection for fast SPECT Monte-Carlo simulation, Cajgfinger, Rit , Létang, Halty, Sarrut. Submitted to PMB

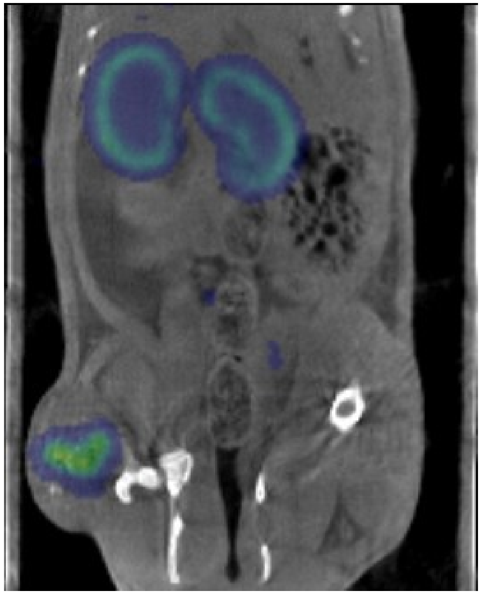
Conclusion and plans

- Use GATE simulations for corrections essential in SPECT quantification
  Attenuation, scatter, dead time, kinetic of the activity distribution, ***partial volume effect*** *etc*

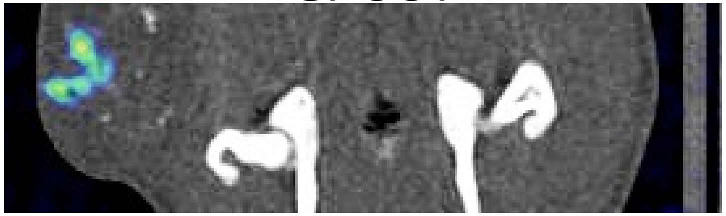
- Implement ARF+FFD for pinhole collimator system

- Validation on data

NanoSPECT/CT



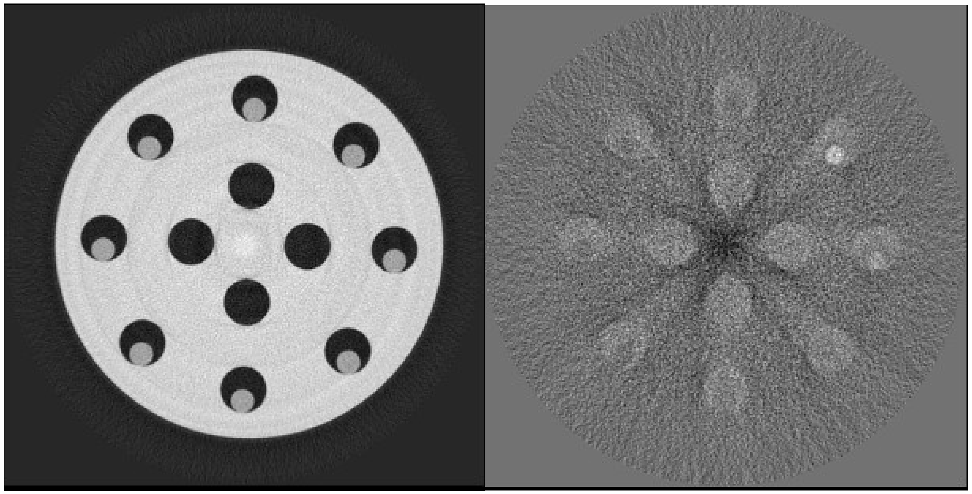
SPCCT



First measurements

Spectral CT (SPCCT)

Water Gadolinium



SPECT/CT

111-In