Advances in PET Technology
Updating the NEMA NU2 2001 standard?

Joel Karp
Department of Radiology
University of Pennsylvania

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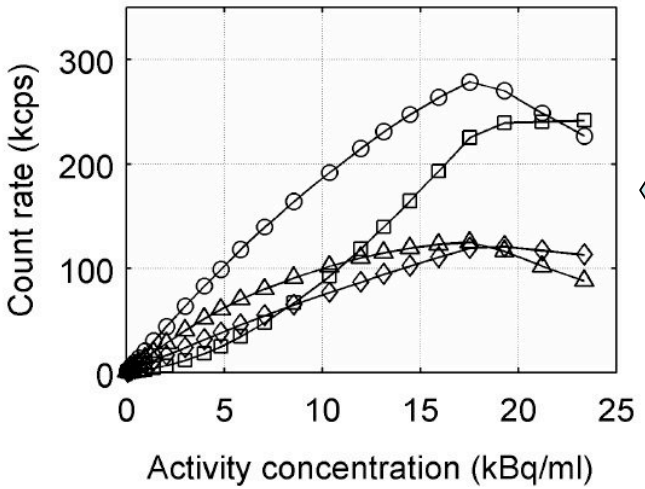
Overview

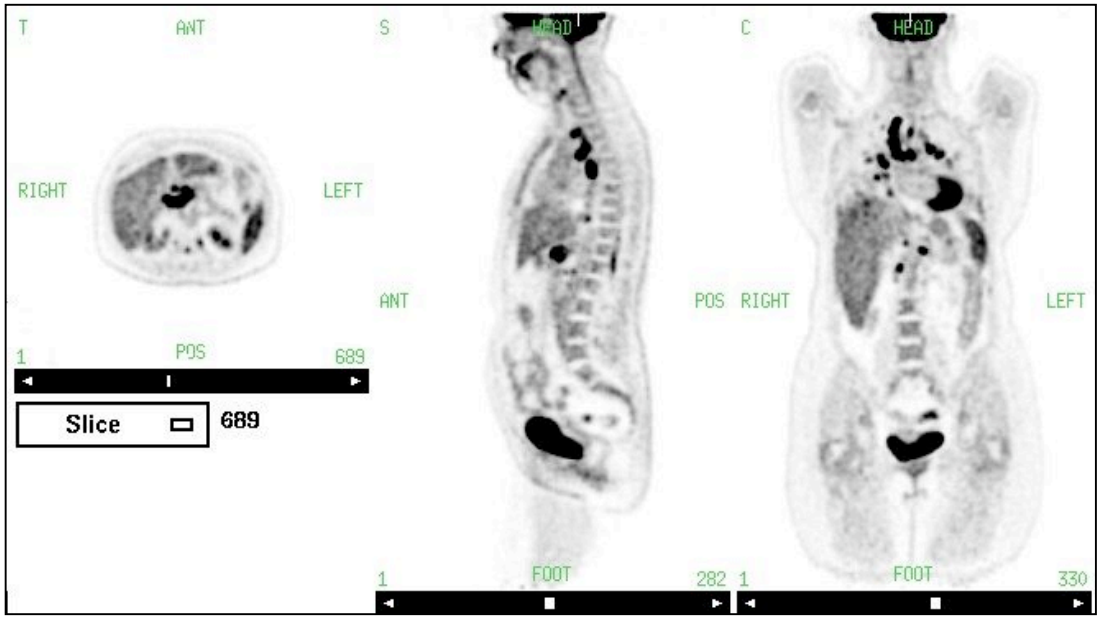
- Review of NEMA NU2
- Does NEMA need update for new technology?
- Is NEMA relevant for clinical imaging?
- Are NEMA tests relevant for quantitative clinical trials?

Why do we need PET performance standards?

- Establish common language to define measurements
- Develop tools (phantoms) for evaluation of scanners
- Structure tests to understand data from in-vivo (patient) studies



?



Initial standardization efforts

- SNM Computer & Instrumentation Council
  - *Karp et al, Performance Standards in Positron Emission Tomographs, JNM 32: 2342-2350, 1991*
- EEC Concerted Action
  - *Performance evaluation of Positron Emission* Tomographs, 1990
  - *Guzzardi et al, Methodologies for performance evaluation of Positron Emission Tomographs, J Nucl biol Med 35: 141-157, 1991*
  - *International Electrotechnical Commission (IEC): Radionuclide imaging devices-characteristics and tests conditions. Part 1, Positron Emission Tomographs,1998*
- NEMA NU2 1994
  - *Performance measurements of Positron Emission Tomographs*

	SNM/NEMA *(intrinsic)*	EEC *(clinical)*
Spatial resolution	Line source in air Sharp (ramp) filter	Line source in water Smooth (clinical) filter
Scatter fraction	20x19cm cylinder Scatter in sinogram	20x19cm cylinder Scatter (contrast) in image
Sensitivity	20x19cm cylinder Tot-scat (mCi/ml)	similar
Count-rate	20x19cm cylinder NEC, deadtime	20x19cm cylinder (head) heart, thorax phantoms
Accuracy of corrections	Uniformity - 20 M/sl Scatter corr., atten. corr., CR linearity	Uniformity - 2 M/sl

NEMA NU2 2001

Performance measurements of Positron Emission Tomographs

- Update existing NEMA NU2 1994
  - emphasis on whole-body imaging
  - extend to scanners with large axial FOV (> 17 cm)

- Applicable to all PET instruments
  - 2D and 3D
  - discrete (multi-ring) and continuous detectors
  - dedicated PET and hybrid cameras

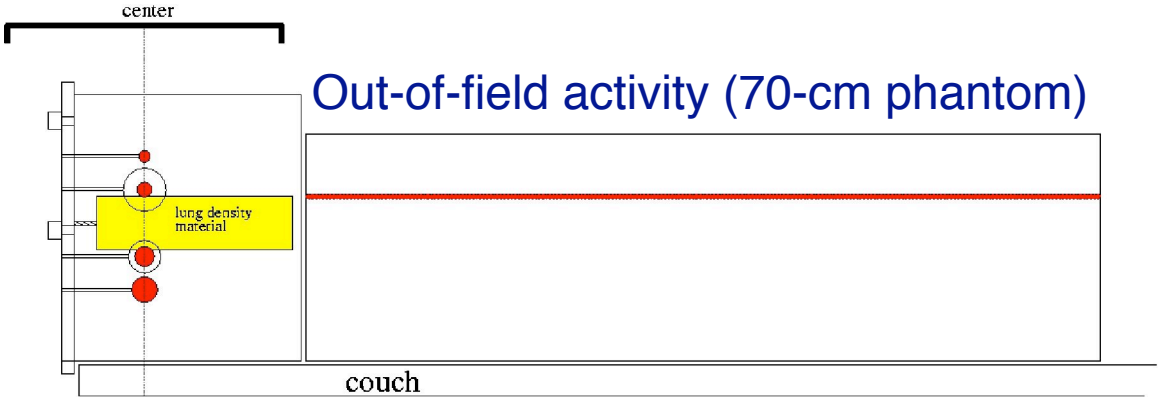
- Simplify and less time consuming

- Daube-Witherspoon et al, PET performance measurements using the NEMA NU2 2001 standard, JNM 43: 1398-1409, 2001

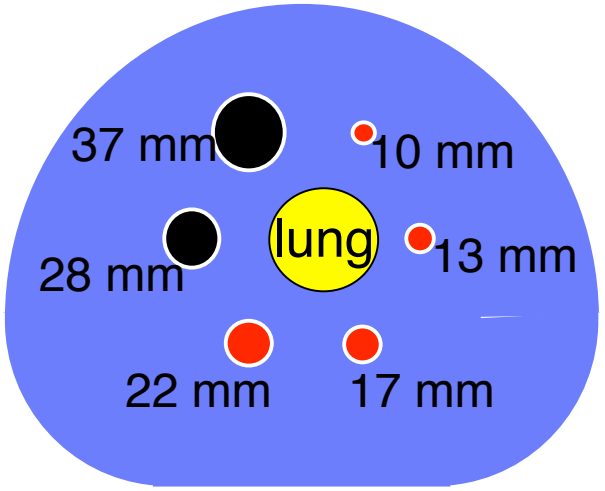
	NEMA NU2 1994 *(brain)*	NEMA NU2 2001 *(body)*
Spatial resolution	Line source in air narrow profile	Point source in air wide profile (fwhm, fwtm)
Scatter fraction	20x19cm cylinder 3 radial positions	20x70cm line in cylinder 1 radial position
Sensitivity	20x19cm cylinder Tot-Scat (mCi/ml)	70cm co-axial lines cps/kBq
Count-rate	20x19cm cylinder	20x70cm line in cylinder
Accuracy of corrections	Uniformity - 20 M/sl Scatter corr., atten. corr., CR linearity	Count-rate linearity corrections

NEMA NU2 2001

Image quality (IEC) phantom



Out-of-field activity (70-cm phantom)



- Focus on lesion studies in whole-body oncology imaging
- Test depends on combination of performance characteristics
- Scan time is defined by clinical protocol
- Includes effects of data correction and image reconstruction
- Provides both qualitative (visual) and quantitative metrics

Diameter	10mm	13mm	17mm	22mm	28mm	37mm
CRC (%)	35	47	70	69	74	82
Var (%)	6.9	6.1	5.2	4.4	3.9	3.2

PET System Specifications

Patented PET Detector Assembly	biograph™ 2	biograph 6	biograph 16	biograph 64
Detector material	Lutetium Oxyorthosilicate (LSO)	Lutetium Oxyorthosilicate (LSO)	Lutetium Oxyorthosilicate (LSO)	Lutetium Oxyorthosilicate (LSO)
Crystal dimensions	6.45 x 6.45 x 25 mm	4.0 x 4.0 x 20 mm	4.0 x 4.0 x 20 mm	4.0 x 4.0 x 20 mm
Crystals per detector block	64	169	169	169
Number of detector blocks	144	144	144	144
Photomultiplier tubes (PMTs)	4 per block	4 per block	4 per block	4 per block
Detector ring diameter	830 mm	830 mm	830 mm	830 mm
Detectors per ring	384	624	624	624
Number of detector rings	24	39	39	39
Total number of detectors	9216	24336	24336	24336
Transaxial FOV	585 mm	585 mm	585 mm	585 mm
Axial FOV	162 mm	162 mm	162 mm	162 mm
Number of image planes	47	81	81	81
Plane spacing	3.375 mm	2 mm	2 mm	2 mm

PET Data Acquisition/ Processing	biograph 2	biograph 6	biograph 16	biograph 64
Coincidence time resolution	500 psec	500 psec	500 psec	500 psec
Coincidence window	4.5 nsec	4.5 nsec	4.5 nsec	4.5 nsec
Acquisition mode	Static, Multibed	Static, Multibed	Static, Multibed	Static, Multibed
Reconstruction time*	<1.0 min/bed	<2.0 min/bed	<2.0 min/bed	<2.0 min/bed
Scatter Fraction	<40% (@400 keV)	<36% (@425 keV LLD)	<36% (@425 keV LLD)	<36% (@425 keV LLD)

*128 x 128 x 47 matrix with all data corrections, AW-OSEM iterative reconstruction, 2 iterations and 8 subsets.

PET Performance Specifications**	biograph 2	biograph 6	biograph 16	biograph 64
Transaxial resolution (NEMA 2001)				
FWHM @ 1 cm	6.3 mm	5.9 mm (4.2 mm***)	5.9 mm (4.2 mm***)	5.9 mm (4.2 mm***)
FWHM @ 10 cm	7.1 mm	6.0 mm (4.8 mm***)	6.0 mm (4.8 mm***)	6.0 mm (4.8 mm***)
Axial resolution (NEMA 2001)				
FWHM @ 1 cm	6.0 mm	5.5 mm (4.5 mm***)	5.5 mm (4.5 mm***)	5.5 mm (4.5 mm***)
FWHM @ 10 cm	7.0 mm	6.0 mm (5.5 mm***)	6.0 mm (5.5 mm***)	6.0 mm (5.5 mm***)
Sensitivity	5.7 cps/kBq (@400 keV)	4.5 cps/kBq (@350 keV)	4.5 cps/kBq (@350 keV)	4.5 cps/kBq (@350 keV)
Uniformity	≤5% variation	≤5% variation	≤5% variation	≤5% variation
Count rate peak NECR	93 kcps@29kBq/cc	93 kcps@29kBq/cc	93 kcps@29kBq/cc	93 kcps@29kBq/cc
Energy Resolution	<19%	<15%	<15%	<15%

** Performance specifications represent average values measured following the methodology of NEMA standard publication NU 2 2001, Performance Measurements of Positron Emission Tomographs, except where noted. Sensitivity and uniformity were measured with 68-Ge sources.

*** HI-REZ optional

PET Performance Specifications**

Transaxial resolution (NEMA 2001)

FWHM @ 1 cm

FWHM @ 10 cm

Axial resolution (NEMA 2001)

FWHM @ 1 cm

FWHM @ 10 cm

Sensitivity

Uniformity

Count rate peak NECR

Energy Resolution

** Performance specifications represe
Measurements of Positron Emissio

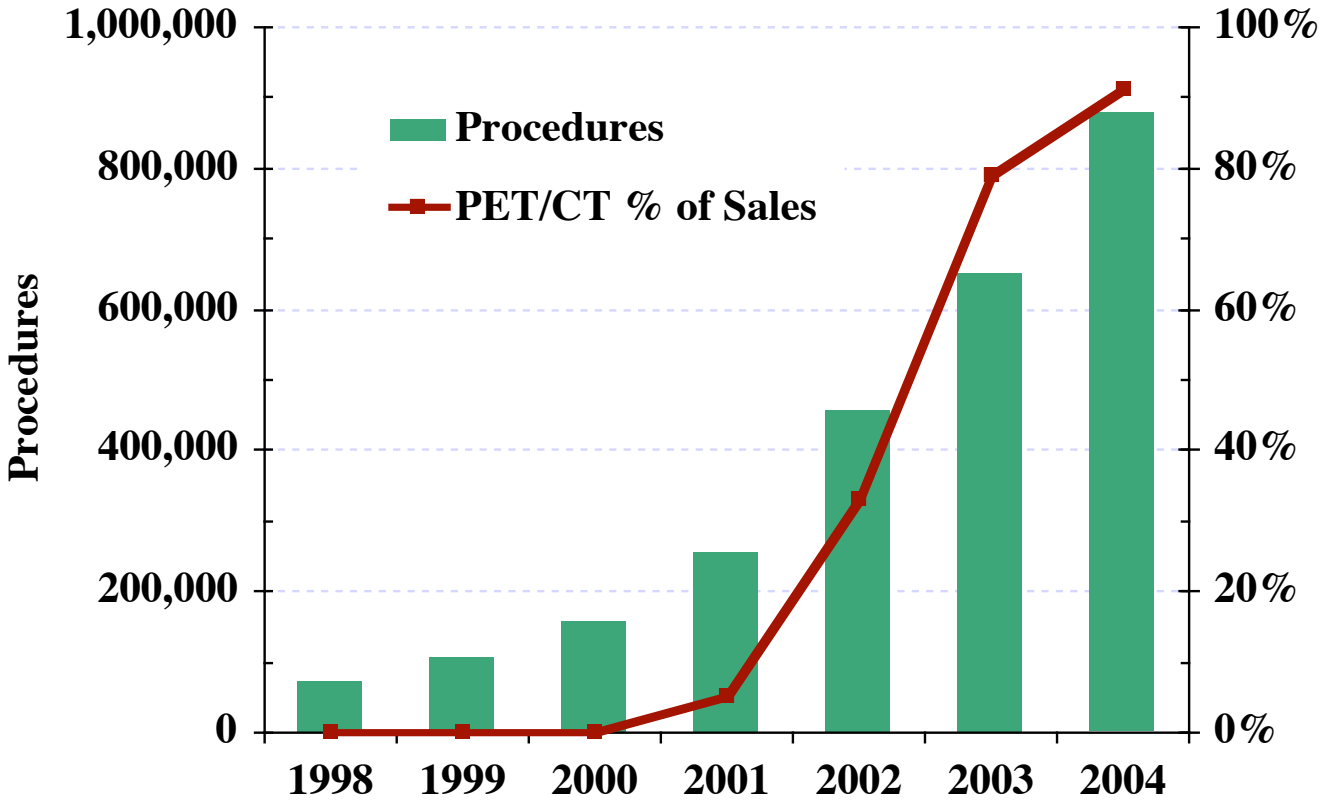
*** HI-REZ optional

Are the NEMA tests still relevant for state-of-the-art PET instruments?

Or do we need an update for new technology?

PET/CT

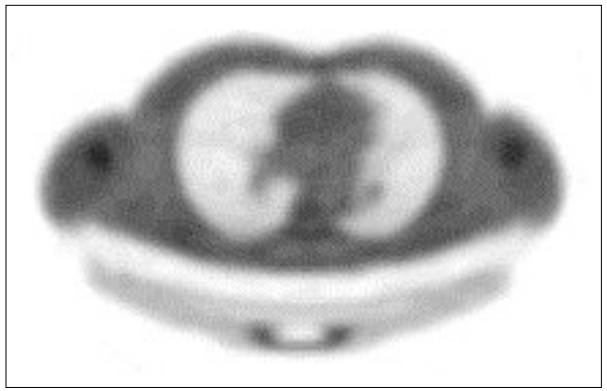
Growth of PET procedures in the U.S.



1998: Reimbursement for FDG-PET. 1st PET/CT prototype built

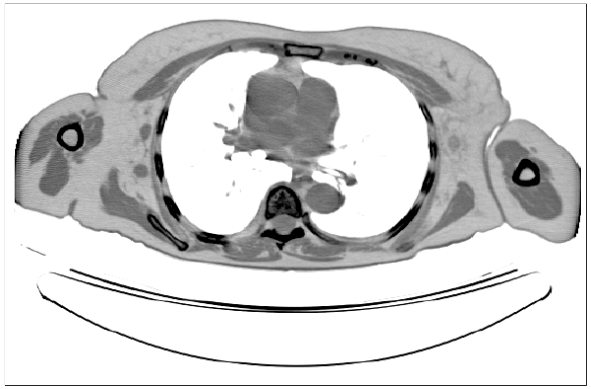
Attenuation correction for PET

Types of transmission images



Single photon Cs-137
(662 keV)

lower noise
5 min scan time
low bias
lower contrast

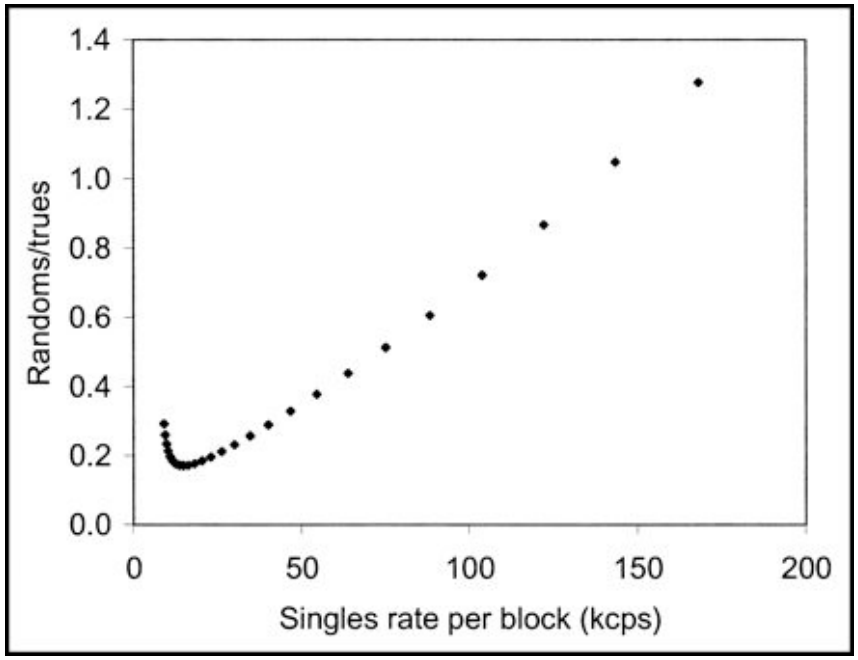


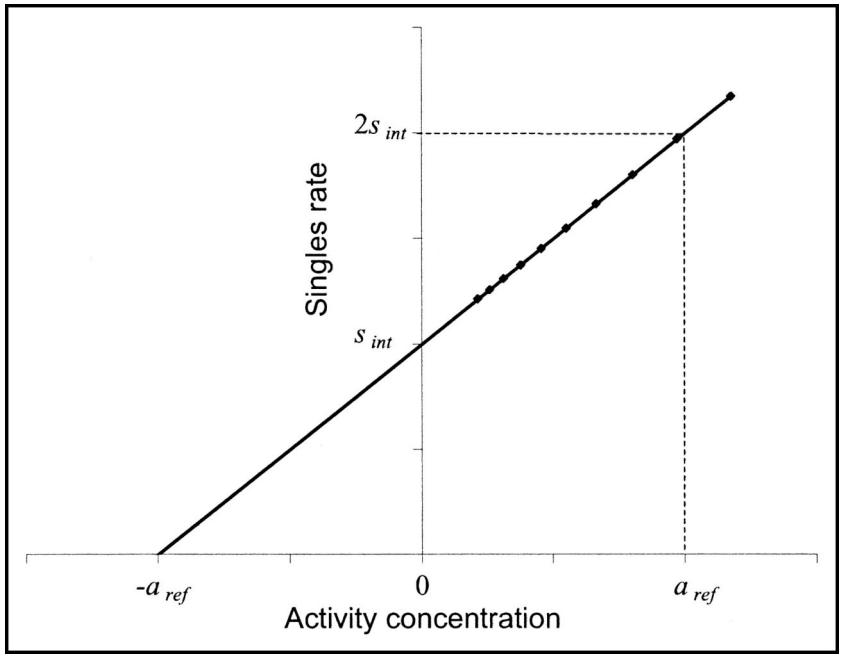
X-ray
(~30-140kVp)

no noise
1 min scan time
potential for bias
high contrast

LSO/LYSO

NEMA NU2 2007 update





Counting-rate test performed on an LSO-based ACCEL

Scatter fraction affected by LSO natural activity

a_{ref} defines the threshold above which the response of the system is determined more by the external radiation than by internal activity.

NEMA NU 2 Performance Tests for Scanners with Intrinsic Radioactivity
Charles C. Watson, PhD, Michael E. Casey, PhD, Lars Eriksson, PhD, Tim Mulnix, PhD, Doug Adams and Bernard Bendriem, PhD

Time-of-Flight

Philips Gemini TF

PET scanner

70-cm bore

18-cm axial FOV

LYSO crystals

CT scanner

Brilliance 16-slice

NEMA NU-2

Spatial resolution: 4.8 mm at 1 cm, 5.2 mm at 10 cm

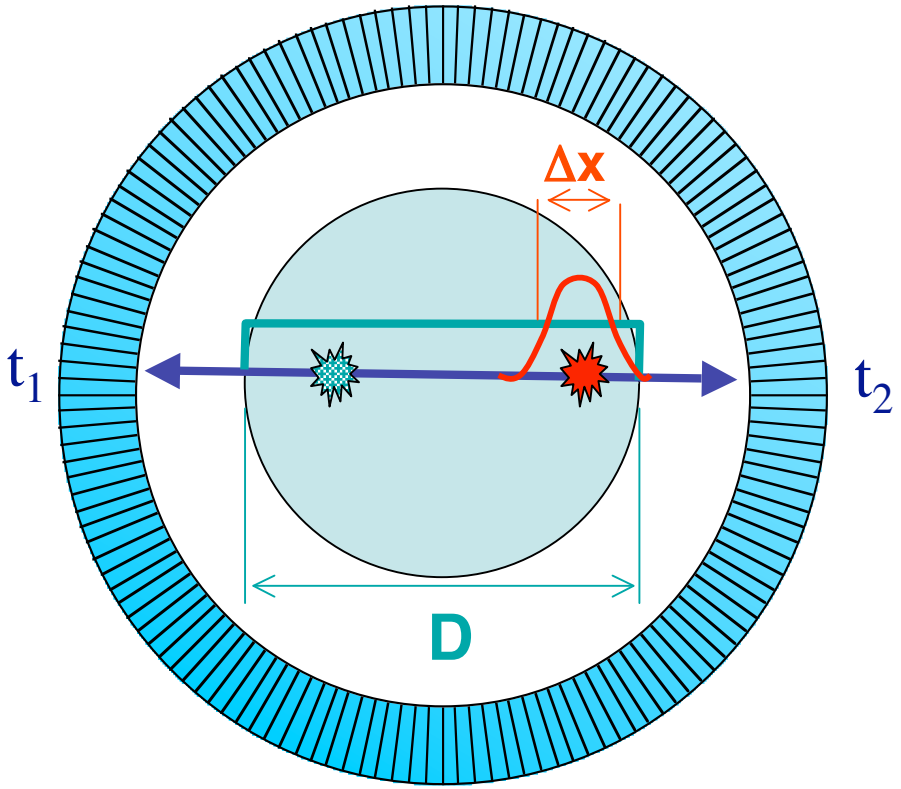
Sensitivity: 6.6 cps/kBq

Scatter fraction (at 440 keV): 27% for 20-cm x 70-cm

Peak NEC: 125 kcps @ 0.42mCi/ml

Timing resolution: 585 ps

How does TOF help?



Δt = uncertainty in measurement of t_1-t_2

Δx = uncertainty in position along LOR

$= c \cdot \Delta t/2$

$SNR^2 \sim NEC$

$NEC_{TOF} / NEC_{non\text{-}TOF} \sim SNR^2_{TOF} / SNR^2_{non\text{-}TOF} = D/\Delta x$

variance reduction for uniform cylinder *(Snyder et al 1981)*

or

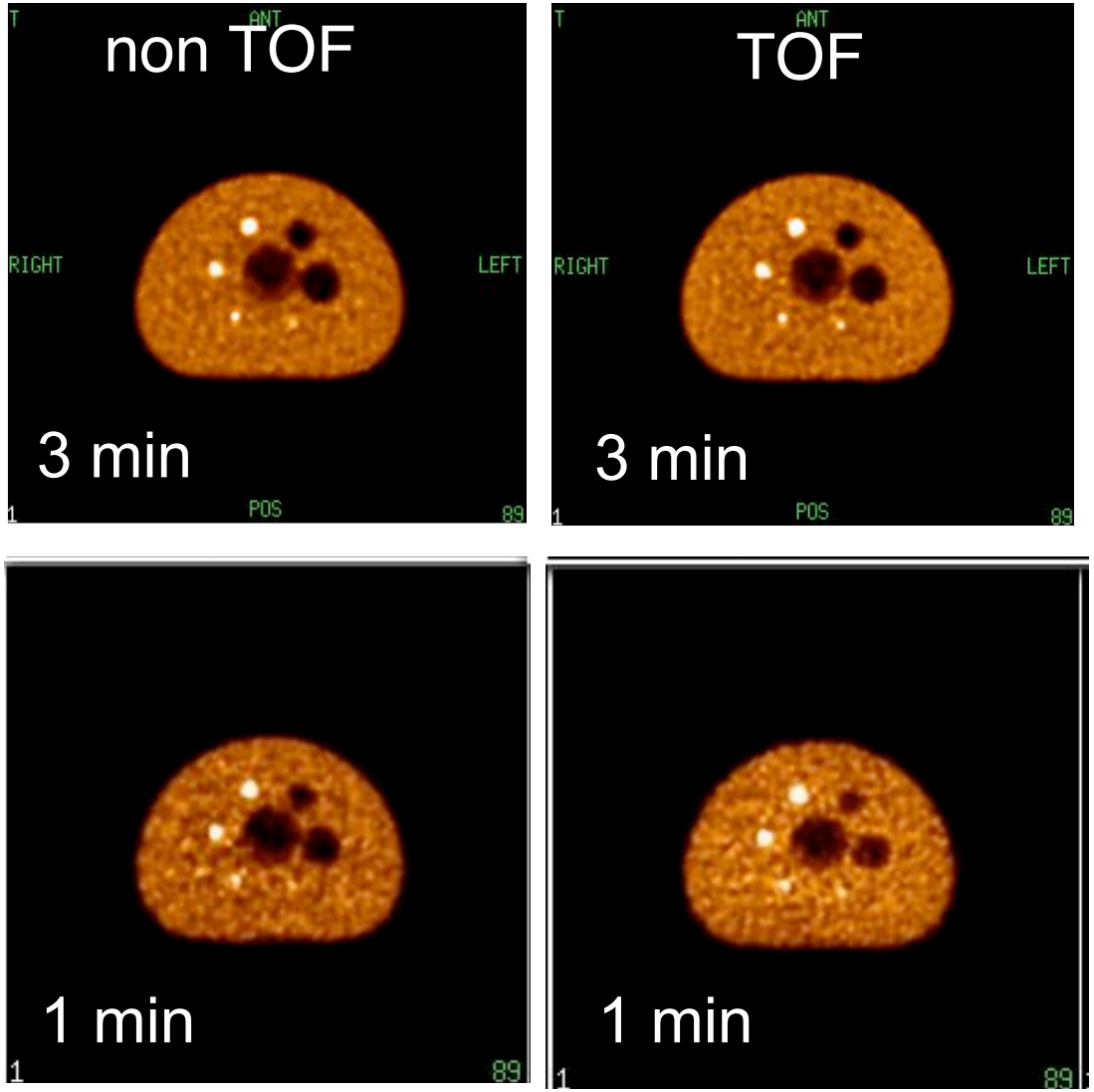
$NEC_{TOF} / NEC_{non\text{-}TOF} \sim D/(1.6 \bullet \Delta x)$

includes effect of reconstruction *(Tomitani et al, 1981)*

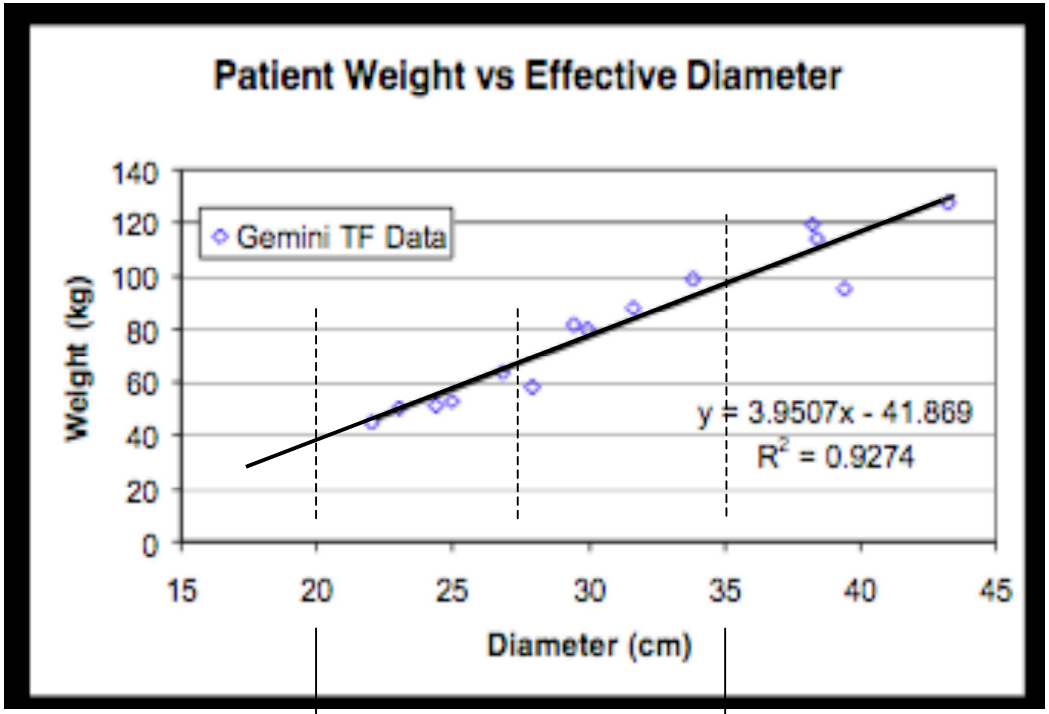
D = 27-cm diameter

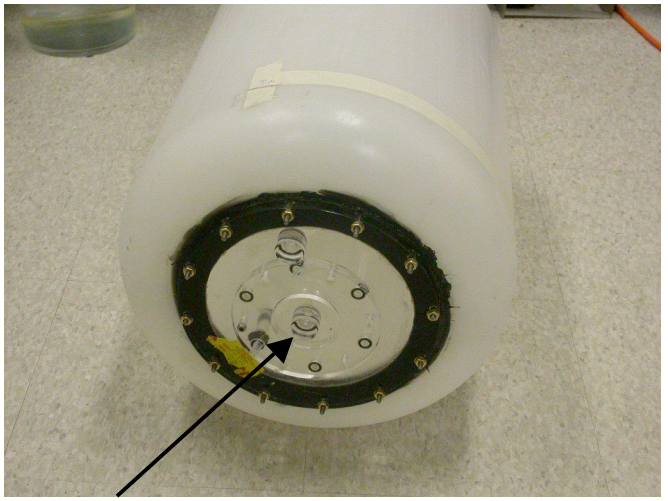
	300ps	600ps	1000ps
D/Δx	6	3	1.8
D/(1.6Δx)	3.8	1.9	1.1

Philips Gemini TF **NEMA IEC phantom** 4:1 contrast
bkgnd A_c = 0.14 μCi/ml

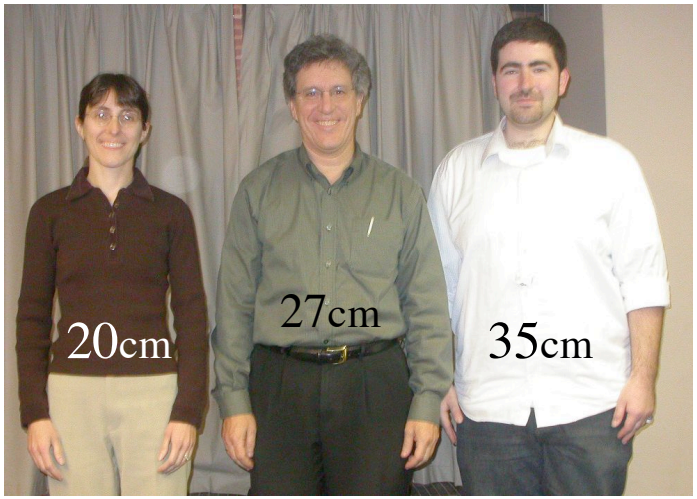


TOF improvement is modest for IEC phantom



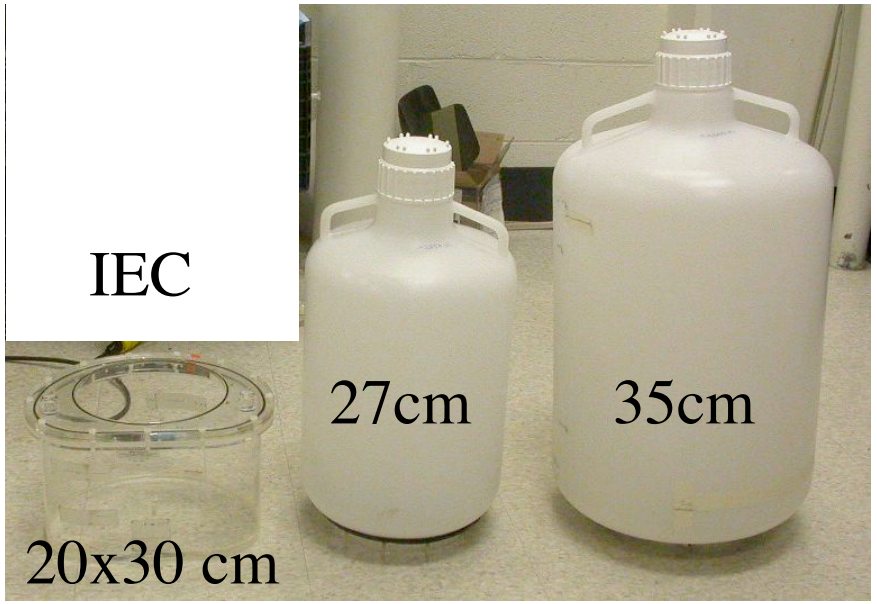


6 spheres: 1.0 -> 3.7cm



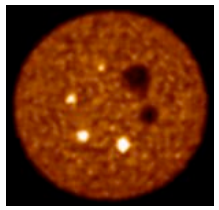
25” belt 34” belt 43” belt

IEC

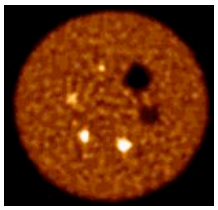


CRC and Noise measures

TOF *Non-TOF* *TOF* *Non-TOF*

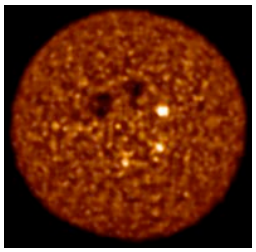


60s

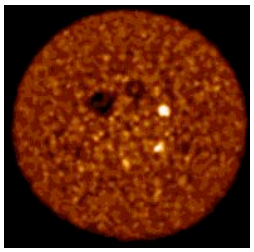


180s

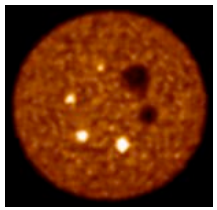
Similar CRC and Noise



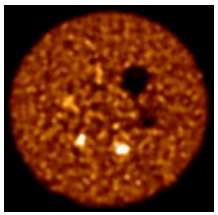
75s



300s

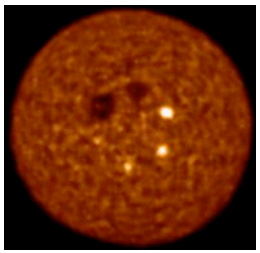


60s

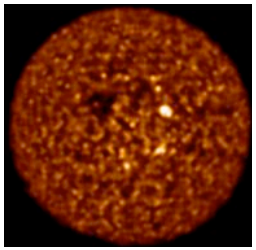


60s

Similar imaging time



120s

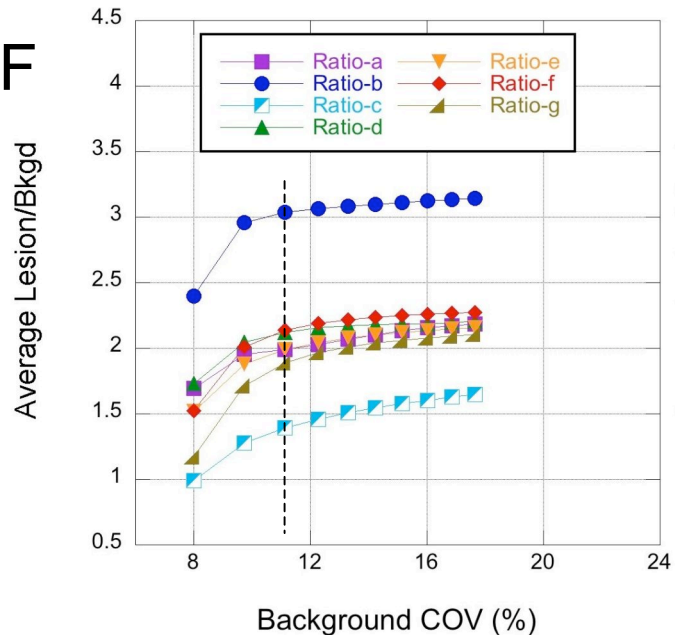


120s

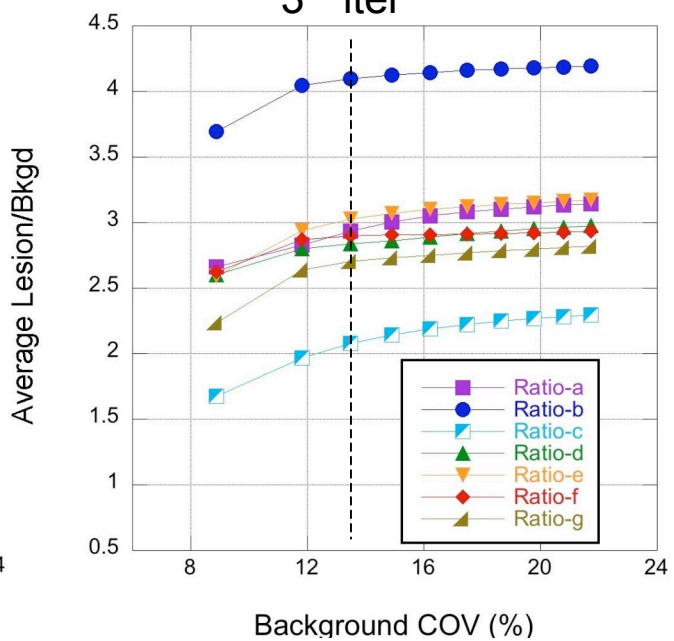
27-cm cylinder

35-cm cylinder

nonTOF

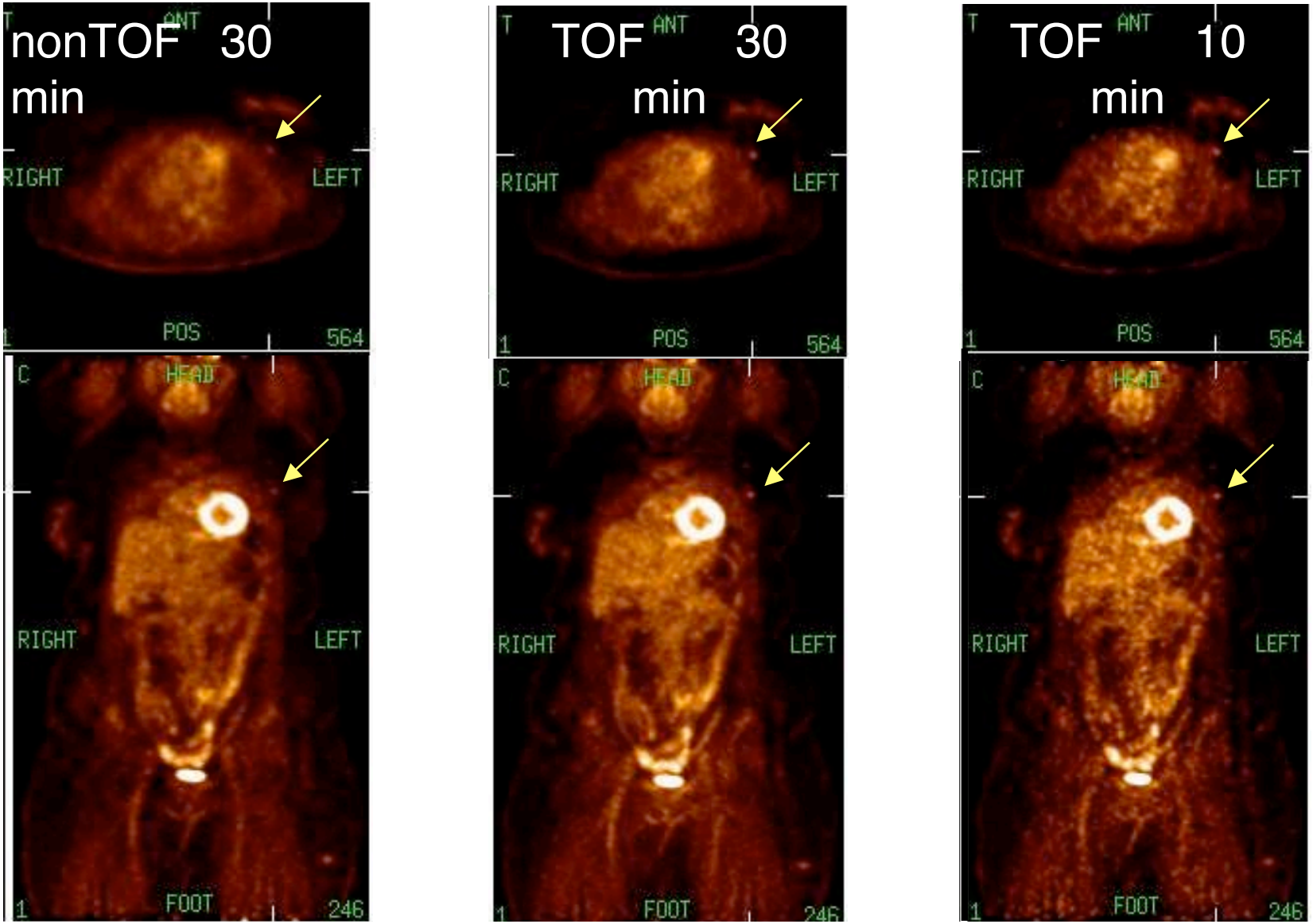


3rd iter



TOF

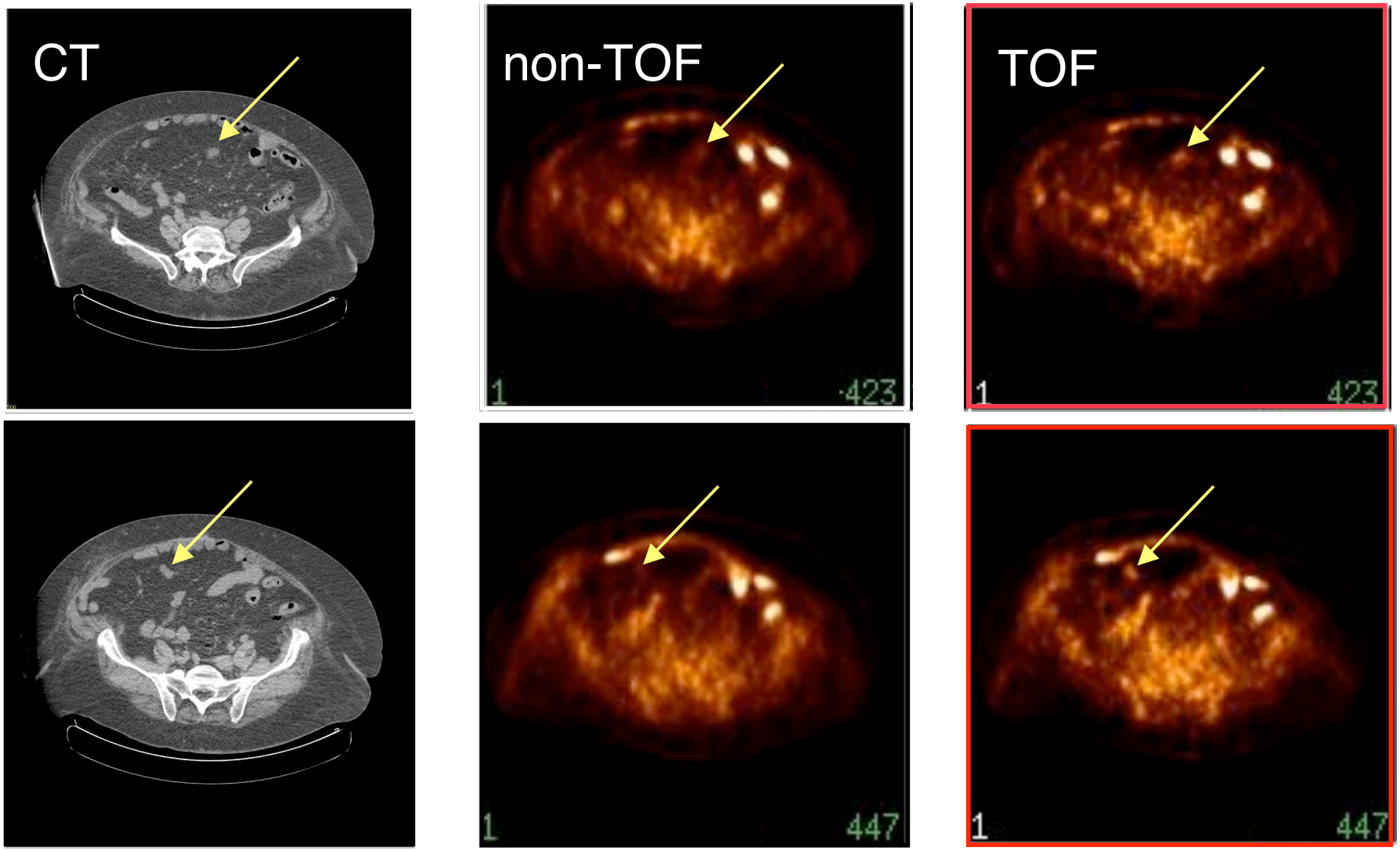
non-Hodgkin's lymphoma 136 kg (45 BMI)



TOF tumor contrast superior (x1.8) for 10 min and 30 min scan

Philips Gemini TF

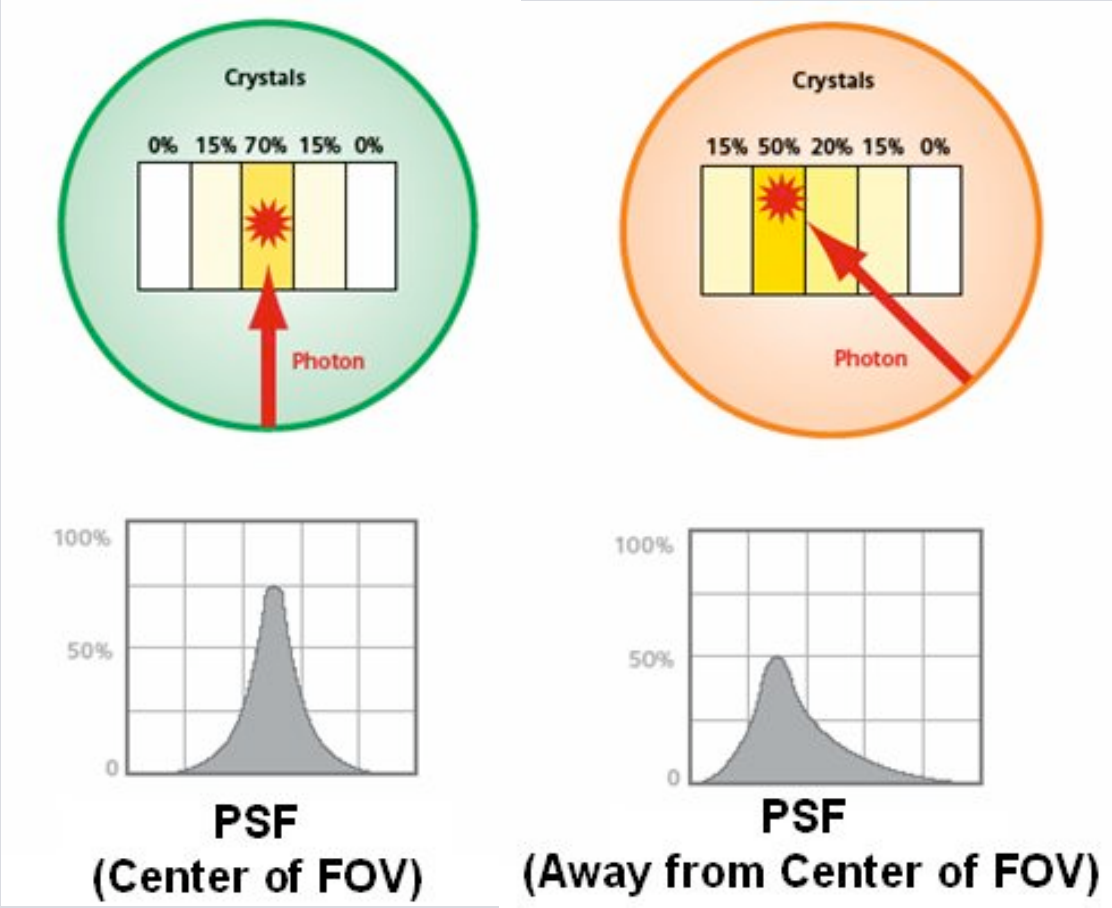
Colon cancer 119 kg (BMI = 46.5) 3 min/bed; 27 min tot



Improvement in lesion detectability with TOF

PSF Recovery

SIEMENS

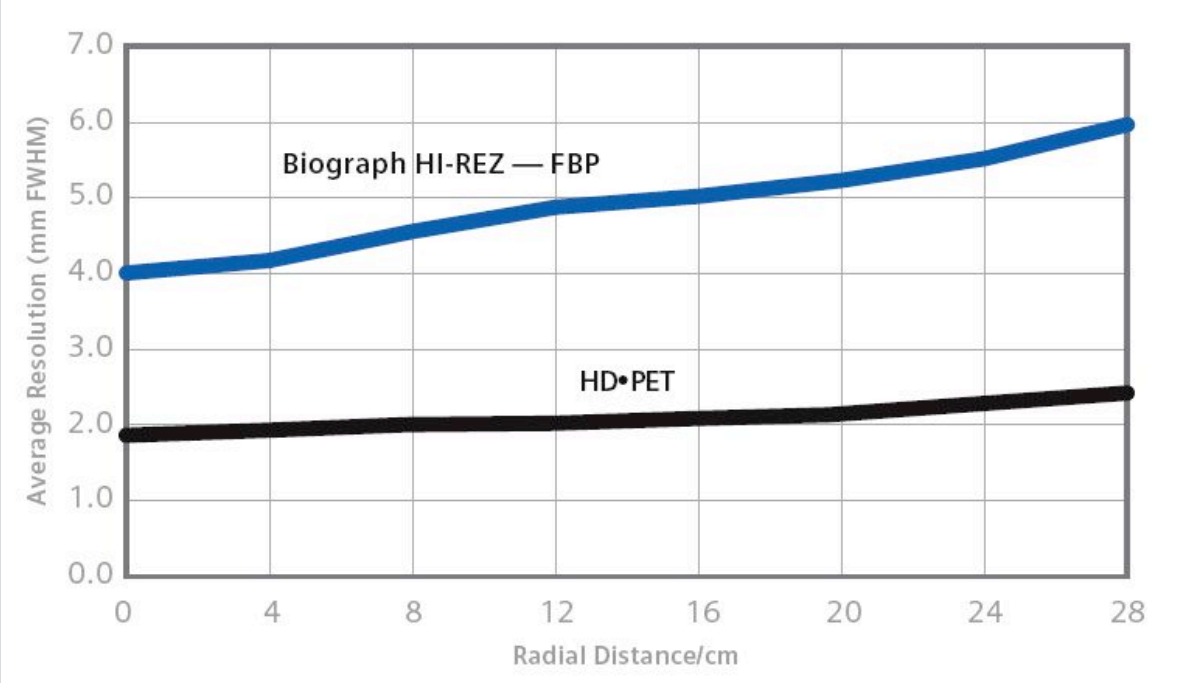


A Point Spread Function (PSF) describes the response of an imaging system to a point source or point object. A system that knows the response of a point source from everywhere in its field of view can use this information to recover the original shape and form of imaged objects.

PSFs are used in precision imaging instruments, such as microscopy, ophthalmology, and astronomy (e.g. the Hubble telescope) to make geometric corrections to the final image.

SIEMENS

HD•PET Technology



HD·PET provides 2x signal to noise improvement and near uniform spatial resolution of 2mm throughout the entire FOV.

* Measurements were taken with a line source suspended in air at radial positions from the center to 28 centimeters in 4 centimeter steps. The Biograph HI-REZ-FBP data were reconstructed with a standard filtered backprojection algorithm after FORE rebinning and the HD•PET data were reconstructed with the TrueX algorithm using six iterations and 14 subsets.

More uniform contrast over the FOV in a realistic WB phantom (12 mm “hot” lesion)

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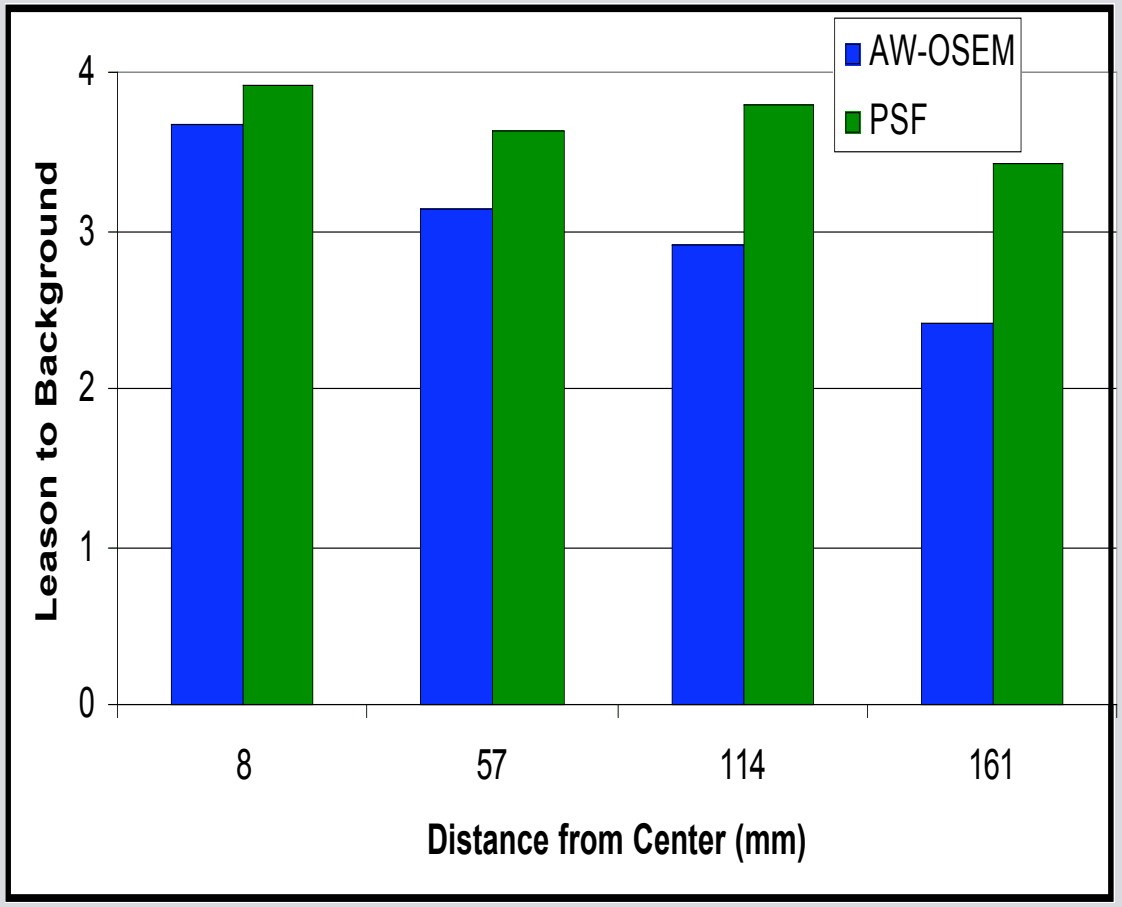
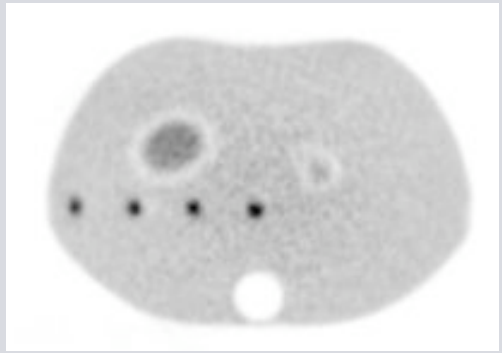
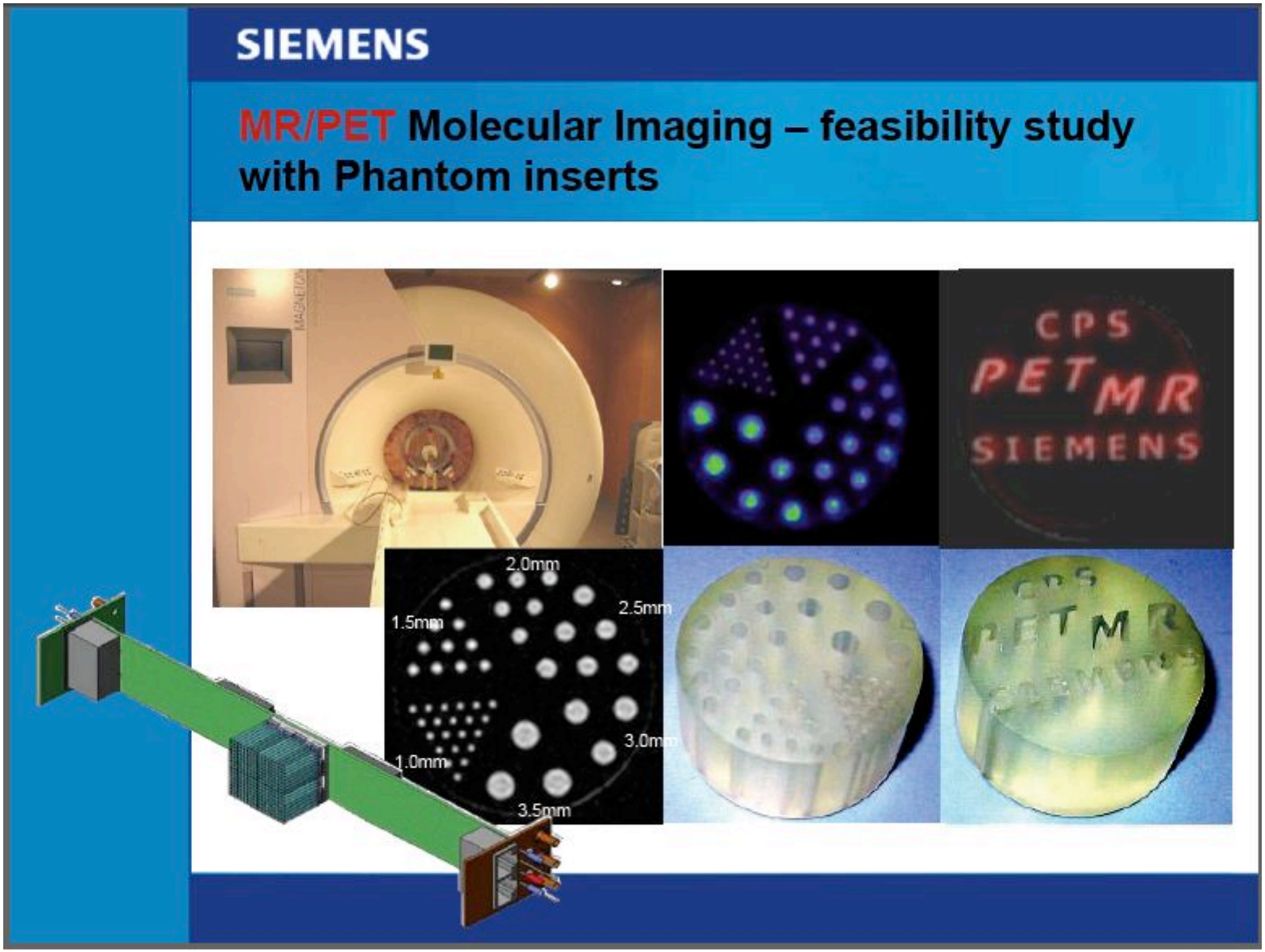


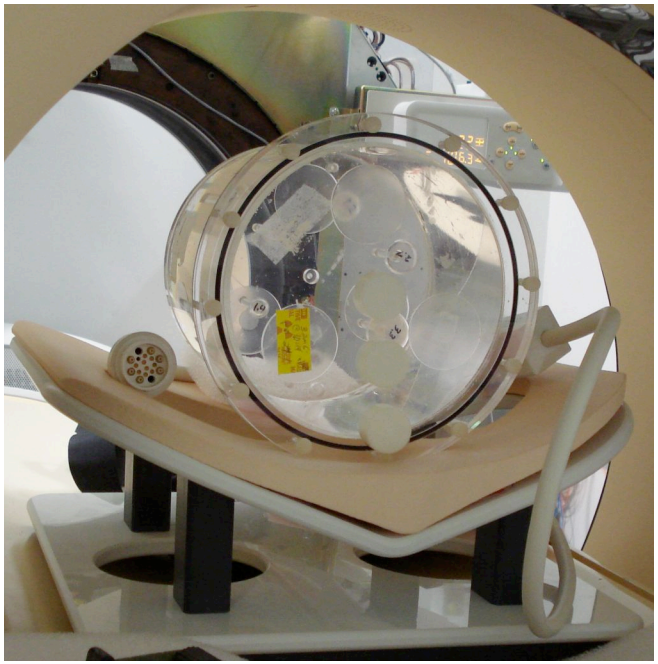


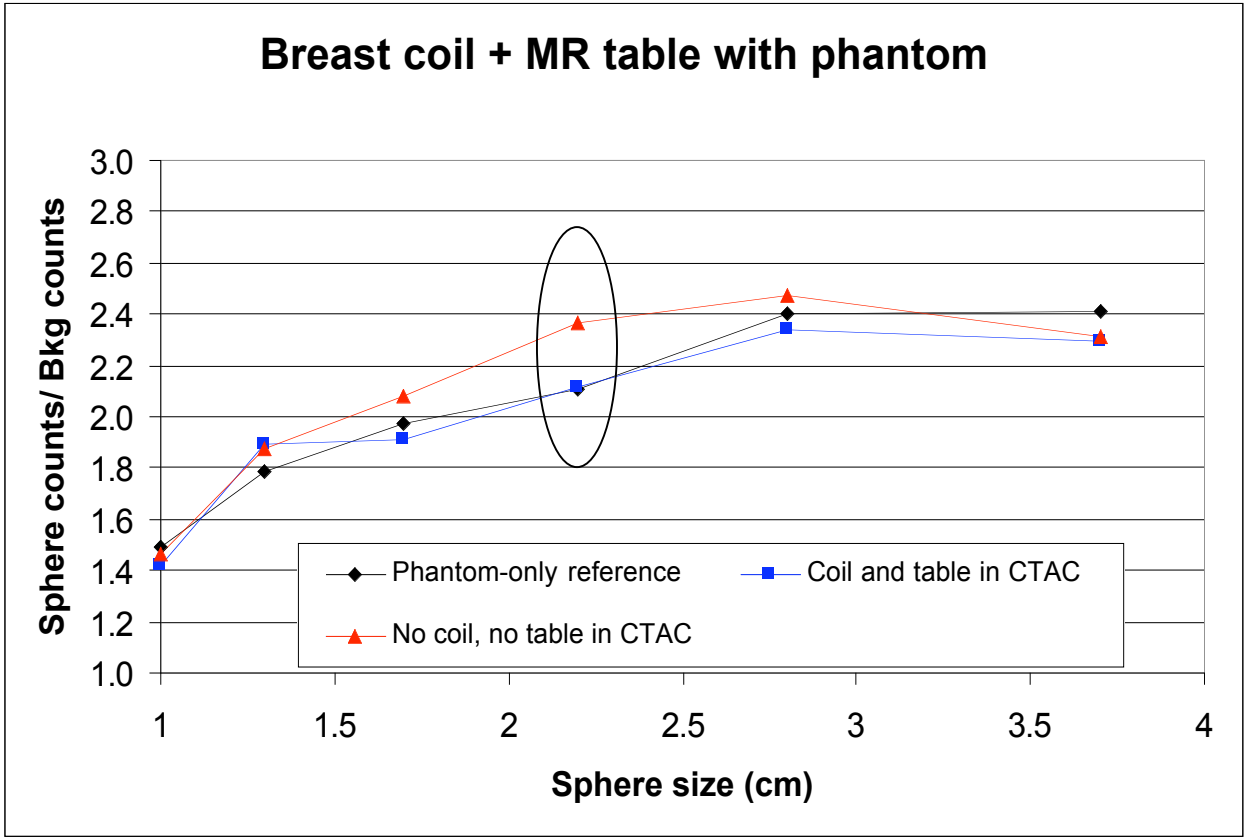
PET/MR


SIEMENS
MR/PET Molecular Imaging – feasibility study with Phantom inserts
2.0mm
2.5mm
1.5mm
3.0mm
1.0mm
3.5mm
CPS
PET MR
SIEMENS

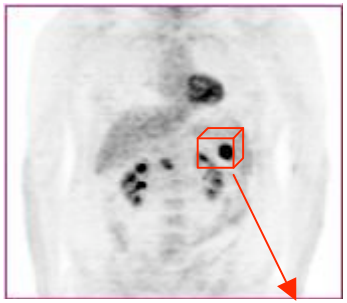
PET quantification with and without attenuation of MR coil

depends on orientation

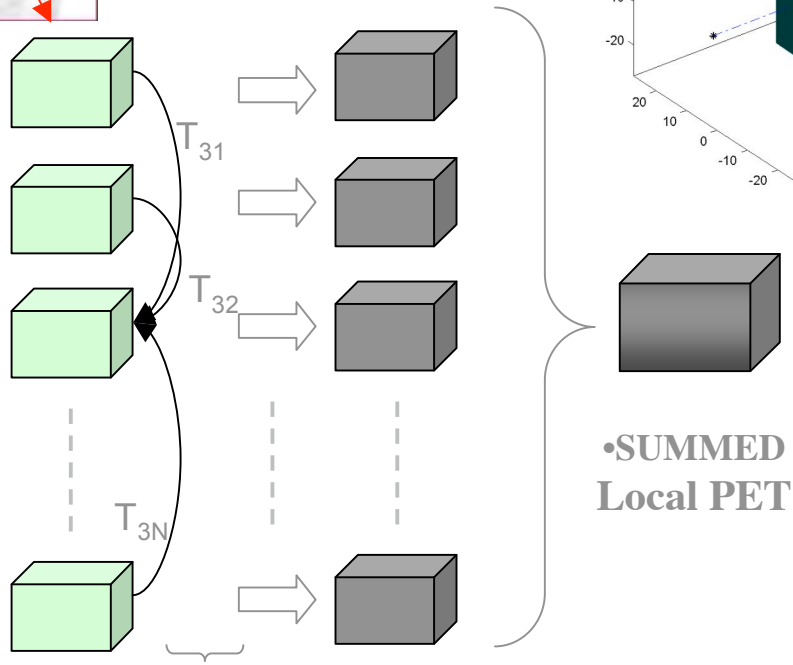




Local Registration - motion correction



Input is local PET volume-of-interest



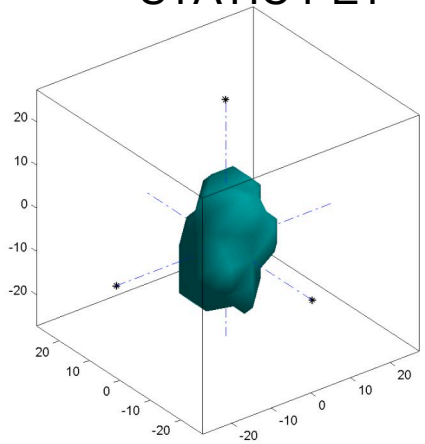
•Transformations

•Reconstructed PET Volumes

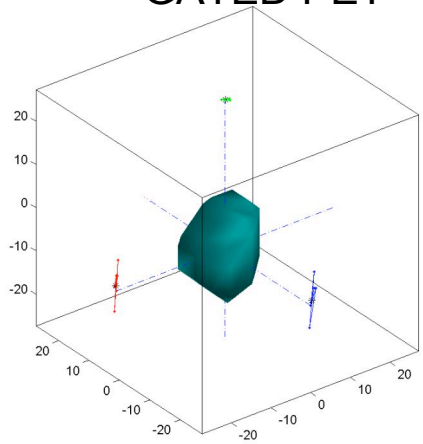
•Registered PET Volumes

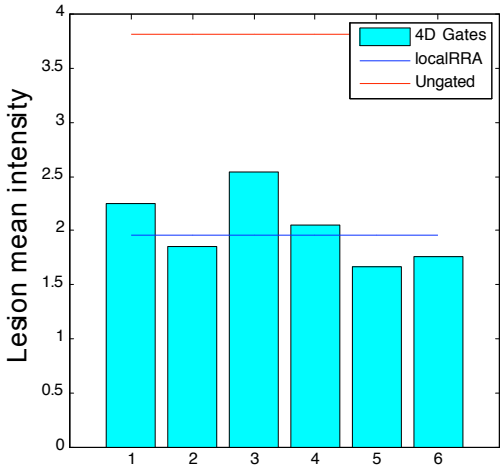
•SUMMED Local PET

STATIC PET



GATED PET





Courtesy Scott Wollenweber, GE Medical Systems

Summary

- Scanner performance evaluation
  - compare to other scanners

- Acceptance testing
  - compare to factory specs

- Optimization of scanner
  - adjust acquisition and reconstruction parameters

  - *need to include effects of new technology*
  - *possible to define intrinsic performance*
  - *more difficult to include effects on reconstruction image* *TOF and PSF can be characterized with new phantoms*