PET/CT QC/QA

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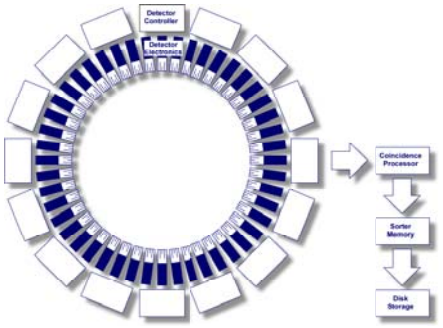
Quality Control in PET

- Verify the operational integrity of the system
  - Detectors
  - Acquisition Electronics
- Maintain consistent and high image quality
- Minimize chances for artifacts
- Catch potential problems early
- Maintain quantitative accuracy
- Eliminate unnecessary repeat scans

Data Flow in a PET System



PET Detectors

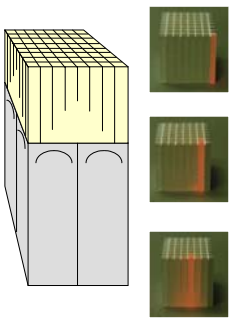
Most modern PET system use a detector technology referred to as Block Detectors.

A large number of scintillation crystals are coupled to a smaller number of PMTs.

In the block detector, a matrix of cuts are made into a solid block of scintillator material to define the detector elements.

The depth of the cuts are adjusted to direct the light to the PMTs.

The light produced in each crystal, will produce a unique combination of signals in the PMTs, which will allow the detector to be identified.

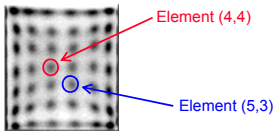


PET Detectors

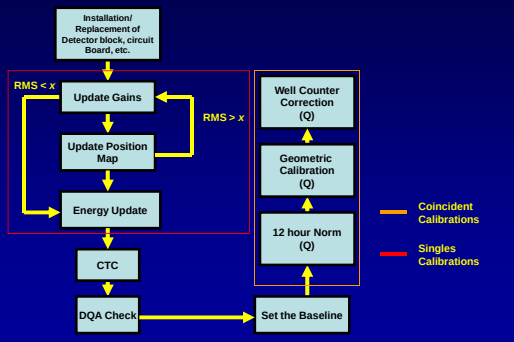
To identify the detector elements, the following positioning indeces are calculated:

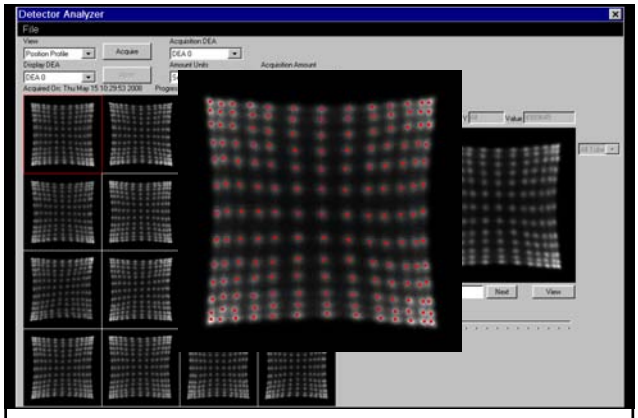
$$X = \frac{A+B-C-D}{A+B+C+D} \qquad Y = \frac{A-B+C-D}{A+B+C+D}$$

Below is the flood response (i.e., X and Y density distribution when exposed to a flood source of 511 keV photons) for a block detector from the ECAT EXACT HR.

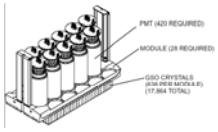


PET Detector Calibration Overview

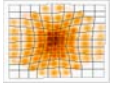


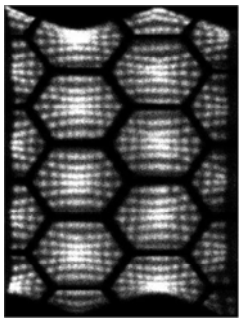


Pixelated Detector System

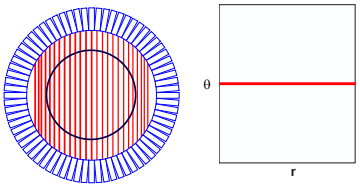


Continuous-pixelated detector



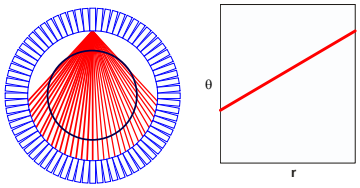


Sinogram



All coincidence lines that are parallel at a given angle form a projection in the sinogram.

Sinogram



All coincidence lines (or lines of response) for a given detector form a diagonal trace in the sinogram.

Daily QC

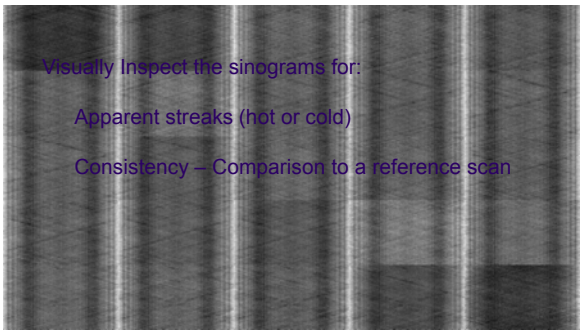
Daily Detector Check

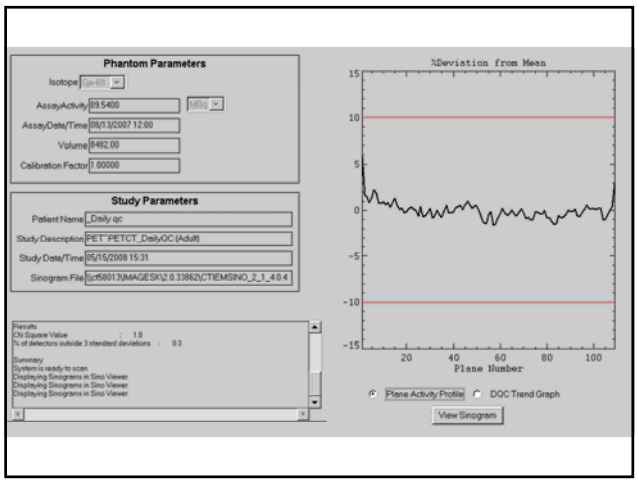
- Transmission/Rotating Rod Sources
- Uniform cylinder phantom (20 cm Ø)

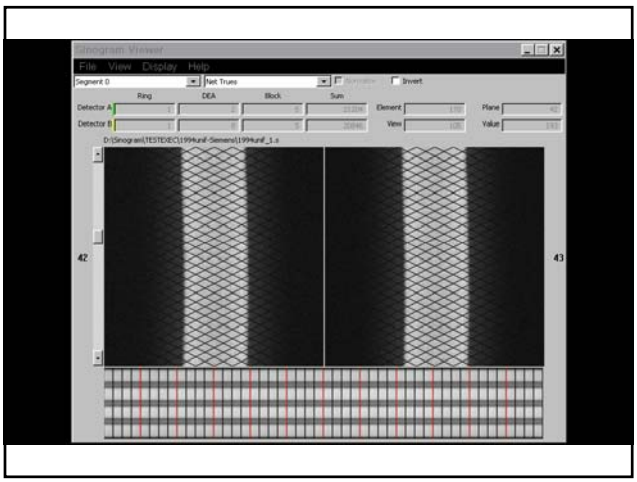
Water Phantom

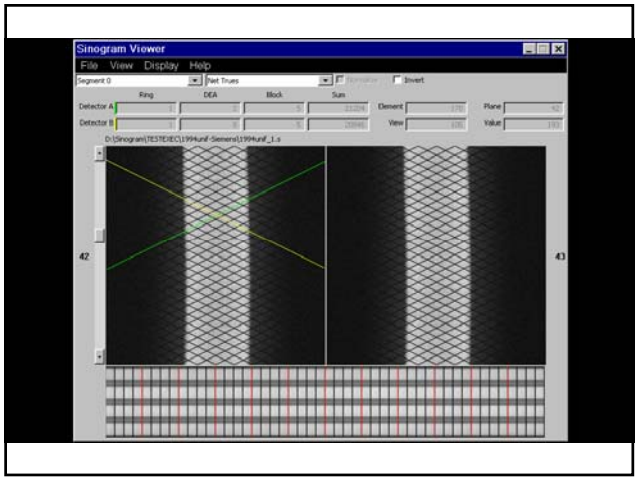
Solid ^{68}Ge Phantom

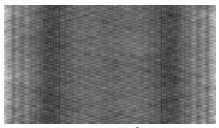
Daily QC / Blank Scan

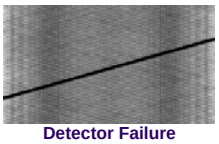


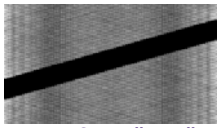






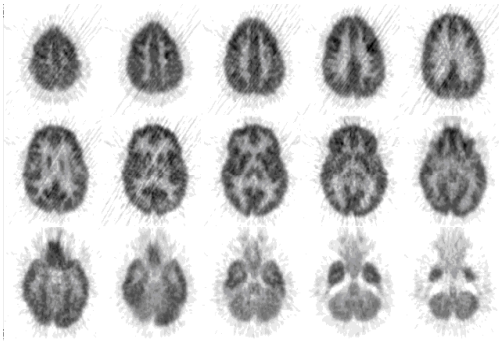

Normal


Detector Failure

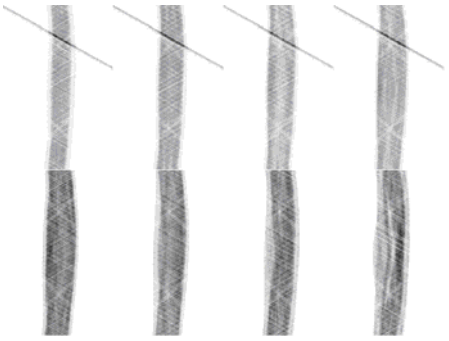

Detector Controller Failure


Sorting Memory Failure

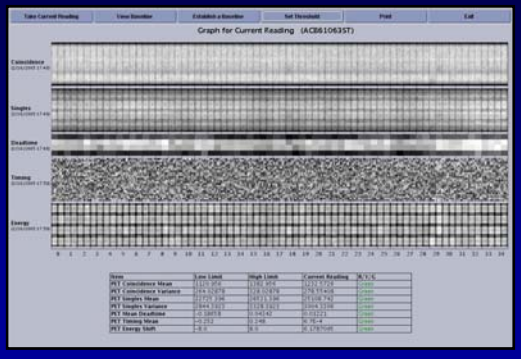
Detector Block Failure



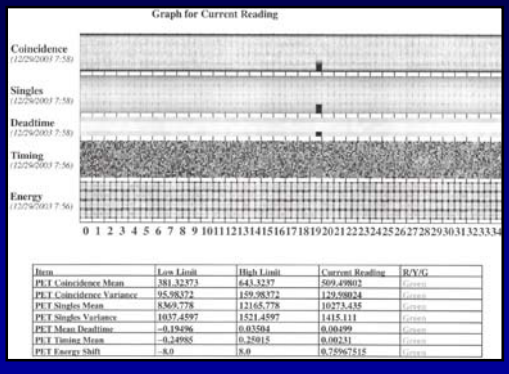
Detector Block Failure



PET Daily QA Scan

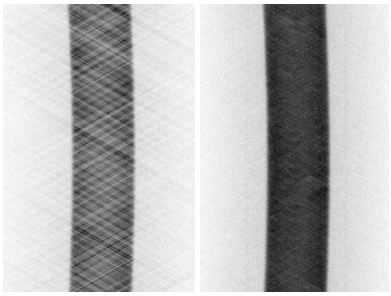


PET Daily QA Scan



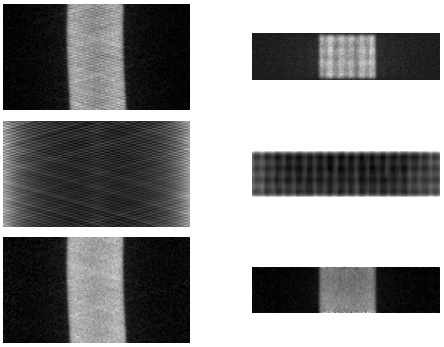
Item	Low Limit	High Limit	Current Reading	R/Y/G
PET Coincidence Mean	381.32373	643.3237	509.49802	Green
PET Coincidence Variance	95.98372	159.98372	129.98024	Green
PET Singles Mean	8869.778	12165.778	10273.435	Green
PET Singles Variance	1037.4597	1521.4597	1415.111	Green
PET Mean Deadtime	-0.19496	0.03504	0.00499	Green
PET Timing Mean	-0.24985	0.25015	0.00231	Green
PET Energy Shift	-8.0	8.0	0.75967515	Green

Daily QC and Normalization

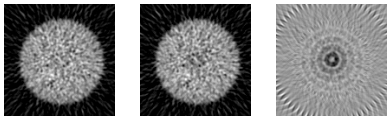


Before Normalization After Normalization

Normalization



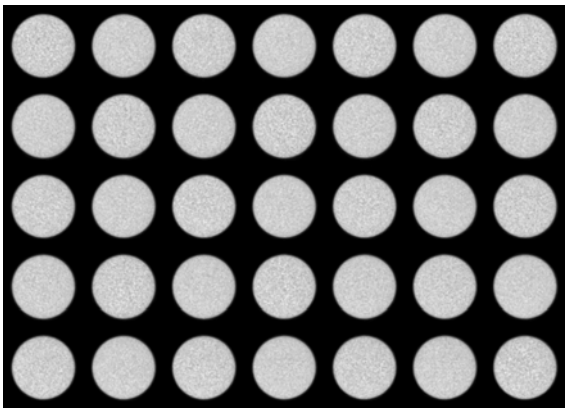
Normalization



Corrected Non-corrected Difference

Daily / Weekly Quantification Scan

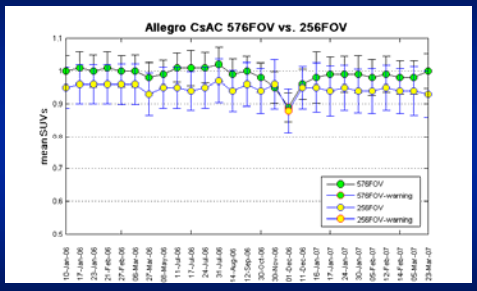
- Scan uniform 20 cm Ø ^{68}Ge or ^{18}F Cylinder
  - Emission & Transmission / CT
- Reconstruct:
  - All corrections applied
  - Standard reconstruction parameters
- Visual inspection
- Compare image ROI activity to calibrated activity
- Always perform after:
  - Service
  - Re-tuning
  - Re-normalization



Quantification Scan

	2D Cylinder **0.0299 µCi/ml**			
	FBP		OSEM	
Calculated Atten. Corr.	0.0296	-1.1%	0.0295	-1.5%
Meas. Atten. Corr. CT	0.0285	-4.7%	0.0284	-4.0%
Meas. Atten. Corr. Rods	0.0242	-19.2%	0.0239	-20.2%

Quality Control
Longitudinal uniformity



Comparison of mean SUVs of VOIs (Allegro CsAC 576FOV vs. 256FOV)

Austin Health

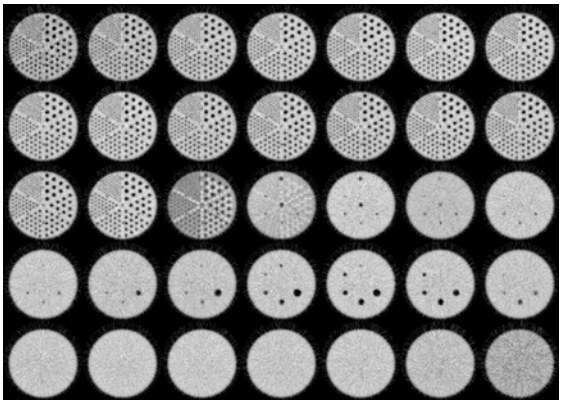
Quarterly QC Procedures

- Detector setup (if needed)
  - PMT tuning
  - Detector setup
  - Coincidence timing
  - (TOF)
- Normalization
- Other cross calibrations (well counter, etc)
- Gantry alignment (for PET/CT)
  - Always after Service
  - Software upgrades

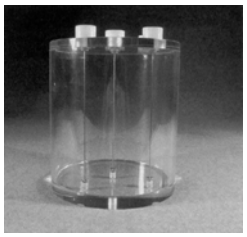
Annual QC Procedures

Perform a sub-set of the acceptance (NEMA) tests:

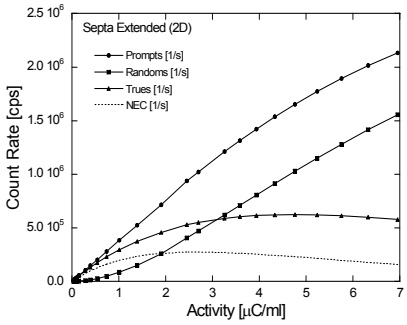
- Uniformity
- Resolution
- Count Rate Test
- Dead Time Correction
- Sensitivity
- Quantification
- Bed motion



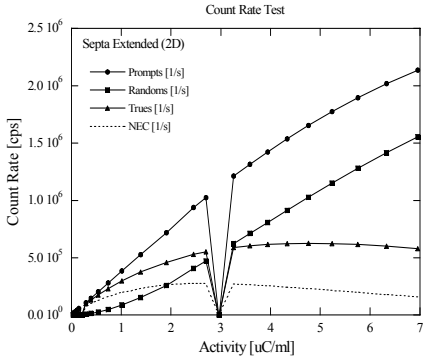
Spatial Resolution

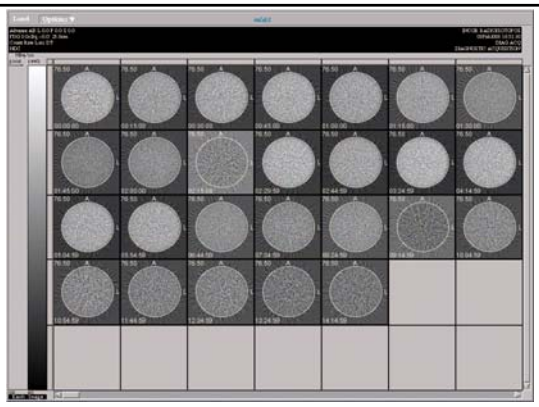


Count Rate Test



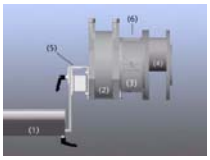
Count Rate Test





Other Test Phantoms

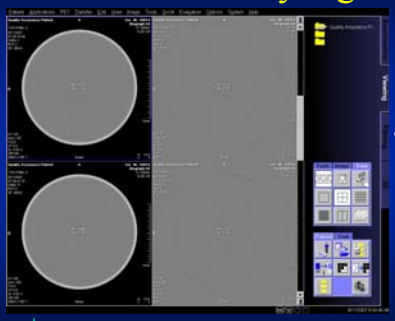
CT QC Phantoms



CT Daily QA Scan

- Normal operations include the following 3 tasks (in order):
- Tube Warmup- A built-in prep scan that gradually increases heat loading in the X-ray tube in order to prevent thermal cracking and eliminate the potential for an arc to occur. It includes a series of exposures made at incrementing kVp
- Daily Air Cals- A built-in prep scan that performs a series of exposures at varying techniques in order to normalize the detector response using *air* as the attenuating media. These scans essentially adjust the detector gains to achieve a uniform response
- Daily QA Phantom scan - Provides data for 3 areas of concern in daily quality assurance

Quality Control
CT daily regimen



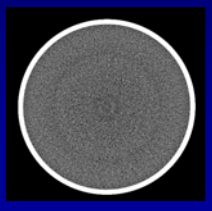
- Scan water layer
  - Measure water HU
    - CTAC
  - Check for artifacts
    - Ring artifacts
      - Redo conditioning
      - Redo Air Cal

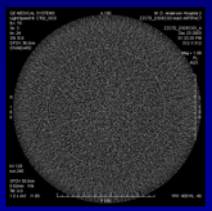
Austin Health

Courtesy: Stefan Eberl, RPA

CT Daily QA Scan

- Artifact Analysis
  - Looking for the presence of artifact
  - *Ring artifact* is the most clinically prevalent in QA scans
  - Caused by non-uniformity in detector response due to gain imbalance or beam obstruction





CT Daily QA Scan

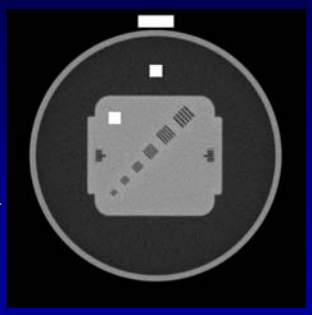
- Uniformity
  - ROIs distributed in homogeneous material should indicate consistent signal (HUs) and noise

CT Daily QA Scan

- Linearity
  - Linear attenuation coefficients track linearly with material density
  - Remember that CT numbers are defined WRT the attenuation coefficient of water:

$$CT(x,y) = 1000\left(\frac{\mu_{(x,y)} - \mu_{water}}{\mu_{water}}\right)$$

  - The mean CT numbers of air (-1000 HU), water (0 HU), and acrylic (120 HU) displayed within an ROI should be consistent with the defined value +/- manufacture specified tolerance

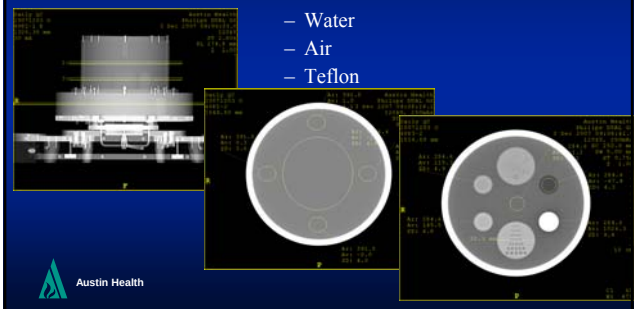


CT Daily QA Scan

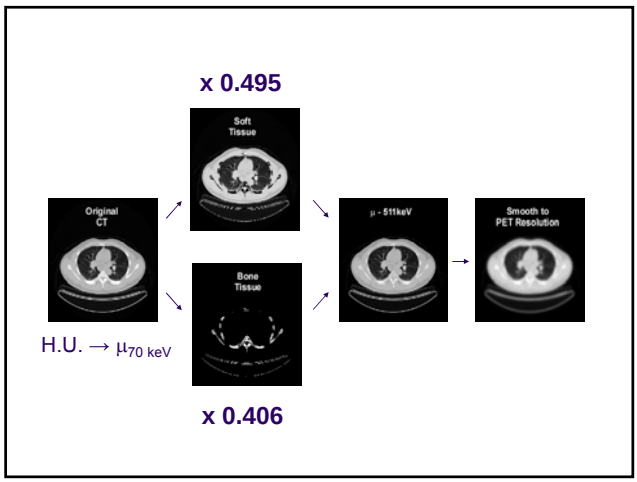
			Water			Linearity			Position OK?
CT Scanner	Date of Scan	Time of Scan	CT # Water	Unif. Max Diff	Std Dev. Water	Acrylic	Water	Air	
ACI5_OC0	20050217	064058	0.1	0.3	4.3	120.9	0.6	-997.1	Yes
ACI6_OC0	20050217	072016	0.5	0.3	4.5	122.3	1.8	-994.7	Yes
ACI7_OC0	20050217	064445	1.9	1.6	4.8	123.5	1.8	-993.1	Yes
ACI9_OC0	20050217	070256	1.9	0.6	4.8	122.8	1.6	-994.6	Yes
ACT3_OC0	20050217	054214	0.1	0.9	4.6	122.1	1.3	-1000.1	Yes
ACT8_OC0	20050217	064124	0.8	0.4	4.9	125.9	1.2	-993.7	Yes
ACT8_OC0	20050217	083945	0.8	0.3	4.4	124.7	1.6	-993.2	Yes
ACT9_OC0	20050217	081749	0.8	0.1	4.8	124.7	0.7	-998.7	Yes
CT02_OC0	20050217	050852	1.2	0.3	4.6	123.9	0.9	-995.3	Yes
CT04_OC0	20050217	062858	0.6	0.7	4.4	128.5	1.1	-994.5	Yes
CT05_OC0	20050217	063521	1.0	0.8	4.7	125.1	1.7	-999.2	Yes
CT06_OC0	20050217	063257	-0.4	1.0	4.6	128.6	0.3	-999.9	Yes
CT12_OC0	20050217	064447	0.1	0.8	4.6	126.3	1.3	-999.4	Yes
DST1_OC0	20050217	062933	0.8	0.1	4.2	126.2	1.1	-993.1	Yes
DST2_OC0	20050217	064315	1.1	0.6	4.5	124.8	0.8	-999.6	No

Quality Control
CT weekly regimen

- HU calibration check
  - Water
  - Air
  - Teflon



Austin Health



Quality Control
CT weekly regimen

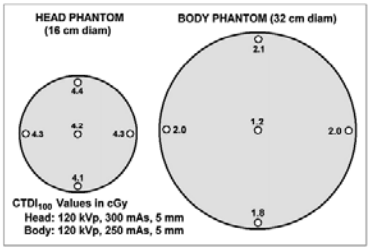
- Hounsfield Unit Calibration
  - ROI means
  - ROI standard deviation range
    - mAs setting accuracy
- kVp, mAs exercising
  - Filament adaptation
  - Collimation
- MTF & Slice thickness
  - Physics layer
- Check error log

Austin Health

CT Daily QA Scan

- Low Contrast Resolution
  - –Qualitative assessment of smallest resolvable hole in a membrane with a CT number similar to that of water

Dosimetry - CTDI

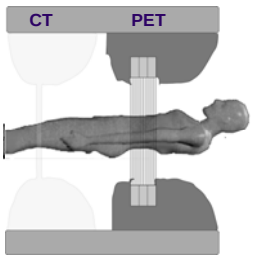


Daily CT QC

- Accuracy of Water Calibration
- Image Noise
- Uniformity
- Artifacts

Monthly/Semi-annual CT QC

- Slice Thickness
- Slice Positioning
- Laser Alignment
- CT Scale
- Resolution
- Low Contrast Resolution
- Dosimetry

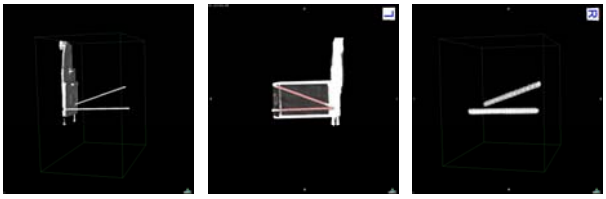


PET/CT Alignment

CT

PET
Transmission Scan

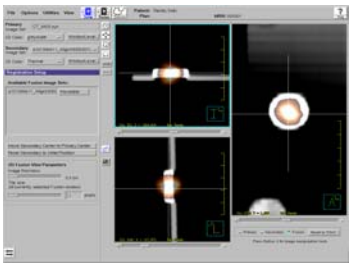
PET/CT Alignment



CT

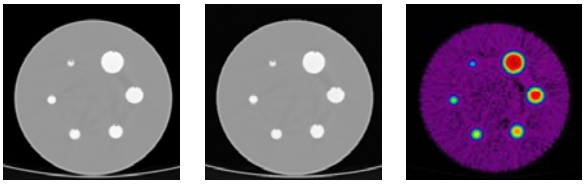
PET
Emission
Scan

PET/CT Alignment



Jaszczak/ACR Phantom

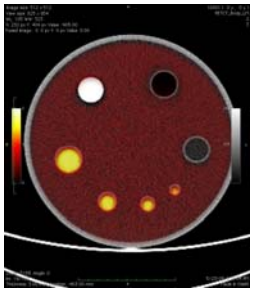
PET/CT Gantry Alignment



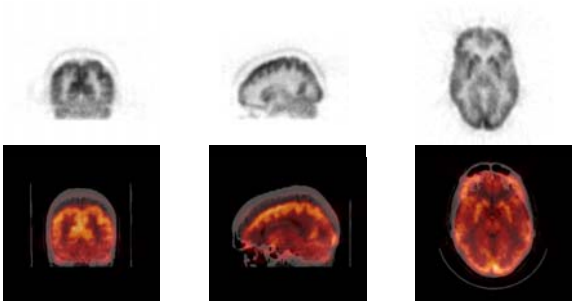
CT

PET

PET/CT Gantry Alignment



System Misregistration



Resources for PET and PET/CT QC

Manufacturers' manual

NEMA NU-2 Publications 2007, 2001 & 1994
AAPM rpt. 72
ACR

Karp J.L. et. al., JNM 32 (12), 1991
Buchert R. et. al., JNM 40 (10), 1999
Geworski L., JNM 43 (5), 2002

Bailey et. al. "Positron Emission Tomography – Basic Science"
Cherry SR & Dahlbom M, in Phelps ME "Molecular Imaging"

Summary

An effective QC/QA program for PET and PET/CT can be implemented with a few relatively simple daily and weekly phantom scans

With training and experience, potential problems can be identified and possibly rectified

A regular QC program will ensure consistent image quality as well as quantitative accuracy

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"Mr. Osborne, may I be excused? My brain is full."