Nuclear Medicine: Gamma cameras, SPECT and PET

A brief introduction for DTU students
Introduction to medical imaging, 2022

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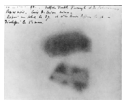
Part 1: Radioactive Decay

Radioactivity – Discovery

- 1896: Henry Becquerel studies phosphorescence and discovers radioactivity (^{238}U)
- 1898: Marie Skłodowska Curie & Pierre Curie discover Radium (^{226}Ra)
- 1903: shared Nobel Prize for "his discovery of spontaneous radioactivity" and "their joint researches on the radiation phenomena discovered by Professor Becquerel"



Radioactivity – Types of Radiation

- Ernest Rutherford: 3 distinct types of radiation:
  - α, β (described and named by Rutherford in 1899)
  - γ (named in 1903, discovered by Paul Ulrich Villard in 1900)
- "Father of Nuclear Physics", Nobel Prize 1908

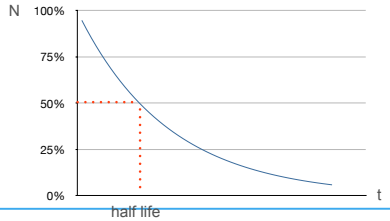
Radioactive Decay

- observation: each nucleus has a constant probability of decay per unit time
- Rutherford's law of decay:

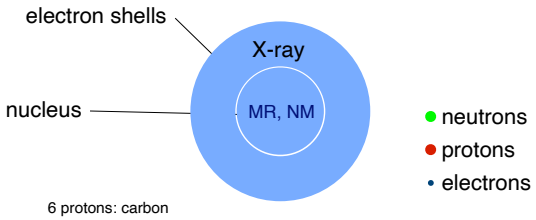
$$N(t) = N_0 \cdot e^{-\lambda t}$$

$$= N_0 \cdot e^{-\ln 2 \, / \, T_{1/2}}$$

half life



Structure of an atom



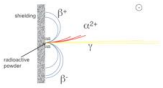
6 protons: carbon

neutrons:
5: ^{11}C
6: ^{12}C
7: ^{13}C
8: ^{14}C

same chemistry
⇒ "tracer"

Part 2: Detection of Radiation

Radiation for Imaging ..



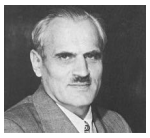
- α^{2+} range: < 1mm (stopped by air)
- $\beta^{\pm}$ range: few mm (stopped by plastic)
- γ penetrating (attenuated by lead)

- only γ can be easily detected outside an object

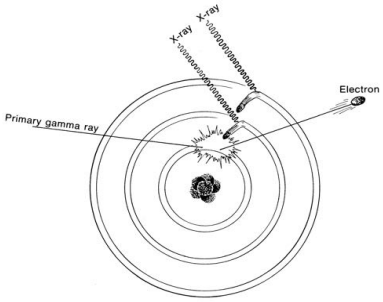
- all decays which involve γ with energies > 80keV are potentially useful for imaging:
  - isomeric transition
  - β^- with subsequent X-ray
  - β^+ has always subsequent annihilation radiation

Interaction of γ with Matter

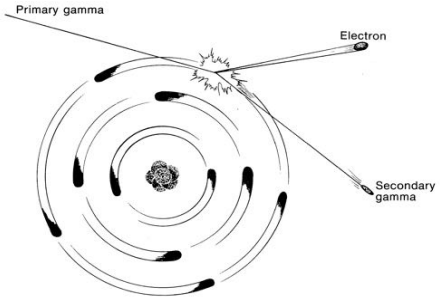
- photo(-electric) effect
- Compton effect
- pair production (energy > 1022 keV)



Photoelectric Effect

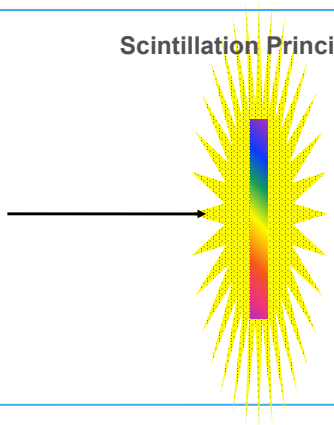


Compton Effect



Scintillation Principle

Na-I (Tl) crystal
(thallium doped sodium iodide)



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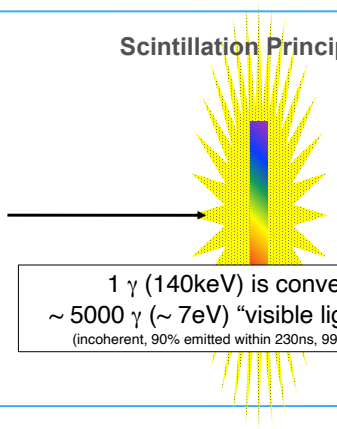
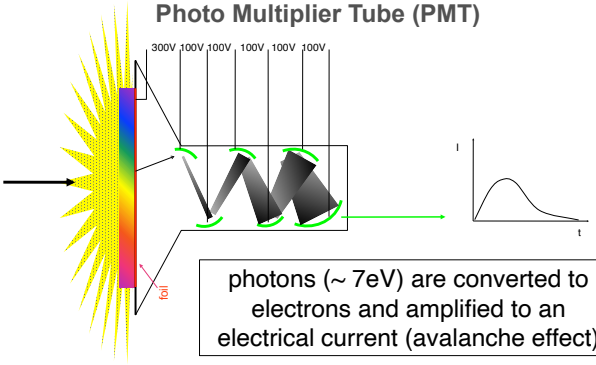


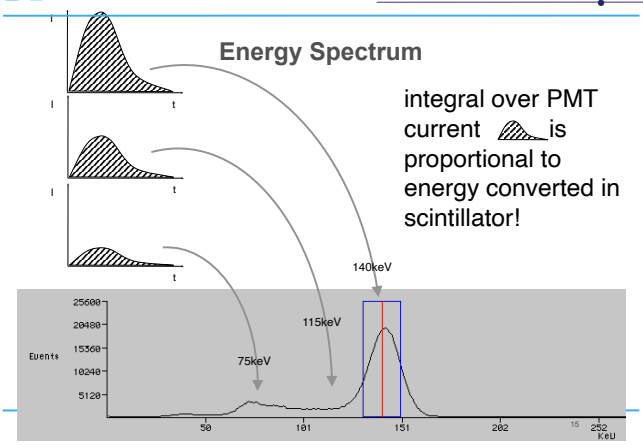
1 γ (140keV) is converted to
~ 5000 γ (~ 7eV) "visible light"-photons
(incoherent, 90% emitted within 230ns, 99% within 150ms)

Photo Multiplier Tube (PMT)



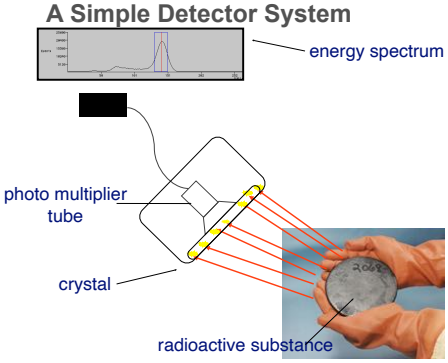
photons (~ 7eV) are converted to electrons and amplified to an electrical current (avalanche effect)

Energy Spectrum



integral over PMT current is proportional to energy converted in scintillator!

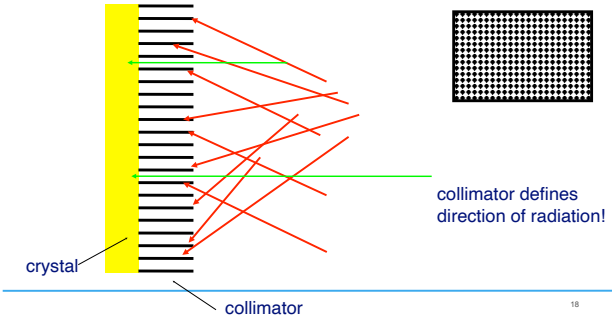
A Simple Detector System



Part 3: Planar Imaging

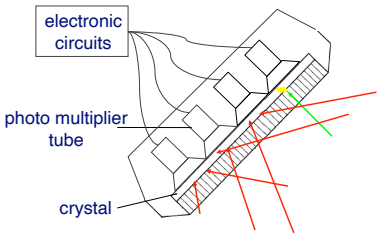
Collimator

- lead mask with pinholes

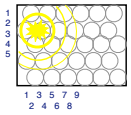


Spatial Resolution!

- 1 crystal + many PMTs + collimator

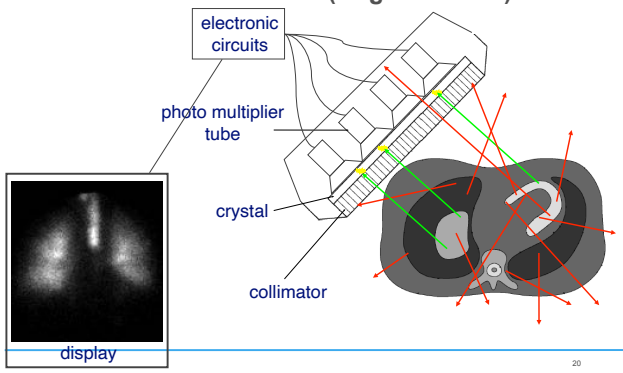


the electronics weighs the inputs from the individual PMTs and calculates the location of the photon

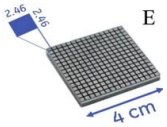


X_{pos} =3%*1 + 6%*2 + 80%*3 + 6%*4 + 3%*5 + 1%*6 +1%*7
=2.42

Gamma Camera (Anger Camera)



The future

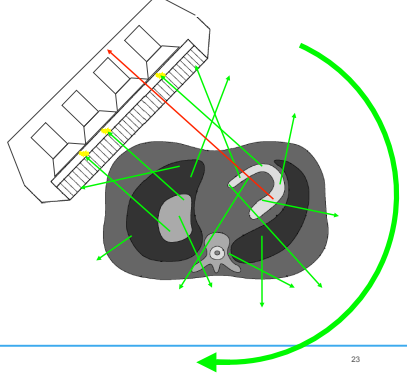


from: Eur J Nucl Med Mol Imaging. 2010 Oct; 37(10): 1887–1902.

Part 4: SPECT

What is SPECT?

Single
Photon
Emission
Computed
Tomography



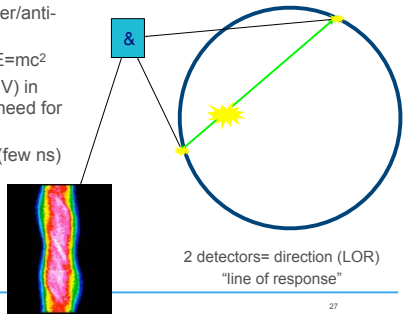
SPECT/CT

Part 5: PET

PET Camera

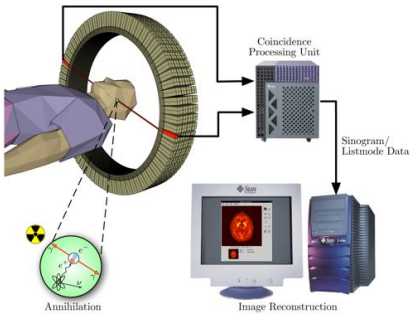
PET acquisition

- primary particle: positron
- e^-/e^+ annihilation (matter/anti-matter reaction)
- rest mass ⇒ energy: $E=mc^2$
- 2 photons (E=2*511 keV) in opposite direction (no need for collimators!)
- coincidence detection (few ns)
- sinogram



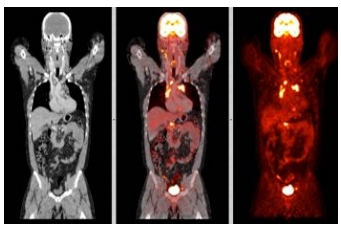
2 detectors= direction (LOR)
"line of response"

PET - schematically



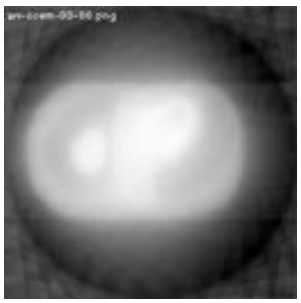
Clinical PET/CT

- combines PET (function) with CT (anatomy)
- virtually noise-free attenuation correction

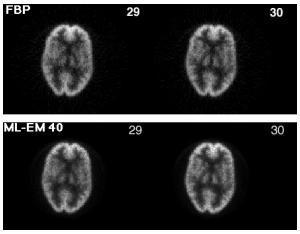


^{18}F-FDG PET/CT

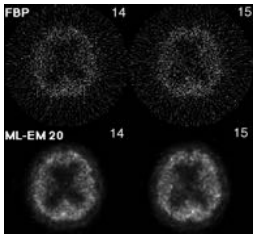
Iterative Reconstruction



Iterative Reconstruction



little noise in images
little benefit



lots of noise in images
large benefit

Part 6: Physiology

What Does an NM Image Show?

- tracer principle
  - 500MBq ^{99m}Tc-MIBI ≈ 10^{14} molecules!
  - 1 µl water ≈ 10^{19} molecules!
- spatial distribution of the radioactive isotope
  - pharmaceutical labeled with radioactive isotope
  - distribution of the pharmaceutical
  - not anatomy but physiology

Anatomy versus Function

- X ray, CT, MR, US:
  - anatomy (mostly)
    - bone
    - soft tissue
    - ...
- nuclear medicine/ molecular imaging:
  - physiology (mostly)
    - perfusion
    - metabolism
    - receptor density
    - ...

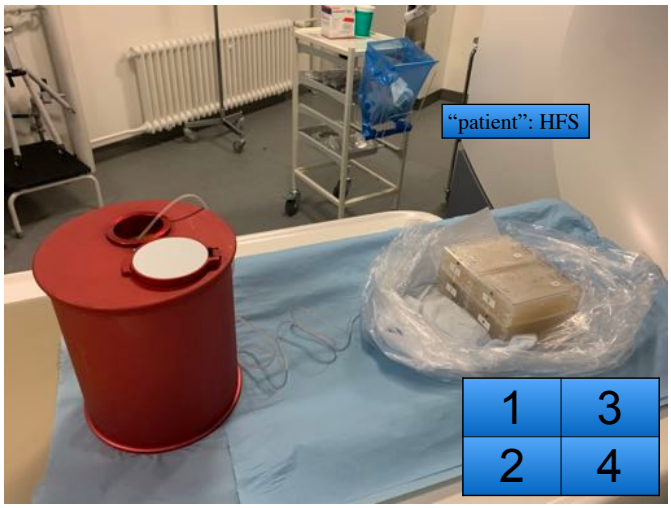
Part 6: Data acquisition 2022

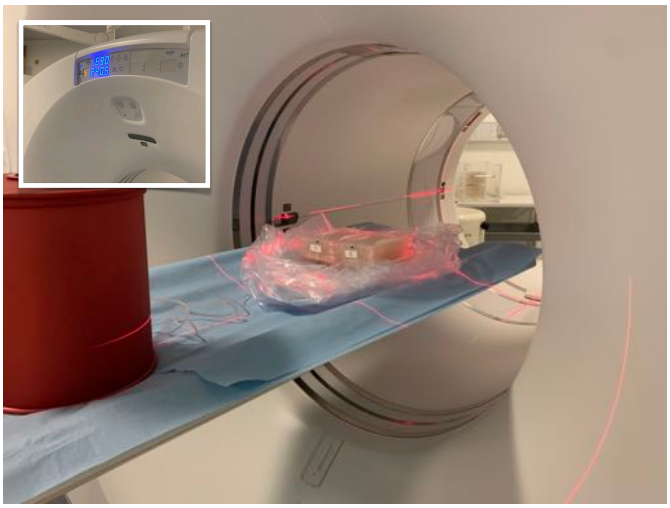
Idea (1)

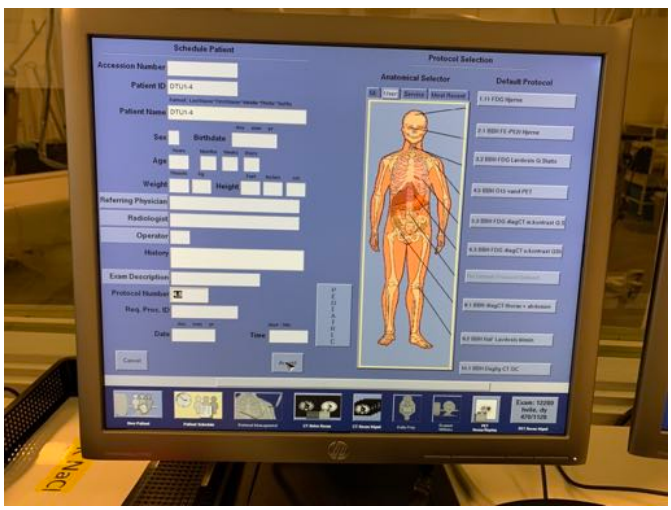
- PET radionuclide: [^{15}O]
  - half-life: ca. 123 s
- PET radiopharmaceutical: [^{15}O]-H_2O
  - bolus injection of [^{15}O]-H_2O
    - pre-flush: 60 s
    - bolus ca. 10 s (radionuclide!)
    - flush: 15 s
  - pumped with constant flow into the phantoms
  - flow: 600 ml/h
- static imaging: summary view over several minutes
- dynamic imaging (3 s per frame): movie
  - reconstructed with 2 different algorithms

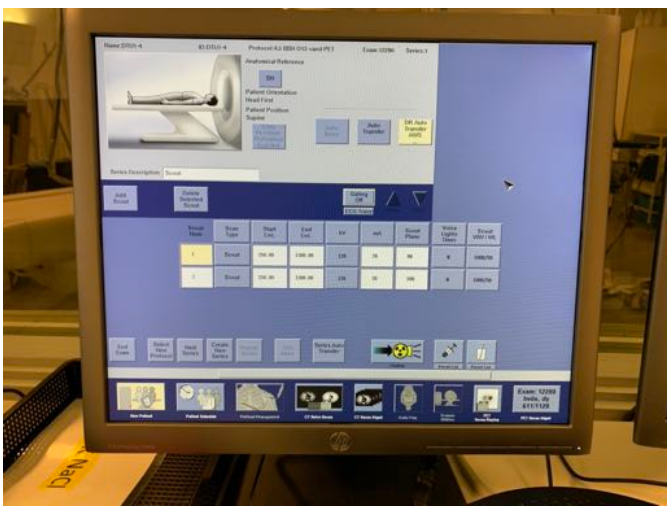
Idea (2)

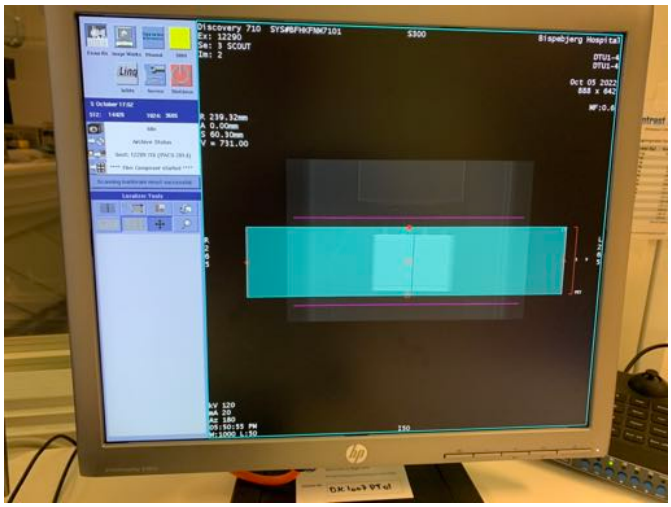
- Scout (top & side view)
  - 2 images
- CT
  - for attenuation correction
  - thin slices
  - thin slices with 25 cm FOV and filter “Detail”
- CT Dose
  - 2 series
- PET
  - static (47 slices)
  - dynamic OSEM (47 slices * 50 frames)
  - dynamic BSREM (47 slices * 50 frames)










Discovery 710
Bispebjerg Hospital
Oct 05 2022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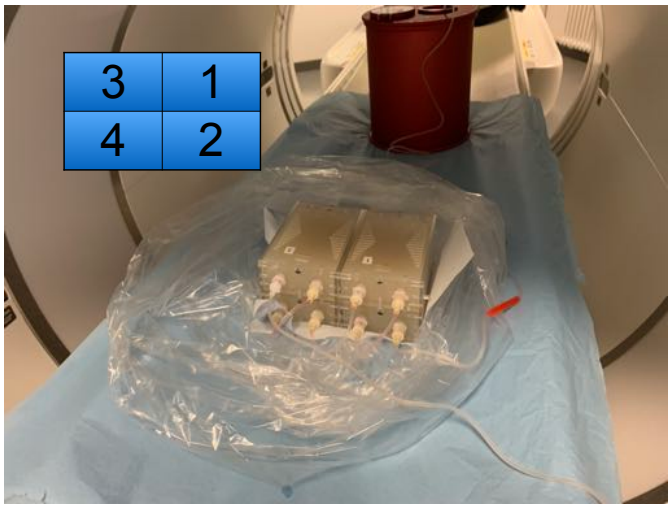
System Countrate (kcps)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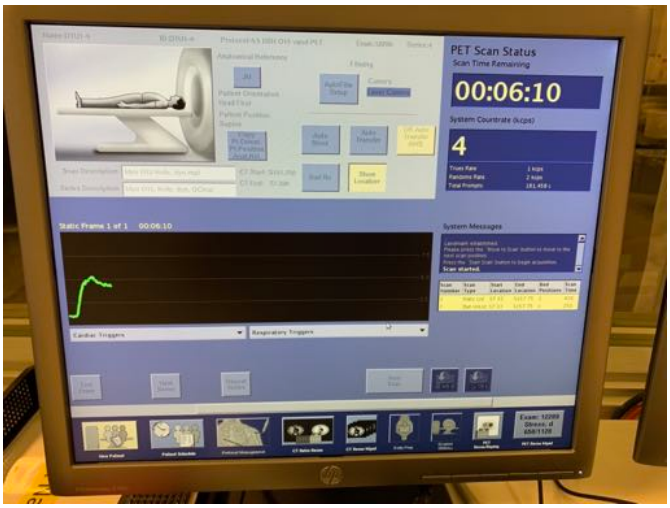
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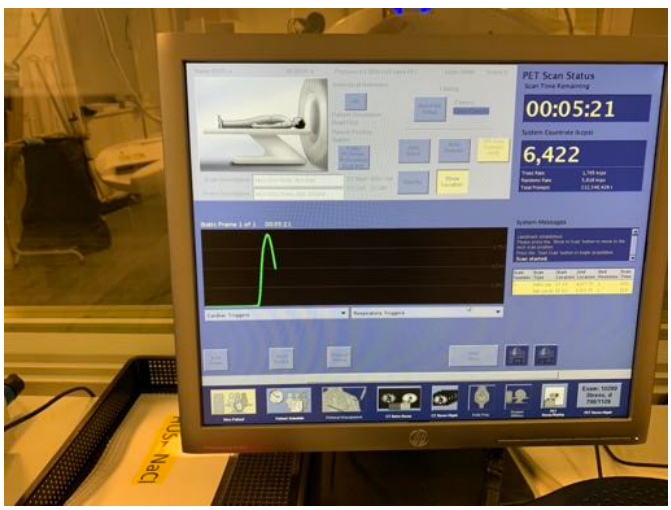
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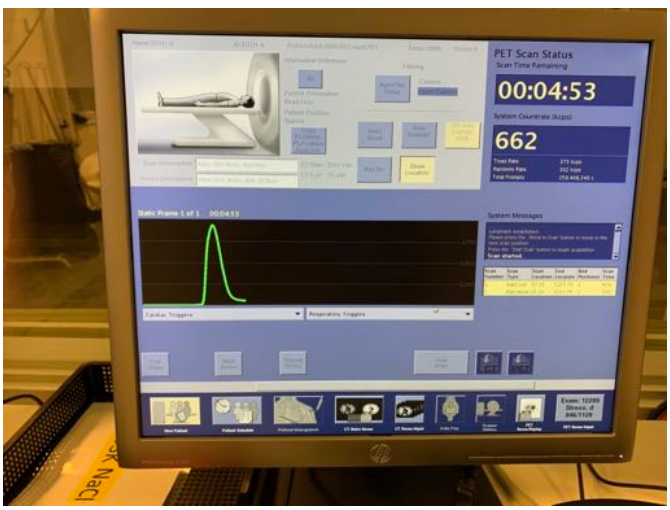
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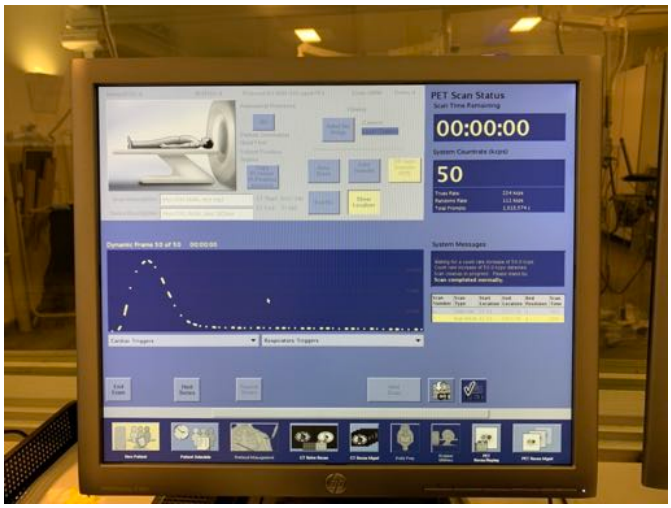
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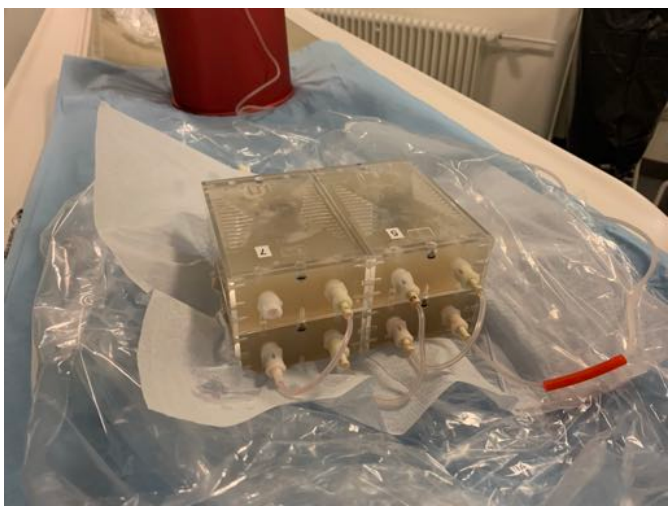

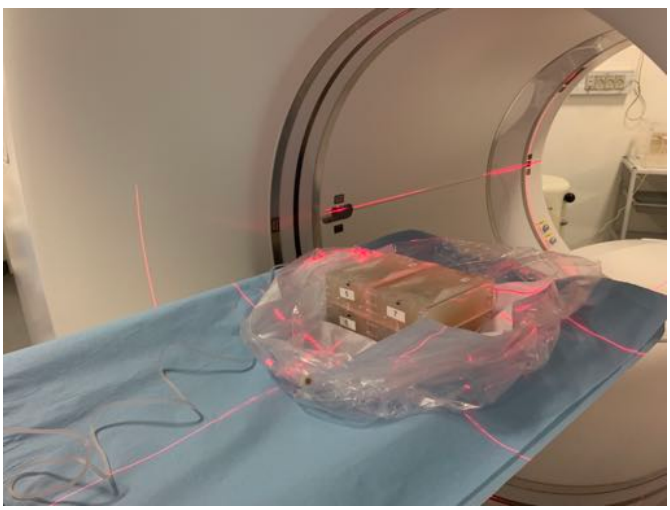

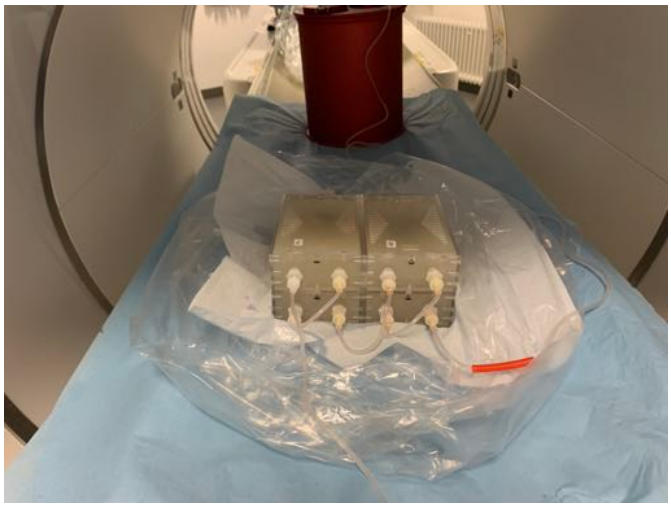

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