SPECT - CT
Quality Control

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Healthier lives through discovery

Plan of the Talk

- ***Why ?***
  - Imaging objectives
  - NEMA standards
- ***What ?***
  - Acceptance tests
  - QC performance tests
- ***How ?***
  - Recommended tests
  - Examples of problems and artifacts

IMAGING OBJECTIVES

& NEMA STANDARDS

Imaging Objectives

- Nuclear Medicine wants to measure as accurately as possible
  - **N - number of photons**
    the number of events recorded in one
    location relative to the other location
  - **X - position of every event**
    to identify the location of the source
    of radiation in the body (including CT localization)
  - **E - energy of every photon**
    to identify "good" photons and separate them
    from background and scatter
  - **T - time of emission**
    to identify coincidences and/or investigate
    temporal changes in activity distribution

QC Objectives 1

- Planar Studies NM:
  - Camera spatial response must be uniform
  - Collimator must not affect uniformity
  - Camera resolution must be optimized
  - Camera sensitivity must be optimized
  - Photon energy must be accurately measured
  - Camera response must be linear with respect to
    - events location
    - photons energy
    - photons intensity

QC Objectives 2

- Tomographic (SPECT) Studies:
  - Camera response must be independent of acquisition angle
  - Response of all detectors must be the same
  - All elements of tomographic study must be properly aligned (such as detectors and bed movements, SPECT-CT co-registration)
- Camera software:
  - Image reconstruction and data processing software must use proper parameters and be free of errors (this includes image reconstruction without corrections and with all possible corrections: attenuation, resolution recovery and scatter)

Performance Tests

- **N**ational **E**lectrical **M**anufacturers **A**ssociation (NEMA) Standards Publications
  - for scintillation (gamma) cameras – **NU 1- 2007,**
  - for position emission tomographs – **NU 2-2007**

and also:

  - for non-imaging gamma probes – **NU 3-2004**
  - for small animal PET – **NU 4-2004**

The purpose of the Standards Publication is to provide a uniform criterion for the measurement and reporting of the system performance by which manufacturer may specify his device.

How Realistic ...?

- All QC tests are designed to check the performance of the imaging system and optimize it for patient studies
- It is important to realize that phantoms are only a limited approximation of the human body
- Real clinical studies are performed at different conditions than performance tests

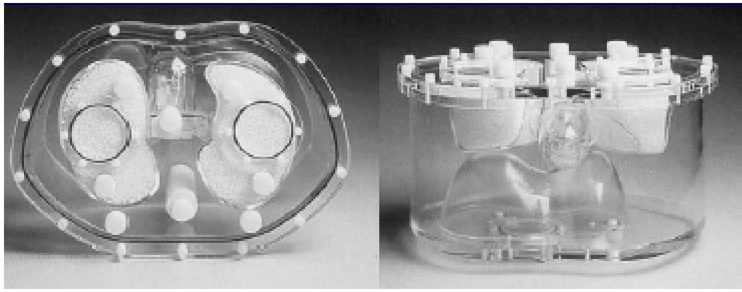
Useful Accessories/Phantoms

- Co-57 flood source with activity 10mCi
  - extrinsic uniformity tests, integrity of collimators
- M → Linearity/resolution phantom with slits in X and Y direction
  - intrinsic linearity and resolution tests
- A block of Styrofoam 10cm thick
- Capillary tubes and petri dish
  - extrinsic resolution, pixel size calibration, camera sensitivity, tomographic resolution, WB resolution
- M → Source support for COR (center of rotation) tests

  GE – does not have any special support,
  Philips – source holder for 3 point sources
  Siemens – source support for 3 or 5 sources

Useful Accessories/Phantoms

- Jaszczak phantom with cold (and fillable) spheres
  - quality of tomographic images,
  tomographic uniformity
- M → CT quality control phantom
  - plastic cylinder with inserts for CT tests
  (uniformity, resolution, contrast, slice thickness
- M → CT-NM registration phantom
  - foam or plastic holder for multiple line/point sources
- Thorax phantom with heart insert, lung and spine
  - for accuracy of attenuation map
  and attenuation correction tests



ACCEPTANCE TESTS

& CAMERA PERFORMANCE

Intrinsic Tests (NEMA)

- Intrinsic flood uniformity
- Intrinsic spatial linearity
- Intrinsic spatial resolution
- Intrinsic energy resolution
- Multiple window spatial registration
- Intrinsic count rate performance
  - count rate at 20% count loss
  - maximum count rate performance
  - input versus observed count rate
- Intrinsic flood uniformity at 75,000 per second
- Intrinsic spatial resolution at 75,000 per second

Extrinsic Tests (NEMA)

- System uniformity
- System sensitivity
- Detector-detector sensitivity variation
- Detector shielding
- Pixel size calibration
- System spatial resolution
  - without scatter
  - with scatter
- System count rate performance
- Collimator hole angulation

Tomographic Tests (NEMA)

- Angular variation
  - of flood uniformity
  - of sensitivity
  - of spatial resolution
- Accuracy of centering of the system
- Reconstructed image uniformity
- System volume sensitivity
- Tomographic spatial resolution
- Jaszczak phantom - sphere visibility

Other Tests

- Multiple head systems
  - comparison of performance for both heads
- Data processing system
  - to test display software, reconstruction software, data analysis software
- Whole body system
  - to test resolution in direction parallel and perpendicular to the camera motion

CT and SPECT-CT tests

- Quality of CT images
  - uniformity, resolution, low and high contrast, X-ray density measure and slice thickness
- Accuracy of SPECT-CT registration
  - Test should be done for all collimators
- Accuracy of attenuation correction with CT system
  - Tests of quality of attenuation map,
    accuracy of μ-values
    uniformity and resolution of attenuation corrected images, quality of correction

Camera Uniformity Test

- Method:
  - intrinsic/extrinsic and qualitative/quantitative,
  - daily test – good indication of (non-specific) image quality,
  - plot data and note trends.
- Global measure:
  - Integral unif. $\rightarrow$ ratio of max. to min. pixel in UFOV, CFOV
  - Coefficient of variation $\rightarrow$ ratio of mean to standard deviation.
- Local measure:
  - Differential unif. $\rightarrow$ max. change in pixel values over 5 adjacent pixels.
  - Spread of differential unif. $\rightarrow$ as above but for every pixel group possible.

Intrinsic or Extrinsic?

- Intrinsic Uniformity test:
    - No collimator
    - Point source at a distance > 5 x camera diameter
  - Tests uniformity of detector
  - Can be done for every isotope of interest

- Extrinsic Uniformity test
    - With collimator
    - Source should be placed at at least 10-15cm from the collimator surface
  - Tests uniformity of detector and collimator
  - Usually done with Co-57 sheet source only

INTRINSIC TESTS

(WITHOUT COLLIMATOR)

What is good uniformity?

- Uniformity calculation
- $$Unif = 100\%\left(\left(\max - \min\right) / \left(\max + \min\right)\right)$$
- NEMA limit for intrinsic uniformity:

	UFOV	CFOV
Integral	**3.5 %**	**2.5 %**
Differential	**2.5 %**	**2.0 %**

- Extrinsic uniformity should be very similar

Some Examples…

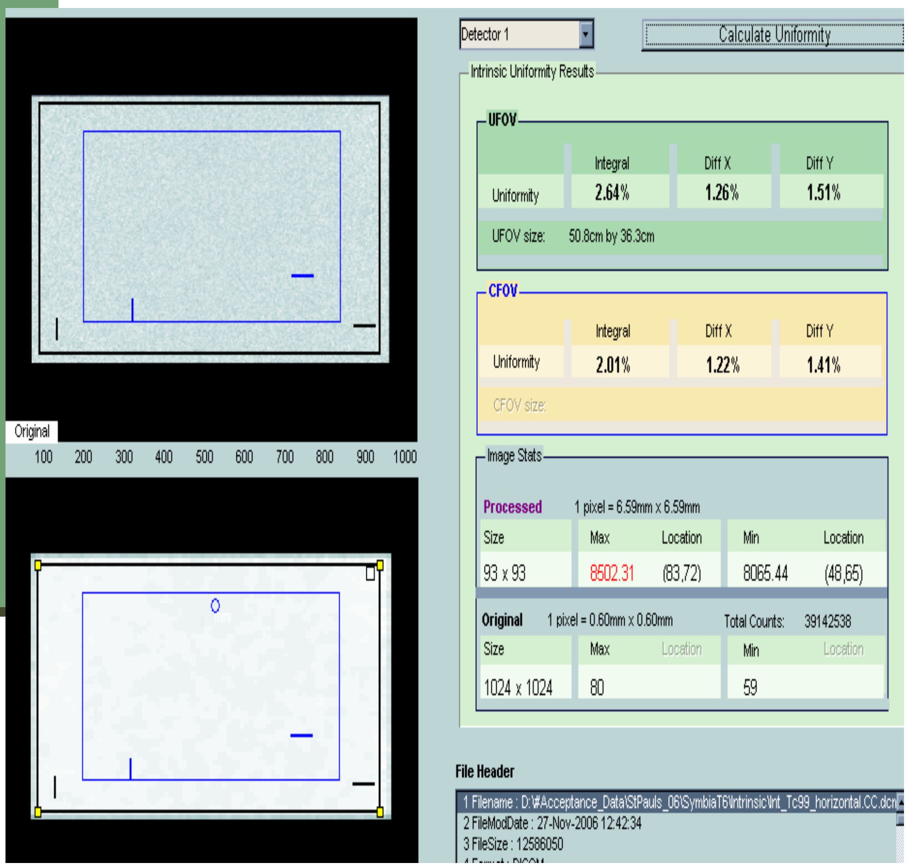
- Intrinsic test examples

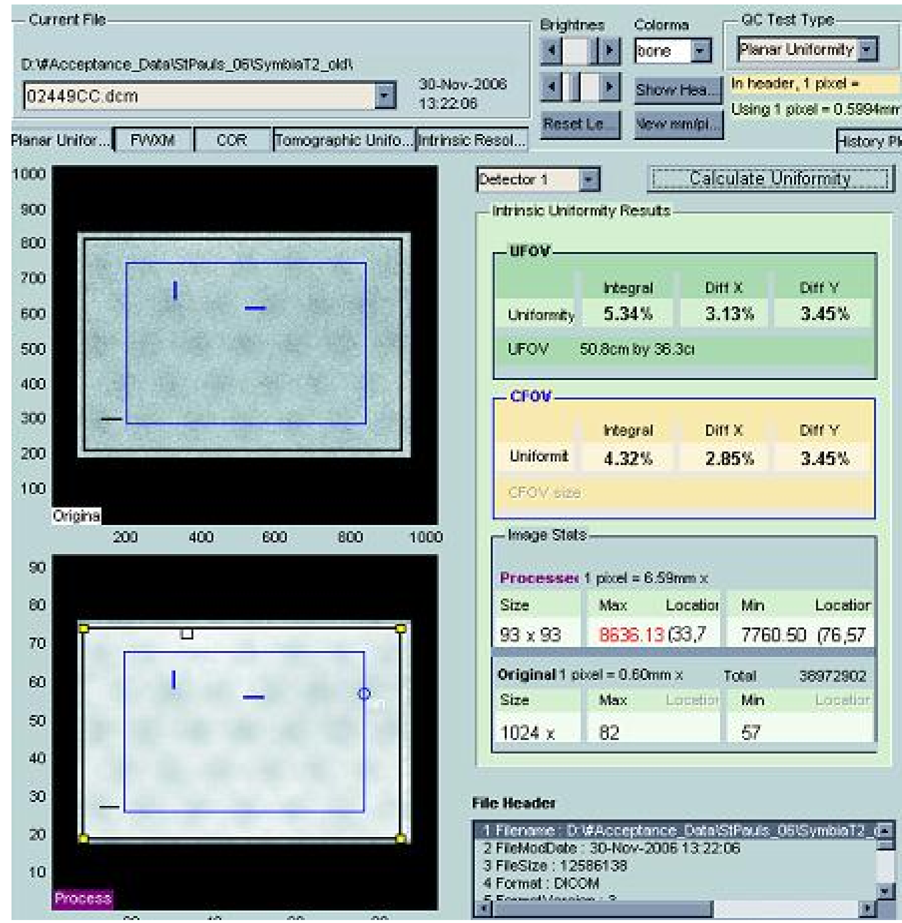
	TC-99m		Ga-67		In-111	
	UFOV	CFOV	UFOV	CFOV	UFOV	CFOV
Integral	1.55	1.50	1.35	1.25	2.87	2.31
Diff. X	0.96	0.96	0.89	0.89	1.17	1.11
Diff. Y	0.98	0.98	1.04	1.04	1.14	1.14

- Extrinsic test examples

	LEHR		LEGP		MEGP	
	UFOV	CFOV	UFOV	CFOV	UFOV	CFOV
Integral	2.40	1.58	2.13	1.60	1.88	1.88
Diff. X	1.13	1.13	1.34	0.96	1.18	1.18
Diff. Y	1.25	1.25	1.22	1.07	1.54	1.54

Uniformity: Good and Bad





Symbia intrinsic uniformity Tc-99m and Ga-67

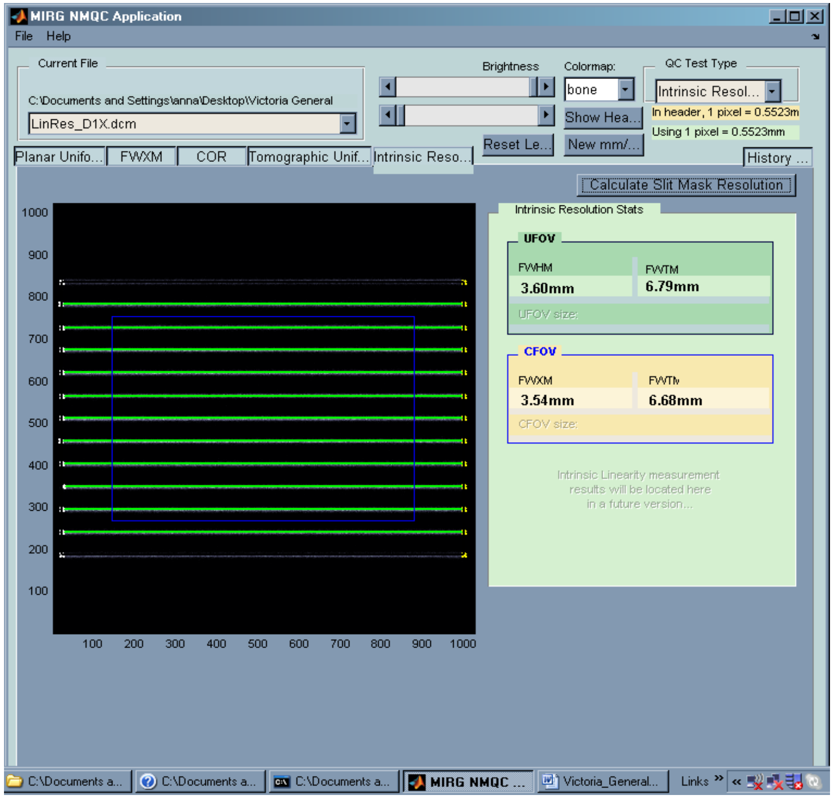
How many counts?

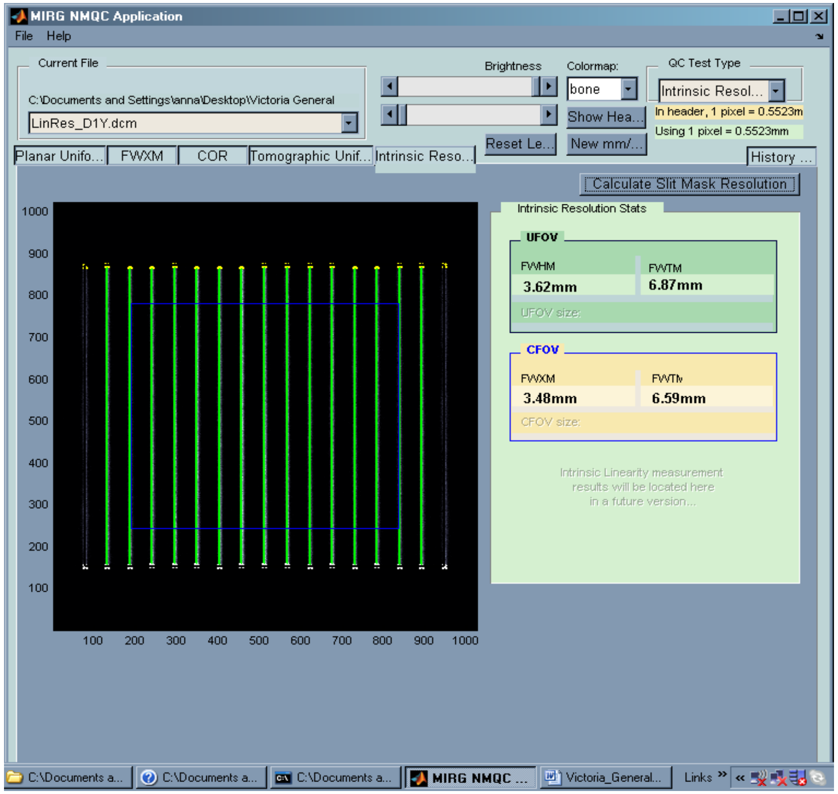
- NEMA recommends using 64 x 64 matrix
  which results in a total of 4096 pixels
- For a uniformity measurement with a statistical
  error of 1% we should collect a minimum of 40M counts
- Why ?
  because relative error = $1/\sqrt{N}$
  - 40M counts means about 10 000 counts /pixel
    which gives a relative error of 1%
  - 4M counts means about 1000 counts/pixel
    and a relative error of 3%
  - 10M counts means about 2445 counts/pixel
    and a relative error of 2%

- **Traditionally floods with 30M counts are collected**

Linearity and Resolution

- Test should be performed on both detectors in X and Y direction

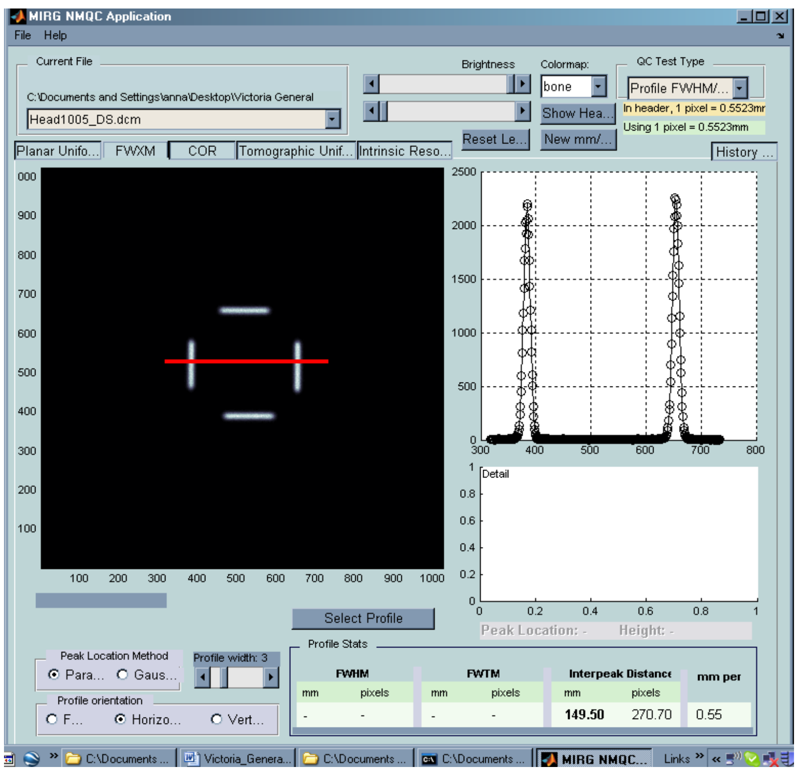


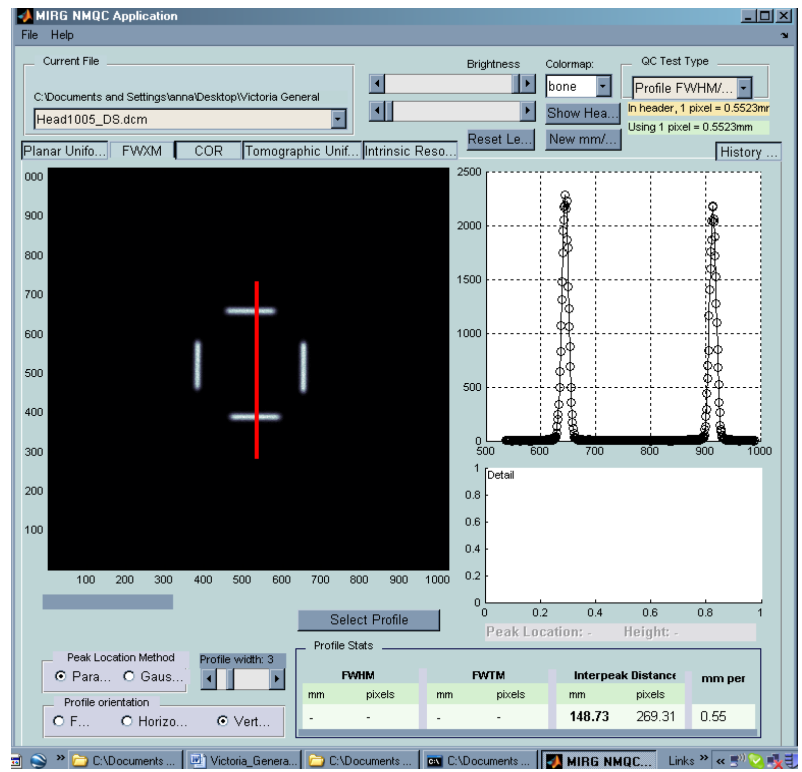


EXTRINSIC TESTS
(WITH COLLIMATOR)

Pixel size calibration

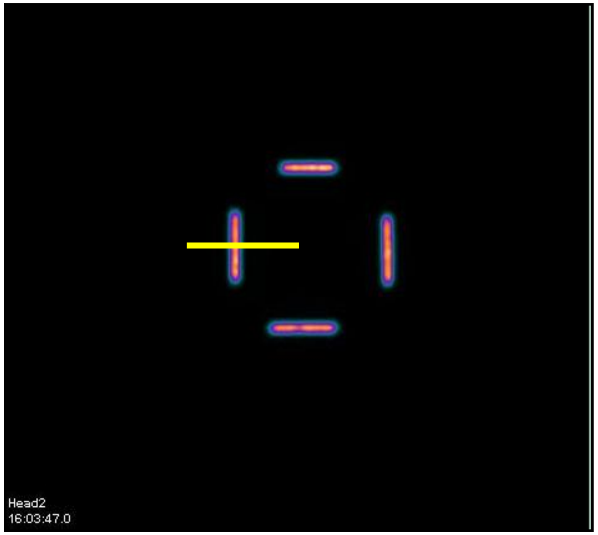
- Test can be performed with capillary tubes placed on Styrofoam block at 10cm from the collimator surface
- Test determines the pixel size and expresses it in mm.

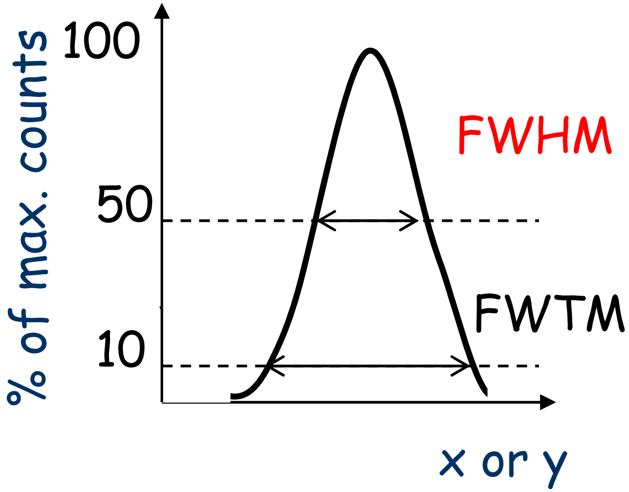




Planar and WB Resolution

- Can be evaluated with bar phantom
  - provides only qualitative test
- Extrinsic resolution can be measured with set of four capillary tubes





What is good resolution?

- NEMA limit for intrinsic spatial resolution:

	CFOV	UFOV
FWHM	4.5 mm	4.5 mm
FWTM	8.4 mm	8.4 mm

- Extrinsic resolution @ 10cm

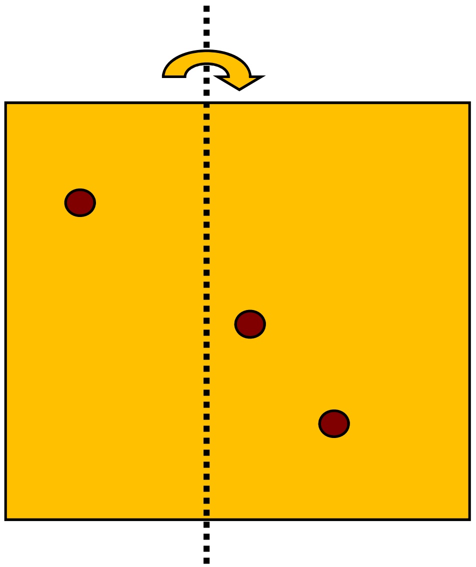
Collimator	LEGP	UHRES	MEGP	HEGP
resolution (mm) collimator only	8.0	6.3	10.7	12.0
resolution (mm) system	8.8	7.4	11.3	12.5
relative sensitivity	1	0.6	0.8	0.4

TOMOGRAPHIC TESTS

(WITH COLLIMATOR)

Center of Rotation test

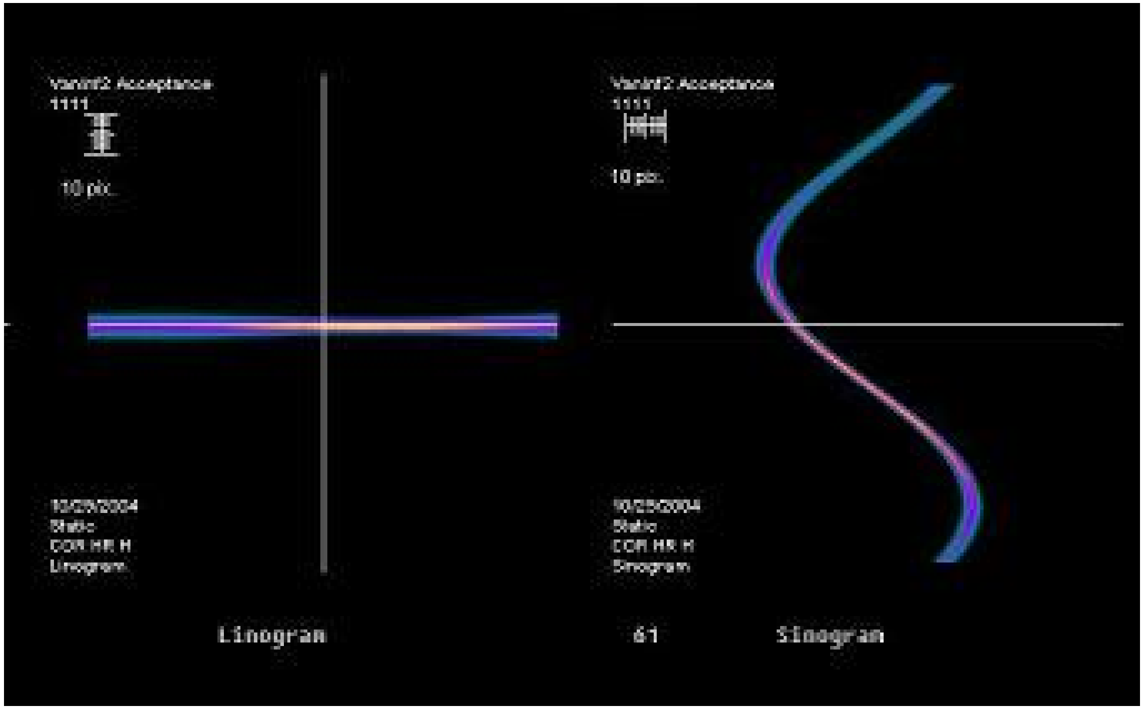
- At least 3 point sources should be used
- Sources should be positioned **off center**
- Sources can be scanned simultaneously or sequentially
- Sinograms for different source locations must be checked
- COR values should be calculated



- Test must be performed for 90º and 180º detector configurations
- Test must be performed for every collimator

What is good COR?

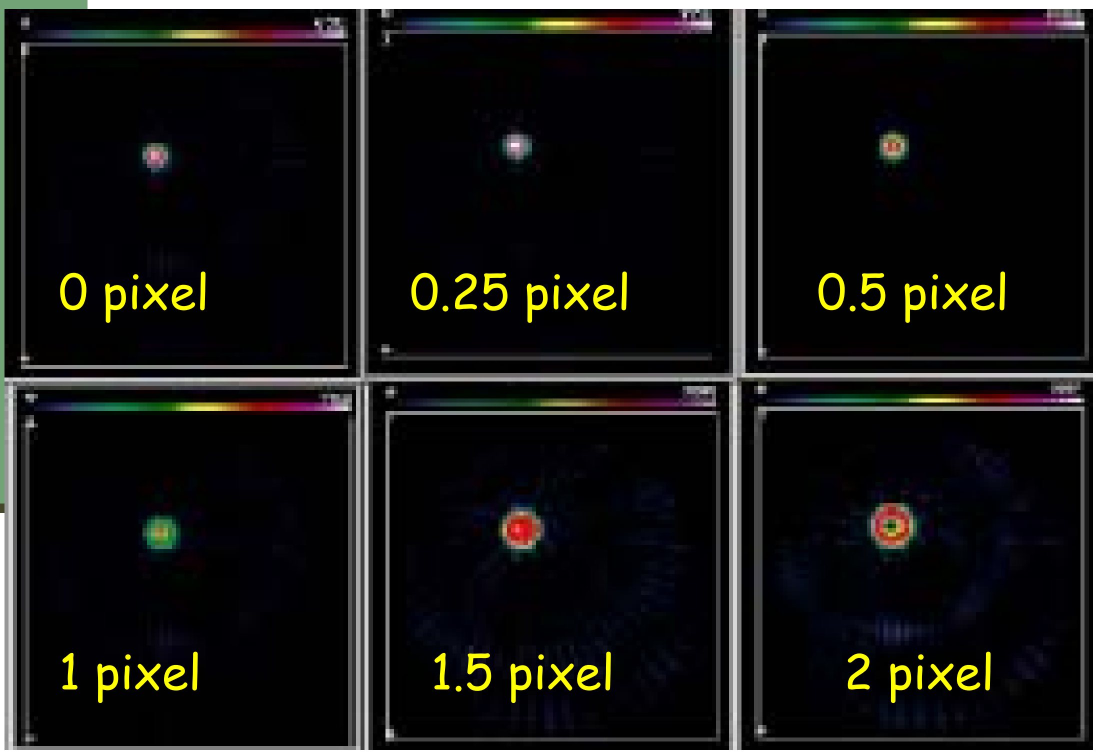
- All sinograms must be smooth for all source locations
- COR value deviation should be less than 0.5mm



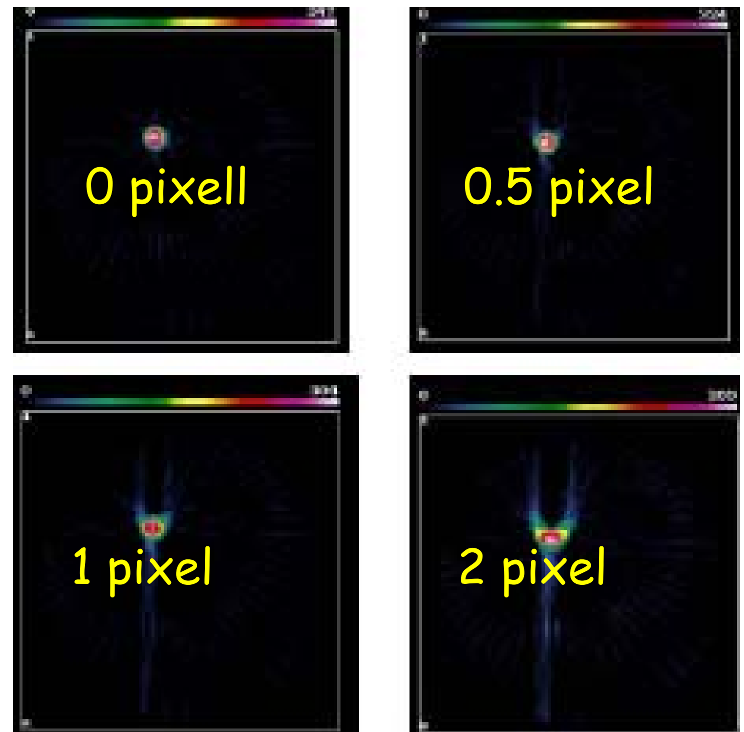
COR problems

COR offset in x-direction,

360° data



180° data

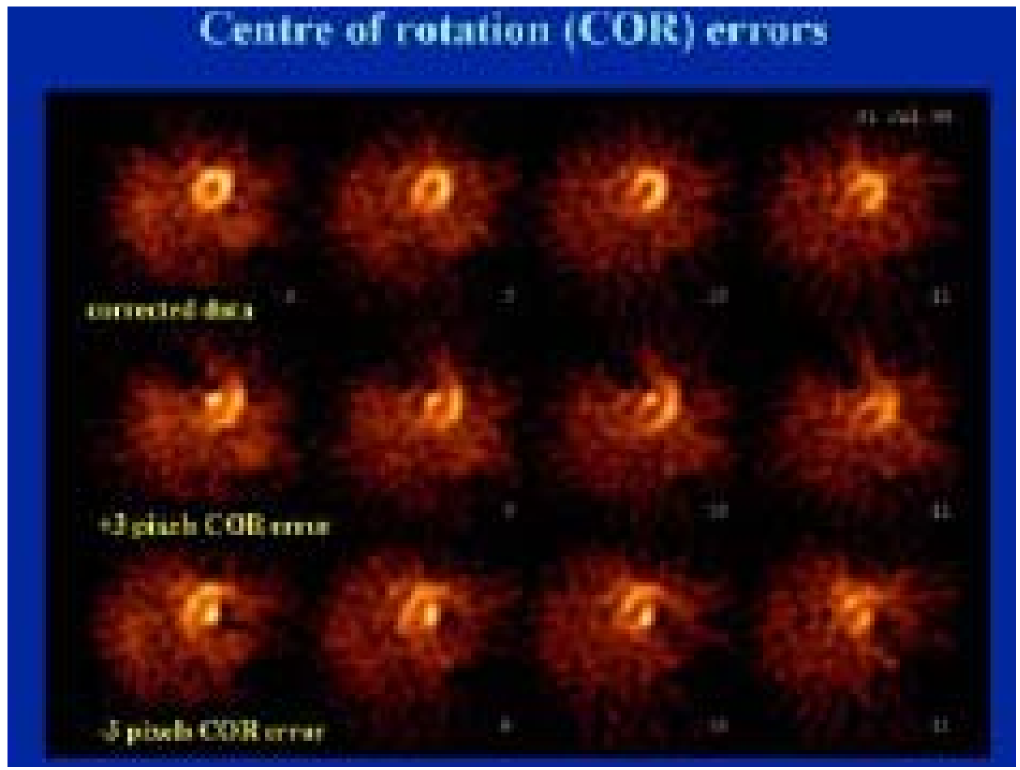


COR problems - dual head

Dual head system

head misalignment

Patient data



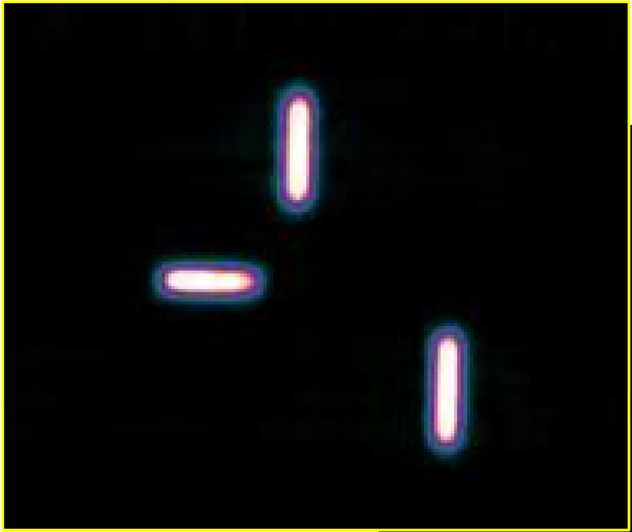
0 pixel

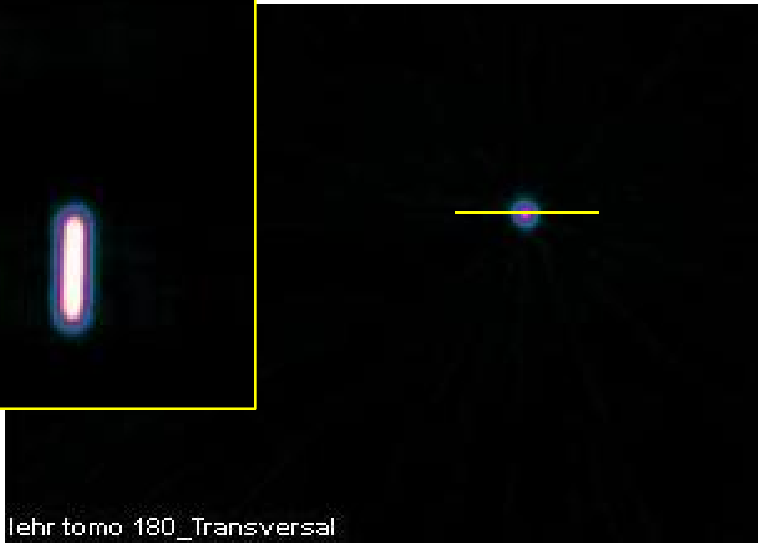
+3pixel

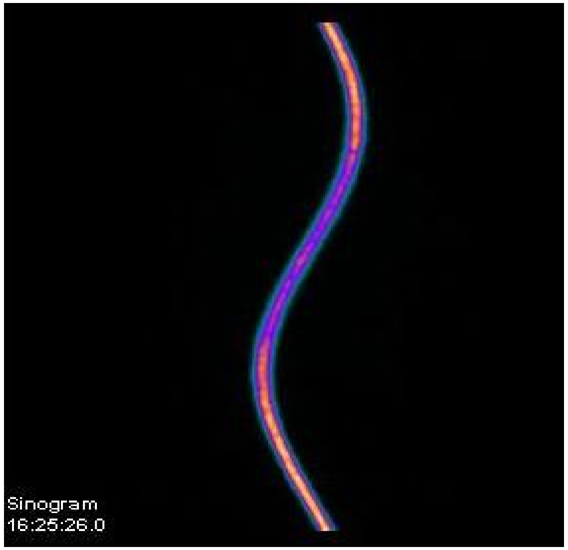
-3pixel

Tomographic resolution & COR

- 4 point sources or capillary tubes placed at different locations in the field of view
- Standard acquisition for all collimators and ROR=23cm
- Provides information about reconstructed resolution
- Provides information about heads alignment

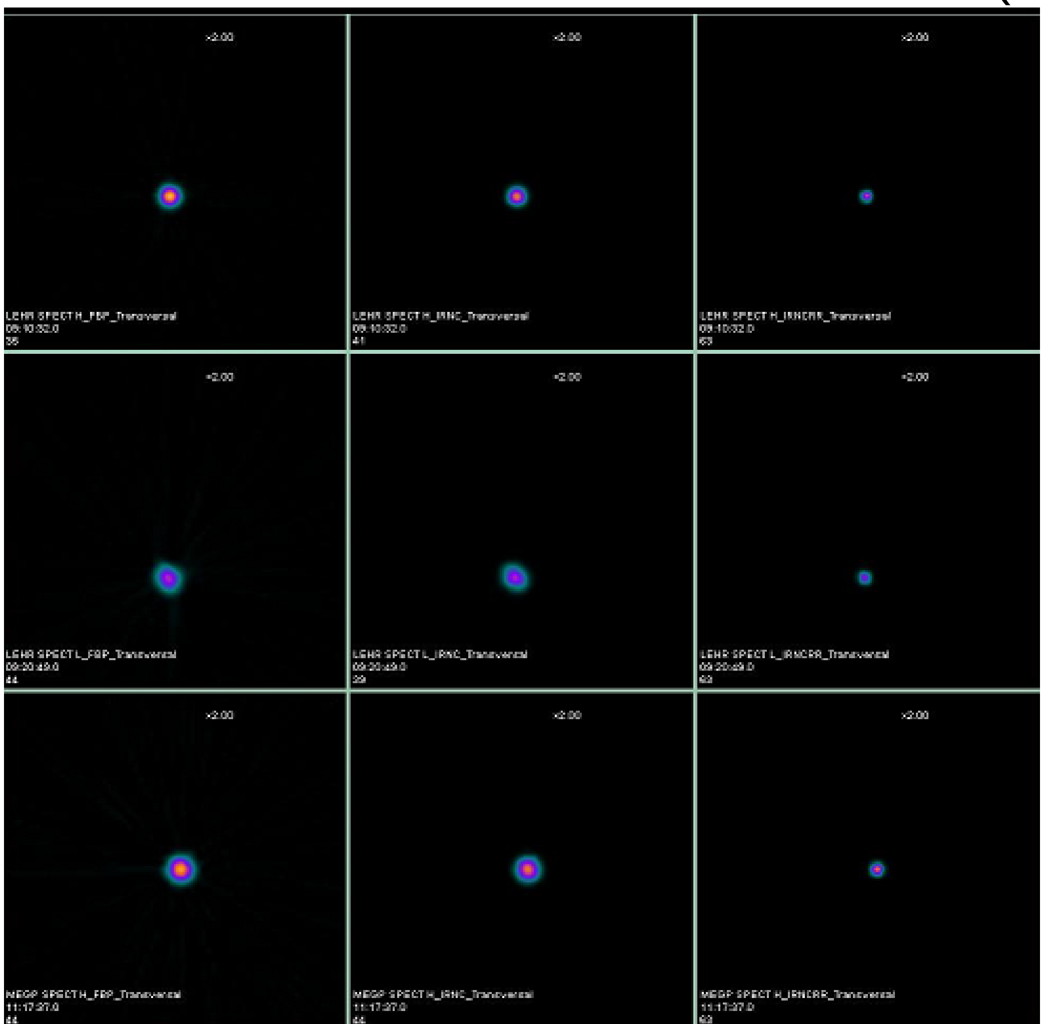






Tomographic Resolution GE

FBP OSEM OSEM + RR (EfB)

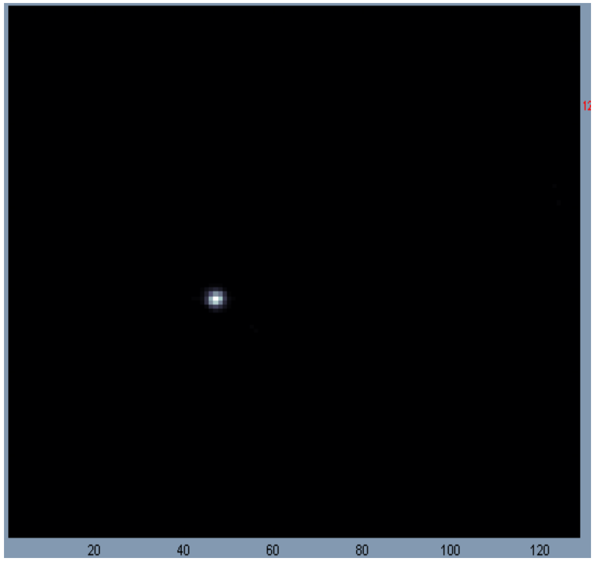


LEHR acquisition 360º

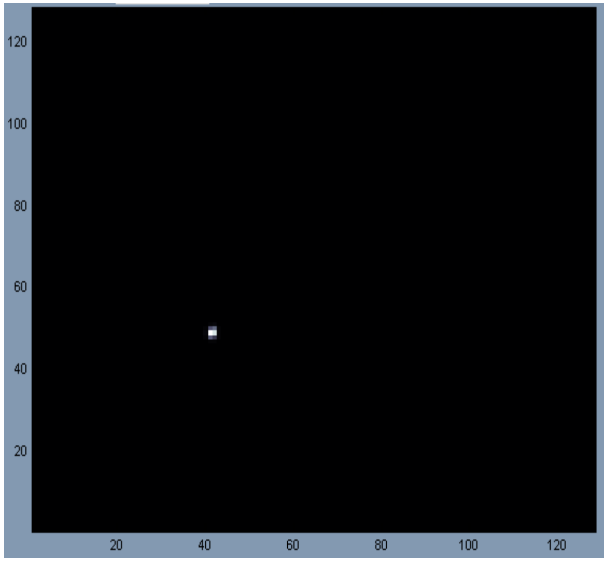
LEHR acquisition 180º

MEGP acquisition 360º

Tomographic Resolution Siemens



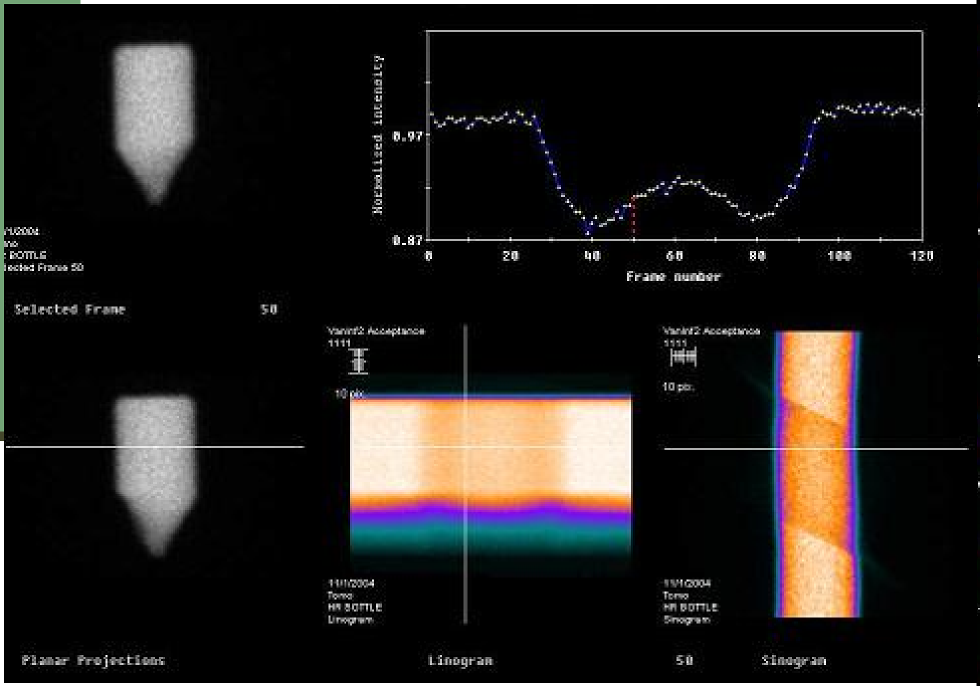
FBP

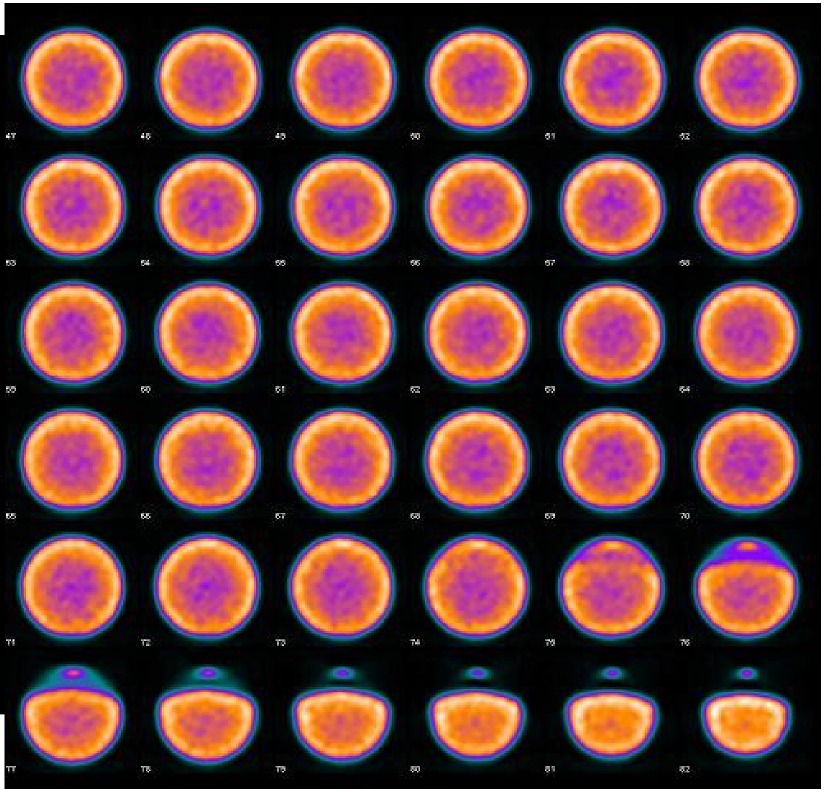


Flash3D

Tomographic uniformity

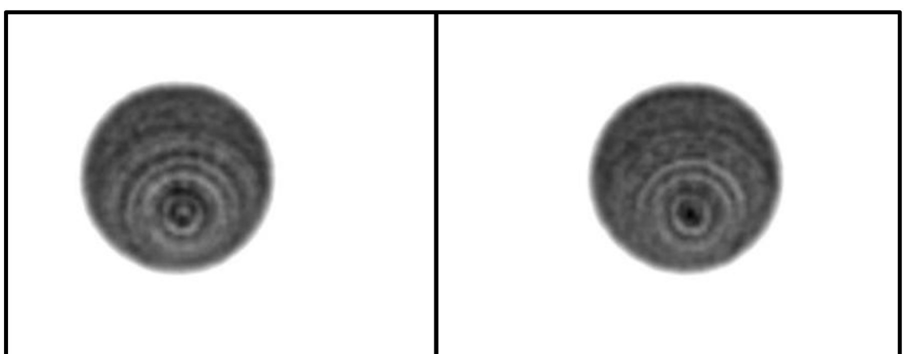
- Jaszczak phantom or Bleach bottle can be used
- Tests tomographic uniformity of the system

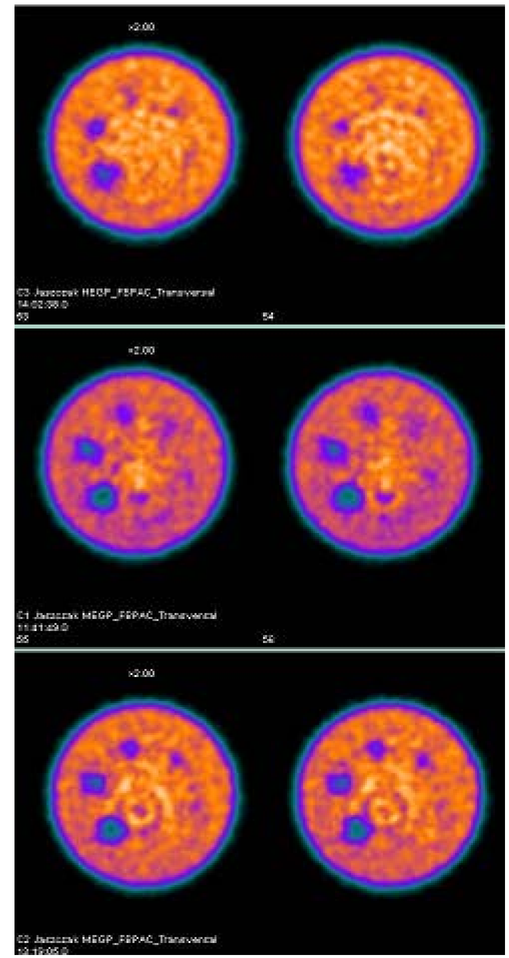




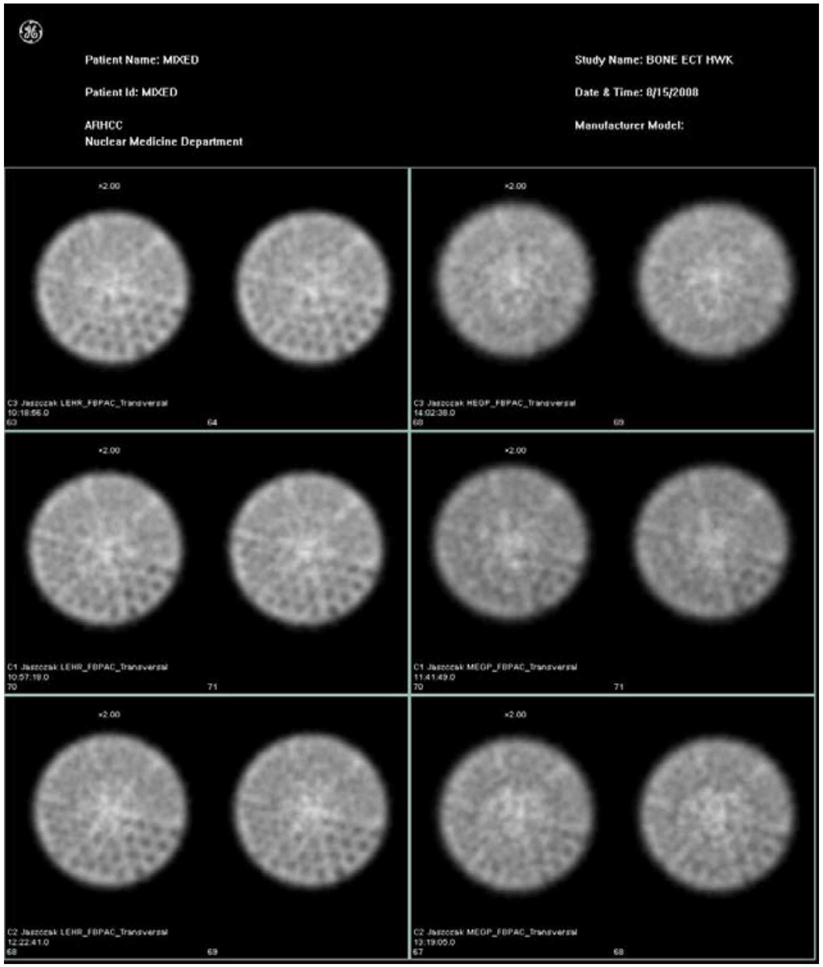
Tomographic uniformity

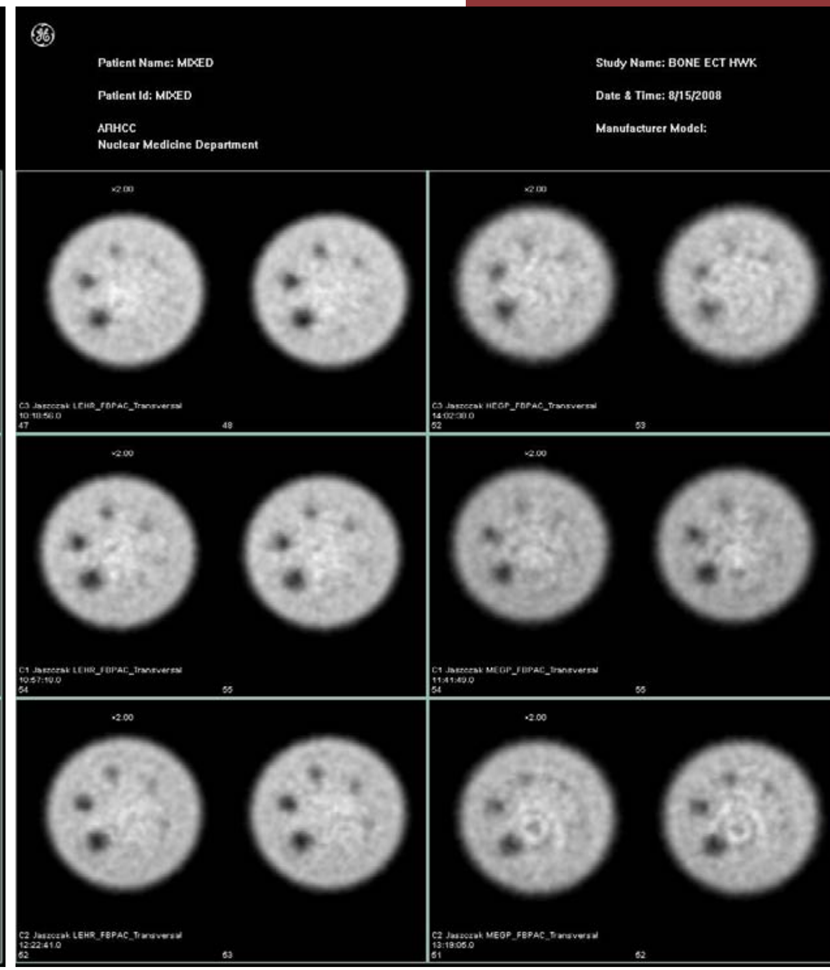
- Tomographic scans are much more sensitive to detector or collimator non-uniformities than planar studies
- Non-uniformities manifest themselves as rings around the axis of rotation





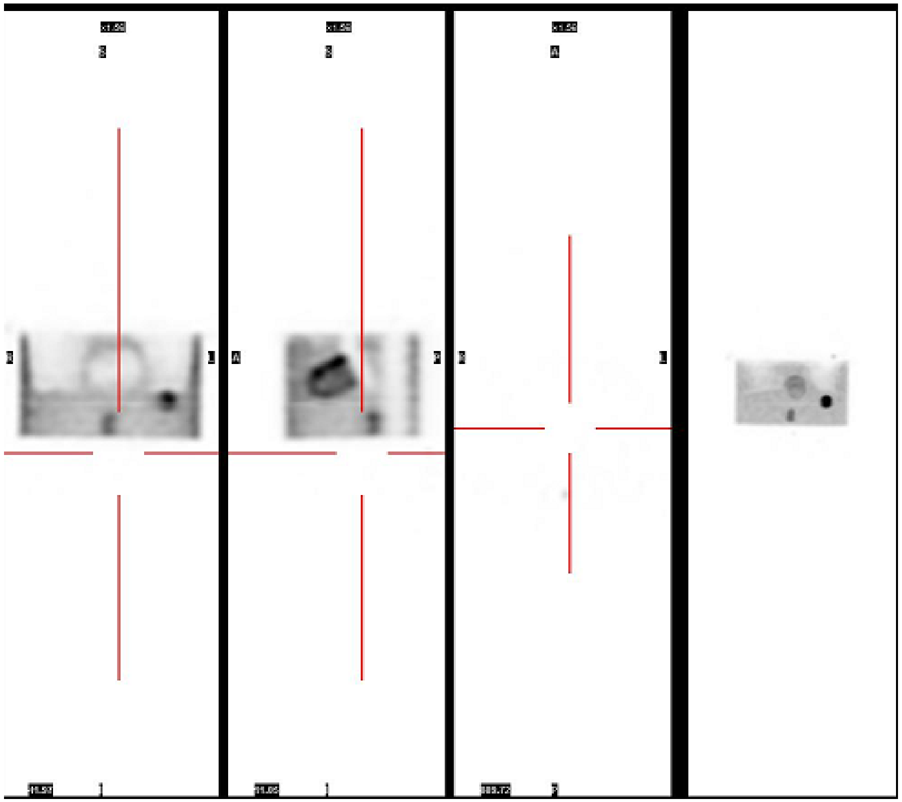
Jaszczak Phantom





Acquisition with MEGP collimator, slight ring artifacts visible in the images

WB SPECT – Multiple Views



- Clearly visible mismatch between sequence of SPECT acquisitions

CT & SPECT/CT TESTS

CT quality control tests

- Tests are very similar to the standard CT quality control
- Special phantom is used (water cylinder with inserts which is supplied with the camera)
- Special support/positioning device is used.
- All tests are performed for:
  - Siemens – three voltage levels 80kV, 110 kV and 130kV
  - GE – one voltage level 140kV
  - Philips – three voltage levels 90kV, 120kV and 140kV.
- When performing tests follow manufacturers instructions.
- Note that there are two sets of tests:
  - “daily tests” to be done daily after CT warm-up
  - “performance tests” (more elaborate) should be done at the camera acceptance and at annual tests

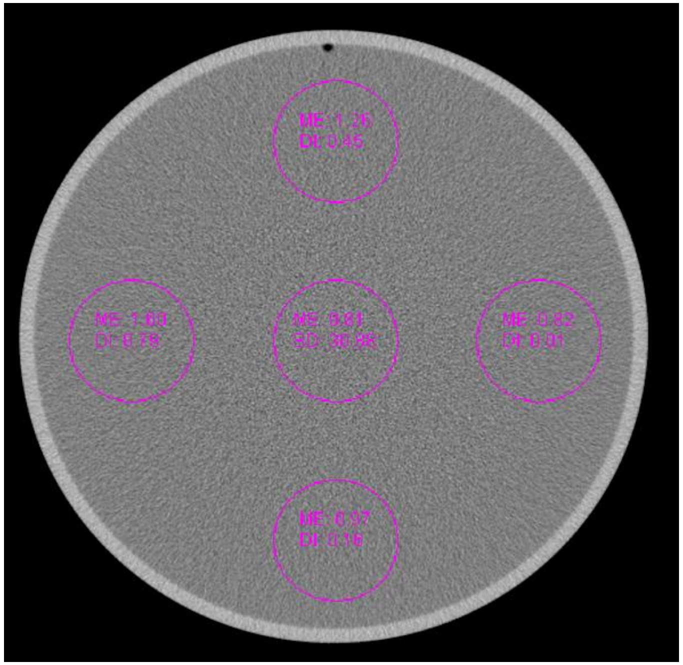
CT quality control tests

- GE – Hawkeye and Philips – Precedence:
  - X-ray uniformity test
    - Compares CT values in 5 spots over uniform area of the phantom
  - CT values accuracy test for high density materials
    - Checks CT numbers for air, water and plastic
  - Contrast test
    - Contrast test using a series of bars
  - Resolution test
    - Visibility of inserts/spheres
  - Slice thickness test
    - Measures thickness of the slice

CT quality control tests

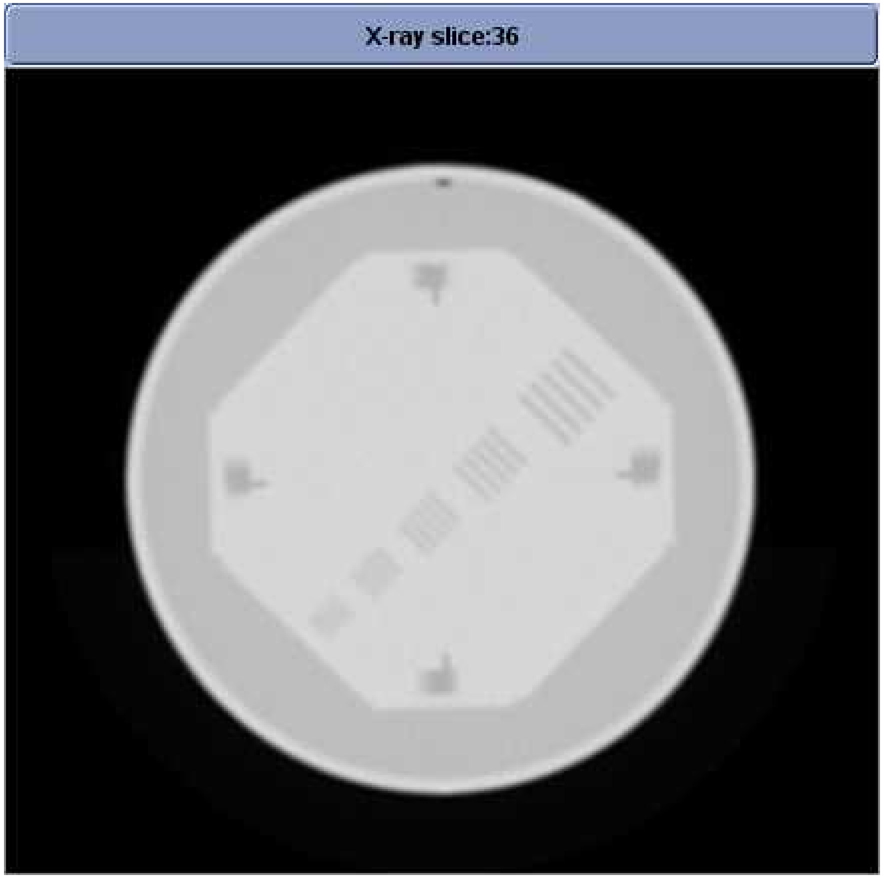
- Siemens – Symbia
  - Light marker test
    - Checks position of light markers
  - quality of MTF (modulation transfer function) at 50%, 10% and 2%
  - image contrast
  - noise levels for all voltages
  - homogeneity of water phantom at 5 positions
  - slice thickness for all six slices

Uniformity/Homogeneity Test



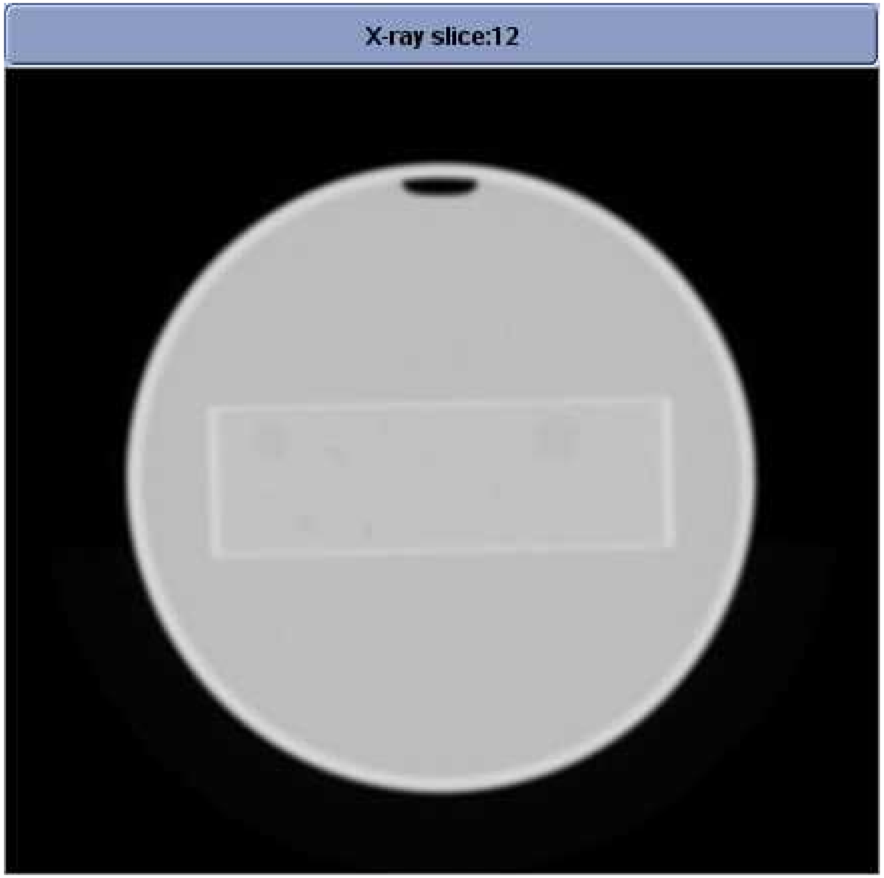
- Homogeneity of the CT-numbers at five different locations in each slice
- The test is performed for every CT slice

X-ray High Contrast Test



- Determines which set of bars is still visible
- Calculates image contrast expressed in number of visible line pairs

X-ray Low Contrast test



- Asks for the number of visible spheres
- Determines the size of the smallest visible sphere

High Density Material and Slice Thickness Tests

- High density material test checks the accuracy of mean density value and standard deviation for
  - plastic
  - water
  - air in the phantom

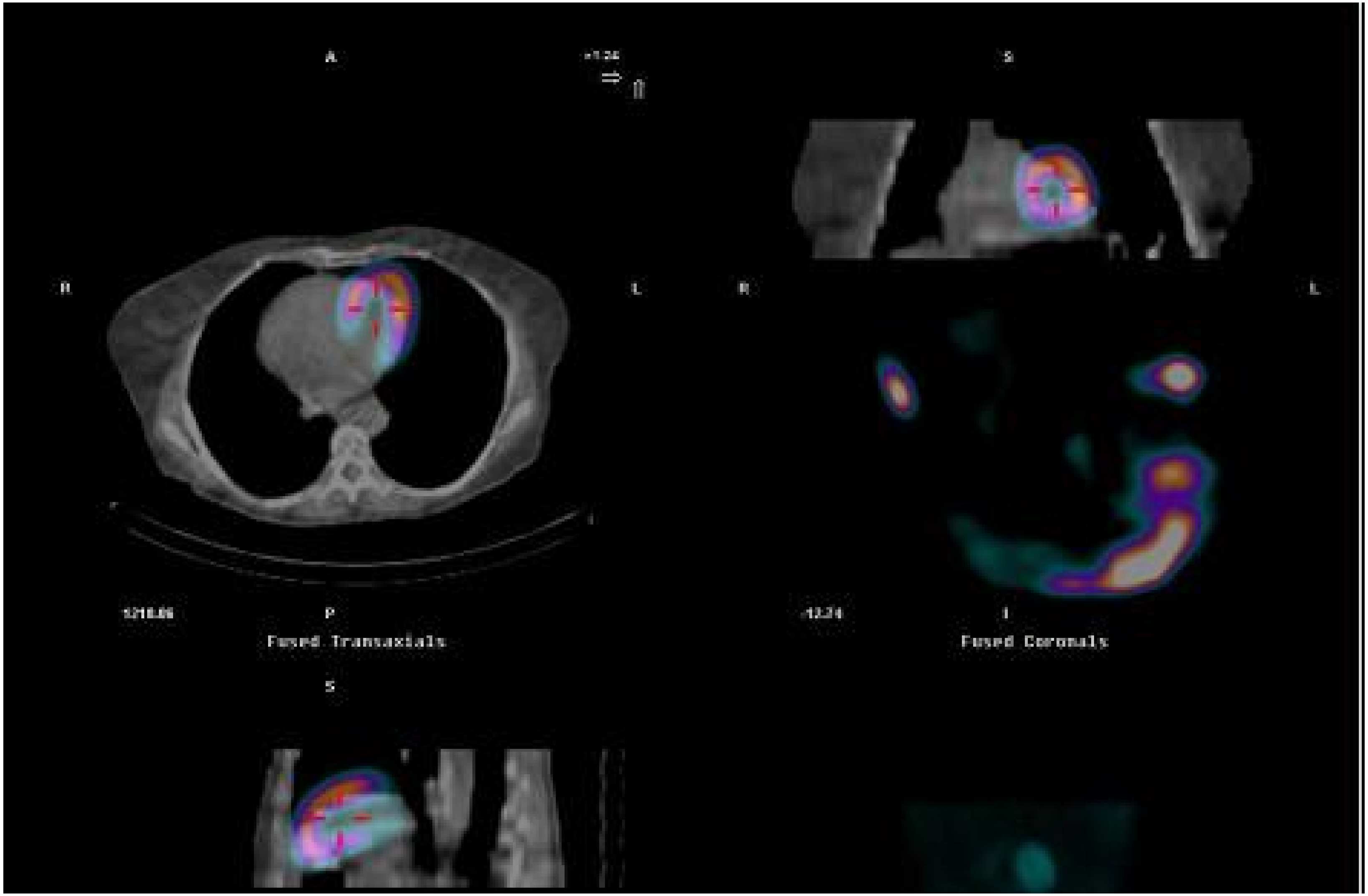
- Slice thickness test measures the accuracy of CT slice determination for four locations in the slice (left, right, top, bottom)

Co-registration SPECT-CT

- Co-registration SPECT - CT test
  - Checks alignment of reconstructed SPECT and CT images in X,Y and Z direction at different locations along axial direction
  - Point sources or syringes filled with activity are used
  - Test should be performed at acceptance and annually or if there is any malfunction

- Co-registration of SPECT and CT images must be checked for **EVERY** patient study before attenuation correction is done

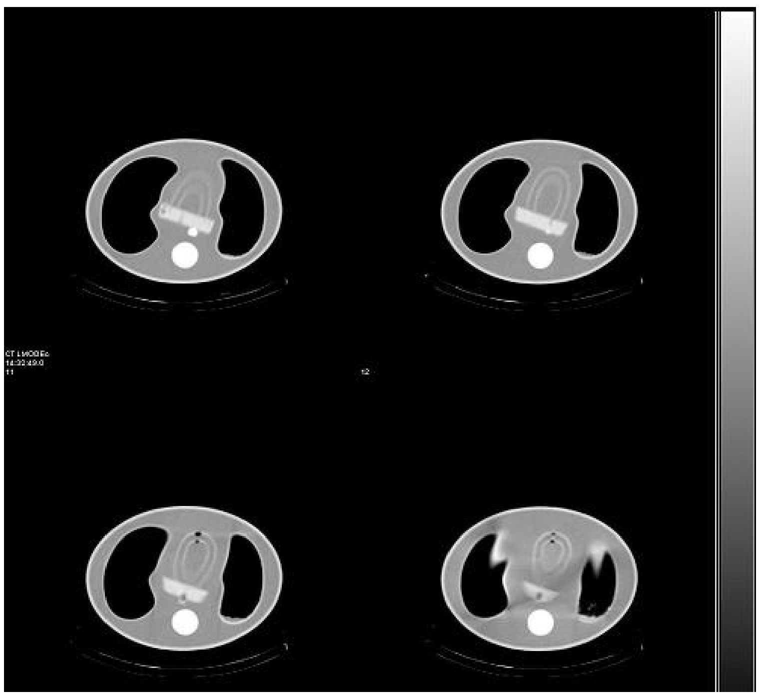
CT-SPECT mis-alignment

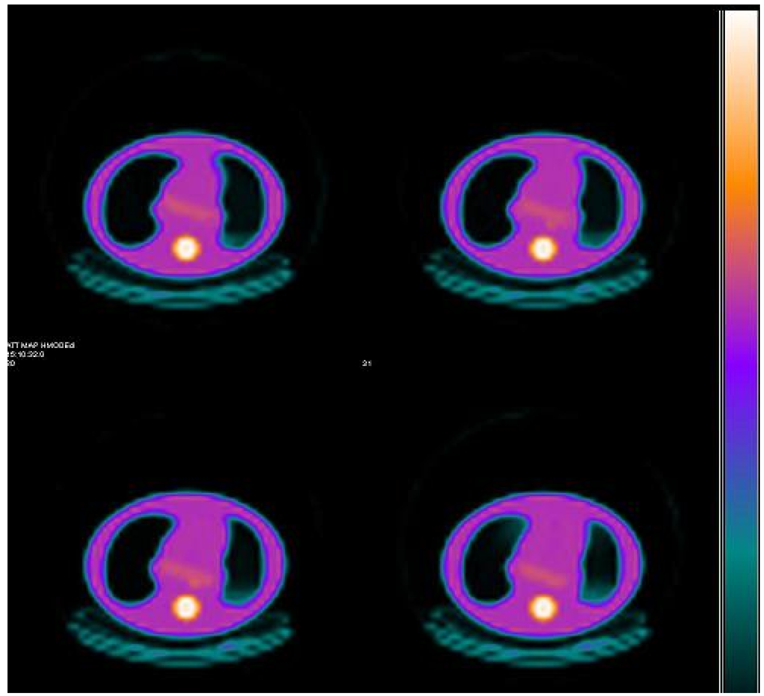


CT-based Attenuation Maps

GE: Hawkeye

CT images (256x256) with slice thickness 0.5 or 1 cm

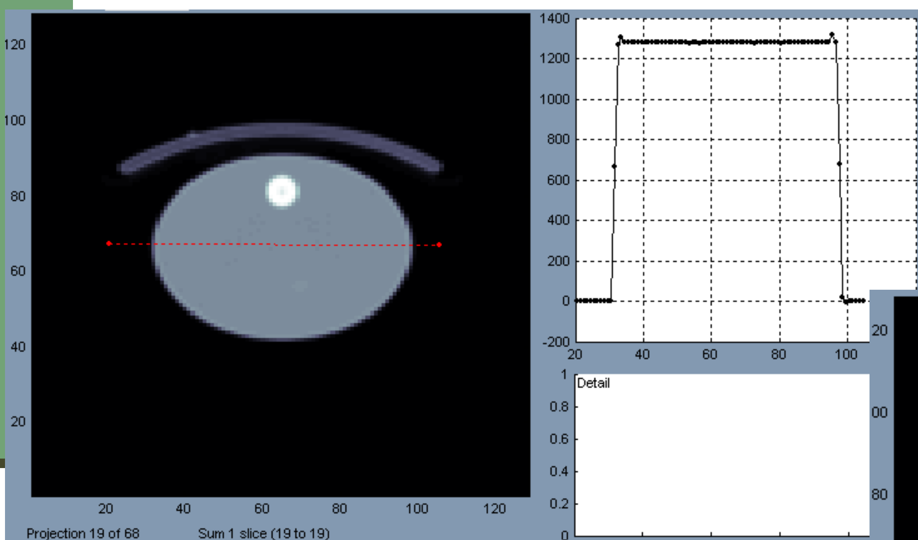




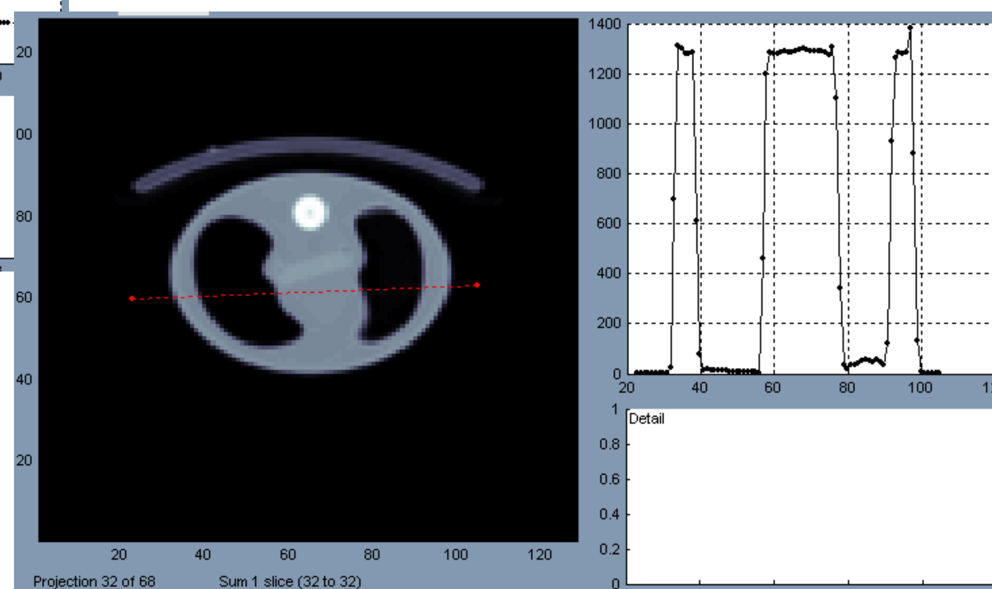
are translated into μ-values for use in attenuation maps with isotropic (cubic) voxels (64x64) or (128x128)

Accuracy of μ-values

- Numerical μ-value should be 0.15 cm^{-1} for narrow beam and 0.12-0.13cm^{-1} for BB attenuation correction

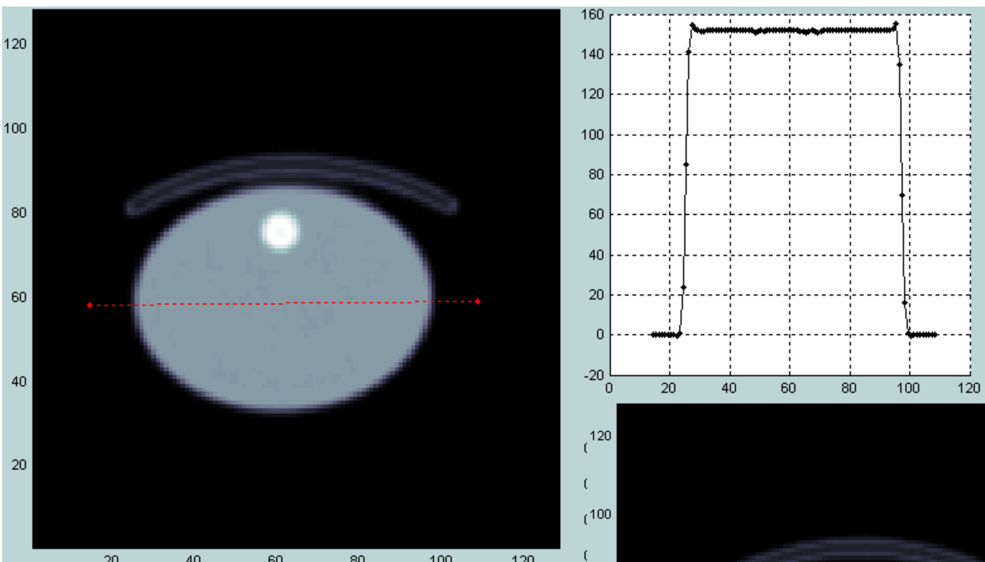


Siemens - Symbia

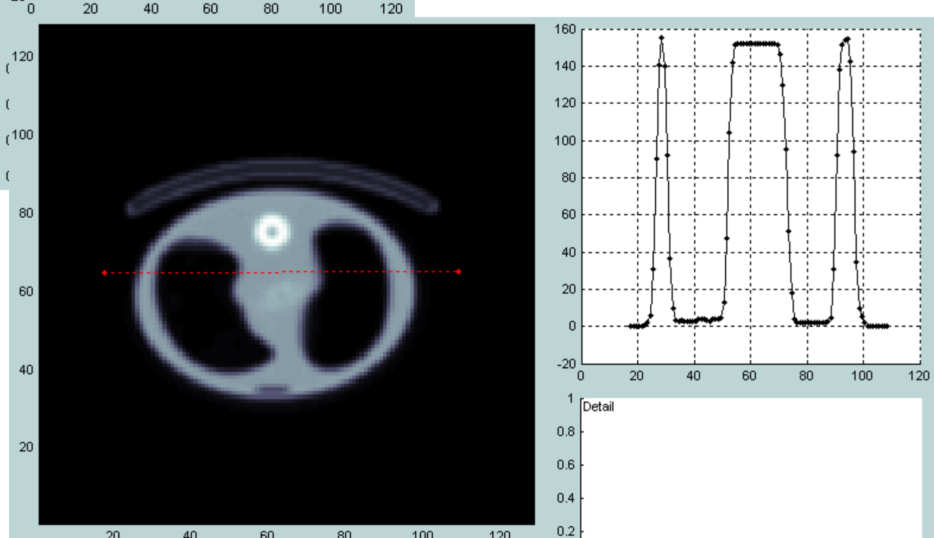


Accuracy of μ-values

- Numerical μ-value correspond to narrow beam, but they will be rescaled to BB before being incorporated into reconstruction algorithm



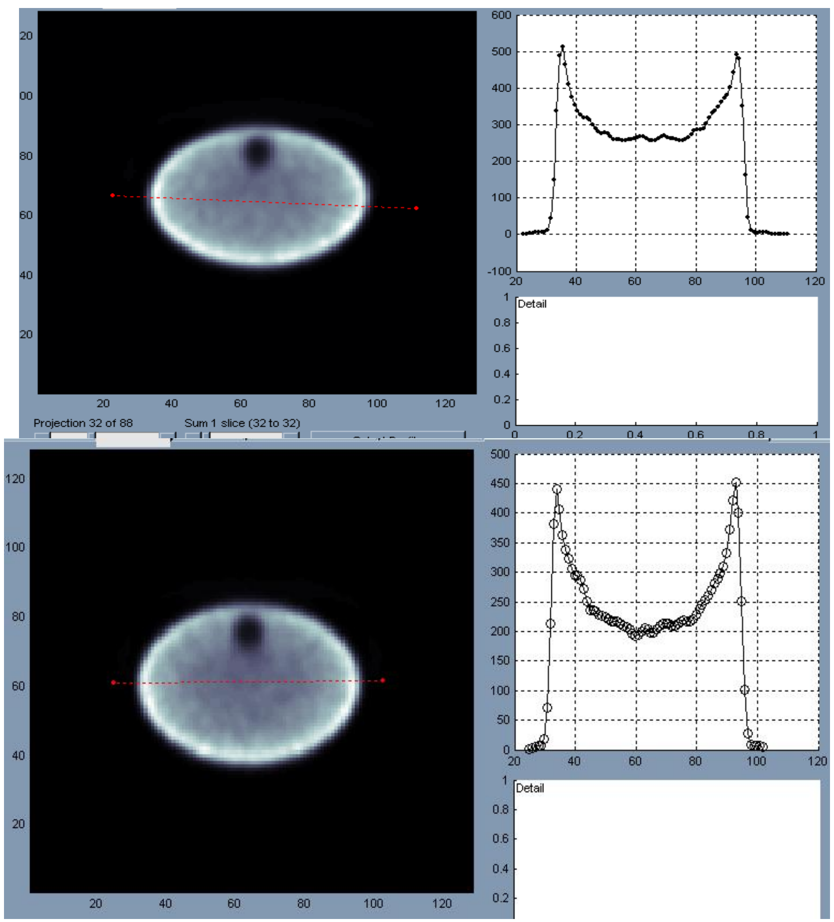
GE - Hawkeye



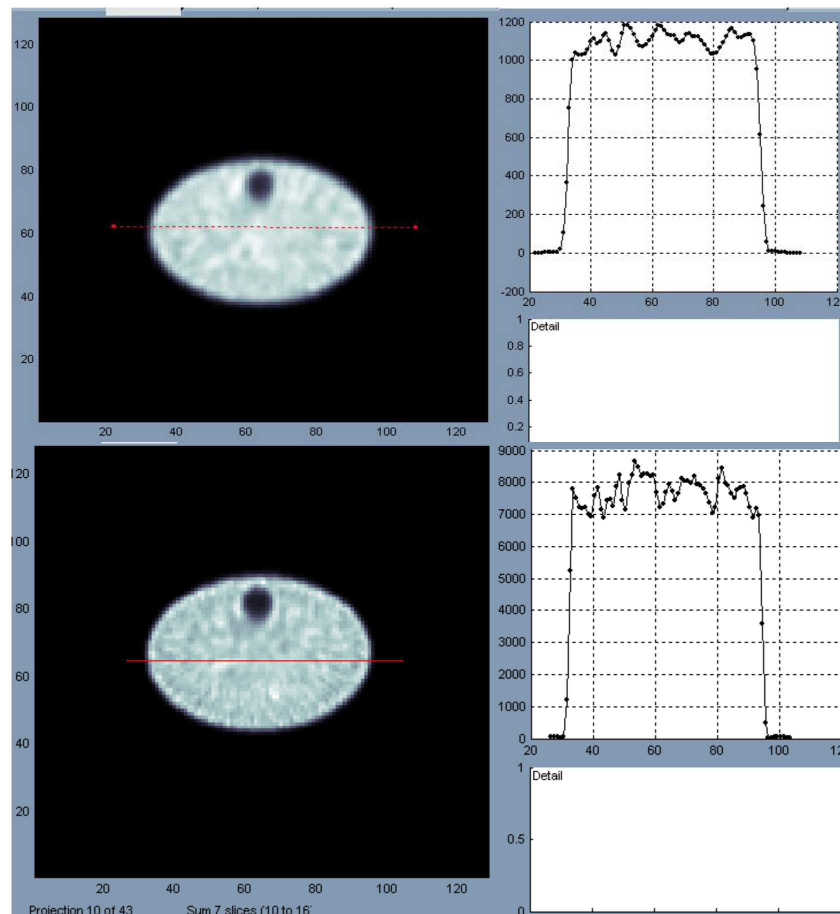
Attenuation Correction - Symbia

Uniform part of the Thorax Phantom

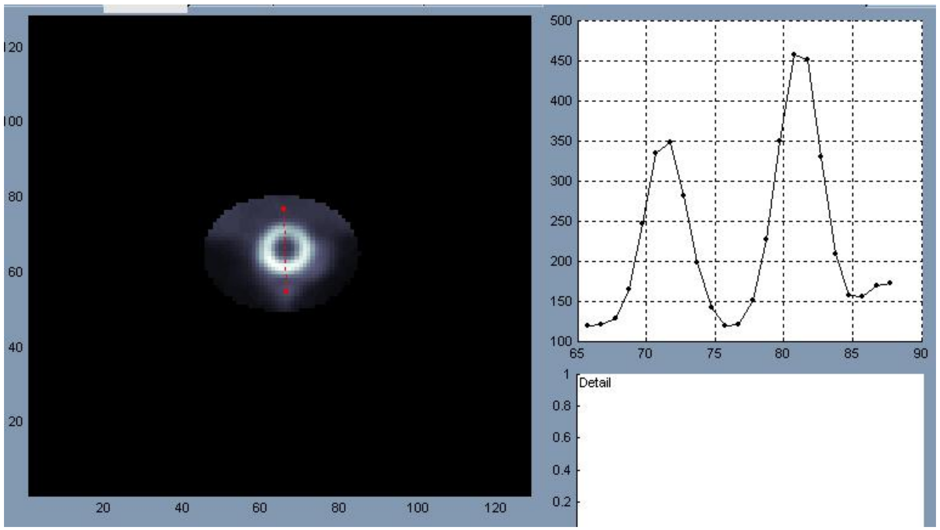
NC



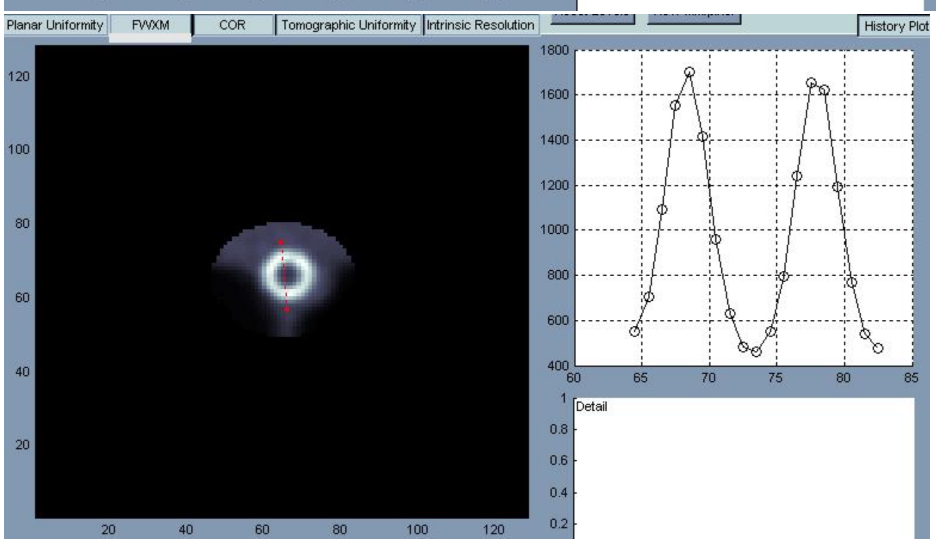
AC



Heart Insert - Siemens Symbia

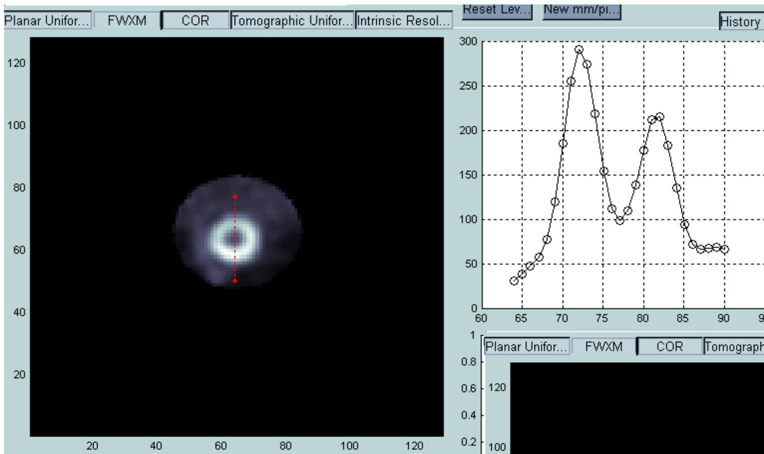


Flash3D
OSEM + RR



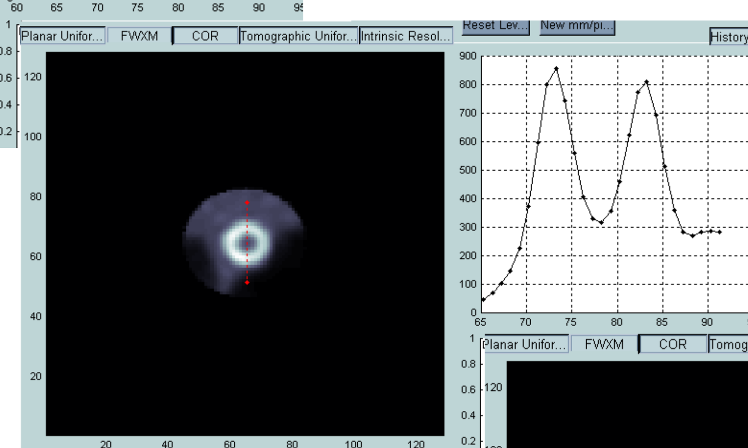
Flash3D
OSEM + AC + RR

Heart Insert – GE Hawkeye

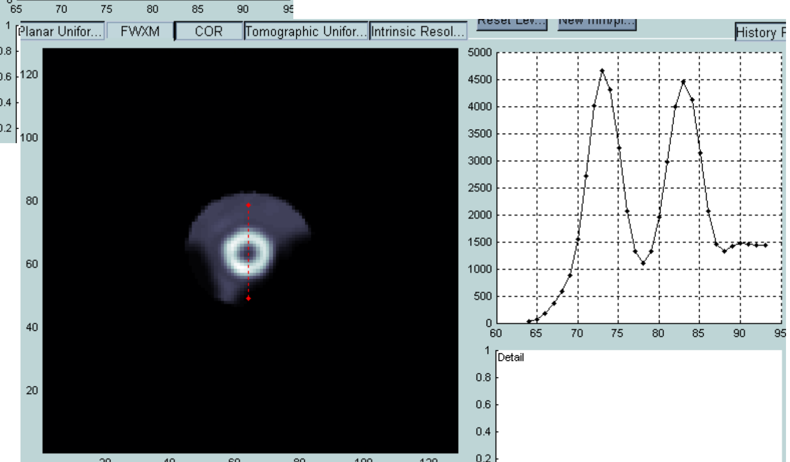


FBP (NC)

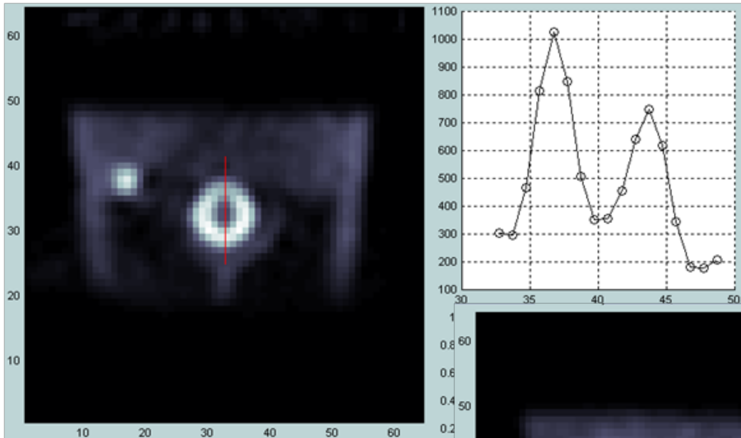
OSEM+AC



Evolution (EfB)
OSEM+AC+RR

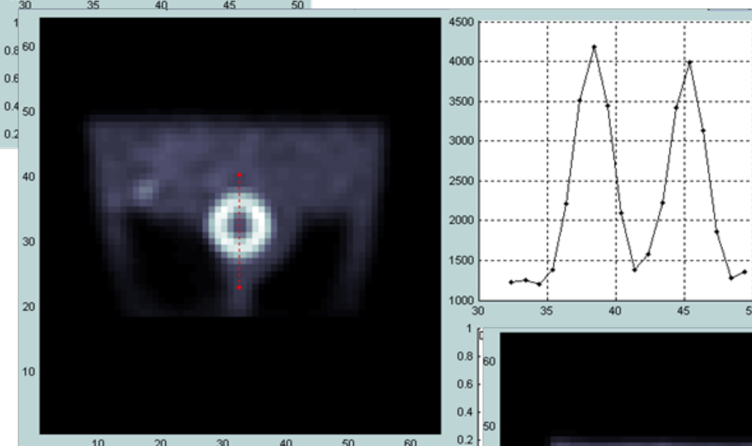


Heart Insert – Philips Precedence

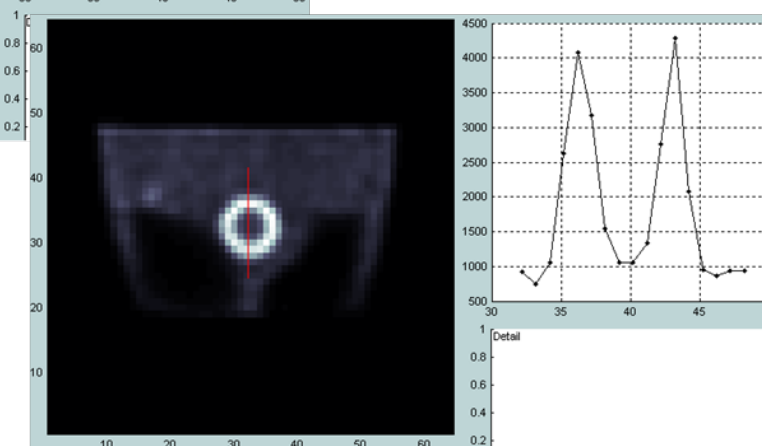


FBP (NC)

OSEM+AC



Astonish
OSEM+AC+RR



Conclusions

- Quality control tests are absolutely essential for assuring proper clinical performance of the camera
- Tests must be designed to be sensitive to the effects which they are suppose to test
- It is VERY important to understand what and why is being tested
- Tests should be performed regularly
- Test results must be analyzed, recorded and compared with previous test results

Thank You !

Canadian
Rocky
Mountains:

Yoho Park

RECOMMENDED TESTS

Daily Tests

- Visual Inspection of the mechanical integrity of the camera
- Background activity check
  - check energy spectrum with window wide open
  - record number of counts in 60 second
  - compare with "normal" background levels
  - check for contamination when higher than usual counts are observed
- Visual check of the shape of energy spectrum and peak position in the energy window for Tc-99m and higher energy isotope (if planned to be used)

Daily Tests

- Intrinsic Flood Field Uniformity test (no collimator, point source Tc-99m) or Extrinsic Flood Field Uniformity (with collimator, Co-57 flood source)
  - acquire at least 10-15 millions counts per detector
  - visually inspect the image for hot and cold spots
  - analyze data using NEMA protocol,
  - record the results in the log-book
  - plot data on a graph to show trend
- CT system tests
  - CT- Uniformity and CT-values
  - Resolution & contrast
  - System/Patient alignment – for every patient study

Weekly Tests

- COR test for 90º and 180º detector configuration
  - if COR values stay constant for 4-6 months
    - this tests can be done monthly/quarterly
- In case when only 4M uniformity flood is acquired daily weekly test should include a 10-15M uniformity test
  - acquire 10M extrinsic flood
  - visually inspect the image for hot and cold spots
  - analyze data using NEMA protocol
  - record the results in the log-book
  - plot data on a graph to show trend

Monthly Tests

- Intrinsic Spatial Resolution (using bar phantom)
  - use acquisition matrix allowing for good resolution
  - acquire 5-10M counts
  - visually inspect the image
  - compare with the results of the previous test
  - record your findings in the log-book
- Extrinsic uniformity for all collimators
  - acquire 30M extrinsic flood
  - visually inspect the image for hot and cold spots
  - analyze data using NEMA protocol,
  - rotate for all collimators testing one set each month
- Intrinsic uniformity for other isotopes (rotate for isotopes)

Every 3-4 months

- Tomographic Uniformity
  - use bleach bottle filled with 10-15mCi of activity
  - acquire normal SPECT study (64x64 matrix with 64 projections over 360^{o})
  - analyze using standard clinical Butterworth filter
  - check for ring artifacts

Annual tests

- Intrinsic uniformity 30M
- Extrinsic uniformity 30M
- System spatial resolution
- COR tests for all collimators
- Tomographic resolution and slice thickness
- Jaszczak Phantom (tomographic uniformity and sphere visibility)
- CT image quality tests
- SPECT-CT registration
- Accuracy of attenuation correction