

Problems and Pitfalls of PET Acceptance Tests

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Acceptance Tests

- Spatial resolution (Capillary tube)
- Uniformity and SUV (Uniformity cylinder phantom)
- Sensitivity (NEMA 2001 sensitivity phantom)
- Scatter fraction, randoms, and count rates (NEMA scatter phantom)
- Accuracy of correction for count loss (NEMA scatter phantom)
- Image quality (NEMA IEC body phantom)
- PET-CT image registration (PET-CT phantom)
- PET-CT AC (PET-CT phantom)
- CT dose index (IMPACT phantom)

Performance Standards

NEMA standards publication for PET:

- National Electrical Manufacturers Association; Washington DC, 1994.
- National Electrical Manufacturers Association; Washington DC, 2001.
- National Electrical Manufacturers Association; Washington DC, 2007.

IEC standards for PET are also available

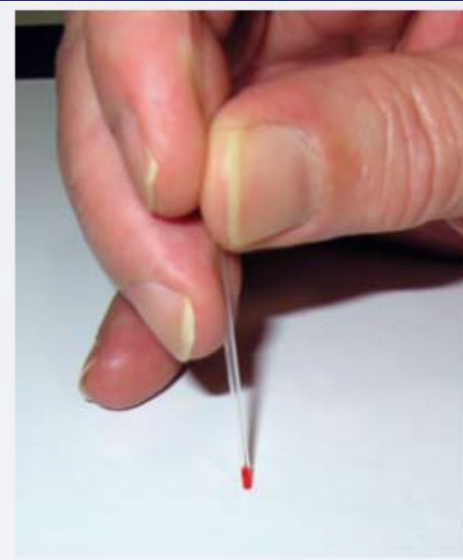
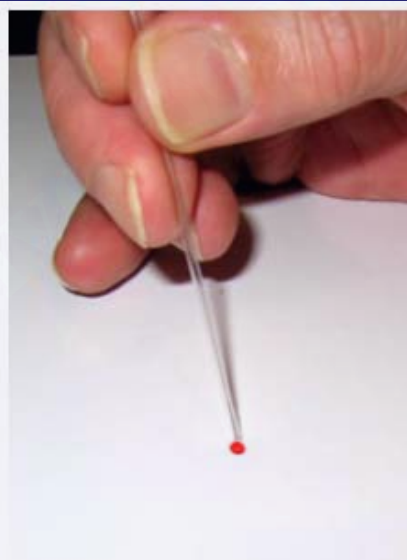
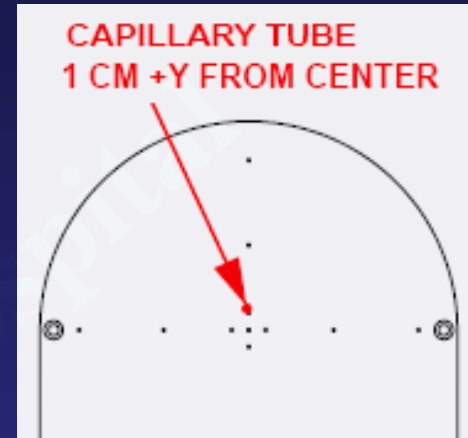
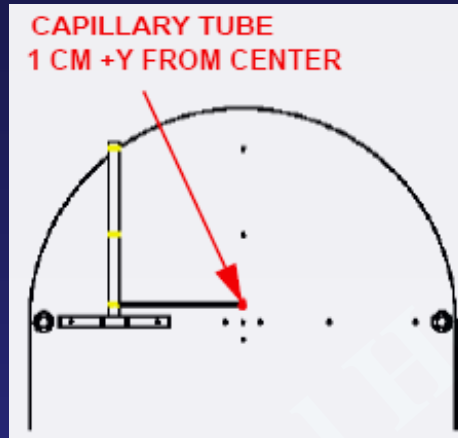
ACR standards for CT:

- American College of Radiology.

Philips Gemini GXL Specifications

- Number of detectors rings: 29
- Number of crystals: 17846 GSOz
- Crystal dimensions: 4(trans) x 6(axial) x 30(radial) mm³
- Number of PMT tubes: 420
- Axial FOV: 180 mm
- Plane spacing: 4mm or 2mm
- Number of image planes: 45(wholebody) or 90(neuro)
- Coincidence window width: 6.5ns
- Energy window (keV): LLD=435 & ULD=665
- Transmission source: Philips Brilliance 6 slice spiral CT

Spatial Resolution Test



- The 100mm glass capillary tube is filled with 0.37 – 1.1MBq of activity.
- The axial extent of the activity in the capillary shall be $<1\text{mm}$.
- Source centering is important and precision can be achieved with the interactive QC program.

Spatial Resolution Measured from GXL

	Measured values	Specifications provided by Philips
Axial resolution measured at 1 cm	5.63 mm	6.0 mm
Axial resolution measured at 10 cm	6.57 mm	6.6 mm

Transverse resolution measured at 1 cm	5.29 mm	5.1 mm
Transverse resolution measured at 10 cm radial direction	6.04 mm	6.1 mm
Transverse resolution measured at 10 cm tangential direction	5.64 mm	5.8 mm

- Some systems report 10 cm transverse resolution by averaging the radial and tangential resolution.

Uniformity and SUV Tests



- Fill 300MBq of ^{18}F for SUV calibration and 75MBq for validation.
- The 30cm length phantom is also used for image uniformity checks.

Sensitivity Test

5 concentric aluminum tubes:

- 6.4 mm outer diameter
- 9.9 mm outer diameter
- 12.7 mm outer diameter
- 15.9 mm outer diameter
- 19.1 mm outer diameter



- The 70cm polyethylene line source tube is filled with 3 - 8 MBq/ml of ^{18}F .
- At least 10,000 trues/slice are collected.

Sensitivity Test Phantom Preparations



This **end cap** set up require line source to be removed to allow removal of Al sleeves.



This Blu-Tack **end cap** is also robust and effective.

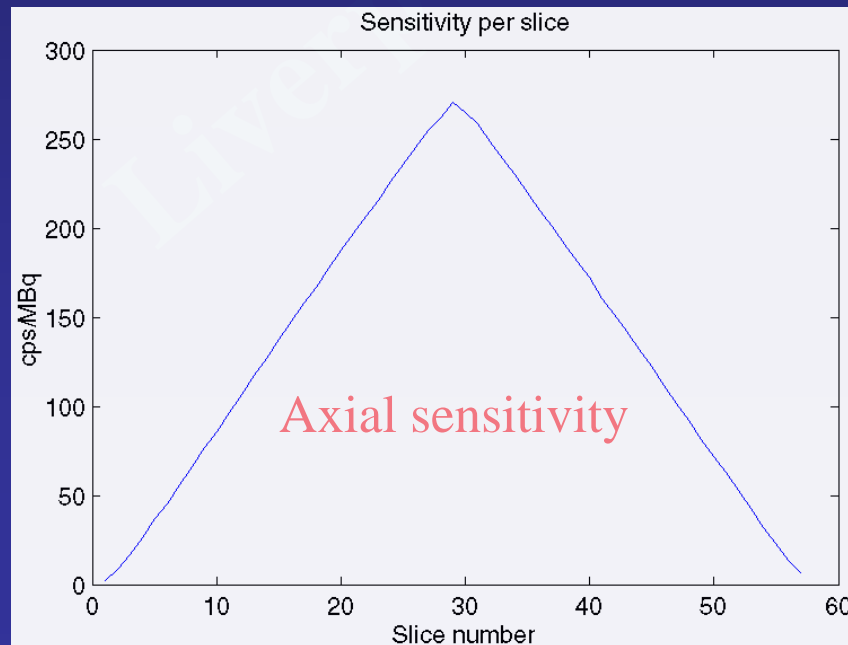


This set up does not...

- The line source should be free of bubble.
- System sensitivity will be overestimated if the length of activity is less than 700 mm.

System & Axial Sensitivity Measured from GXL

	Pre-optimisation	Post-optimisation	Specifications provided by Philips
System sensitivity at the centre	8.05 kcps/MBq	7.77 kcps/MBq	8.0 kcps/MBq
System sensitivity at 10 cm off centre	8.33 kcps/MBq	7.87 kcps/MBq	8.3 kcps/MBq

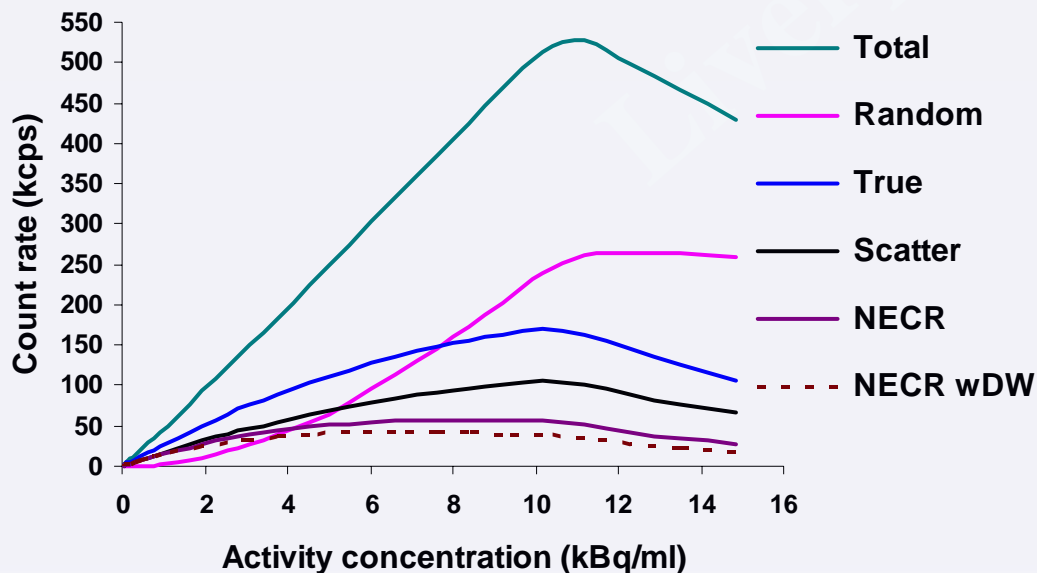


Scatter Fraction, Count Loss, Count Rate, and Randoms Measurements



- NEMA PET scatter phantom and a line source.
- The line source is filled with 500-600 MBq of ^{18}F .
- Data shall be acquired at intervals until count loss rates of true events $< 1\%$ of the total, and random rates $< 1\%$ of true rates.

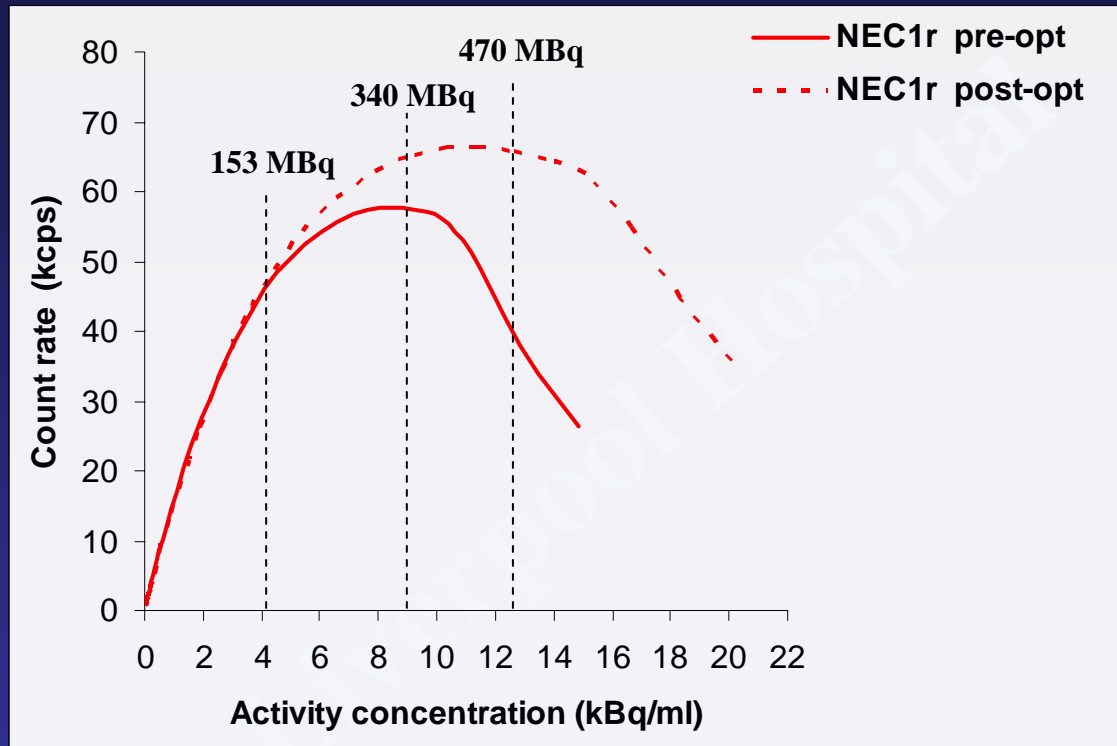
Count rate versus activity concentration



Start Frame	End Frame	Duration
1	8	15 min
9	14	30 min
15	25	60 min

Total acquisition time = 16 hrs

Noise Equivalent Count Rate (NECR)



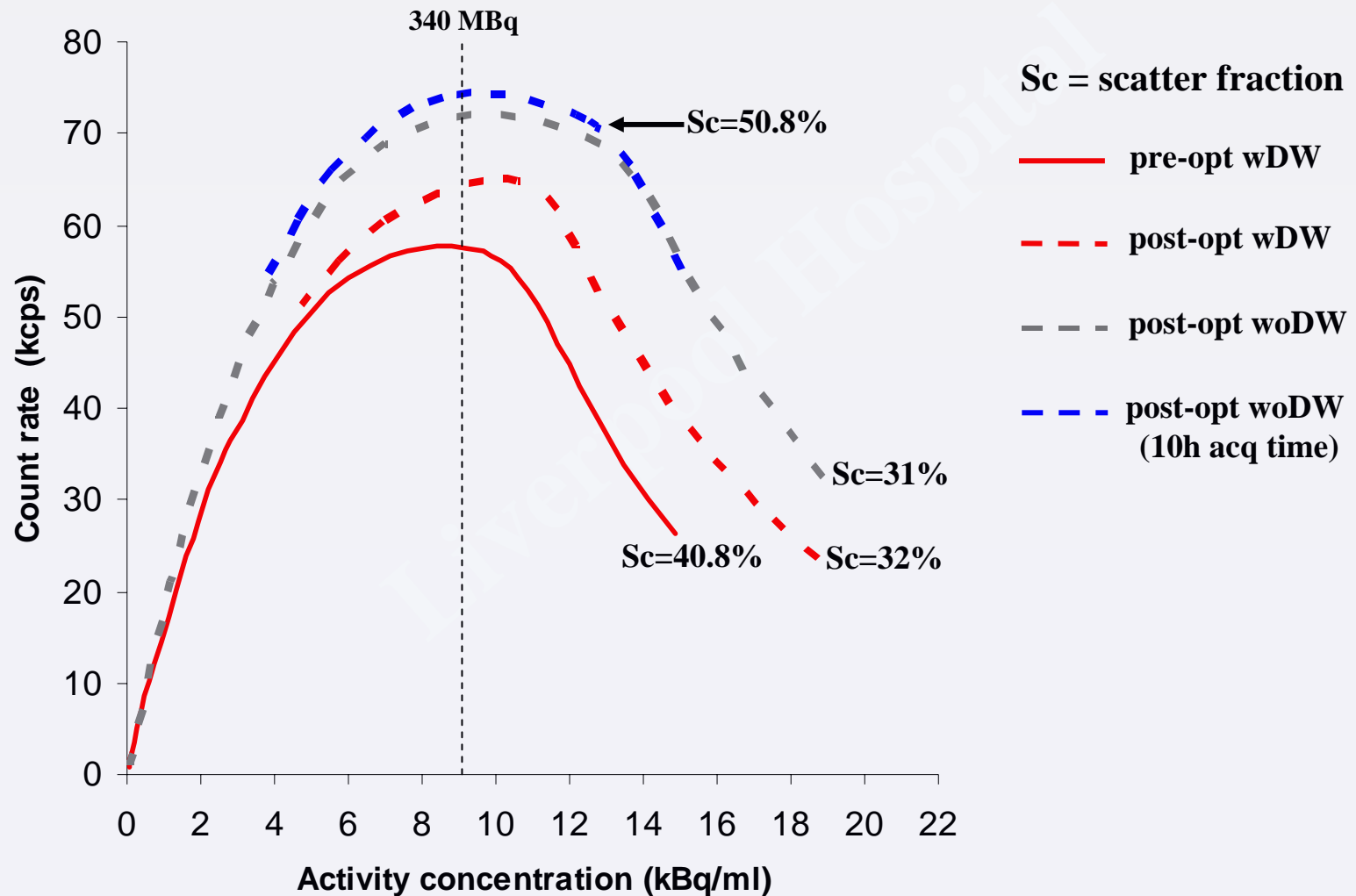
470 MBq = 272 MBq after decay & excretion are considered
340 MBq = 197 MBq after decay & excretion are considered
153 MBq = 87 MBq after decay & excretion are considered

Scatter Fraction and Peak Count Rates

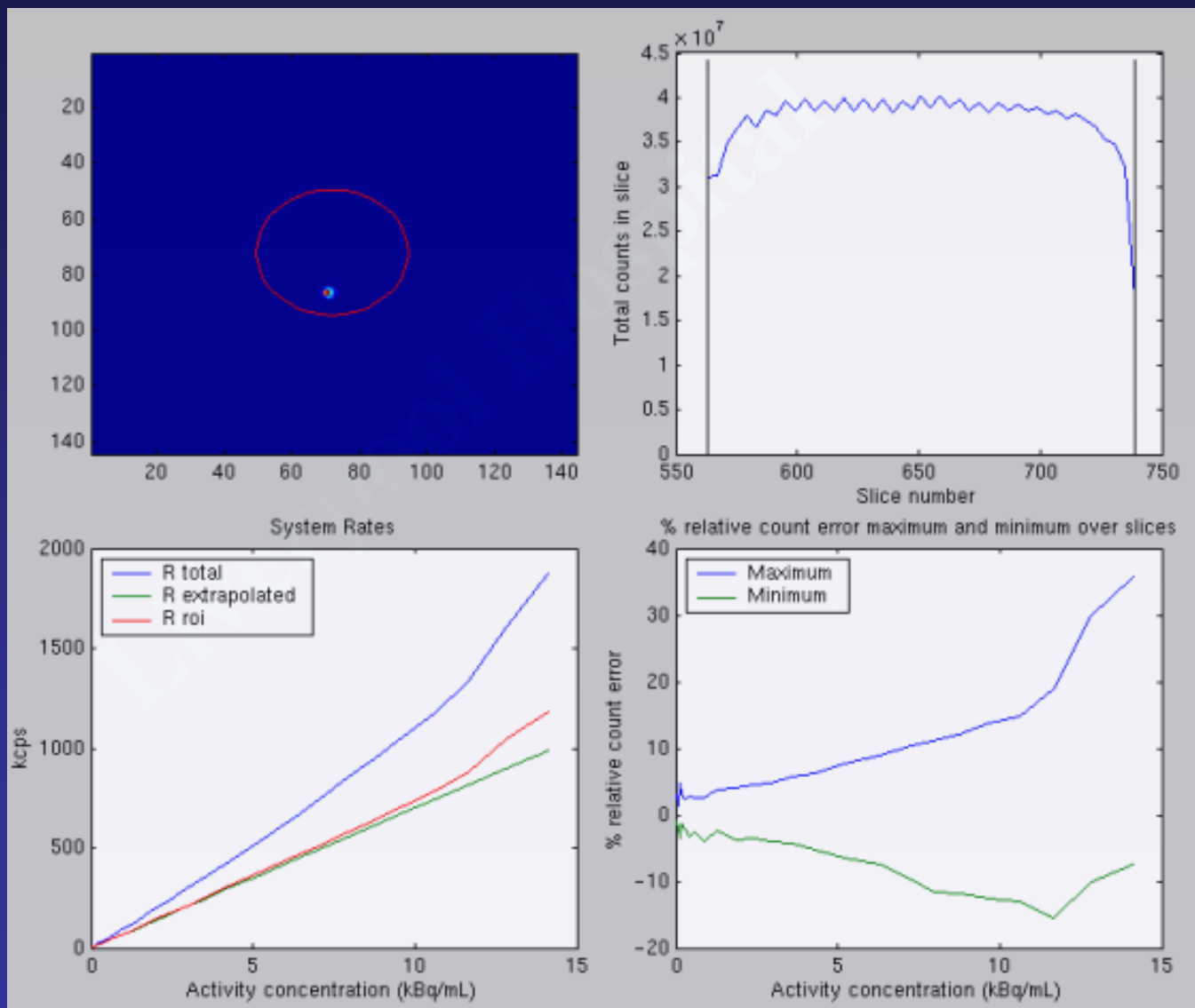
	Pre-optimisation	Post-optimisation	...	Accepted values	Specifications provided by Philips
Initial activity (MBq)	370-444MBq as recommended by Philips and later revised to 500-600 MBq which is more appropriate				
Scatter fraction	40.8% LLD = 410 ULD = 665	33.9% LLD = 435 ULD = 818	... LLD = ??? ULD = ???	32.5% LLD = 435 ULD = 665	35.0%
Peak true count rate	171.44 kcps @ 9.97 kBq/cc	225.9 kcps @ 15.6 kBq/cc	...	181.8 kcps @ 11.6 kBq/cc	? kcps @ ? kBq/cc
Peak NECR (1r)	58.17 kcps @ 8.66 kBq/cc	68.49 kcps @ 10.7 kBq/cc	...	64.9 kcps @ 10.6 kBq/cc	70.0 kcps @ 11.0 kBq/cc

- ↑ LLD ↓ scatter & ↑ ULD ↑ pulse pileup

Scatter Fraction and NECR

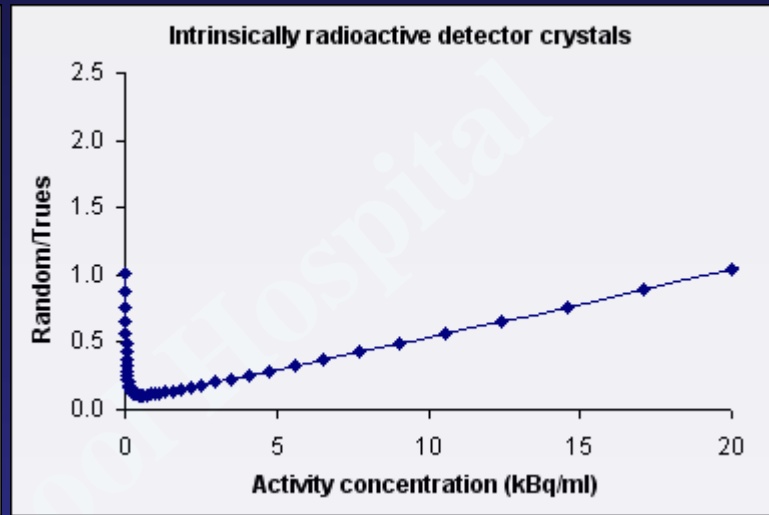
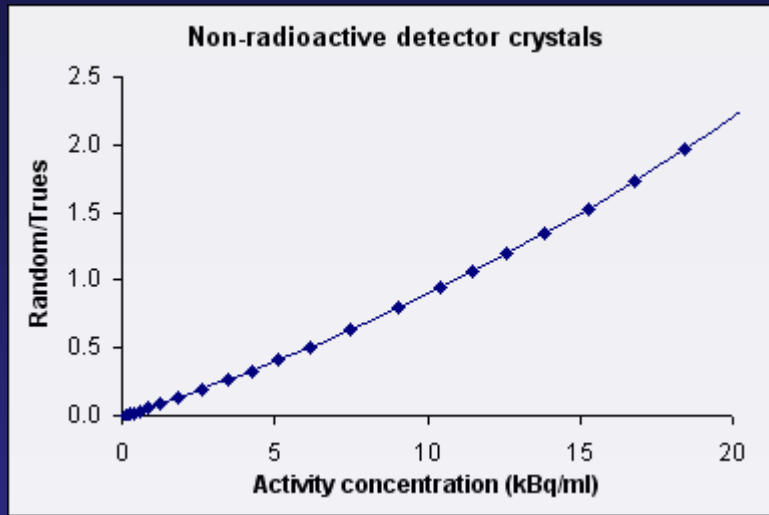


Accuracy of Corrections for Count Loss and Randoms



The maximum bias for the end slices where axial sensitivity is low is 13.6% @ 9.64 kBq/ml.

Accuracy of Correction and Sensitivity Tests from Intrinsically Radioactive Components

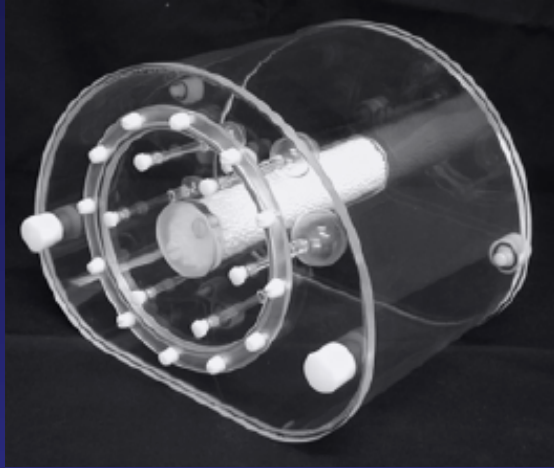


- The plot on the right (courtesy of RPAH) shows increased randoms at low activity concentration.
- The plot on the right also shows that the randoms fraction shall not be too low in the acquired data for sensitivity and accuracy of count loss correction tests.

Scatter Phantom Preparations

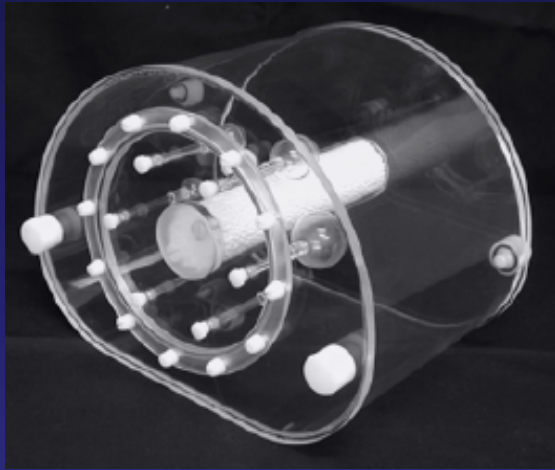
- The analysis software may rely on correct phantom positioning when defining regions for analysis.
- It is important for the phantom and line source to be parallel to the z-axis of the scanner. Some ROI will be off-centre and count rates will be wrongly estimated if the phantom is placed at an angle to the z-axis.
- Incorrect source length will affect the estimation of activity concentration at peak NEC, peak trues etc. The errors due to source lengths are <1% if the ± 5 mm NEMA requirement is adhered to.

Image Quality Test: Accuracy of Attenuation and Scatter Corrections

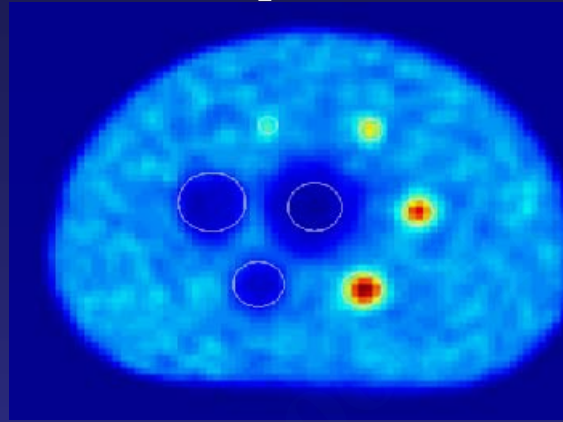


- The IEC body phantom is filled with 74MBq of ^{18}F and the activity ratio between hot spheres and the background 4:1.
- The line source in the scatter phantom is filled with 125 MBq of ^{18}F .
- The analysis software relies on correct phantom positioning.
- The plane through the centres of the spheres needs to be perpendicular to the z-axis of the scanner, as only one plane/slice is used for estimating the activity in the spheres.

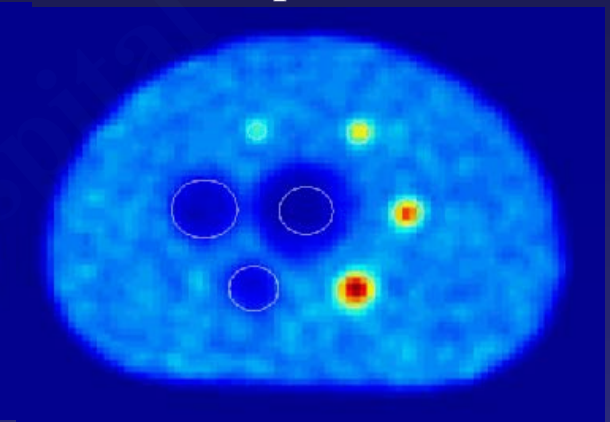
Image Quality Test: Accuracy of Attenuation and Scatter Corrections



Pre-optimisation



Post-optimisation



- Underestimation of the activity will occur in some of the spheres if the phantom is placed at an angle to the z-axis (even slightly!).
- The plane through the centres of the spheres to be located in the centre of the axial FOV where slice sensitivity is at maximum.

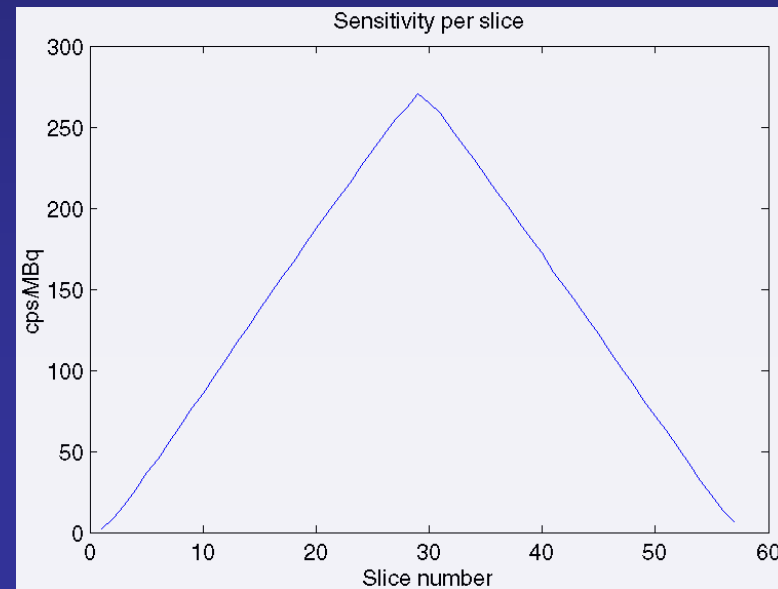


Image Quality Measured from GXL

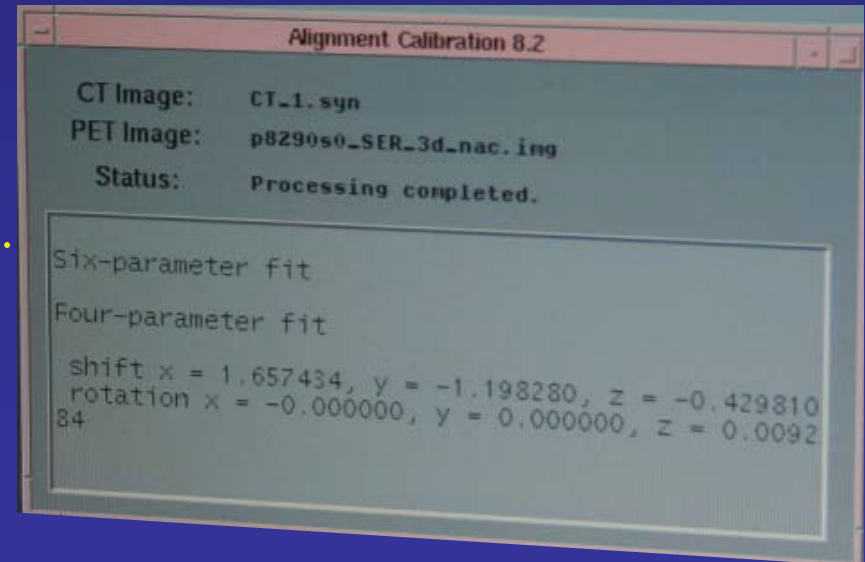
Diameter of the hot & cold spheres (IEC body phantom)	Contrast ratio pre-opt	Contrast ratio post-opt	Background variability pre-opt	Background variability post-opt	Specifications provided by Philips
10 cm (h)	16.52	18.77	7.53	6.46	n/a
13 cm (h)	32.96	33.40	6.76	5.93	n/a
17 cm (h)	49.42	49.59	5.89	5.29	n/a
22 cm (h)	56.20	62.56	4.89	4.67	n/a
28 cm (c)	62.43	54.11	4.09	4.11	n/a
38 cm (c)	69.19	64.57	3.35	3.53	n/a

PET-CT Image Registration

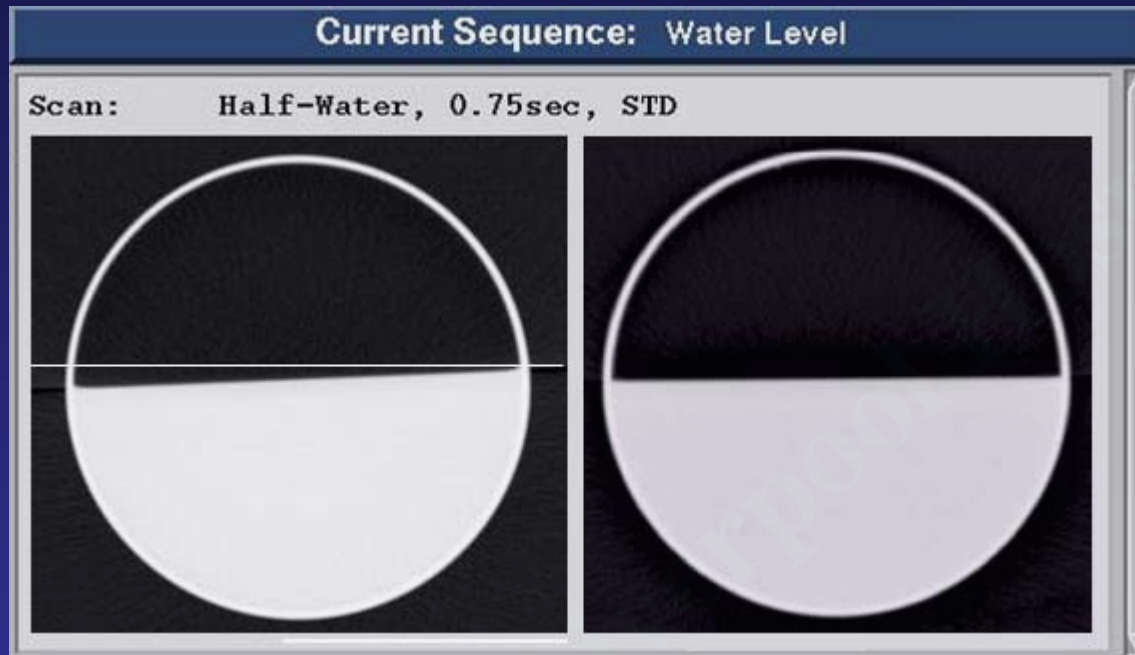


- Use spirit level to balance the six point source phantom set up
- Acquire 25 million counts with PET & CT gantries in closed and open positions.

Warning: each one of the six ^{22}Na point sources has 370kBq of activities, and together they have a reading of $\sim 100\mu\text{Sv}/\text{hour}$ at 10 cm distance.

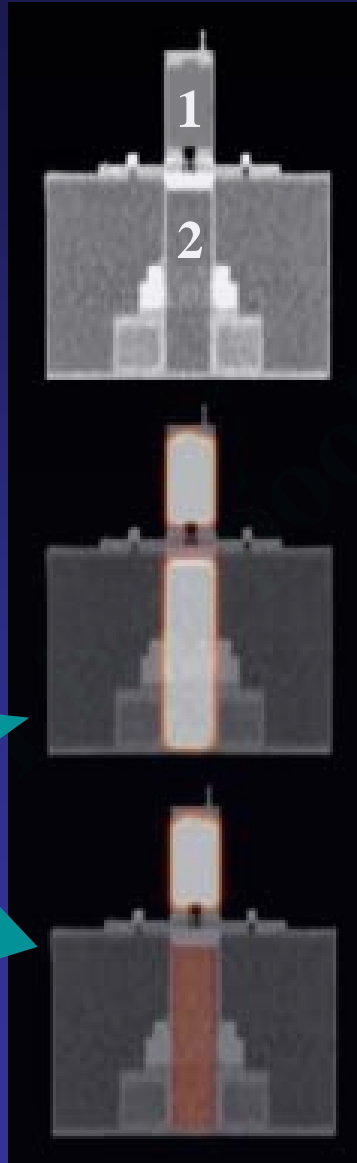


PET-CT and RTP-CT Image Registration with Water Level Test



- This water level test is for calibration of reconstruction reference frame.
- The start and end column test range need to be within the inner circumference of the phantom.
- This test should also be carried out on the RTP CT scanner.

PET-CT Attenuation Correction Test



- The volume of interest in 1 and 2 are filled with 0.34MBq/ml of ^{18}F .

SUV=20.1, Min=19.2, Max=20.6

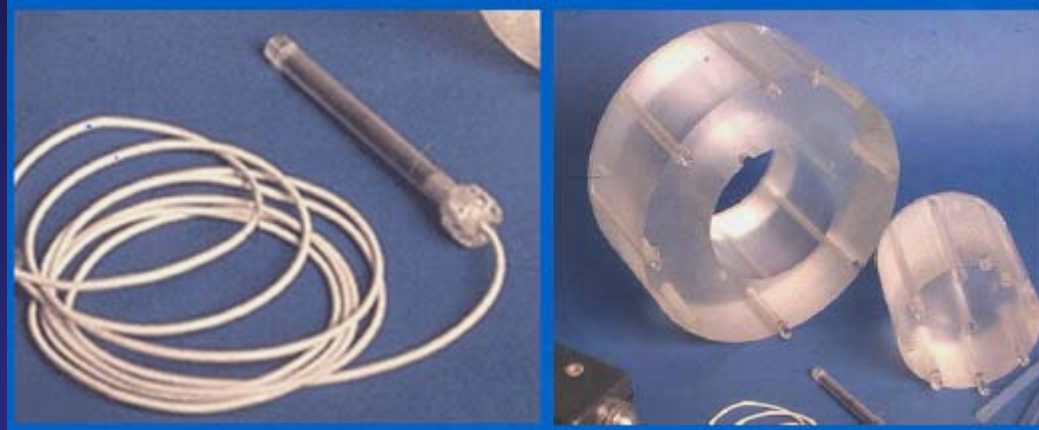
SUV=21.8, Min=21.3, Max=22.5

• AC reconstruction

• Non AC reconstruction

Apart from AC tests, the PET-CT phantom can also be used to measure accuracy of the PET & CT image registration.

CT Dose Index (CTDI) Test



- CTDI head and body perspex phantom with density \approx water.
- 10cm pencil ionisation chamber is used, but not ideal for a multi-slice CT scanner test.

CTDI for Gemini GXL

The measured $CTDI_w$ and the displayed $CTDI_w$ for GXL 6 slice CT scanner differ by **~7% for head phantom** and **~3% for body phantom** for a pitch value = 0.9

	Measured $CTDI_w$ values for attenuation correction only	Target values for diagnostic scan
Head	7.9 mGy (140kVp, 40mAs, 3x6mm) (pitch=0.9)	~50 mGy (140kVp, 373mAs, 3x6mm) (pitch=0.9)
Body	2.2 mGy (140kVp, 20mAs, 3x6mm) (pitch=0.9)	~15 mGy (140kVp, 203mAs, 3x6mm) (pitch=0.9)

$$CTDI_w = \frac{CTDI_{centre} + 2 \times CTDI_{periphery}}{3} \text{ mGy}$$

Conclusions

Phantom preparation and data acquisition set up can be a source of error, which includes:

- accuracy of the measured activity.
- accuracy of the residual activity in needle and syringe.
- correct volume of activity.
- assay time.
- duration of the data acquisition.
- phantom positioning.

Randoms correction based on delayed window technique (if available) should be used to report count rates – as it is used routinely in clinical studies and it also demonstrates the impact on counting electronics of a scanner.

Image reconstruction algorithms are not included in the acceptance tests.

Improvements are needed for the CTDI tests.

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