

CT Quality Control:  
A Nuclear Medicine Physicist's  
Perspective

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## ..or CT QC

- Around the topic in 1800 seconds or less!!
  - In this timescale the objective is to provide an awareness of the range and importance of QC tests that can be performed for those unfamiliar with hybrid cameras.....
  - .. and for those who are ...
  - ... a reminder!!

# PRIMARY GOALS OF QA

- All imaging procedures undertaken are appropriate for the clinical situation
- All images have the necessary clinical information required – acquisition parameters and noise level appropriate for either anatomical localisation or attenuation correction.
- There is correct and timely interpretation of the images

# SECONDARY GOALS OF QA

- Radiation exposure to the patient is minimized
- The patient is subjected to the minimum inconvenience
- The cost of the procedures are optimised for the objective of the test

# IEC 601-1 Definition of QA and QC

- **Quality Assurance** –
  - “Planned and systematic actions to provide adequate confidence by ensuring that a product or service will satisfy given requirements for quality.
- **Quality Control (QC)** –
  - “Operational techniques and activities that are used to fulfil requirements for quality.

# What is the Minimum Required?

- Device(s) to measure kVp and dose
- Beam alignment tool
- High and Low Resolution phantom
- High purity aluminium sheet for HVL
- Good protocols
- Good service support

# Quality Control

- QC is that part of a QA program that achieves the desired quality by a series of well defined technical procedures.
- Examples include:-
  - Correct registration of CT and PET/SPECT images to ensure correct registration of images.
  - Images optimised to ensure image noise and patient dose maximise benefit to patient.

# Benefit of QC

- By establishing a comprehensive Quality Control program for a radiology department it becomes much easier to find the cause of any poor quality images and quickly correct any problems.

# Information on QC Programs (1)

- To assist in such programs there are a large number of publications of standards and technical reports from either National Standards Associations or else international bodies such as the IEC who have produced a number of standards relating to x-ray equipment.

## Information on QC Programs (2)

- A good starting point is to review any local standards in force, and then supplement these by the appropriate international standards for areas not covered by the national standard.

- **Indication and position of tomographic section AS/NZS 3200.2.44:2005 Paragraph 29.202.101**
  - *a) Scout view possible with light beam indication  $\leq 2\text{mm}$*
  - *b) Viewable in 500 Lx and  $\leq 3\text{mm}$  width*
  - *c) Move bed  $> 30\text{cm}$  and return to within 1mm with 135Kg evenly on bed.*
- **Gantry and patient support AS/NZS 3200.2.44:2005 Paragraph 22.4.101 a) b) c) Means to stop within set limits of motions 0.5 deg and 10mm and able to free patient if they could be trapped.**
- **Focus-skin distance (FSD) AS/NZS 3200.2.44:2005 Paragraph 29.1.104 Minimum 15cm**
- **Accuracy of radiation output AS/NZS 3200.2.44:2005 Paragraph 50.101 Manufacturer to provide documented accuracy for kVp, mA and linearity**

- **Safety measures against excessive radiation**  
*AS/NZS 3200.2.44:2005 Paragraph 29.1.105*
  - *a) Cannot exceed 110% of set or 1 rotation*
  - *b) Terminate within 1 sec of data failure*
  - *c) Can terminate where scans etc > 0.5 sec*
  - *d) Need to reset after one of above terminations*
  - *e) Warning and confirmation by operator if more than 1 scan in a series*
  - *f) Able to reconstruct if interrupted*
- **Half Value Layer** *AS/NZS 3200.2.44:2005*  
*Paragraph 29.201.5 Table 101 Minimum HVL*  
*80 – 2.4, 90 – 2.7, 100 – 3, 110-3.4, 120-3.8, 140-4.6*

- **Dose Information provided in the CT scanner accompanying documents**
- *AS/NZS 3200.2.44:2005 Paragraph 29.1.102.1 Comprehensive CTDI data and deviations from values*
- *AS/NZS 3200.2.44:2005 Paragraph 29.1.103.1 Paragraph 29.1.103.2. Z- Axis Dose profiles if > 3 slice widths then at least min, max and mid.*
- **Dose Information displayed on the controls** *AS/NZS 3200.2.44:2005 Paragraphs 29.1.103.3 & 4*

# IMAGE QUALITY

- The quality of an image is determined by a number of factors, but our prime test must be as to whether it will lead to a correct and timely diagnosis for the patient.

# Image Problems

- Problems can be divided into two major areas, **Technical** errors and **Human** errors.
- Some problems are quite easily divided into one or other of these groups, but in some cases it is not clear what is the cause. If one addresses the **technical** aspects first, then it has been found that the cause of a poor quality image is probably human error.
- To assess which cause is the most probable, it is important to have a well documented series of test results- If possible extending back to the original installation and test results.

# Equipment Tests

- There are three main types of tests to be carried.
  - **Acceptance tests**
  - **Status Tests**
  - **Constancy Tests**

# ACCEPTANCE TESTS

- **Aim** - Acceptance of performance of equipment as agreed between manufacturer and owner of the equipment (as specified in contract)
- **Characteristics** - Measurement of key parameters
- **Frequency** - At installation and after major modifications
- **Responsibility** - Manufacturer and **user**.

# STATUS TEST

- **Aim** - Determination of level of performance
- **Characteristics** - Measurement of key parameters
- **Frequency** - initially, after modification, and and on departure from constancy
- **Responsibility** - Manufacturer and user or their representative

# CONSTANCY TEST

- **Aim** - Checking the constancy of performance.
- **Characteristics** - Relative measurements (non-absolute values)
- **Frequency** – Routinely (daily, weekly monthly etc), immediately after maintenance and when malfunction is suspected
- **Responsibility** - USER or his representative

# Maintenance Records

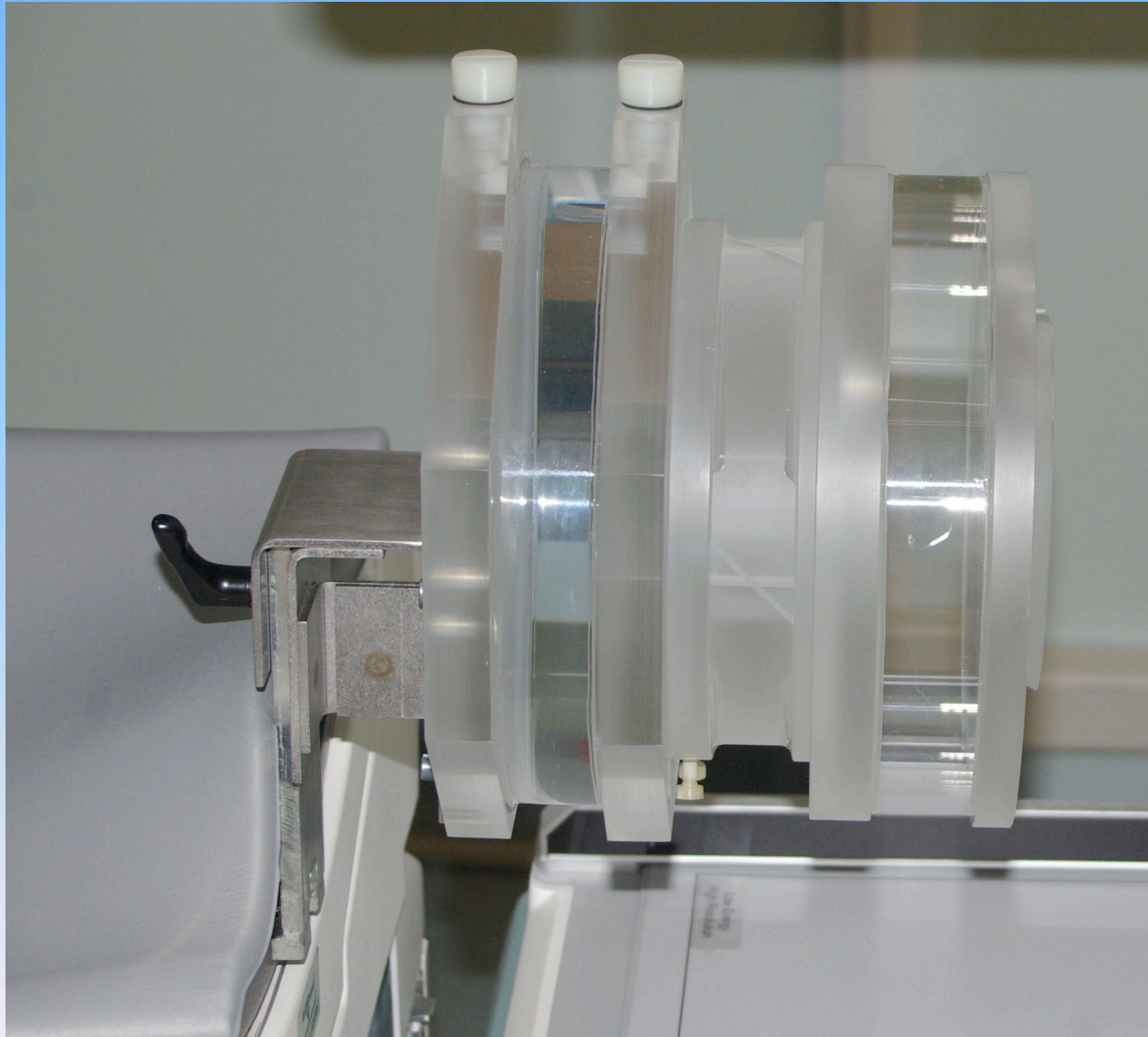
- A service history is an important part of the program
- Records of faults and solutions are invaluable to minimise downtime as well as ensuring equipment is safe to use.
- Troubleshooting is simplified greatly.

# Equipment Records

- Required for measuring equipment subject to drift or change e.g. dosimeters, kVp meters survey meters for shielding assessment etc.
- These should include a record of all calibrations of the equipment.
- Details of service and faults should also be recorded.

# What CT QC is Required

- Daily checks of:-
  - CT value calibration (HU)
  - Pixel noise (SD)
  - Tube Voltage
- Typically uses CT Phantom supplied by manufacturer
- Can be carried out by MRS (Nuc Med Technologist)
- Records kept on console workstation ... but often never reviewed – just pass or fail status.
- **Control charts or regularly reviewed records are essential.**



CT Quality  
Phantom  
with uniform  
water filled  
section, slice  
thickness  
phantom and  
wire  
phantom for  
MTF  
measurement.

*Courtesy  
Siemens  
Medical  
Systems*

# Other QC Tests

- These are carried out at longer frequencies e.g. Acceptance, Monthly, Annually or following maintenance and include:-
  - CTDI
  - Low Contrast Detectability
  - Slice Sensitivity Profile
  - Monitor Performance
  - Exposure Reproducibility
  - HVL

# QC and image analysis

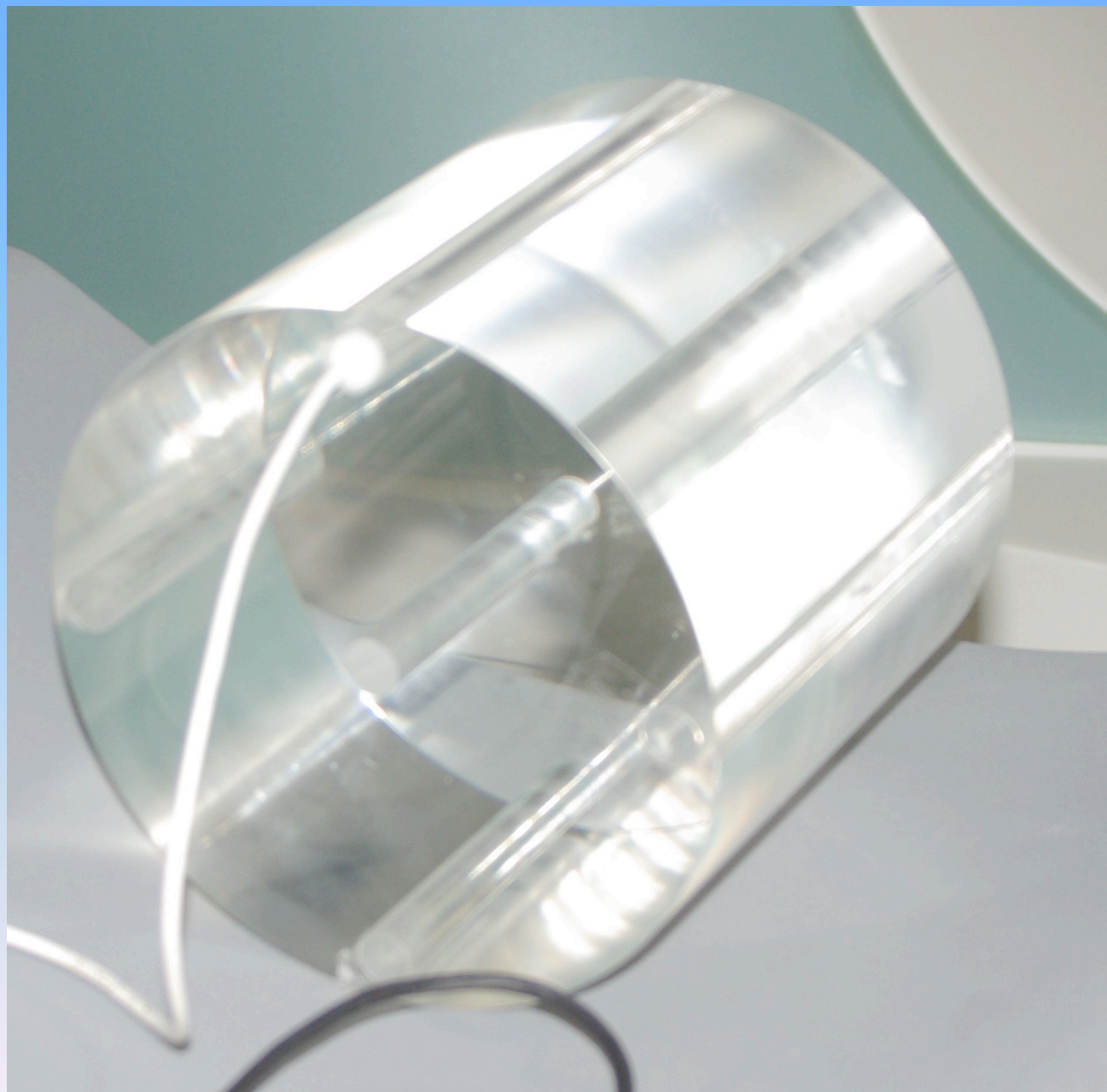
- It is very important not to just think of QC as just providing a set of numbers that either meet or fail a given standard and passing a morning set of QC tests does not guarantee optimal performance throughout a “clinical” day.
- Constant appraisal of images is also part of a QA program, and recognition and correct response to image artifacts is essential.

# Artifacts (1)

- Patient related
  - Partial volume Dark streaks or Hounsfield Bars (may need thinner slices)
  - Beam Hardening – streaks, light areas and cupping effect (appropriate corrections or filtering can reduce)
  - Metal Artifacts cause black or white streaks, or stellar effect on image
  - Patient motion can cause objects to move in or out of slice – can correct from sinogram

# Other Artifact Causes

- System is not calibrated properly or has drifted due to time, temperature changes, or component failure.
- Detector response changes can cause ring or arc artifacts or blurred areas.
- Mispositioning of patient where bowtie filter is used can cause unwanted effects
  - These effects can be mitigated by ensuring regular system calibration through the working day and also appropriate positioning of the patient in the gantry.



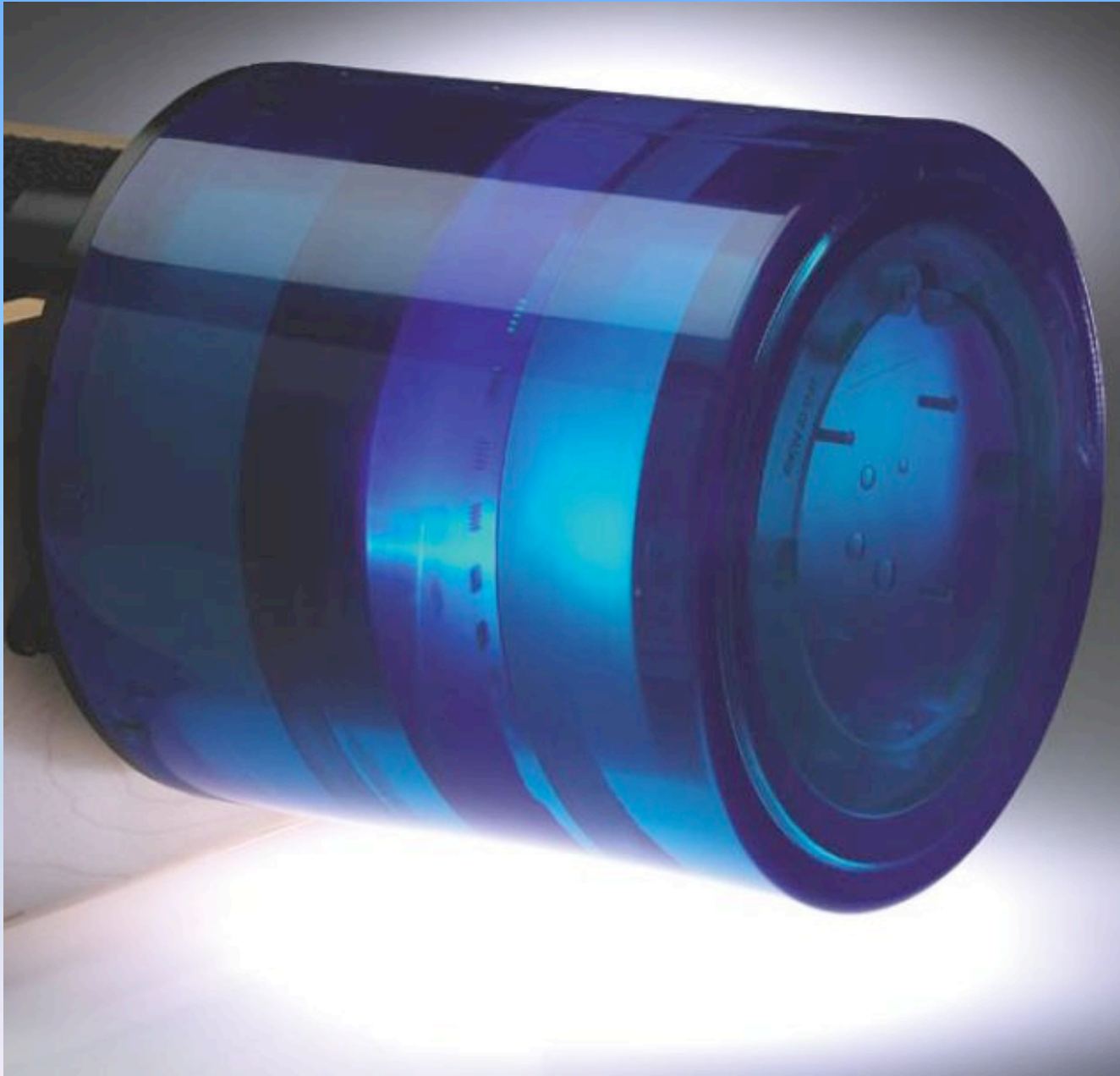
CT perspex Head  
Phantom for  
 $CTDI_{100}$   
measurements  
with 100 mm CT  
chamber located  
in 12 O'clock  
position and  
perspex rods  
filling 3, 6, 9 and  
center positions.



Failing to find a 70 kg physicist – table movement can be checked using suitable alternative weights readily available in the department. Bed should travel both continuously and in steps to within 1mm

# CT Phantoms

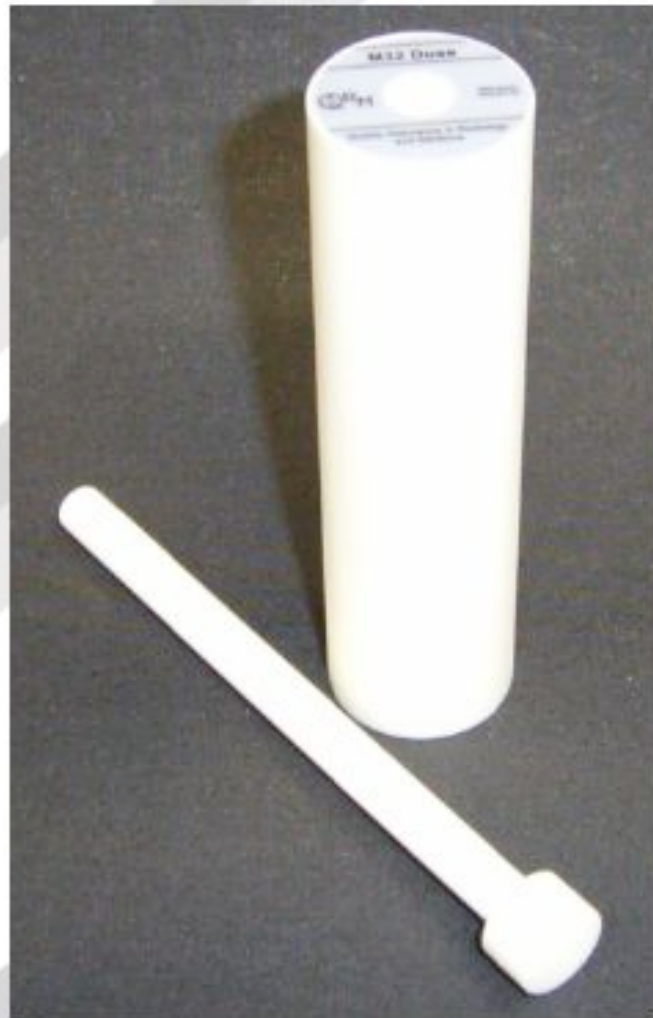
- There are a wide variety of these available and most systems come with a basic phantom that can be used to carry out a number of constancy checks including:-
  - Slice thickness
  - Homogeneity
  - Noise
  - MTF
  - Low and high contrast resolution



CATPHAN



AAPM CT  
Performance  
Phantom



**QRM-MicroCT-Dose** mouse-size phantom

CT phantoms  
available for all  
“nuclear medicine”  
patients

# Basic Tests

- These are the tests available to the ordinary user without requiring access to service mode.
- Carrying out such tests will not change any of the operating parameters of the CT.
- Results can be used to verify correct operation as well as indicate gradual changes that may impact the images obtained.

# Basic QC tests carried out daily

- System tests on operating parameters such as kVp.
- In air calibration to check for detector drift and correct functioning of electronics.
- Check of CT value for water
- Pixel noise calculation

		Water [HU]	Sigma [HU]	Voltage [kV]
row 1	Reference:	0.00	---	80.0
	Tolerance:	+/- 4.00	---	+/- 8.0
	Result:	1.58	---	79.8
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	-0.67		
row 1	Reference:	0.00	19.50	110.0
	Tolerance:	+/- 4.00	+/- 1.95	+/- 10.0
	Result:	1.97	18.72	109.4
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	0.21		
row 1	Reference:	0.00	18.40	130.0
	Tolerance:	+/- 4.00	+/- 1.84	+/- 10.0
	Result:	1.96	17.81	129.2
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	0.59		

Daily Check of CT Number for water at operational kVps of 80, 110 and 130 kVp

# Quality Slice Results



Date: 10.09.2007 16:27:28

	Nominal [mm]	1.00	1.50	2.50	4.00	5.00
row 1	Reference [mm]	1.00	1.50	2.50	4.00	5.00
	Tolerance [mm]	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50
	Result [mm]	1.06	1.61	2.52	4.02	4.66
row 2	Reference [mm]	1.00	1.50	2.50	4.00	5.00
	Tolerance [mm]	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50
	Result [mm]	1.13	1.62	2.50	4.08	4.88

# Quality Homogeneity Results



Date: 10.09.2007 16:28:16

		Mean	Diff.	Diff.	Diff.	Diff.
ROI		center	3	6	9	12
110.0 [kV]						
row 1	Reference [HU]:	0.00	0.00	0.00	0.00	0.00
	Tolerance [HU]:	+/- 4.00	+/- 2.00	+/- 2.00	+/- 2.00	+/- 2.00
	Result [HU]:	1.97	-0.90	-0.66	-0.52	-0.75
row 2	Reference [HU]:	0.00	0.00	0.00	0.00	0.00
	Tolerance [HU]:	+/- 4.00	+/- 2.00	+/- 2.00	+/- 2.00	+/- 2.00
	Result [HU]:	0.99	0.83	0.41	0.11	0.42
130.0 [kV]						
row 1	Reference [HU]:	0.00	0.00	0.00	0.00	0.00
	Tolerance [HU]:	+/- 4.00	+/- 2.00	+/- 2.00	+/- 2.00	+/- 2.00
	Result [HU]:	0.92	1.05	0.54	0.67	0.73
row 2	Reference [HU]:	0.00	0.00	0.00	0.00	0.00
	Tolerance [HU]:	+/- 4.00	+/- 2.00	+/- 2.00	+/- 2.00	+/- 2.00
	Result [HU]:	0.61	1.10	0.86	0.49	0.92

# Quality Slice Results



Date: 10.09.2007 16:27:28

	Nominal [mm]	1.00	1.50	2.50	4.00	5.00
row 1	Reference [mm]	1.00	1.50	2.50	4.00	5.00
	Tolerance [mm]	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50
	Result [mm]	1.06	1.61	2.52	4.02	4.66
row 2	Reference [mm]	1.00	1.50	2.50	4.00	5.00
	Tolerance [mm]	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50	+/- 0.50
	Result [mm]	1.13	1.62	2.50	4.08	4.88

# Laser Alignment

- Radiology Physicist
  - Pin
  - Sheet film in a pack
  - Darkroom
  - Rule
    - (traceable to national standard of course)
  - Copy of AAPM Report 39

# Laser Alignment

- Nuclear Medicine Physicist
  - Systems CT QC phantom
  - Ability to talk service engineer into giving you access to the scanners service mode.
- Quick and Dirty Check that laser lines intersect in the centre of the field
  - Position a pencil using lasers
  - Scan
  - Pencil lead shows up clearly on scan and location can be checked using cursor tool
  - Check for both internal and external lasers (if fitted).

# Image Noise

- Daily checks of image noise validate the correct detector response for a standard set of exposure parameters. This test is sensitive to:-
  - X-Ray tube performance
  - Detector response
  - System storage and data processing
- This is a fundamental daily check of the CT system easily accomplished by scanning a uniform phantom and a statistical analysis of the image.

## Quality Noise Results

Date: 04.12.2007 08:43:23

		Water [HU]	Sigma [HU]	Voltage [kV]
row 1	Reference:	0.00	---	80.0
	Tolerance:	+/- 4.00	---	+/- 8.0
	Result:	1.58	---	79.8
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	-0.67		
row 1	Reference:	0.00	19.50	110.0
	Tolerance:	+/- 4.00	+/- 1.95	+/- 10.0
	Result:	1.97	18.72	109.4
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	0.21		
row 1	Reference:	0.00	18.40	130.0
	Tolerance:	+/- 4.00	+/- 1.84	+/- 10.0
	Result:	1.96	17.81	129.2
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	0.59		

## Quality Noise Results

Date: 10.09.2007 16:28:47

		Water [HU]	Sigma [HU]	Voltage [kV]
row 1	Reference:	0.00	---	80.0
	Tolerance:	+/- 4.00	---	+/- 8.0
	Result:	0.72	---	79.8
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	-0.43		
row 1	Reference:	0.00	19.50	110.0
	Tolerance:	+/- 4.00	+/- 1.95	+/- 10.0
	Result:	2.15	18.64	109.6
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	0.72		
row 1	Reference:	0.00	18.40	130.0
	Tolerance:	+/- 4.00	+/- 1.84	+/- 10.0
	Result:	1.51	17.08	129.4
row 2	Reference:	0.00		
	Tolerance:	+/- 4.00		
	Result:	1.13		

Change in noise over a 3 month period - minimal

## **Additional Tests requiring access to service mode or specialised dosimetry equipment**

- CTDI
- HVL
- MTF
- Image registration
- HU for different materials
- Voxel size

# CTDI

- Validation of CTDI measurements has required the use of pencil ionisation chambers typically 100mm long.
- The increasing use of multislice CT with beam widths now extended to 16cm for the new Toshiba 320 slice system is being addressed by the radiology physicists and caution is required when using CTDI values for multislice CTs with beam widths  $> 5\text{cm}$ .

	Center A	Surface B
80.0 [kV]		
Reference [mGy/100mAs]:	0.90	2.72
Tolerance [mGy/100mAs]:	[+/- 0.18]	[+/- 0.54]
DLP [mGycm]:	1.76	4.30
Result [mGy/100mAs]:	0.77	2.40
110.0 [kV]		
Reference [mGy/100mAs]:	2.61	6.77
Tolerance [mGy/100mAs]:	[+/- 0.52]	[+/- 1.35]
DLP [mGycm]:	5.07	10.50
Result [mGy/100mAs]:	2.24	5.94
130.0 [kV]		
Reference [mGy/100mAs]:	4.20	10.21
Tolerance [mGy/100mAs]:	[+/- 0.84]	[+/- 2.04]
DLP [mGycm]:	4.55	8.91
Result [mGy/100mAs]:	3.55	8.92

Validation of CTDI calibration - manufacturers tolerance for this system is +/- 20%

# Quality MTF Results



Date: 05.12.2007 14:26:38

	50%	10%	2%
wire in air; 2x1mm; U90s			
Reference [lp/cm]:	9.00	12.30	14.00
Tolerance [lp/cm]:	+/- 0.90	+/- 1.23	+/- 1.40
row 1	8.79	12.21	14.01
row 2	8.66	12.43	14.01

Whilst the data provided is a good test of ongoing performance, it does not provide the limiting resolution value (5%) and is measured in air – forthcoming standards are expected to be in a medium such as perspex.



HVL Measurements require tube to be locked or in 12 o'clock position for above configuration, suitable chamber / electrometer combination and high purity aluminium filters – minimum HVL of 2.4mm at 80 kVp or 4.6mm at 140 kVp is required to ensure adequate tube filtration.

# CT and NM Image registration

- Initially calibrated using vendor supplied registration phantom
- On SPECT/CT cameras can be readily checked by SPECT/CT scan of a  $\text{Co}^{57}$  point source or on a PET/CT by using an appropriate NM/CT/MRI fiducial marker with a positron point source.
- This would be a good monthly check along with multihead registration test for a PET/CT or SPECT/CT camera or following gantry separation for service.

# Limiting Resolution

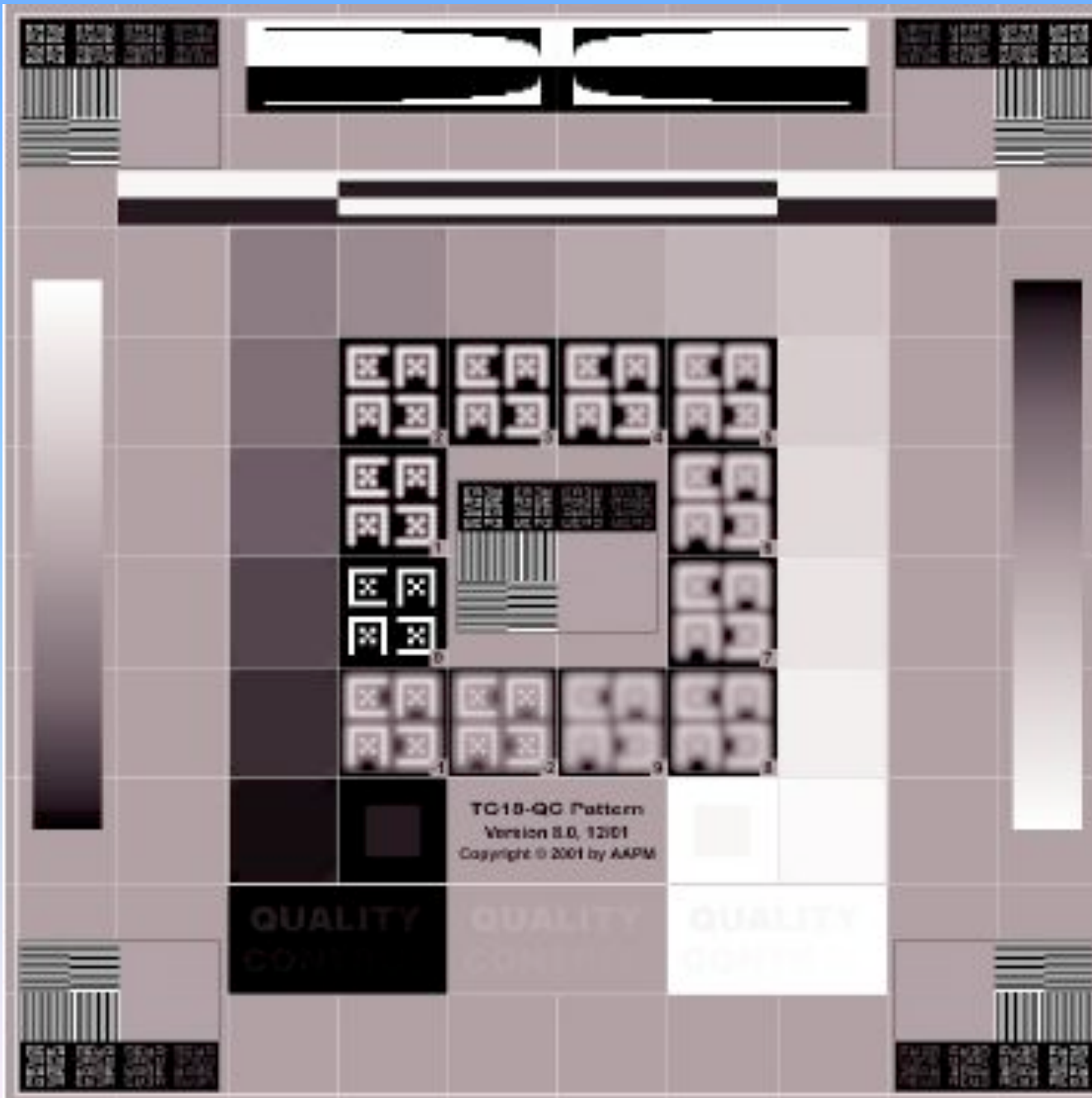
- Unlike film-screen systems with a limiting resolution of between 4 - 20 line pairs/mm, CT is limited to between 0.5 – 2 lp/mm. It is possible to use a line pair gauge to measure this, but easier to use a CT phantom incorporating a tantalum or similar fine wire.
- System software is used to generate the Modulation Transfer Function and the limiting resolution taken as the frequency where it drops to 5%.

# Limiting Resolution

- Most systems would incorporate this test in the monthly system QC tests.
- They do not however necessarily use the reconstruction algorithms used clinically and this should be checked and repeated using these if appropriate.

# Monitor QC

- Monitor QC is an often forgotten aspect of digital imaging.
- The AAPM Taskgroup 18 report provides a comprehensive guide to this.
- As a simplified approach, use of the QC test image provides advantages over the familiar SMPTE test pattern.



TG18-  
QC  
Test  
Pattern

# Final Hint

- Same as the first.
  - Get a good working relationship going with your service engineer.
  - Include your acceptance tests as part of contract – some companies may charge a considerable fee for access to the NEMA test software “built in” to many hybrid cameras.

# Where to go for further information

- [www.impactscan.org](http://www.impactscan.org)
- [www.acmp.org](http://www.acmp.org)
- [www.aapm.org/pubs/reports/](http://www.aapm.org/pubs/reports/)
  - Especially reports 39 and 74
- AS/NZS 3200.1:1998
- AS/NZS 3200.2.44:2005
- [www.anzsnm.org](http://www.anzsnm.org) – Presentations from previous SIG meetings
- Local legislation requirements