ROUTINE QUALITY CONTROL TESTS FOR FULL FIELD DIGITAL MAMMOGRAPHY SYSTEMS

NHSBSP Equipment Report 0702
Version 1
February 2007

Enquiries about this report should be addressed to:

Sarah Cush
NHS Cancer Screening Programmes
Email: sarah.cush@cancerscreening.nhs.uk

Published by:

NHS Cancer Screening Programmes
Fulwood House
Old Fulwood Road
Sheffield
S10 3TH

Tel: 0114 271 1060
Fax: 0114 271 1089
Email: info@cancerscreening.nhs.uk
Web site: www.cancerscreening.nhs.uk

This report is available in PDF format on the NHS Cancer Screening Programmes website

Typeset by Prepress Projects Ltd, Perth (www.prepress-projects.co.uk)
Printed by Charlesworth

CONTENTS

PREFACE

This document is the first guidance for mammography practitioners on routine quality control tests for digital mammography systems. It is expected that the guidance will be updated as the use of digital equipment in breast screening becomes more widespread.

The NHSBSP is grateful to the following for help in developing and writing these guidelines:

Sarah Cash
Anna Burch
Patsy Whelehan
Kenneth Young

1. INTRODUCTION

Direct digital radiography (DR) and computerised radiography (CR) systems are now being used routinely for mammography in the NHS Breast Screening Programme (NHSBSP). Routine quality control (QC) is essential to ensure that the equipment is performing as expected and meets NHSBSP standards. This guide describes the recommended routine QC tests which should be undertaken by radiographic staff. It is based on the European protocol for the quality control of the physical and technical aspects of mammography screening[1] and on current knowledge and understanding of digital systems.

Guidance on commissioning and the routine testing of full field digital mammography systems is given in NHSBSP Equipment Report 0604.[2] These tests are undertaken by physicists. Baseline values need to be established at installation in conjunction with the local physicist and again if conditions are changed.

Routine tests recommended by the manufacturer of the x-ray set, workstation or printer for the calibration or maintenance of systems should be added to this test protocol. Some systems have built-in tests for the detector and/or display, and it is noted that manufacturers will continue to develop such automated QC systems. The local physicist should be asked to advise whether any built-in tests are suitable for use in place of the tests described in this document.

All quantitative and qualitative data generated by routine tests and observations should be recorded. Examples of data recording forms are given on the NHS Cancer Screening Programmes website (www.cancerscreening.nhs.uk).

The routine QC tests for DR and CR systems are summarised in Tables 1 and 2.

The only CR system so far evaluated by the NHSBSP that meets the European guidelines for quality assurance in breast cancer screening and diagnosis is the Fuji Profect/5000MA.[3] The recommended tests for CR systems therefore relate only to this system. Future revisions of the guidelines will include other accepted CR systems.

Table 1 Recommended routine QC tests for DR systems

Frequency	Test	Section
Daily	Checks on acquisition and reporting monitors	2.1
Daily	System check	3.1
Daily	Printer checks using test pattern	9.1
Weekly	Check of contrast-to-noise ratio	3.2
Weekly	Image quality tests	4
Weekly	Uniformity check	3.3
Monthly	AEC thickness check	3.4
Monthly	Test of reporting monitors	2.2
Monthly	Mechanical safety and function checks	7
As required	Detector flat-field calibration	5
As required	Repeat analysis	8
As required	Printer checks following software upgrade	9.2

Table 2 Recommended routine QC tests for CR systems

Frequency	Test	Section
Daily	Checks on acquisition and reporting monitors	2.1
Daily	System check	3.1
Daily	Printer checks using test pattern	9.1
Weekly	Check of contrast-to-noise ratio	3.2
Weekly	Image quality tests	4
Weekly	Uniformity check	3.3
Monthly	AEC thickness check	3.4
Monthly	Test of reporting monitors	2.2
Monthly	Mechanical safety and function checks	7
Six monthly	Image plate matching and artefact check	6.3
As required	Image plate erasure	6.1
As required	Image plate cleaning	6.2
As required	Repeat analysis	8
As required	Printer checks following software upgrade	9.2

2. MONITOR CHECKS

Monitor checks should be performed on both the acquisition and reporting* monitors under recommended† working conditions. It should be noted that cathode ray tube (CRT) and flat panel displays (FPD) may have different types of problems.

* The term 'acquisition monitor' is used here to denote a monitor used by the mammographer when performing the mammogram (also known as a review or secondary monitor). The term 'reporting monitor' is use to denote a monitor in the workstation used by the film reader when reporting the mammogram (also known as a diagnostic or primary monitor).
† Ambient light should be less than 10 lux for primary display devices.

2.1 Daily checks on acquisition and reporting monitors

Method

- Check for obvious faults such as flicker, gross distortion, artefacts (see Appendix 1).
- Check general condition.
- Clean if necessary (follow the supplier's instructions).
- Look at the text and lines on the screen – are they sharp and straight?
- Optional – display a test pattern or standard clinical mammogram and check that its appearance has not changed significantly.
- Keep a record of all checks, note any problems and take action to get them corrected.

2.2 Monthly test of reporting monitors

The test uses the TG18-QC or SMPTE test patterns shown in Figures 1 and 2.[4] Refer to the supplier or local physicist for advice on how to display these.

Method

- Check that the room brightness is as recommended‡, with no glare from other monitors, light boxes or windows.
- Clean the monitors (follow the supplier's instructions).
- Display the TG18-QC or SMPTE pattern on each reporting monitor in turn.
- Examine the image carefully under working conditions, and check that:
  - there are no significant reflections on the monitor
  - borders are completely visible
  - lines are straight
  - the active display area is centred on the screen
  - the 5% square is visible within the larger 0% square (area A)
  - the 95% square is visible within the larger 100% square (area B)
  - each grey scale step from 0% to 100% can be distinguished from the adjacent squares (see dotted arrows)
  - the text on the pattern is sharp and in focus
  - the vertical and horizontal lines in the high contrast line pair images at the centre and corners of the pattern are all distinguishable.
- Record the results for each monitor.

‡ Ambient light should be less than 10 lux for primary display devices.

Remedial level

If the system fails any of the above checks then take action to correct the problem.

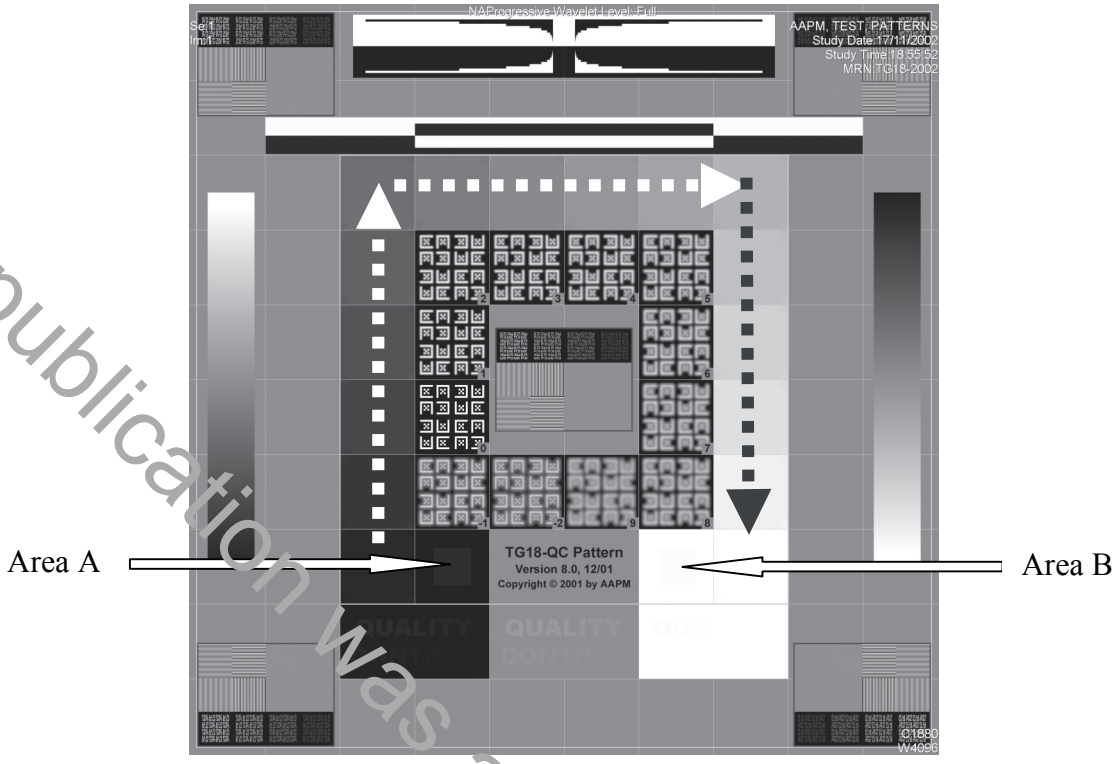


Figure 1 TG18-QC test pattern.

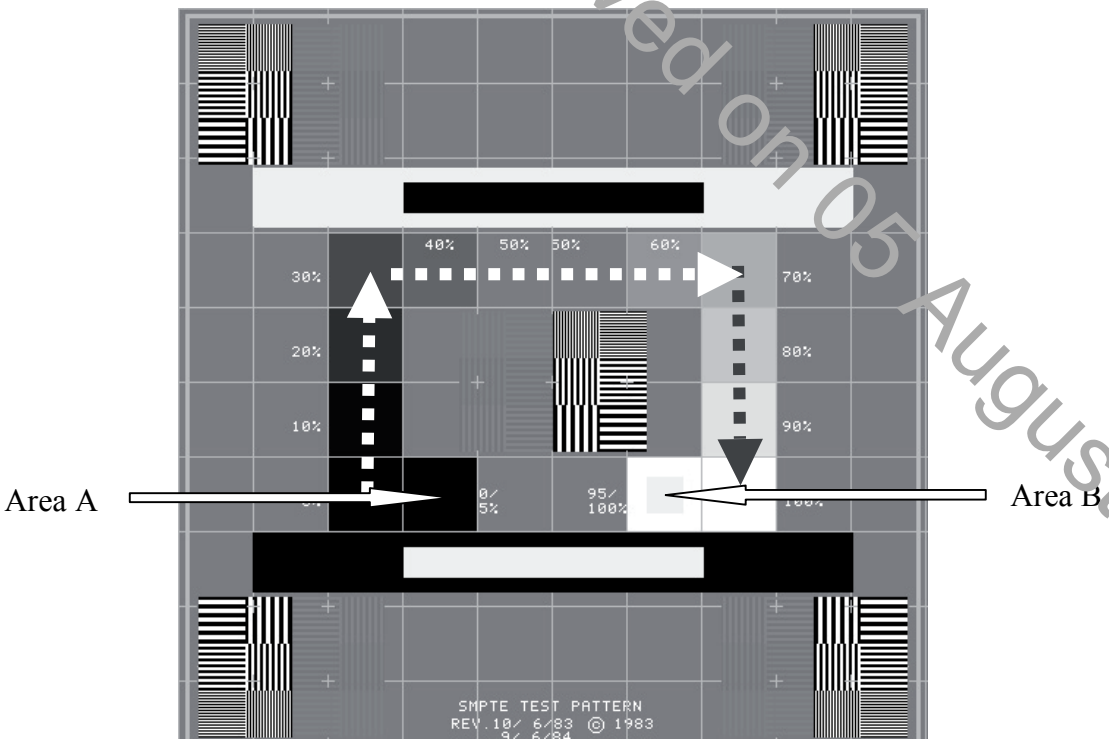


Figure 2 SMPTE test pattern.

3. SYSTEM CHECKS WITH PERSPEX BLOCKS

These tests will detect changes in the performance of the x-ray set or the image receptor. Full size Perspex blocks are preferable for these tests so that the uniformity of the whole field of view can be checked. See Appendix 2 for details of test object design.

For Fuji CR systems, use the TEST/CONTRAST read program and change the EDR mode to Semi-X 2 before reading the image plate.

3.1 Daily system check

Method

- Position test object on unit (see Appendix 2) – alternatively, a plain Perspex block can be used for this test.
- Compress to 100 N (10 kg).
- Expose using clinical settings.
- Record post exposure factors (kV, target/filter, mAs).
- Record system-dependent indicator of dose to detector (eg mean pixel value, exposure index, S value).
- Inspect image for artefacts and variations in the noise pattern using a narrow window setting (high contrast) (see Appendix 1 for a discussion on the type of artefacts seen with different systems).

If region of interest (ROI) facility is available

- Draw ROI as shown in Figure 3 and record the mean (M) and standard deviation (SD) of the pixel value.
- Divide M by SD to calculate the signal-to-noise ratio (SNR).

$$SNR = \frac{M}{SD}$$ (see Appendix 3 for example of the calculation)

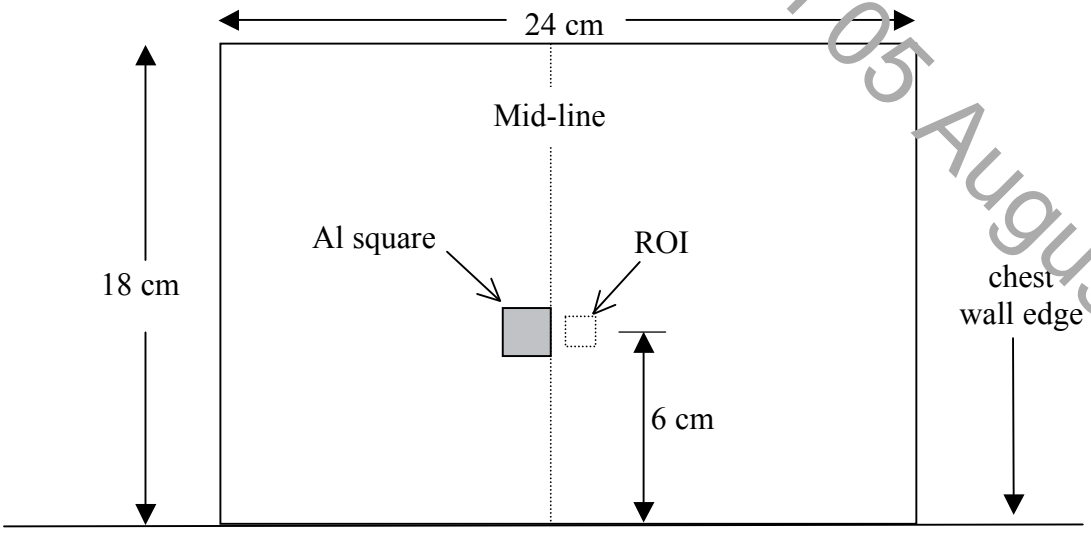


Figure 3 ROI for SNR measurement (if plain Perspex is used for this test, the aluminium square is not present and the ROI can be positioned on the mid-line if preferred, but care needs to be taken to ensure consistent positioning of the ROI from day to day).

Remedial levels

mAs	baseline ± 10% (provided kV and filter are the same as for the baseline measurement)
Detector dose indicator	baseline ± 10%
SNR	baseline ± 20%

If any of the levels are exceeded then take action to correct the problem.

3.2 Weekly check of contrast-to-noise ratio (CNR)

If region of interest (ROI) facility is available

Method

- Use the image of the test object from the daily test (see 3.1).
- Draw two ROIs as shown in Figure 4.
- Record the mean (M1) and standard deviation (SD) of the pixel value in ROI 1.
- Record the mean (M2) of the pixel value in ROI 2.
- Subtract M2 from M1 and divide by SD to calculate the signal-to-noise ratio (CNR):

$$\text{CNR} = \frac{\text{M1} - \text{M2}}{\text{SD}}$$ (see Appendix 3 for example of the calculation)

Remedial level

CNR	baseline ± 20%

If this level is exceeded then take action to correct the problem.

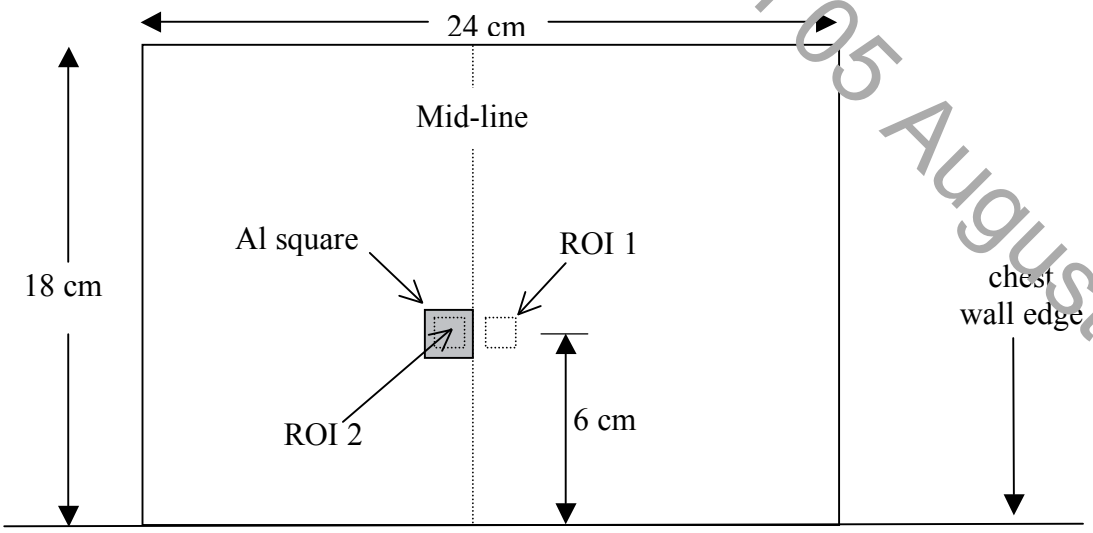


Figure 4 ROIs for CNR measurement.

3.3 Weekly uniformity check

Uniformity should be visually checked on a weekly basis using the image of the test object or plain Perspex from the daily test. By setting a narrow grey scale window areas of non-uniformity will be seen. Magnify or zoom the image electronically and inspect it in a systematic fashion to look for artefacts such as faulty clusters of pixels or areas of unusually low noise (where the background mottle appears blurred or smoother than other areas of the image). This is particularly important for some DR systems.

If region of interest (ROI) facility is available

Method

- Draw ROIs as shown in Figure 5 (DR) or Figure 6 (CR).
- Record the mean pixel value (Mcentre) in the central ROI.
- Record the mean pixel values in the other ROIs and find the one that is most different from Mcentre – call this Medge.
- Calculate the maximum percentage deviation from the central value as follows:

$$\text{MaxDev} = \frac{\text{Mcentre} - \text{Medge}}{\text{Mcentre}} \times 100$$

Refer also to the European protocol which provides details of weekly flat field checks for CR and DR systems (pages 128 and 129, section 2b.2.2.3.1 and 2b.2.2.3.3).

Remedial level

> 10% maximum deviation from the value at centre.

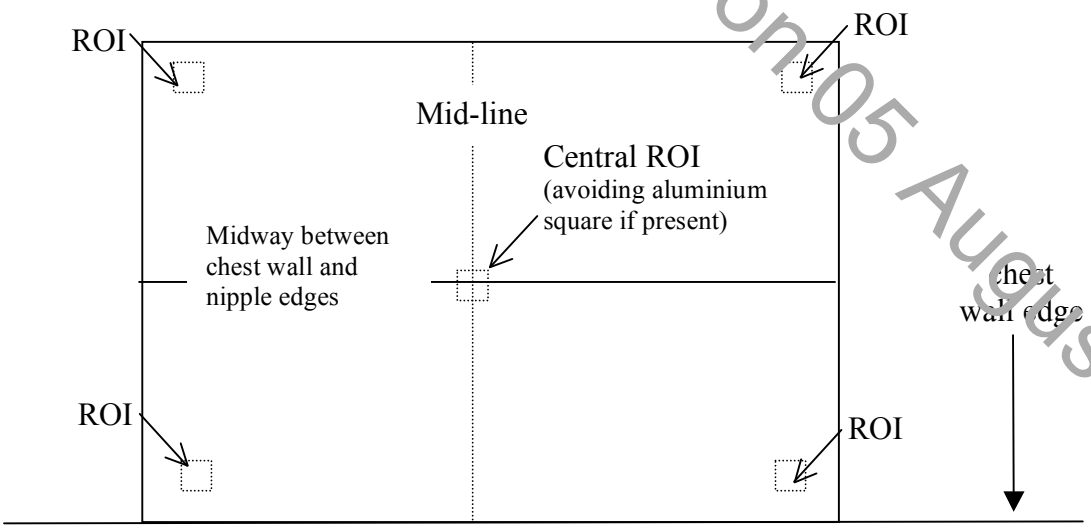


Figure 5 ROIs for uniformity check on DR system.

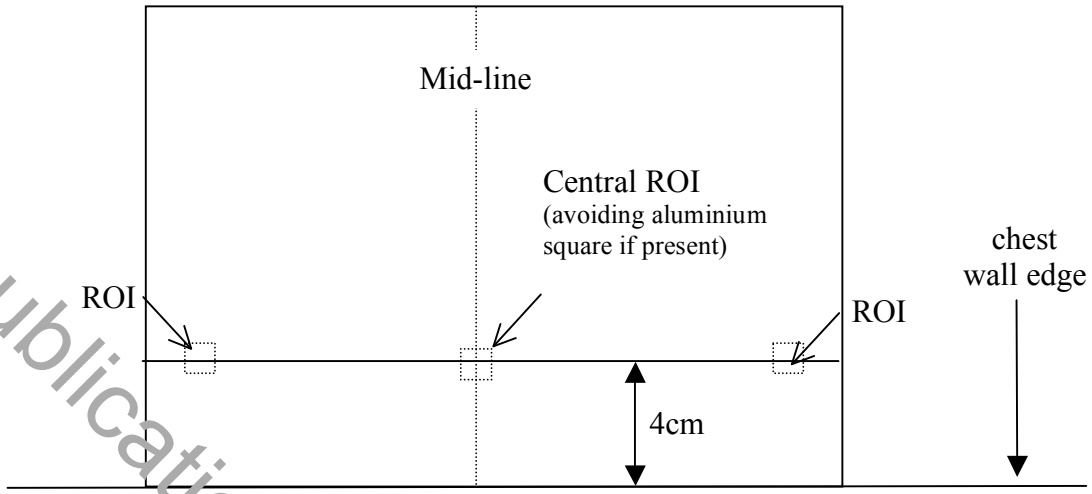


Figure 6 ROIs for uniformity check on CR system.

3.4 Monthly AEC thickness check

Method

- Position 2 cm, 4/4.5 cm and 6/7 cm Perspex blocks in turn on unit.
- Compress to 100 N (10 kg).
- Expose using clinical settings.
- Record post exposure factors (kV, target/filter, mAs).
- Record system-dependent indicator of dose to detector (eg mean pixel value, exposure index, S value).
- Inspect image for artefacts and variations in the noise pattern using a narrow window setting (high contrast) – see Appendix 1.

If region of interest (ROI) facility is available

- Measure SNR and compare with baseline values (see 3.1).
- Measure CNR and compare with baseline values (see 3.2).

Remedial levels

Detector dose indicator	baseline for that thickness ± 10%
SNR	baseline for that thickness ± 20%
CNR	baseline for that thickness ± 20%

No disturbing artefacts should be visible.
If any of the levels are exceeded then take action to correct the problem.

4. WEEKLY IMAGE QUALITY TESTS

Special test objects for routine checks of digital mammography systems are under development and may be recommended in the future. Pending the availability of such test objects, image quality should be tested with one or both of the following:

- TOR(MAM) test object on 3 cm Perspex. Use exposure factors typical of those used clinically, under AEC control if available. Since this test object has features similar to a breast, a clinical image processing algorithm should be used.
- TOR(MAS) test object on 4 cm Perspex. Use exposure factors typical of those used clinically, under AEC control if available. Since this test object contains 'non breast-like' features, the image should preferably be unprocessed (consult the manufacturer).

For Fuji CR systems, use the TEST/CONTRAST read program and a SEMI-X2 read mode for TOR(MAS) test object.

Method
- Examine each image in the format used for clinical reporting (soft copy reporting monitor or hard copy).
- Use standard window and level and image processing and view under standard conditions.
- Check by comparison with the baseline image.

For digital systems the TOR(MAM) is preferable to the TOR(MAS). A study undertaken by Pascoal[5] showed that the TOR(MAM) performed better with digital systems.

Remedial level
The image should be scored and compared with the baseline image.

5. DETECTOR FLAT-FIELD CALIBRATION (DR SYSTEMS ONLY)

Some DR detectors may have a non-uniform response (due to variations in sensitivity, faulty pixels etc). Also, there are non-uniformities in the x-ray beam due to the anode heel effect and x-ray beam divergence. Some DR systems correct for these inherent non-uniformities by a process of flat-fielding. Flat-field correction maps are obtained using a standard beam attenuator (usually a Perspex block) for one or more exposure conditions (eg different target/filter combinations and focal spot sizes). Some systems require the user to carry out this flat-fielding process periodically, and it is therefore included here although it is not strictly a QC test. On other systems this is carried out by the service engineer at routine service visits.

Method
- Carry out the flat field calibration according to manufacturer's protocols.
- Record and initial that the procedure has been performed.

6. IMAGE PLATE (IP) CHECKS (CR SYSTEMS ONLY)

6.1 Image plate erasure

Fuji recommends that any cassettes left in the x-ray room, or left un-used for a few days (eg over a weekend) should be erased using the image reader 'secondary erasure' cycle before use, to remove any 'fog' from the IP.

6.2 Image plate cleaning

Under normal environmental conditions, Fuji does not recommend routine cleaning of image plates. If cleaning is required, it should be performed according to the current Fuji protocol.

6.3 Six-monthly image plate matching and artefact check

This procedure should also be carried out on new image plates. Image plates and cassettes should be matched in both their sensitivity (S value per unit exposure) and in the mAs derived under automatic exposure control. Full size Perspex blocks are preferable for these tests so that the whole IP can be checked for artefacts.

Method
Using each IP in turn:

- Conduct primary erasure before starting.
- Place 4 cm thickness of Perspex on the breast support table (if more convenient, other thicknesses such as 4.5 or 5 cm would also be suitable).
- Place IP cassette in the bucky.
- Operate the unit in a fixed kV, automatic mAs mode – select 28 kV (or the kV in normal use), Mo target, Mo filter.
- Make an exposure and record the mAs value.
- Read the IP after a standard delay time (eg 1 minute) – use the TEST/SENSITIVITY read program and set to SEMI-X 2 read mode for this test.
- Record the S value.
- View image with a narrow display window and check for artefacts.
- Repeat for each IP.

Then:

- Calculate the mean (average) mAs value for all IPs.
- Calculate the mean S value for all IPs.

Remedial levels
mAs value mean ± 5%
S value mean ± 10% (this allows for variation due to mAs and variation in IP sensitivity).
Plates showing scratches or marks should be cleaned and the test repeated. Plates with permanent scratches or marks should be removed from service.

7. MONTHLY MECHANICAL SAFETY AND FUNCTION CHECKS

Check the safety and function of the system. It is recommended that a local checklist is drawn up for each system to identify relevant features to be checked (eg items that are safety-critical or areas known to be prone to faults). This should be based on the guidance in NHSBSP Publication 63,[6] plus additional items specific to the local system, for example:

- environmental checks (some digital systems are particularly sensitive to environmental conditions such as temperature and humidity)
- checks relating to the reporting workstation (ergonomics).

Keep a record of all checks, note any problems and take action to get them corrected.

8. ANALYSIS OF REPEAT IMAGES

The need for repeat images is usually reduced with digital systems but a log of repeat examinations still needs to be kept. The design of the PACS/digital system should allow for repeat/reject analysis. These should be flagged and held with the patient records.

Relevant data should still be collected and input on the breast screening IT system (NBSS). Guidance on collecting, monitoring and reporting repeat examinations (NHSBSP Good Practice Guide No 4, Version 2[7]) should be followed.

The NHSBSP minimum standard for repeat examinations for film screen mammography is < 3% of total examinations: this may need to be reduced for digital mammography.

9. PRINTER CHECKS

The printer is set up on installation when the engineer should ensure that the hard copy matches the soft copy image. Hard copy quality can be checked subjectively by using a standard mammography test object, such as TORMAM.

9.1 Daily printer checks using test pattern

Printer checks should be carried out using standard viewing conditions each day that the printer is used. Print the TG18-QC or SMPTE test pattern (see section 2.2) or the manufacturer supplied test pattern and perform the following checks:

- *Geometrical distortion* – check image is printed without geometrical distortion; borders should be completely visible and straight lines should be straight.
- *Contrast visibility* – in the TG18-QC or SMPTE test pattern, the 5% and 95% squares should be clearly visible.
- *Printer artefacts* – check test pattern for printer artefacts (see Appendix 1); no disturbing artefacts should be visible.
- If a densitometer is available, measure densities and compare with baseline values.

9.2 Printer checks following software upgrade

After software changes or an upgrade, it may be advisable to print both a test pattern and a clinical image to confirm that the hard copy remains similar to the soft copy display.

10. FILM DIGITISERS

The desirable features for film digitisers for mammography images are:

- 50 micron square digital sampling
- optical density range of 0 to 4.0
- grey scale sampling of 12 bit or greater
- predictive orientation labelling that assigns the view to an image.

Digitised image quality should be checked using the TOR(MAM) as with the printer testing.

11. IMAGE ARCHIVES – MOBILE UNITS

Data held on hard drives on mobiles must be secure. This means that the drive needs to be removable or password protected. It is therefore important that a written protocol is developed which covers the safe transfer of images from digital imaging systems placed on mobiles onto the diagnostic workstation or PACS.

12. SMALL FIELD DIGITAL MAMMOGRAPHY SYSTEMS

The medical physics service should perform tests on small field digital systems (including Faxitrons) according to NHSBSP Report 01/09[8] on a six-monthly basis and whenever a new digital detector is installed. These include tests of the detector, the display monitor and the hard copy system as per the tests for full field systems. It is recommended that local protocols should be developed for more frequent testing by mammographers in conjunction with the medical physics service. Such protocols should include tests of:

1 AEC performance (eg record pixel value and mAs for exposure of Perspex block)
2 uniformity and artefacts (eg inspect image of Perspex block)
3 contrast (eg between different thicknesses of Perspex).

REFERENCES

1. European protocol for the quality control of the physical and technical aspects of mammography screening. Part B: Digital mammography. In: *European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis*, 4th edition. Luxembourg: European Commission, 2006.
2. *Commissioning and Routine Testing of Full Field Digital Mammography Systems*. NHS Cancer Screening Programmes, 2006 (NHSBSP Equipment Report 0604, Version 2, available at www.cancerscreening.nhs.uk).
3. *Evaluation of the Fuji Profect Computerised Radiography System*. NHS Cancer Screening Programmes, 2006 (NHSBSP Equipment Report 0605).
4. *Assessment of Display Performance for Medical Imaging Systems*. American Association of Physicists in Medicine (AAPM). Online report 03, 2005 (available at www.aapm.org/pubs/reports/OR_03.pdf).
5. Pascoal A. *European Radiology*, 2006, Supplement 1 to Vol. 16; 255.
6. *Quality Assurance Guidelines for Mammography Including Radiographic Quality Control*. NHS Cancer Screening Programmes, 2006 (NHSBSP Publication No 63).
7. *Collecting, Monitoring and Reporting Repeat Examinations*. NHS Cancer Screening Programmes, 2006 (NHSBSP Good Practice Guide No 4, Version 2).
8. *Commissioning and Routine Testing of Small Field Digital Mammography Systems*. NHS Cancer Screening Programmes, 2001 (NHSBSP Occasional Report 01/09, being revised).

APPENDIX 1: EXAMPLES OF ARTEFACTS

Inspect an image of a uniform test object on a monitor – adjust the window width (WW) to about 10% of the window level (WL) and use magnification if required. To determine whether an artefact arises from the detector or display, rotate or pan it – if the artefact moves with the image it arises from the detector, if it stays in the same place it arises from the monitor.

Detector artefacts – DR systems

- Faulty individual pixels, clusters of pixels or lines of pixels – may be always black, always white, or randomly fluctuating. May or may not disappear after 'flat fielding'. Significance depends on how many pixels are involved and where they are located.
- In scanning-type DR systems, faulty pixels may give rise to linear artefacts perpendicular to the scan direction.
- Loss of resolution (blurring) in one or both directions, in one part of the detector or all over – may be seen as a subtle change in the background noise pattern, the image will appear smoother (less noisy) where it is blurred.

Detector artefacts – CR systems

- Dust on the image plates shows as white dots.
- Scratches/cracks on the image plate show as white lines.
- Dirt in the reader can cause a fine white line perpendicular to the chest wall (ie in the direction that the IP moves through the reader). The same line will be seen with all IPs.
- Roller marks are sometimes seen where the image plate has been damaged during scanning. This may also cause a straight white line perpendicular to the chest wall – but only on one IP.

Monitor artefacts – cathode ray tube (CRT)

- Distortion, possibly due to interference from other electrical devices.
- Note that some monitors have one or more fine horizontal black lines – these are part of the monitor's calibration system and are NOT artefacts.

Monitor artefacts – flat panel display (FPD)

- Faulty pixels.

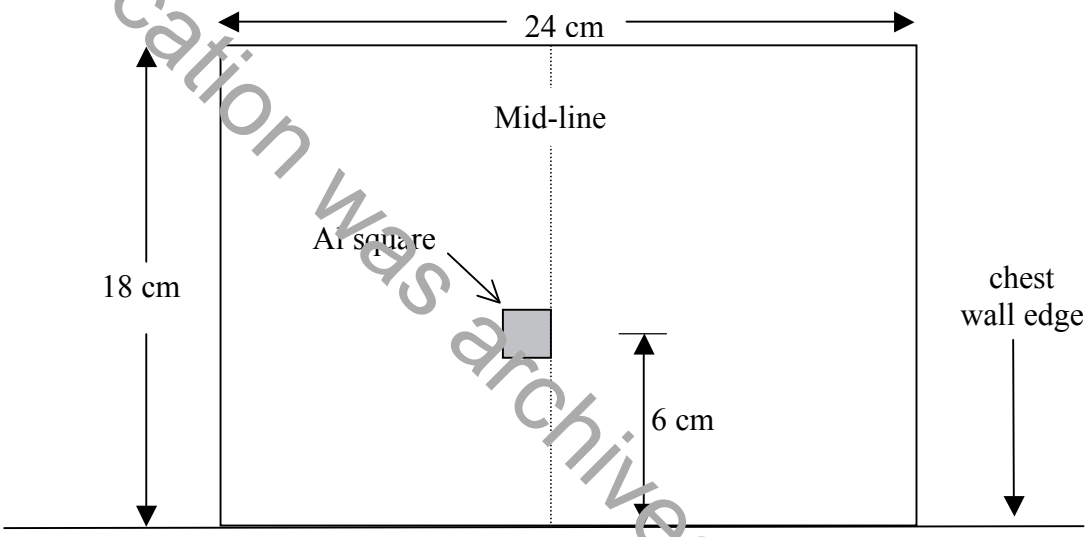
Printer artefacts

If artefact is only seen on hard copy, then it is caused by the printer.

- banding and streaking
- fine line in direction of film travel
- pick off.

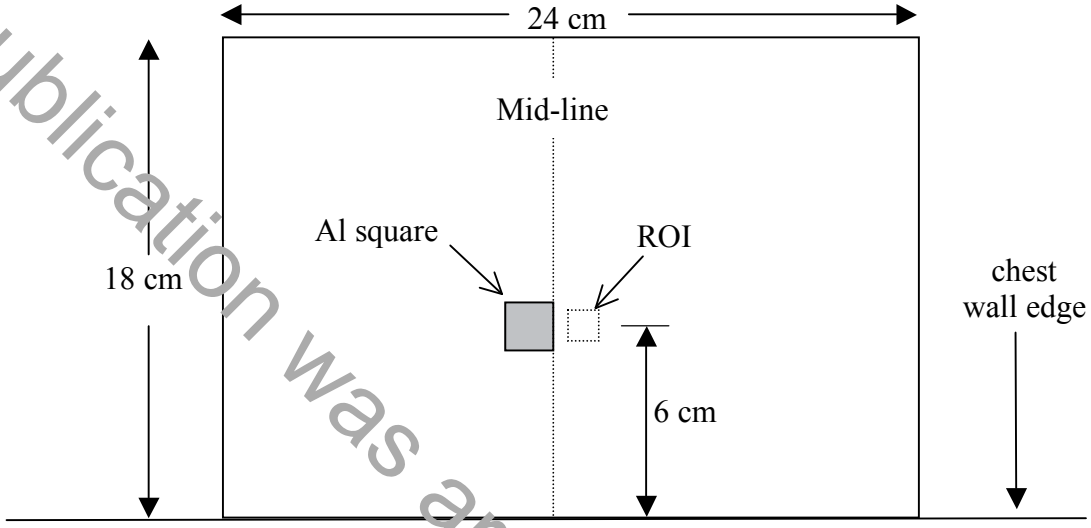
APPENDIX 2: DESIGN OF TEST OBJECT

Perspex block 4.5 cm thick with 0.2 mm aluminium foil to provide contrast. The aluminium should be a square approximately 2 cm × 2 cm with one edge on the mid-line and its centre 6 cm from the chest wall edge. It needs to be fixed to prevent movement. The height of the aluminium above the breast platform is not critical so it can be sandwiched between Perspex layers. Glue or tape should not be used as they will show up and distort the measurements.



APPENDIX 3: EXAMPLES OF SNR AND CNR CALCULATIONS

SNR example



Baseline value of SNR is 50 for this example
20% of 50 is 10
Lower remedial level = 50 – 10 = 40
Upper remedial level = 50 + 10 = 60

Measurement 1:
Mean pixel value in ROI = M = 397.1
Standard deviation of pixel values in ROI = SD = 8.1

$$\text{SNR} = \frac{\text{M}}{\text{SD}} = \frac{397.1}{8.1} = 49.0$$

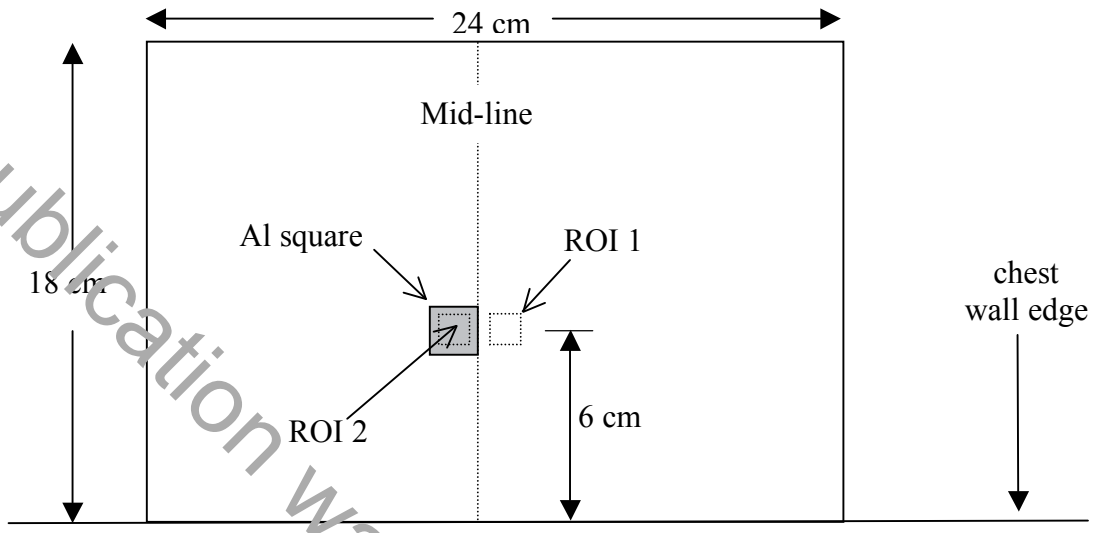
This is between the lower and upper remedial levels, so this measurement PASSES the test.

Measurement 2:
Mean pixel value in ROI = M = 405.2
Standard deviation of pixels values in ROI = SD = 6.3

$$\text{SNR} = \frac{\text{M}}{\text{SD}} = \frac{405.2}{6.3} = 64.3$$

This is above the upper remedial level, so this measurement FAILS the test.

CNR example



Baseline value of CNR is 7.7 for this example
20% of 7.7 is 1.5
Lower remedial level = 7.7 – 1.5 = 6.2
Upper remedial level = 7.7 + 1.5 = 9.2

Measurement 1:
Mean pixel value in ROI 1 (Perspex) = M1 = 386.7
Standard deviation of pixel values in ROI 1 = SD = 7.5
Mean pixel value in ROI 2 (Perspex plus aluminium) = M2 = 328.3

$$\text{CNR} = \frac{\text{M1} - \text{M2}}{\text{SD}} = \frac{386.7 - 328.3}{7.5} = \frac{58.4}{7.5} = 7.8$$

This is between the lower and upper remedial levels, so this measurement PASSES the test.

Measurement 2:
Mean pixel value in ROI 1 (Perspex) = M1 = 386.7
Standard deviation of pixel values in ROI 1 = SD = 7.5
Mean pixel value in ROI 2 (Perspex plus aluminium) = M2 = 341.2

$$\text{CNR} = \frac{\text{M1} - \text{M2}}{\text{SD}} = \frac{386.7 - 341.2}{7.5} = \frac{45.5}{7.5} = 6.1$$

This is below the lower remedial level, so this measurement FAILS the test.