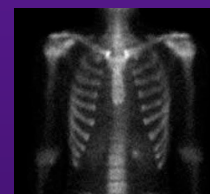
Introduction to Emission Tomography

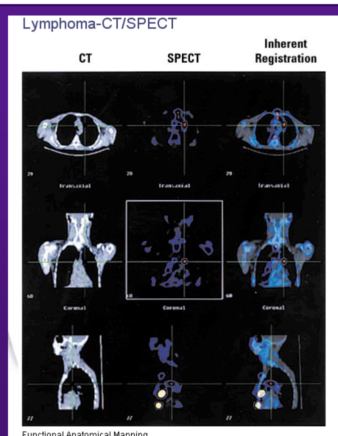
Tom Lewellen

June 2006

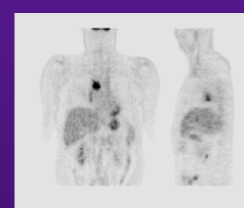
You have heard about planar imaging with Nuclear Medicine gamma cameras



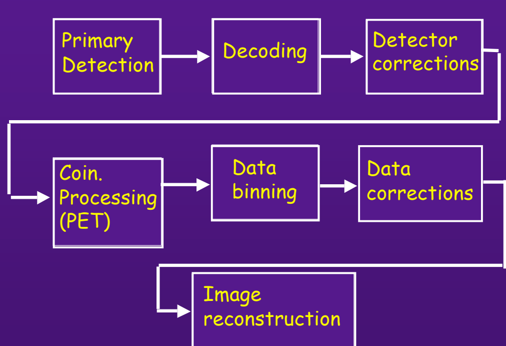
Now, we look at SPECT....



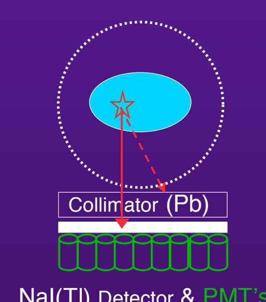
... and Pet



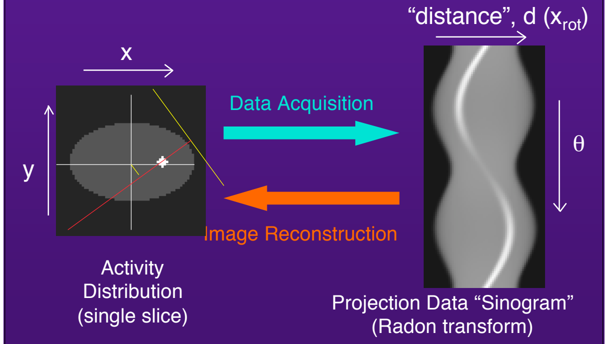
The basic steps to make a tomographic image

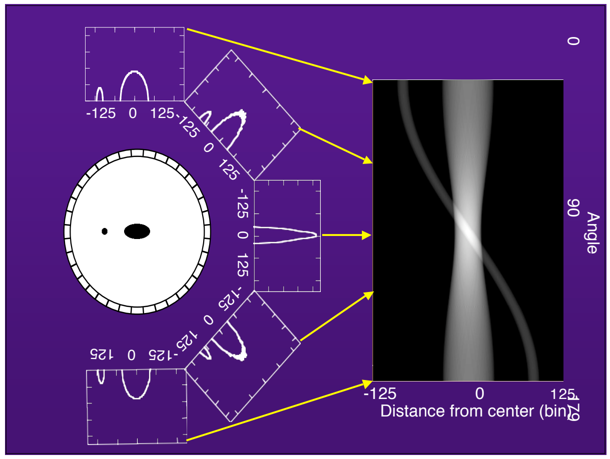


Single Photon Emission Computed Tomography (SPECT)

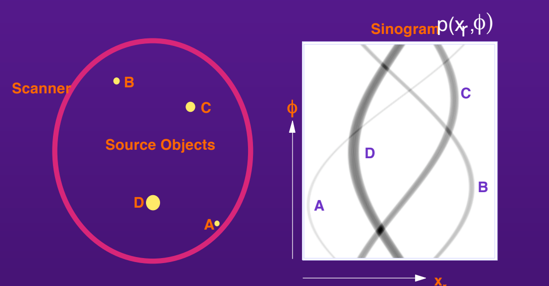


Intro to Emission Tomography
(PET and SPECT)





Sinogram Example

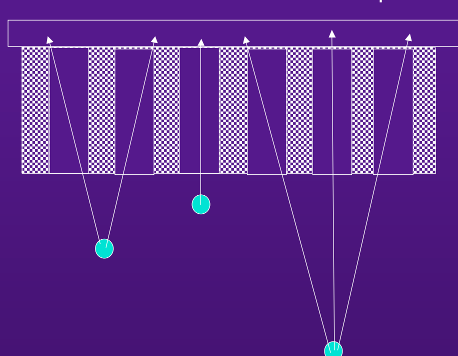


- The sinogram is p(x_r,ϕ) organized as a 2D histogram

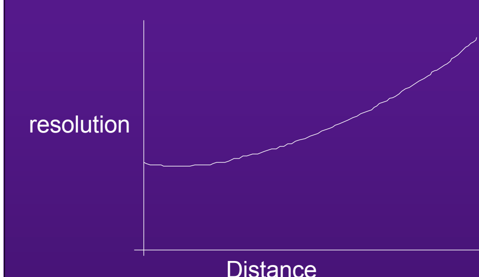
Real world detection

- Imaging systems are not perfect
- Several aspects of photon transport need to be considered and in some cases corrected ….

Loss of resolution with depth

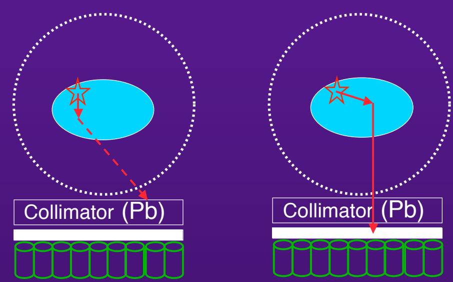


System Resolution



$$R_{system} = \sqrt{R^2_{detector} + R^2_{collimator}}$$

Scatter & Attenuation in SPECT



Attenuation

Count deficit because of scatter and PE absorption

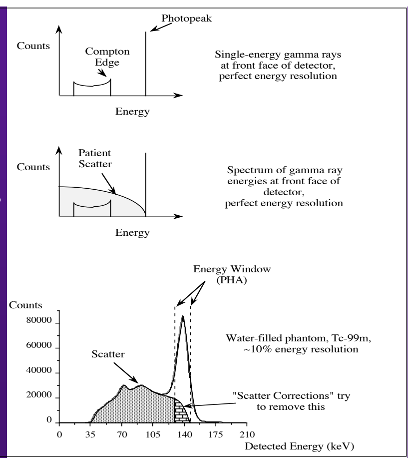
Scatter

Count excess and misplaced events from Compton scatter within the patient

Energy Windowing

- Partial discrimination between scatter and non-scatter (true) events.

What does the PHA do?



What about attenuation?

Need an attenuation map and a reconstruction algorithm

Attenuation map…

- Two basic approaches:
  - 1. Assume the body is bag of water, draw an ROI around object and renormalize the image data.
  - 2. Use an external source to acquire attenuation data (poor man's CT) or add a CT scanner to the SPECT system.

Which to use?

An example of the "bag of water" approach is in the text (Chang method) - not really used much since the basic assumption is not realistic.

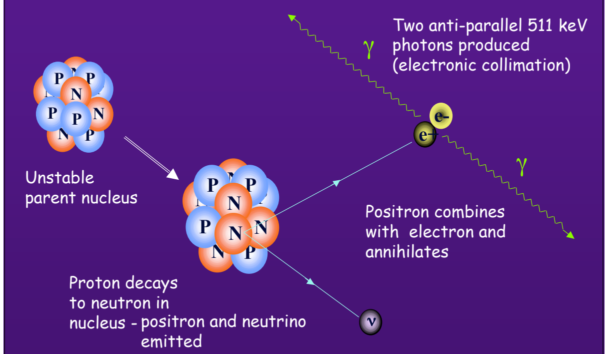
Using measured attenuation data requires an iterative reconstruction algorithm - more about that later in the talk.

Most of the time, we do not use attenuation correction in SPECT

What is different about PET?

Gamma rays in coincidence!

PET basics - positron annihilation

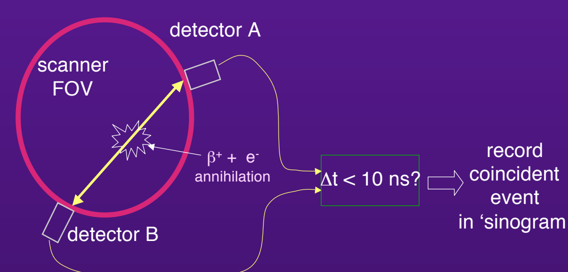


A few things to note about positron decay

1. Range of positron (< 2 mm for F-18)
2. Non-collinearity - the gamma rays are not exactly at 180 degrees, the FWHM of the angular spread is ~ 0.3 degrees
3. Resolution effects, like gamma cameras, generally add in quadrature:

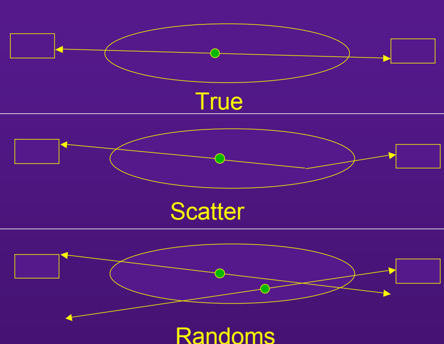
$$FWHM = \sqrt{FWHM_{\det}^2 + FWHM_{colin}^2 + FWHM_{range}^2}$$

Coincidence Timing

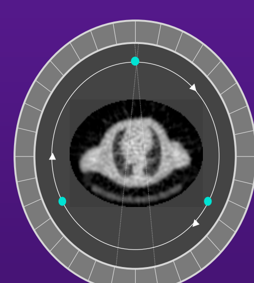


- No need for collimation, thus much higher sensitivity than SPECT
- Also correction for attenuation is easier.
- Simpler chemistry, but you need a cyclotron

Types of coincidence events

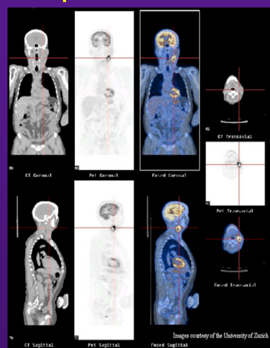


Transmission scanning in PET



- **Transmission rod sources rotate around the patient**
- **Acquisition is a high energy CT scan**
- **Data allows accurate attenuation correction**

The modern option - CT

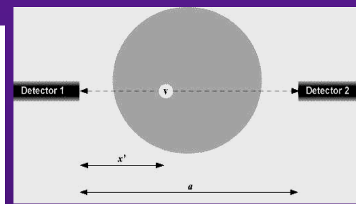


Images courtesy of CPS and GEMS web sites.

Effects of Attenuation in PET

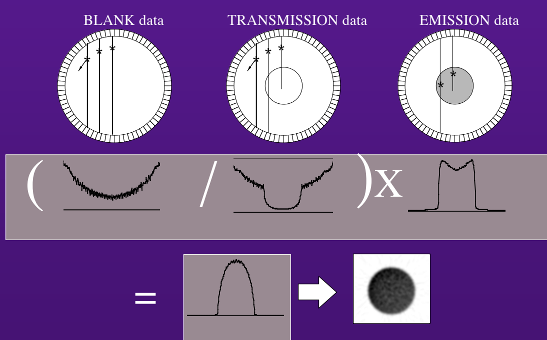
$$P_1 = e^{-\int_0^{x'} \mu(x)dx}$$

$$P_2 = e^{-\int_{x'}^{a} \mu(x)dx}$$

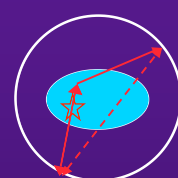


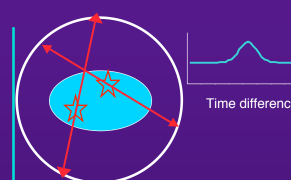
$$P_C = P_1 P_2 = e^{-\int_0^{a} \mu(x)dx}$$

Attenuation Correction
For PET

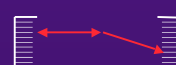


Scatter & Randoms in PET



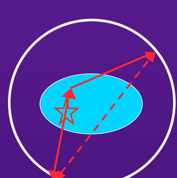


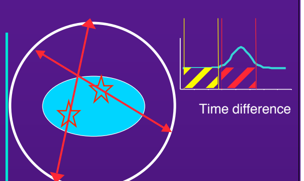
In-plane scatter usually accepted
Out-of-plane scatter usually rejected



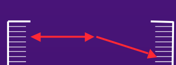
- Random coincidence rate, R ∝ S^2
- True coincidence rate, T ∝ S
- R can be estimated using a delayed coincidence technique, so randoms can be accurately subtracted. But, this increases the noise.

Scatter & Randoms in PET



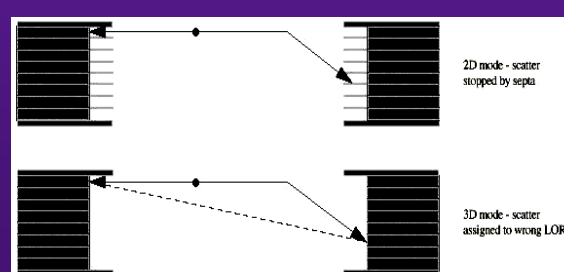


In-plane scatter usually accepted
Out-of-plane scatter usually rejected



- Random coincidence rate, R ∝ S^2
- True coincidence rate, T ∝ S
- R can be estimated using a delayed coincidence technique, so randoms can be accurately subtracted. But, this increases the noise.

What is the difference between “2D” and “3D” modes of operation



3D is not perfect!

Complex topic - not enough time to cover it today

A few points

- 3D => more counts than 2D
- BUT, randoms and scatter are higher => reduced image quality.
- Generally great for brains, still open for debate for body imaging!

So, we have binned the data - now what?

Image Reconstruction

- Takes raw sinogram from scanner and estimates underlying distribution (e.g. tracer concentration, tissue density)
- Can treat as a black box (involves complex mathematics)
- There are, however, important user-specified control parameters that affect the noise/resolution trade-offs

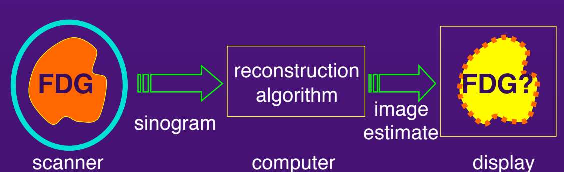
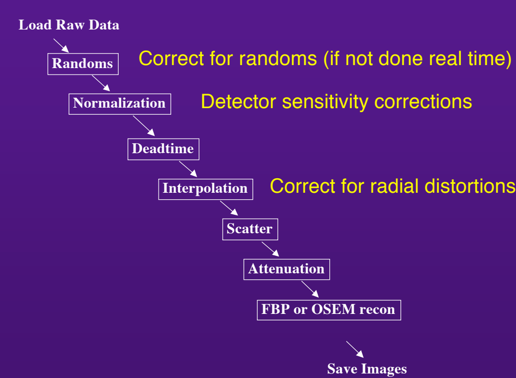
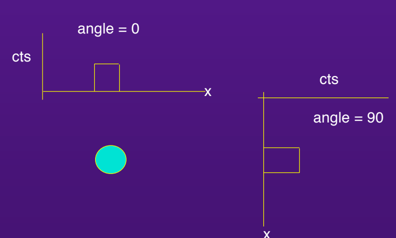


Image reconstruction - the basic flow

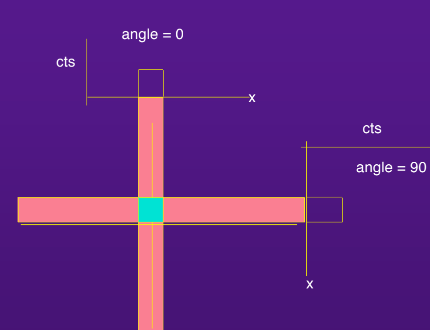


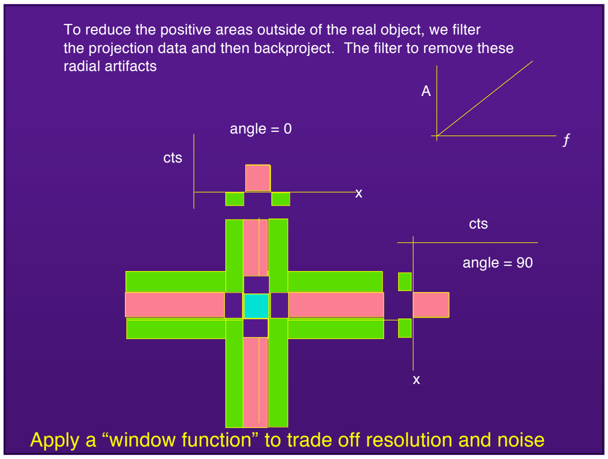
Reconstruction of images from projections - FBP

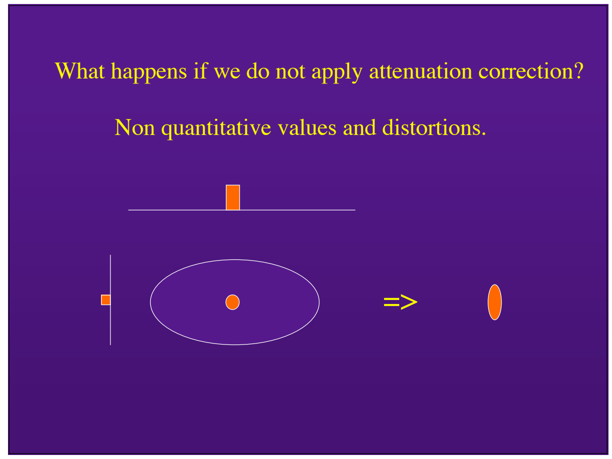
Consider a pillbox of activity and a series of projections

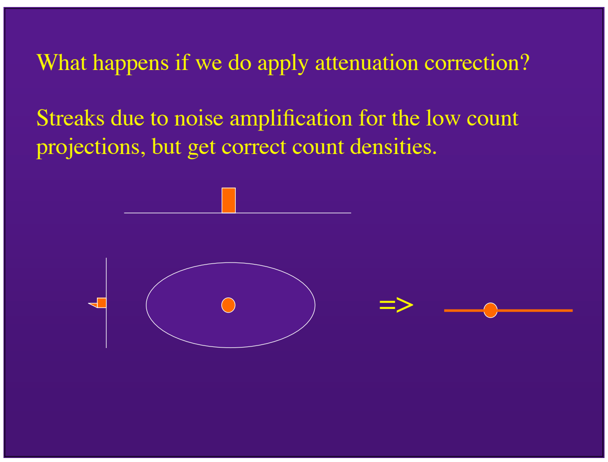


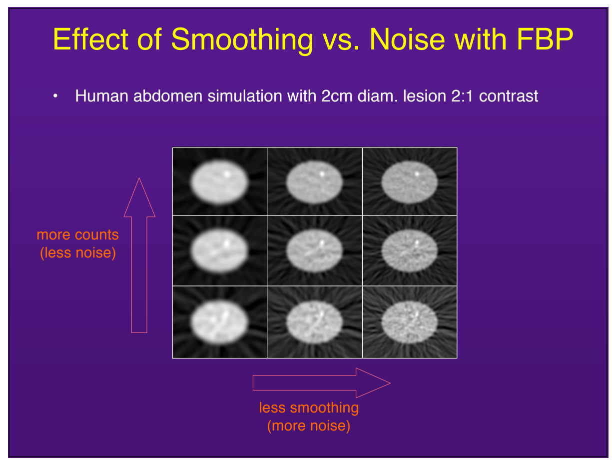
Now we backproject the acquired data

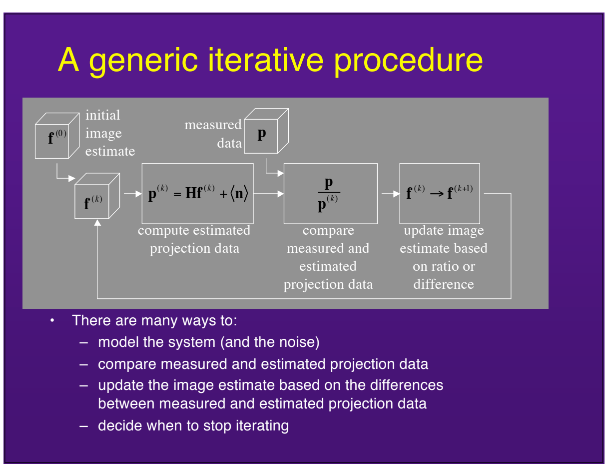


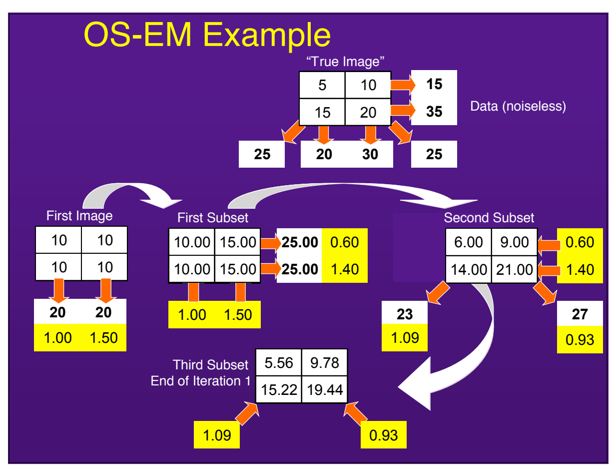

To reduce the positive areas outside of the real object, we filter the projection data and then backproject. The filter to remove these radial artifacts
A
f
angle = 0
cts
x
cts
angle = 90
x
Apply a “window function” to trade off resolution and noise


What happens if we do not apply attenuation correction?
Non quantitative values and distortions.
=>


What happens if we do apply attenuation correction?
Streaks due to noise amplification for the low count projections, but get correct count densities.
=>


Effect of Smoothing vs. Noise with FBP
• Human abdomen simulation with 2cm diam. lesion 2:1 contrast
more counts
(less noise)
less smoothing
(more noise)

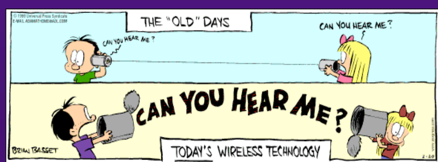

A generic iterative procedure
initial image estimate
measured data
compute estimated projection data
compare measured and estimated projection data
update image estimate based on ratio or difference
• There are many ways to:
– model the system (and the noise)
– compare measured and estimated projection data
– update the image estimate based on the differences between measured and estimated projection data
– decide when to stop iterating


OS-EM Example
“True Image”
5 10
15 20
15
35
Data (noiseless)
25 20 30 25
First Image
10 10
10 10
20 20
1.00 1.50
First Subset
10.00 15.00
10.00 15.00
25.00 0.60
25.00 1.40
1.00 1.50
Second Subset
6.00 9.00
14.00 21.00
0.60
1.40
23
1.09
27
0.93
Third Subset
End of Iteration 1
5.56 9.78
15.22 19.44
1.09
0.93

A final thought

How many counts do we really need?

As many as we can get!!



Some test questions

D68. Positron cameras detect:

A. Positrons of the same energy in coincidence.
B. Positrons and electrons in coincidence.
C. Photons of different energies in coincidence.
D. Annihilation photons in coincidence.
E. Annihilation photons in anticoincidence.

D69. Spatial resolution of PET systems is determined by:

A. Detector size.
B. The ring diameter of the system.
C. The detector material.
D. Energy of the positron emitter in use.
E. All of the above.

D76. The spatial resolution of a SPECT image vs. a stationary image with the same camera is:

A. Much worse.
B. Slightly worse.
C. The same.
D. Slightly better.
E. Much better.

What about contrast resolution?
Same
Worse
Better

D77. The major limitation on the resolution of an FDG scan on a modern whole body PET scanner is:

A. Range of the positron.
B. Image matrix size.
C. The physical size of the individual detectors.
D. The non-collinearity between the annihilation photons.
E. Attenuation correction.

Why? Camera res ~ 5 mm, positron range ~ 2 mm

Non-collinearity (100 cm diameter) ~ 3.5 mm.
Range + non-collinearity ~ 4 mm

D78. A nuclear medicine resident discovers, just prior to injecting a Tc-99m bone scan agent, that the patient had a PET scan 3 hours ago at 9 a.m. in another hospital. When should the resident recommend that the bone scan be performed?

A. Straight away. There is no interference between the Tc-99m and F-18, since they can be distinguished by energy discrimination.
B. Wait until 3 p.m. allowing a 6-hour interval between tests (>3 half lives of F-18).
C. Wait until the next day to ensure complete decay of the F-18.
D. Postpone for one week, to ensure any residual long lived F- 18 daughters have decayed.

D77. Some dedicated PET scanners can perform both 2-D and 3-D scans. The difference is:

A. 2-D scans acquire transaxiai images and cannot display coronal or sagittal images.
B. 3-D scans acquire the data directly in coronal or sagittal planes.
C. 2-D scans acquire the data one slice at a time, whereas 3D scans acquire all slices simultaneously.
D. Only 3-D scans can be corrected for attenuation.
E. 2-D scans have septa in front of the detectors to reduce events from scattered photons.

D78. Positron cameras detect:

A. Positrons of the same energy in coincidence.
B. Positrons and electrons in coincidence.
C. Photons of different energies in coincidence.
D. Annihilation photons in coincidence.

D79. The assigned values in each pixel in the reconstructed image of SPECT represent:

A. Densities.
B. Absorption factors.
C. Attenuation factors.
D. Radioisotope concentrations.

D85. All of the following are true statements about PET scanning, ***except:***

A. Radioisotopes are cyclotron produced.
B. Positrons are not detected directly.
C. Coincident detection at 180° is required.
D. Images are generally axial tomograms.
E. The detector photopeak is centered at 1.02 MeV.