Evaluation of PET Scanners, Acceptance Testing and QC

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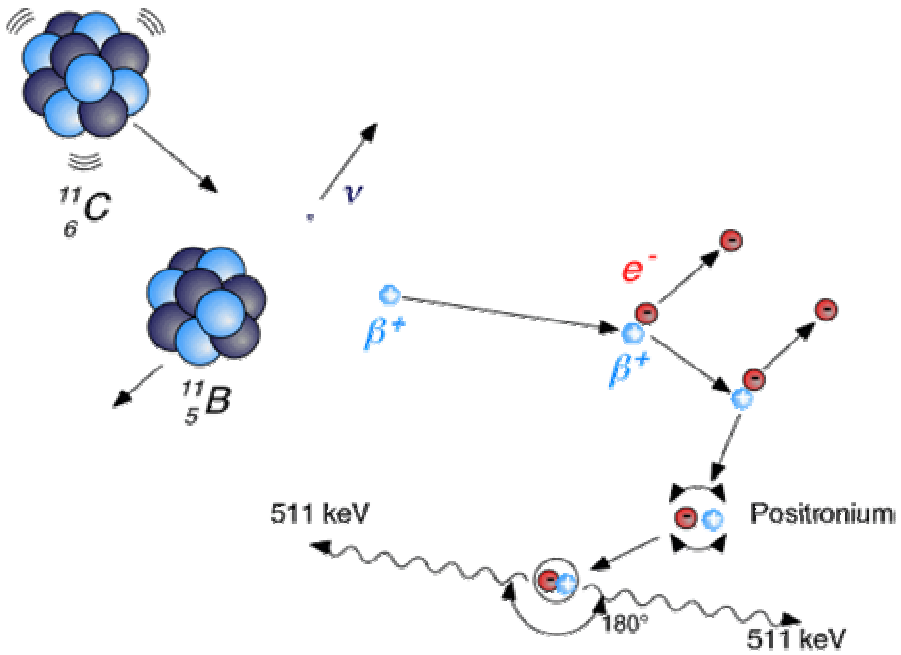
Topics Covered

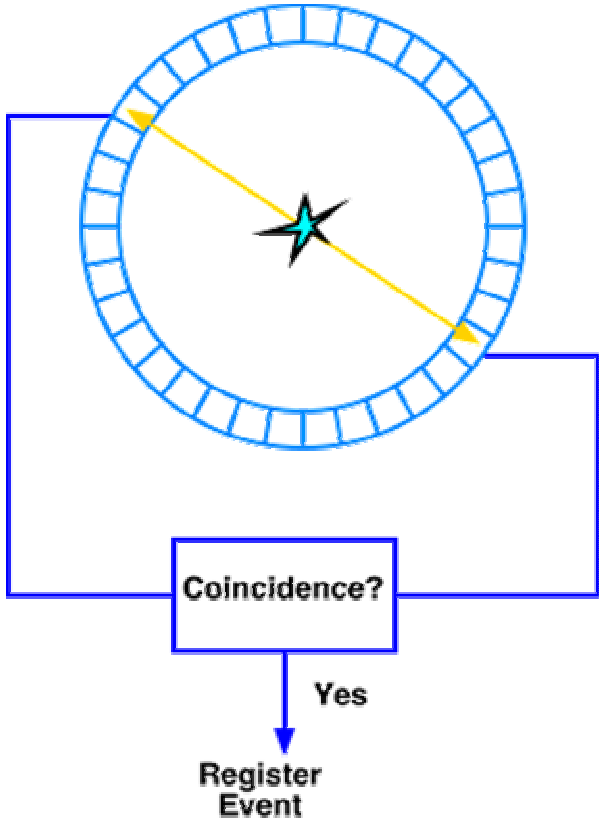
- Basic Principles of PET
- PET Scanner Performance Measures, Specifications and Evaluation
- TSSC Document on Minimum PET requirements
- Acceptance Testing
- Quality Control/Calibration

Positron Annihilation

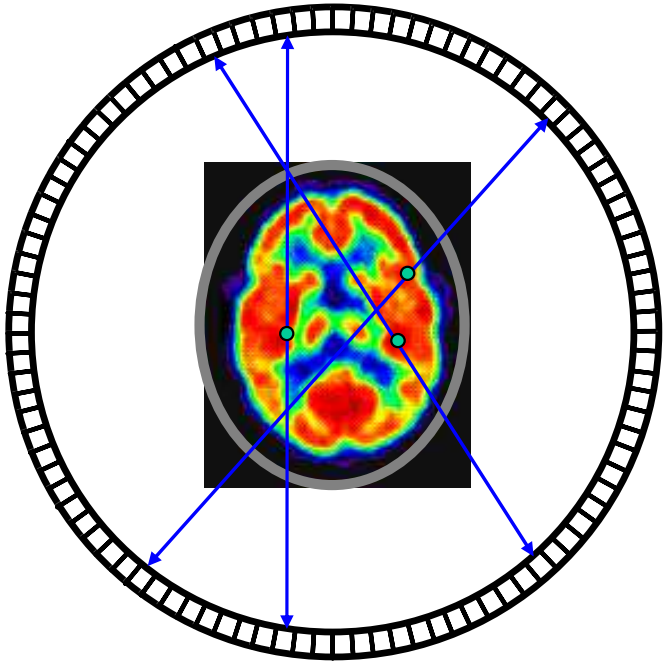


Coincidence Detection

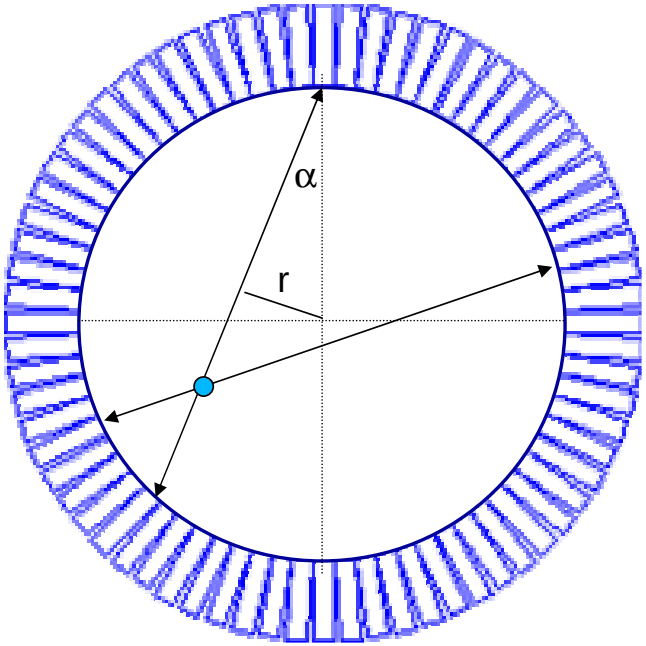
- When photons are detected by 2 detectors in coincidence within a specified time window, an event (prompt) is registered
- the line joining the 2 detectors defines the coincidence Line of Response (LOR)

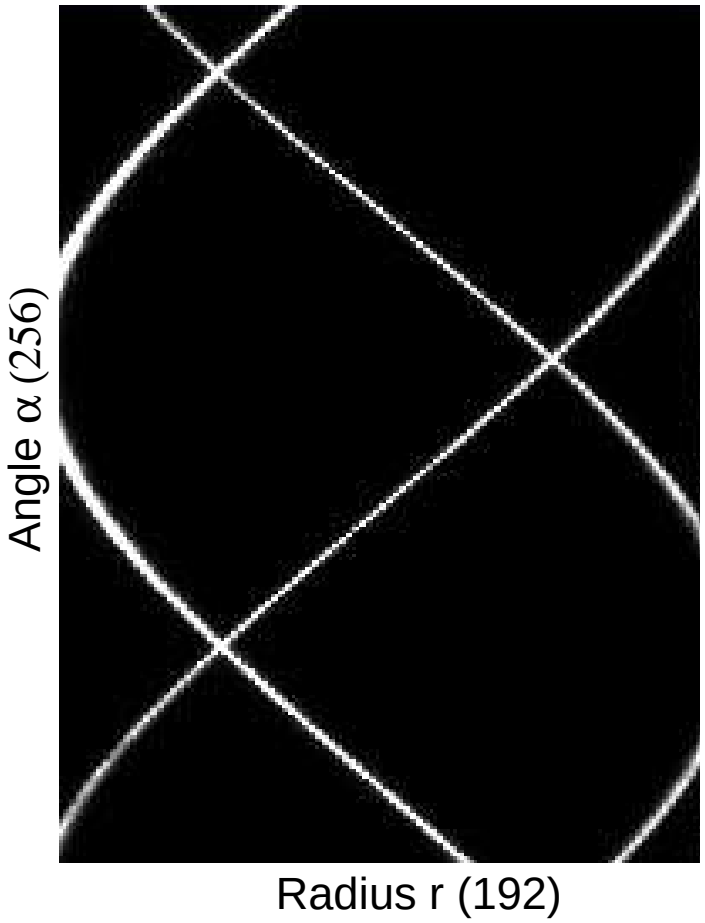


LORs are reconstructed to form tomographic slices

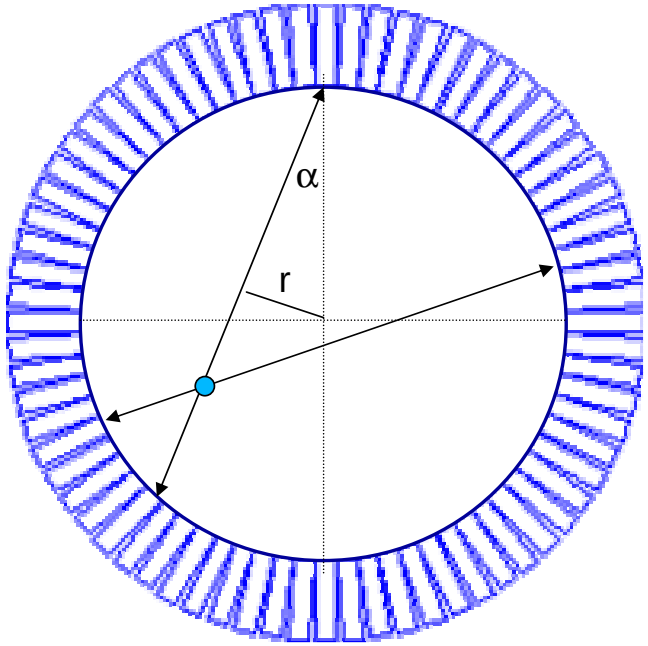


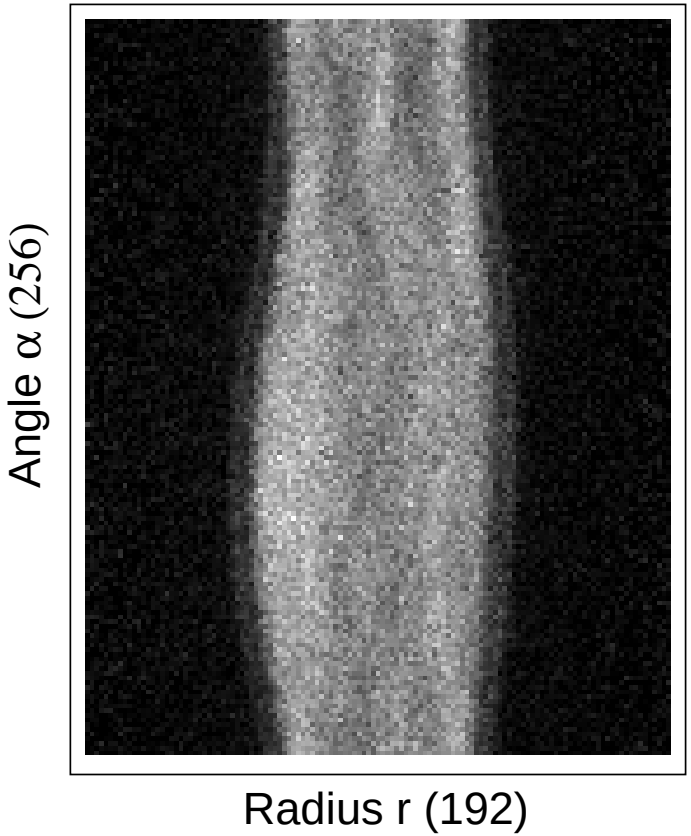
Sinogram of Stationary 3 Rod Sources



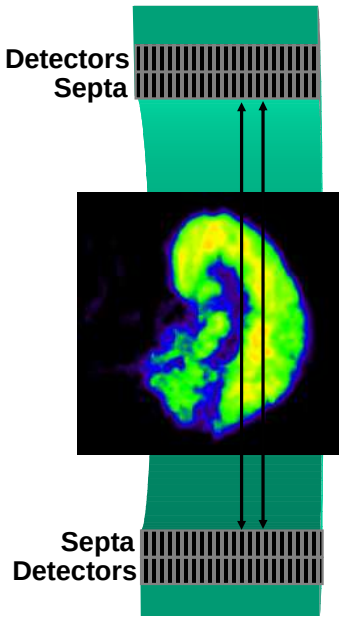


Sinogram

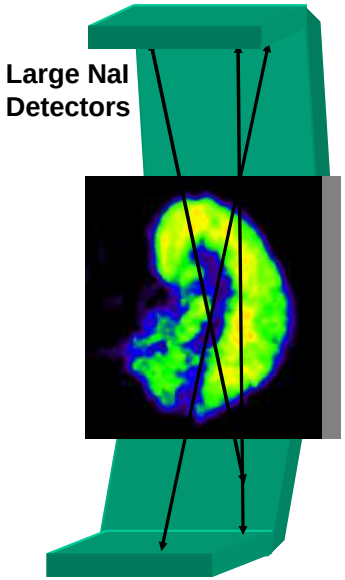




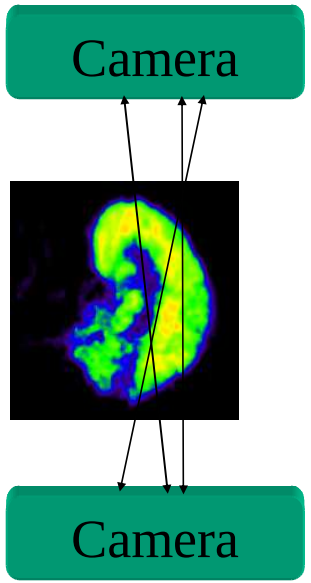
Some PET Designs



Ring System - 2D



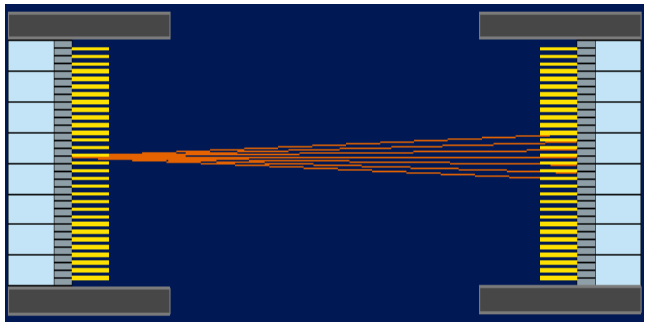
Panel/Large Area Detectors



Camera System 3D

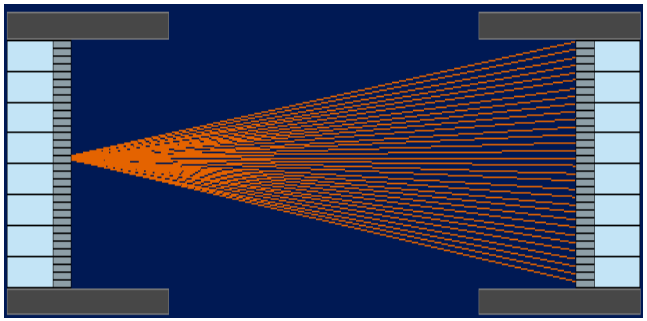
2D & 3D Scanning

2D acquisition mode



- septa employed
- low efficiency
- higher dose required
- longer scan times
- lower scatter (15-25%)
- Conventional 2D reconstruction

3D acquisition mode



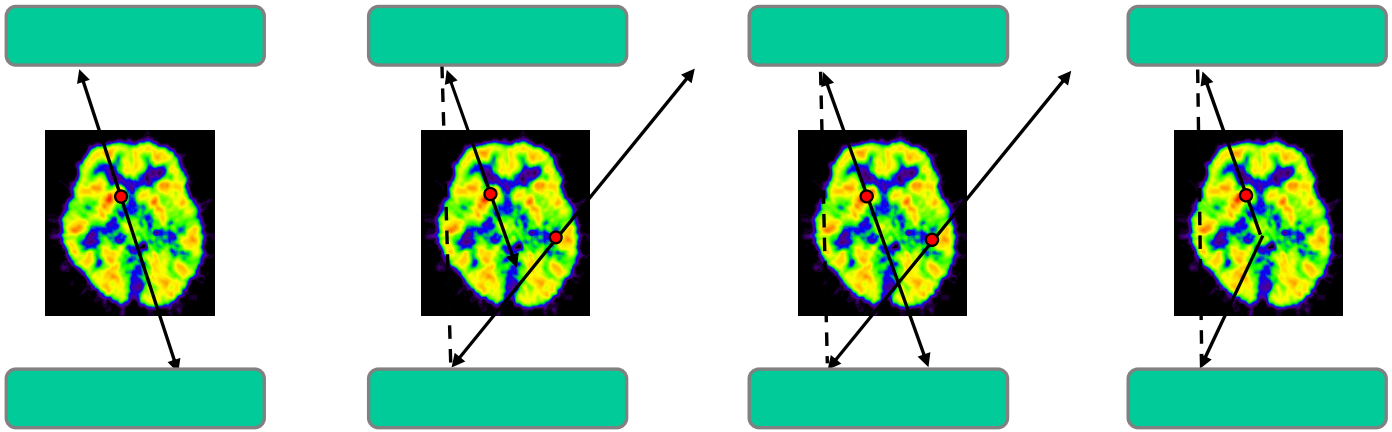
- no septa
- high efficiency
- lower dose required
- short scan times
- higher scatter (40-60%)
- 3D reconstruction algorithm required

Event (Count) Types in PET

- Coincidence counting ie counts have to be detected in 2 detectors within the set coincidence timing window (τ = 6 – 12 ns)
- Event types detected
  - Singles – predominate, high count rate detector
  - Trues or prompts – give valid image information
  - Accidental or Random Coincidences
  - Scatter
  - Multiples

Coincidence Event Types

- Not all coincidence events are desirable, only true unscattered coincidences contribute useful data for image formation



True Coincidence

ü

Random/Accidental Coincidence

ß

$R_{1,2} = 2\tau S_1 S_2$

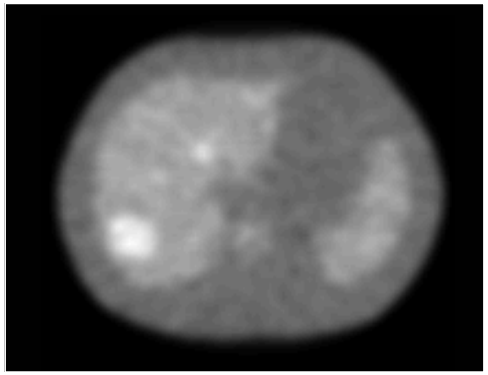
Multiple Coincidences

ß

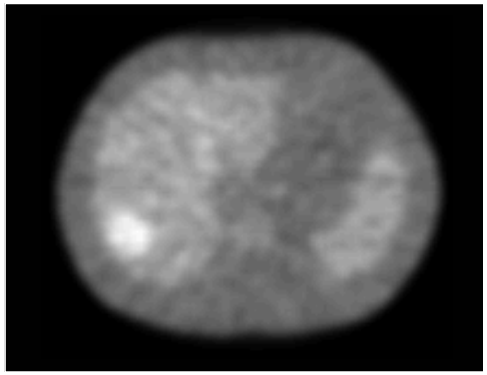
Scattered Coincidence

ß

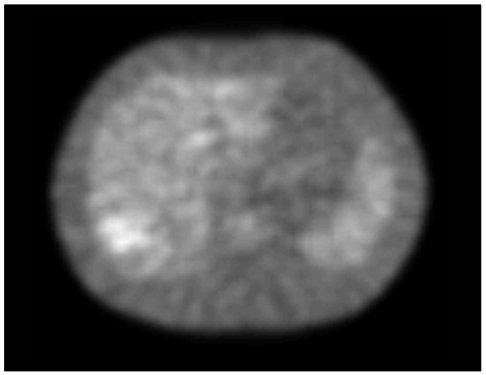
Effect of NEC and Randoms Correction



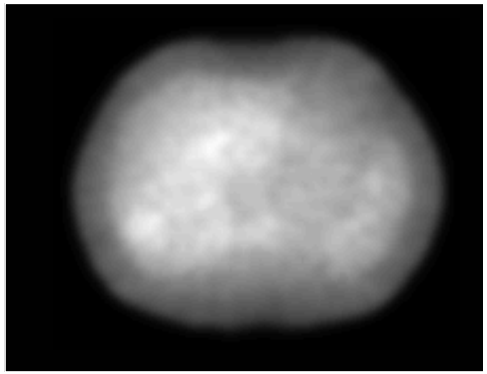
Trues = 30k/s, NEC = 24 k/s
Randoms = 6k/s, Scatter = 3k/s



Trues = 30k/s, NEC = 15 k/s
Randoms = 15k/s, Scatter = 15k/s



Trues = 15k/s, NEC = 7.5 k/s
Randoms = 7.5k/s, Scatter = 7.5k/s



Trues = 15k/s, NEC = 7.5 k/s
Randoms = 7.5k/s, Scatter = 7.5k/s
No Randoms/Scatter Correction

Noise Equivalent Countrate (NEC)

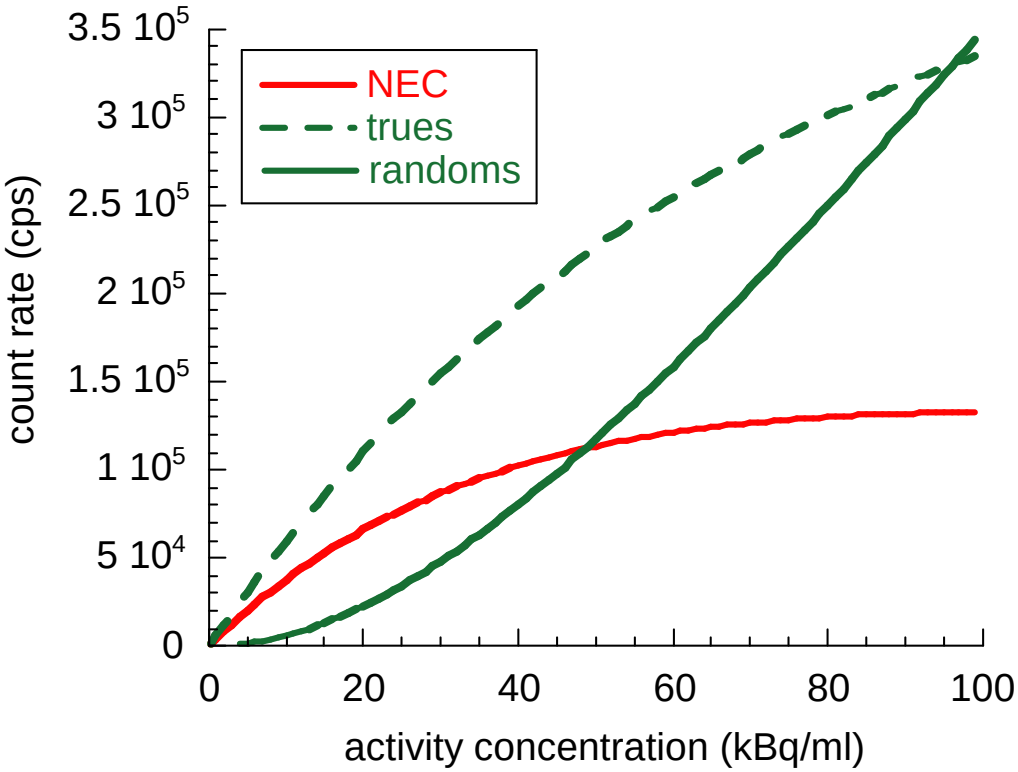
- Need a method for estimating effective image noise as a function of trues, randoms and scatter

$$NEC = \frac{N_t}{1 + \frac{N_{sc}}{N_t} + \frac{2k_{ph}N_r}{N_t}}$$

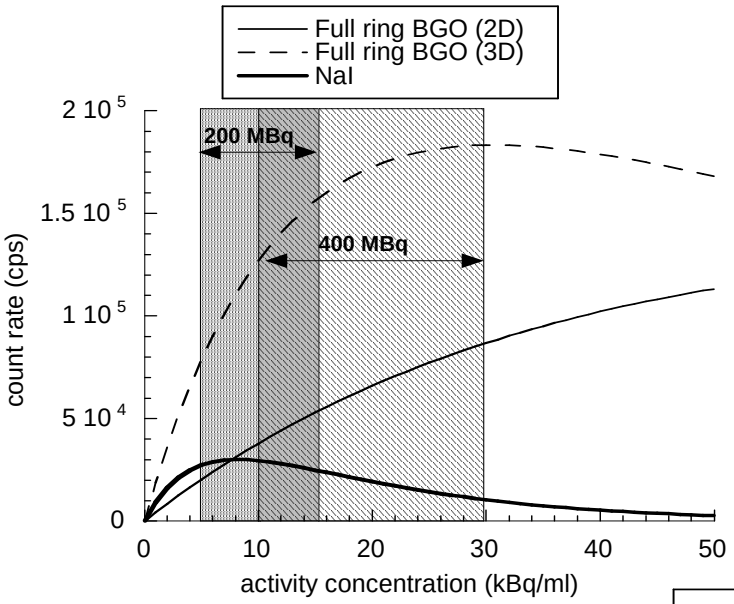
N_t	Trues Count Rate
N_{sc}	Scatter Count Rate
N_r	Random Count Rate
k_{ph}	Projection Factor (0.18 brain, 0.33 torso)

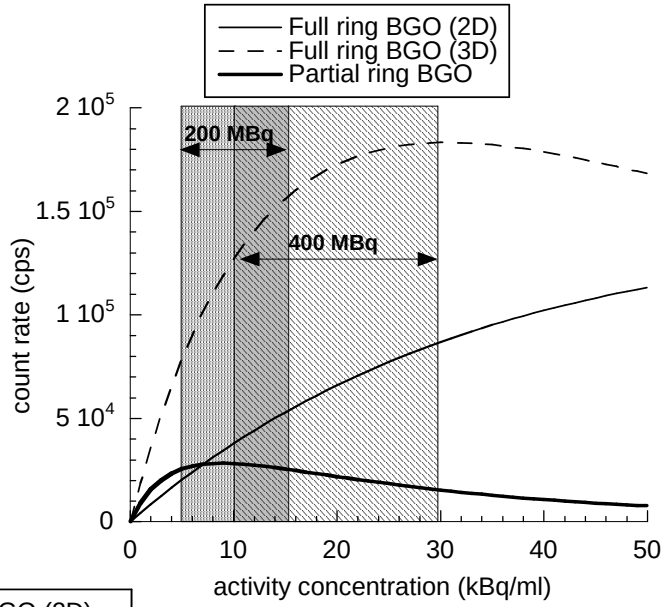
Countrate Performance

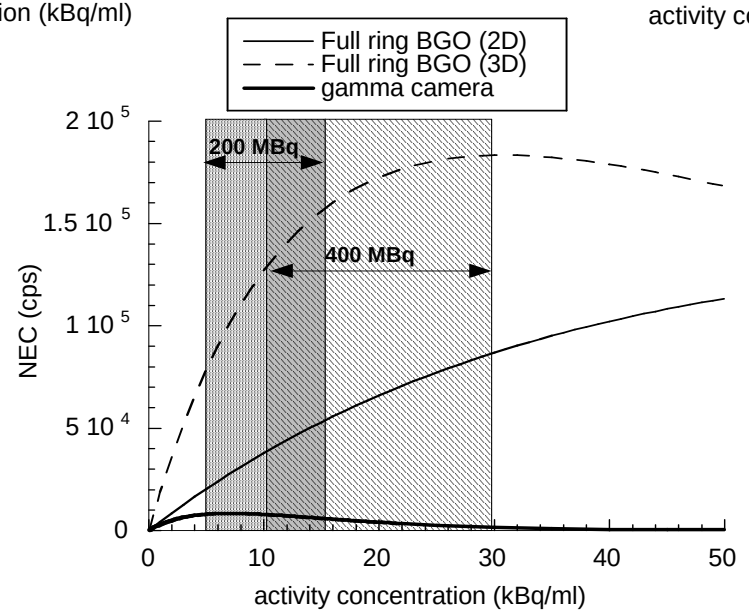
(Full Ring BGO - 2D)



NEC Curves


Full ring BGO (2D)
Full ring BGO (3D)
NaI
200 MBq
400 MBq
count rate (cps)
activity concentration (kBq/ml)

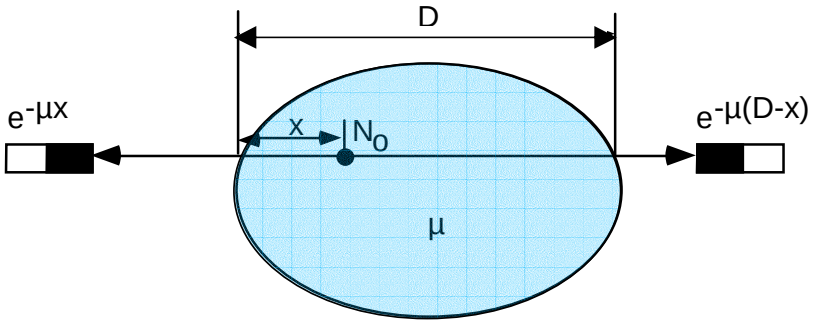

Full ring BGO (2D)
Full ring BGO (3D)
Partial ring BGO
200 MBq
400 MBq
count rate (cps)
activity concentration (kBq/ml)


Full ring BGO (2D)
Full ring BGO (3D)
gamma camera
200 MBq
400 MBq
NEC (cps)
activity concentration (kBq/ml)

Attenuation Correction

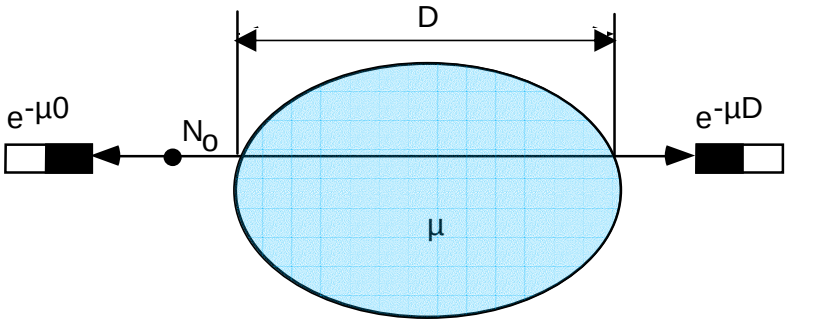
- Attenuation is independent of source position along a given LoR

Internal source



$$N = N_0 e^{-\mu x} e^{-\mu(D-x)}$$
$$= N_0 e^{-\mu D}$$

External source



$$N = N_0 e^{-0} e^{-\mu D}$$
$$= N_0 e^{-\mu D}$$

Attenuation Correction Factor ACF = N_0/N

N_0 is unattenuated count, N is attenuated count of transmission source

Attenuation Correction

- Exact analytical attenuation correction is possible with PET
  - $EM_{cor} = EM_{meas} * (TM_{nopatient}/TM_{patient})$
  - $TM_{nopatient}$ – Blank Scan
- Transmission based attenuation correction in PET is the rule, rather than exception
- Post injection transmission measurement mandatory
- Transmission measurement methods
  - Positron emitting TM source ($^{68}Ge/^{68}Ga$)
  - Singles transmission source (^{137}Cs)
  - CT based attenuation correction (Conversion from Hounsfield units to attenuation factors at 511 keV)
- Time required for transmission measurement should be as short as possible!

Factors that Affect Image Quality

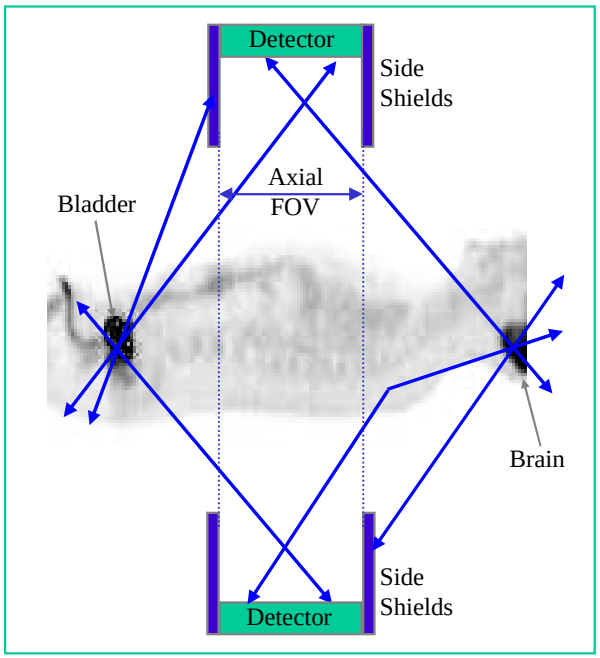
- Random coincidences
- Variability in detector efficiencies
- Dead time
- Scattered coincidences
- Photon attenuation
- Other factors:
  - Limited spatial resolution (partial volume effect)
  - Non isotropic spatial resolution (depth of interaction effect)
  - Noise (sensitivity limit)
  - Reconstruction/processing algorithms
  - Scan Time
  - Attenuation, randoms & scatter correction

Performance Measurement Standards

- **NEMA Standards Publication NU 2-1994**: Performance Measurement of Positron Emission Tomographs. National Electrical Manufacturers Association; Washington DC, 1994
- **NEMA Standards Publication NU 2-2001**: Performance Measurement of Positron Emission Tomographs. National Electrical Manufacturers Association; Washington DC, 2001.
- **IEC 61675-1:1998; AS/NZS 4545.1:1999**. Radionuclide imaging devices – Characteristics and test conditions. Part 1: Positron emission tomographs

- Recommended recent paper:
  - Daube-Witherspoon ME et al. PET Performance Measurements Using the NEMA NU 2-2001 Standard. *J Nucl Med 2002*; 43 (10):1398-1409

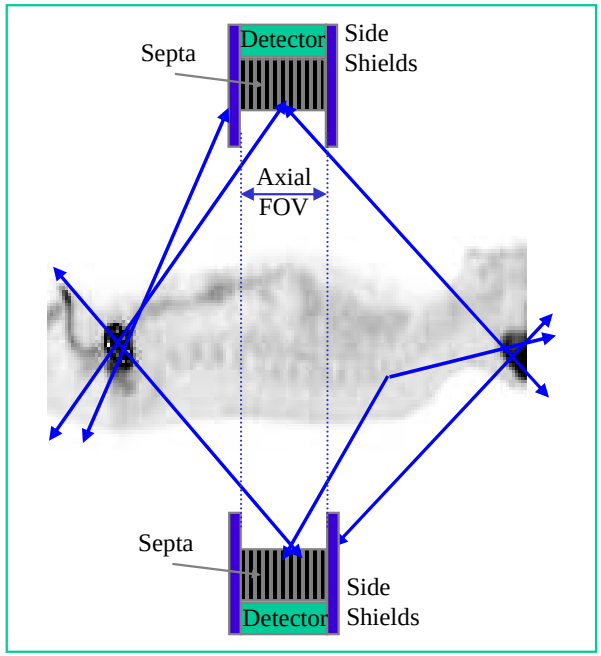
Effect of Activity Beyond Axial FoV



3D

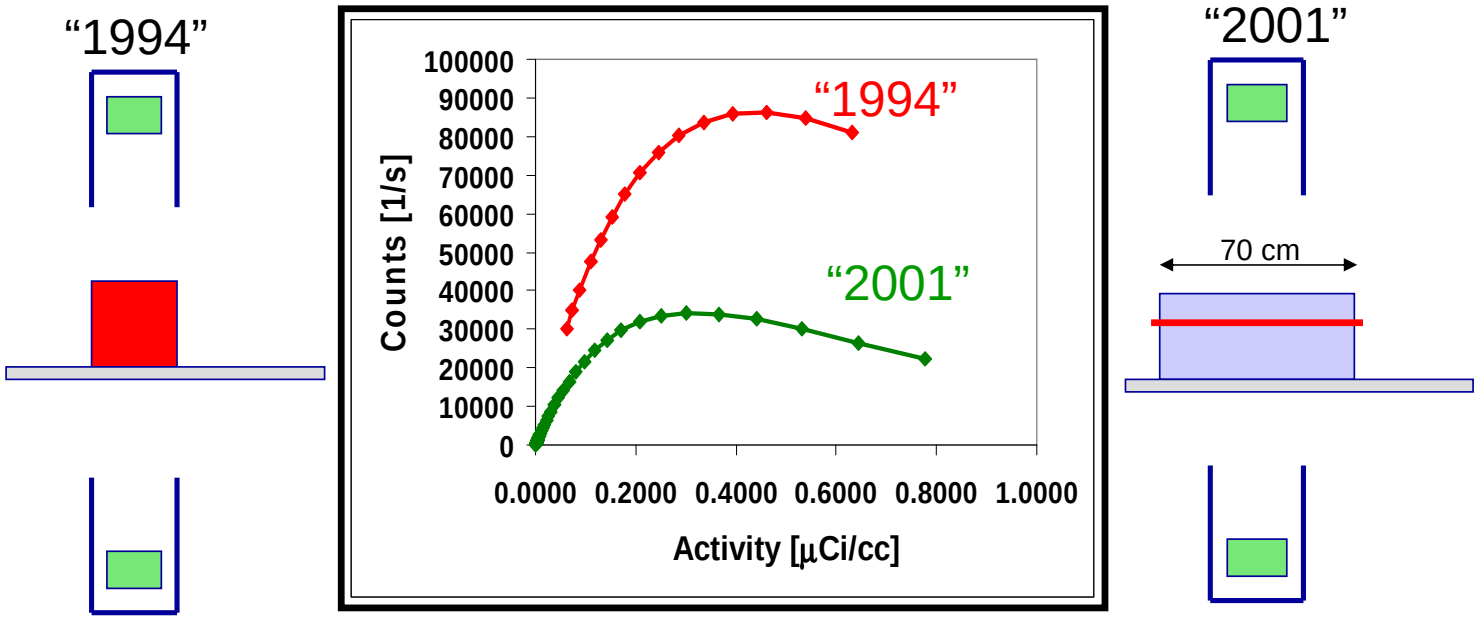
↑Singles, Scatter & Randoms

↓NEC



2D

NEMA NU2-1994 vs NU2-2001
NEC Measurements



Phantoms – Nema & IEC

Phantom	NEMA	IEC
20 cm x19 cm Cylinder	(Brain)	ü
IEC Whole Body Phantom	ü	ü
IEC Whole Body Arms	ß	ü
20 cm x 70 cm Line Phantom	ü	ß
Line Source Attenuating Sleeves	ü	ß

^{18}F is the radioisotope used for all tests for NEMA & IEC

IEC Whole Body Phantom length is ≥18 cm ie not extended phantom

Tests Performed – NEMA & IEC

Performance Parameter	NEMA	IEC
Spatial Resolution	ü	ü
Sensitivity	ü	ü
Scatter Fraction	ü	ü
Randoms Fraction	ü	ß
Count Rate Losses	ü	ü
NEC	ü	ß
Correction Accuracy		
Count Losses	ü	ü
Randoms	ü	ß
Attenuation	ü	ü
Scatter	ü	ß
Image Quality	ü	ß

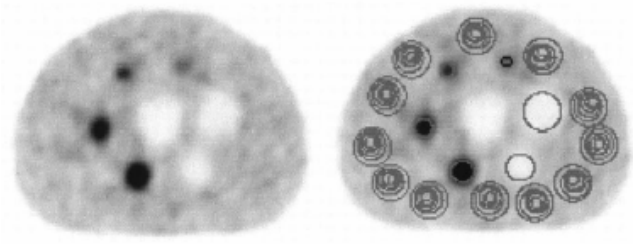
Tests for same performance parameter can vary considerably between NEMA & IEC

TABLE 5
Peak Counting Rates for NU 2-1994 and NU 2-2001 Standards

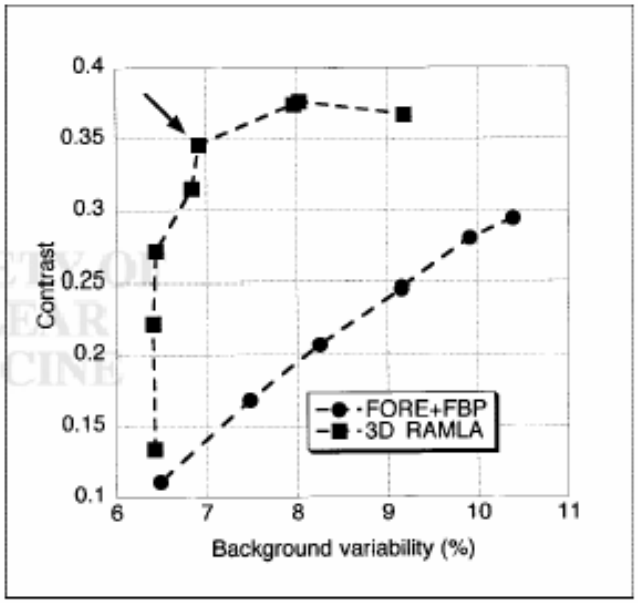
Acquisition mode	Standard	Peak NEC rate (kcps)	Activity concentration at peak NEC (kBq/mL)	Peak true rate (kcps)	Activity concentration at peak trues (kBq/mL)
2D*	NU 2-1994	261	152	557	267
2D†	NU 2-2001	125	58	189	58
3D	NU 2-1994	146	24	449	53
3D	NU 2-2001	19.2	7.15	109	19.7

*Data from (*16*).
†Results were not at peak NEC or peak true rates because there was insufficient activity in source to measure these peak rates.
Data were acquired on GE Advance scanner. As point of reference, typical average activity concentration seen in clinical FDG study is 3–4 kBq/mL, for 370-MBq injection in 70-kg patient after 1-h uptake period.

Image Quality Measurement



From: *J Nucl Med 2002; 43:1398-1409*



NEMA vs IEC:AS/NZS

- NEMA more comprehensive and more representative for whole body studies
- Attempts to provide information on image quality
- Measuring techniques can be quite different
  - Results for same performance parameter (eg sensitivity) not directly comparable
- Manufacturers use NEMA to specify their systems
- Should use local standard (IEC:AS/NZS), but
  - TSSC Interim Recommendations for PET Accreditation are based on NEMA
  - ANZSNM has purchased NEMA phantoms (70 cm & sensitivity phantom, but not IEC WB phantom)

Scanner Selection/Evaluation

- Define what is being used for
  - Whole body, brain etc
- Required through-put
- Scanner & Isotope cost
- Scanner Type
  - PET or PET/CT
  - 3D only vs 3D & 2D only capability
  - CT only transmission or CT + transmission source
- Crystal technology
  - BGO, GSO, LSO, NaI etc
- Scanner performance
  - Resolution, sensitivity, peak NEC etc
- *Which scanner gives the best images in shortest time and preferably at lowest cost!*

Scanner Selection/Evaluation

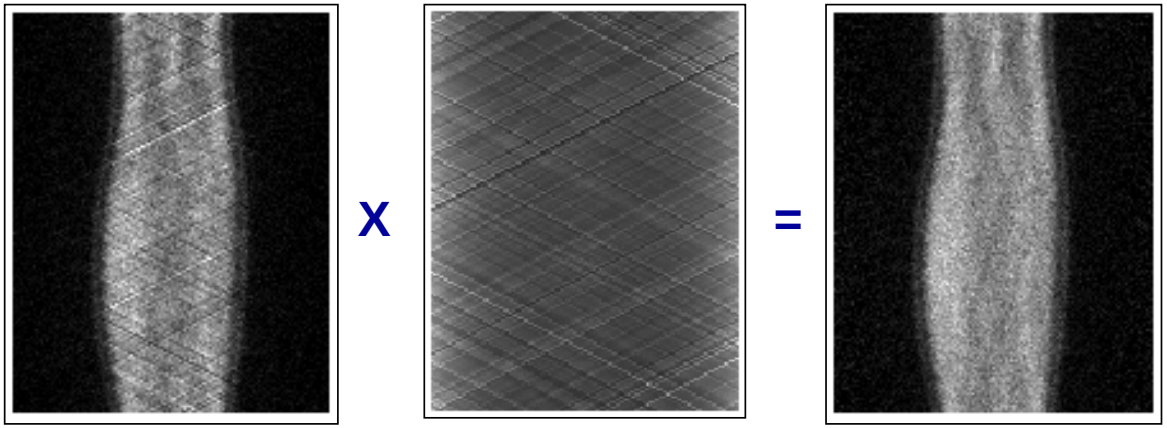
- Some local documents
  - ANZSNM TSSC Interim Recommendations for PET Accreditation (Technical Aspects)
  - Report on PET Scanning Technology prepared for PET Review Technical Subcommittee of the Commonwealth Department of Health and Age Care
- Set minimum standards, currently achievable by dedicated PET scanners (including partial ring scanners!), but not gamma camera based cө incidence systems

Acceptance Tests

- Perform manufacturers recommended tests only
- Perform sufficient NEMA tests to show compliance with TSSC minimum performance requirements
- Perform full set of NEMA or IEC:AS/NZS tests
- Resources required for NEMA tests
  - NEMA phantoms
  - Analysis S/W tools and expertise
  - ^{18}F
- ANZSNM has purchased set of NEMA phantoms
  - 70 cm & sensitivity phantoms, but not IEC WB phantom
  - Loan can be arranged by contacting Steve Meikle at RPAH (steve@nucmed.rpa.cs.nsw.gov.au)

Quality Control & Calibration

Normalization



Acquired sinogram

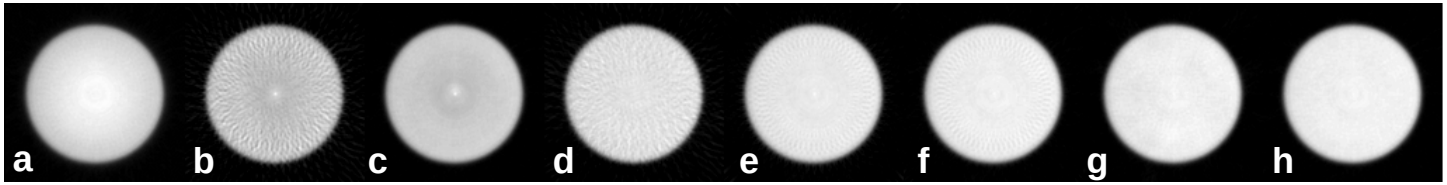
X

Normalization matrix

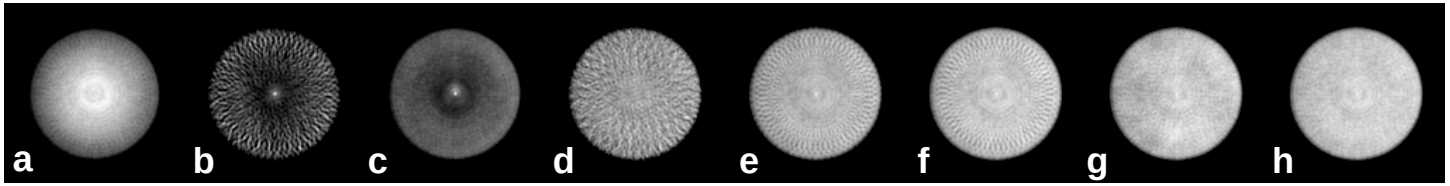
=

Normalized sinogram

Normalization Effects



Scaled 0-100%



Scaled 70-100%

a) no scatter correction
b) no normalization
c) no correction for radial profile
d) no crystal efficiency correction
e) no transaxial block profile correction
f) no crystal interference correction
g) no time alignment correction
h) fully normalised and scatter corrected

Quality Control

- Depends on Scanner, but some common requirements
- *Detector drift check*
  - Daily, either based on change in sinogram (visual or numeric comparison) or drifts of baseline, peaks
- *Blank Scan for transmission*
  - Daily to weekly for ^{68}Ge, every several months for ^{137}Cs, daily for CT.
- *Absolute activity measurement calibration (SUV)*
  - Every several months or as required
- *Normalisation, calibration (peaks etc)*
  - 1 to several months or as required

Additional QC for PET/CT

- CT QC
  - Several quick scans to check and calibrate mA, kVp etc
- Spatial co-registration between CT and PET
- Check communication between CT and PET

Conclusions

- Don’t really have any but, ….