PET/CT QC/QA

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Learning Objectives

- Summarize the signal processing steps for coincidence detection
- Understand the components of a daily QA procedure
- Identify and trouble shoot possible sources of failure in daily QA
- List the recommended frequency of QA/QC tests
- Describe the process of scanner calibration
- Name the different components of the NEMA test used for PET acceptance testing
- Understand the meaning of the results of the NEMA tests.

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Outline

- PET Basics
- PET Detectors and data flow
- Daily QC Procedures
- QC Evaluation Techniques
- Examples of Common Problems
- Quarterly and Annual QC Procedures

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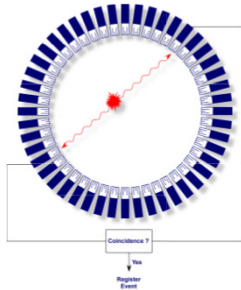School of Medicine

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Quality Control in PET

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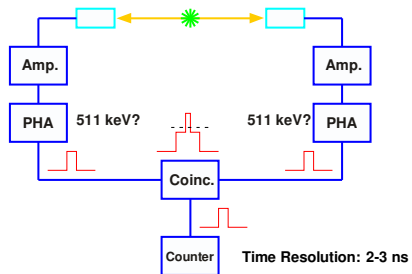
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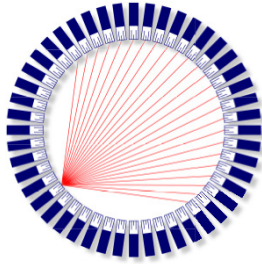
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Coincidence Detection

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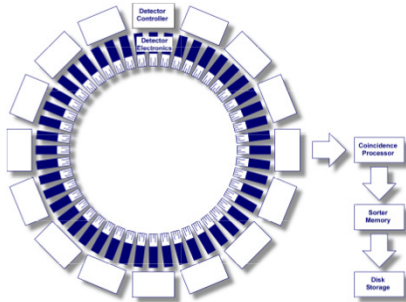### Coincidence Detection

Amp.		**Amp.**
PHA 511 keV?		511 keV? **PHA**
	Coinc.	
	Counter	**Time Resolution: 2-3 ns**

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Coincidence Detection

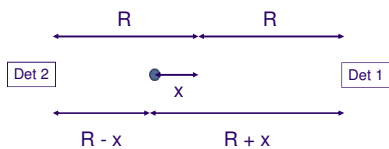## Data Flow in a PET System

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Time-of-flight PET

$$s = v \cdot t$$
$$R + x = vt_1$$
$$R - x = vt_2$$
$$2x = v(t_2 - t_1) \Rightarrow x = \frac{c\Delta t}{2}$$
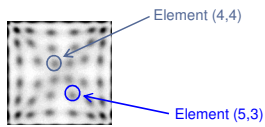
Time Resolution: ~300 ps

PET Detectors

Segmented block of BGO or LSO scintillator

Reflector material packed in saw cuts

Four single-channel photomultiplier tubes

PMT_C

PMT_A

PMT_D

PMT_B

Y

X
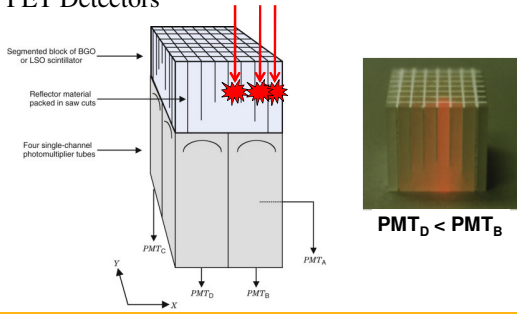
$PMT_D < PMT_B$

PET Detectors

- To identify the detector elements, X- and Y- positions are calculated for each event:
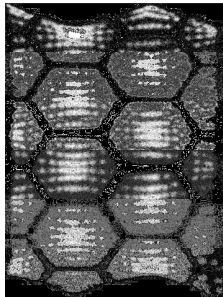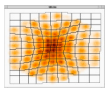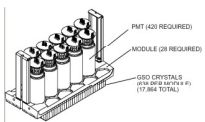
$$X = \frac{(PMT_A + PMT_B) - (PMT_C + PMT_D)}{PMT_A + PMT_B + PMT_C + PMT_D}$$

$$Y = \frac{(PMT_A + PMT_C) - (PMT_B + PMT_D)}{PMT_A + PMT_B + PMT_C + PMT_D}$$

Element (4,4)

Element (5,3)

Pixelated Detector System

PMT (420 REQUIRED)

MODULE (28 REQUIRED)

GSO CRYSTALS
(636 BER MODULE #)
(17,864 TOTAL)
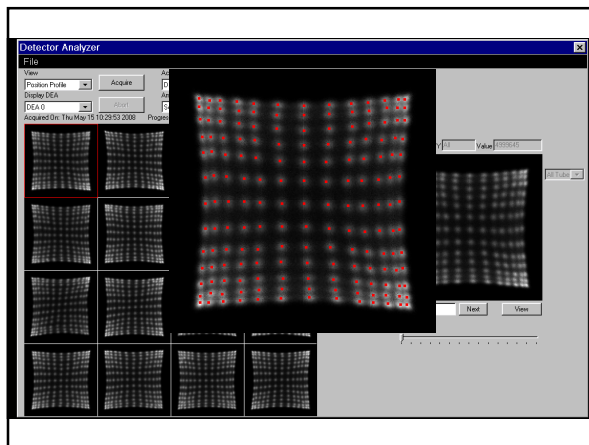
Continuous-pixelated detector

PET Detector Calibration

• Balancing of PMTs

• Identification of Peaks/Detectors in Flood Histogram

• Acquire Energy Spectra / Set Energy Thresholds

• Time Alignment

• Challenge:
  • Large number of detector blocks (~200)
  • Large number of detector elements (>30,000)

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Daily QC

• Detect small drifts in the system
  • Detector Gain Drifts (Efficiency, Scatter Fraction, Randoms)
  • Timing
  • Quantification
• Challenges:
  • Large number of detector blocks (~200)
  • Large number of detector elements (>30,000)
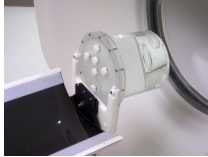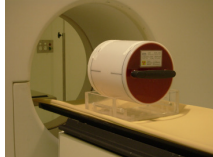 • Time constraint (< 1 hr)

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Daily QC Scan
- Transmission/Rotating Rod Sources
- Uniform cylinder phantom (20 cm Ø)
- Also used for calibration (Counts ➜ Bq/ml)
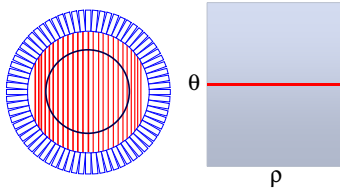
Water Phantom
Calibrated w. Dose Calibrator

Solid ^{68}Ge Phantom
Pre-calibrated

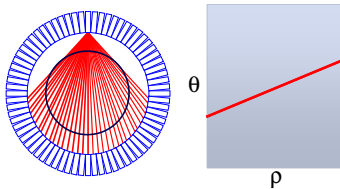David Geffen
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Sinogram

θ

ρ

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

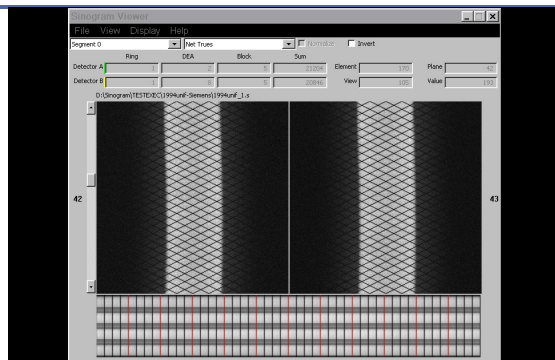David Geffen
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Sinogram

θ

ρ

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

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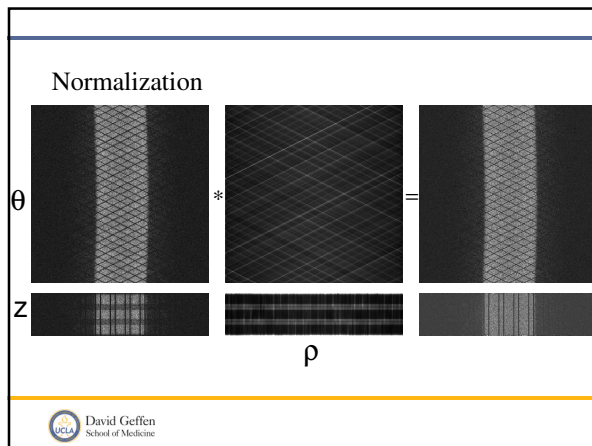School of Medicine

Daily QC / Blank Scan

Visually inspect the sinograms for:

Apparent streaks (hot or cold)

Consistency – Comparison to a reference scan

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PET Daily QA Scan

Normalization

θ   *   =

z

ρ

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Normalization

After Detector
Tuning

Before PM

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Normalization

After Detector
Tuning w. norm

Before PM
w. norm

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When things go wrong…

Normal

Detector Failure

Detector Controller Failure

Sorting Memory Failure

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Detector Block Failure

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Detector Block Failure

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reference | zero sensitivity | twofold sensitivity

Buchert et. al. JNM 40, 1999

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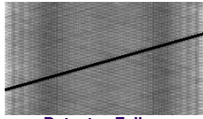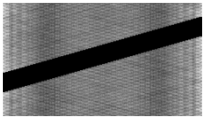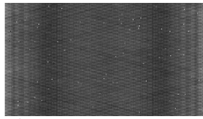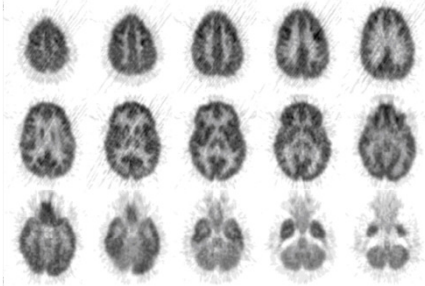School of Medicine

PET Daily QA Scan

Graph for Current Reading

Coincidence
(12/29/2003 7:58)

Singles
(12/29/2003 7:58)

Deadtime
(12/29/2003 7:58)

Timing
(12/29/2003 7:56)

Energy
(12/29/2003 7:56)

0 1 2 3 4 5 6 7 8 9 1011121314151617181920212223242526272829303132333 4

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	8369.778	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

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System Calibration

• Calculates Conversion Factor : Image A.U. ➔ Bq/ml

• Scan uniform 20 cm Ø ^{68}Ge or ^{18}F Cylinder

  • Calibrated Activity, Time & Volume

  • Emission & Transmission / CT

• Reconstruct:

  • All corrections applied

  • Standard reconstruction parameters

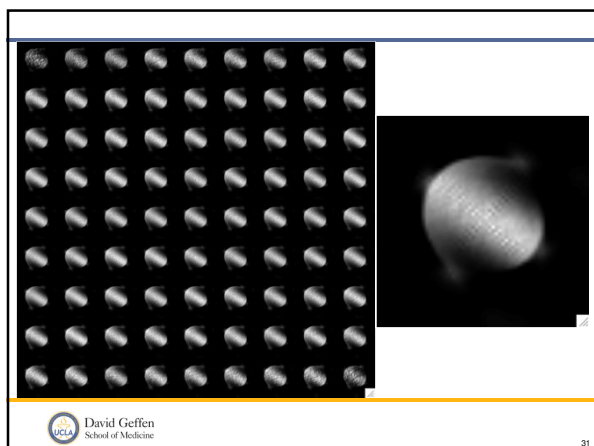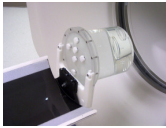• Calibration Factor :

   Calibrated Act. Conc. / ROI of Image (A.U.)

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Daily QC Scan / Siemens mCT

Acquire ^{68}Ge Cylinder Scan (100-200Mcts)   **Centered!**

Generation of Normalization Factors

Evaluation of Daily QC Components

• Block Noise

• Block Efficiency

• Measured Randoms

• Scanner Efficiency

• Scatter Ratio

• Calibration Factor) & Image Plane Efficiency

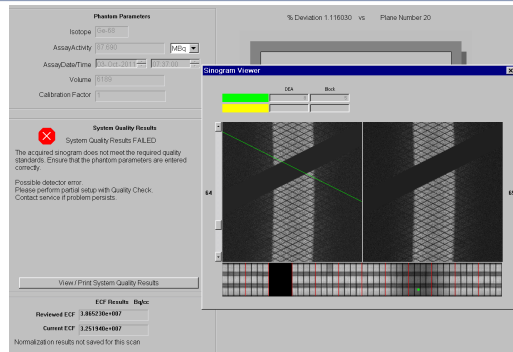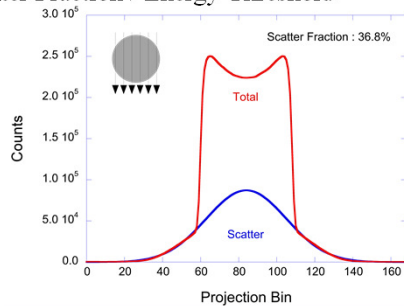• Timing Offset, Width and Time Alignment Fit

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Daily QC Scan / Siemens mCT

Detailed System Quality Report

Item	Upper Bound	Lower Bound	Value	Decision
Block Noise	3 [crystal]	0 [crystal]	0 Blocks out of range	Passed
Block Efficiency	120 [%]	80 [%]	0 Blocks out of range	Passed
Measured Randoms	115 [%]	85 [%]	101.9 [%]	Passed
Scanner Efficiency	27.04 [cps/Bq/cc]	14.56 [cps/Bq/cc]	20.5 [cps/Bq/cc]	Passed
Scatter Ratio	36.3 [%]	29.7 [%]	31.7 [%]	Passed
Scanner efficiency correction factor (ECF)	4.1e+007 [Bq*s/ECAT counts]	2.21e+007 [Bq*s/ECAT counts]	3.257e+007 [Bq*s/ECAT counts]	Passed
Image Plane Efficiency	5 [%]	-5 [%]	0 Planes out of range	Passed
Block Timing Offset	0.5 [bin]	0 [bin]	0 Blocks out of range	Passed
Block Timing Width	5 [bin]	0 [bin]	0 Blocks out of range	Passed
Time Alignment Residual	2 [mm]	0 [mm]	1.1 [mm]	Passed
Time Alignment Fit (x / y)	2 [mm]	0 [mm]	0.3 [mm] / 0.3 [mm]	Passed

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Scatter Fraction / Energy Threshold


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CT Daily QA Scan

- Normal operations include the following 3 tasks (in order):

- <u>Tube Warmup</u>- 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

- <u>Daily Air Cals</u>- 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

- <u>Daily QA Phantom scan</u> - Provides data for 3 areas of concern in daily quality assurance

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Quality Control
CT daily regimen
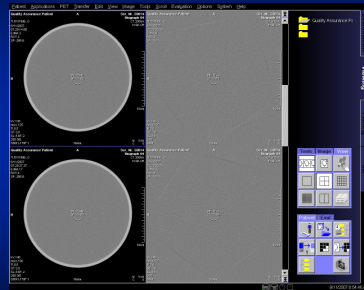
- Scan water layer
  - Measure water HU
    - CTAC
  - Check for artifacts
    - Ring artifacts
      - Redo conditioning
      - Redo Air Cal

Austin Health

Courtesy: Stefan Eberl, RPA

Quarterly QC Procedures
- Quantification Check
- Gantry alignment (for PET/CT)
- Other cross calibrations (well counter, etc)

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Quantification Scan

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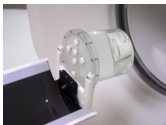 - Emission & Transmission / CT
- Reconstruct:
  - All corrections applied
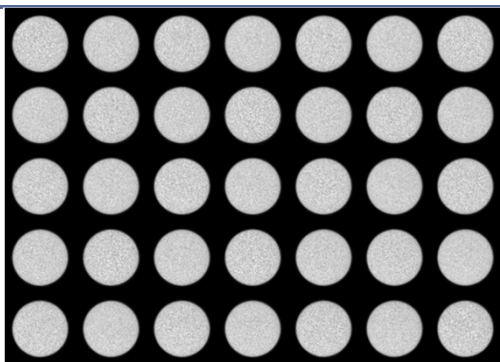 - Standard reconstruction parameters
- Visual inspection
- Compare image ROI activity to calibrated activity
- Always perform after any service or detector adjustments

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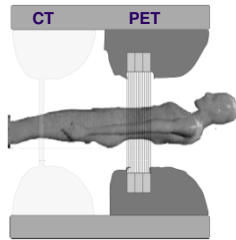School of Medicine

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Quantification Scan

	^{18}F 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%

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PET/CT Gantry Alignment

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```
ERROR: undefined
OFFENDING COMMAND: f'~

STACK:
```