Department of Health
PUBLIC HEALTH SERVICES - RADIATION PROTECTION UNIT

Tasmanian Government

Recommended Quality Assurance Programme for X-ray Apparatus used in Diagnostic Imaging

This technical guide has been produced for radiation specialists, if you require this information in a different format, please contact Radiation Protection on (03) 6166 7256 or radiation.protection@health.tas.gov.au

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Summary of Quality Assurance Requirements

This document provides recommendations to carry out the minimum quality assurance tests and performance criteria of X-ray equipment (fixed and mobile) used for diagnostic imaging in Tasmania. These tests are meant to be relatively simple and take minimal amount of time to perform, making them ideal tests to be performed by radiographers or imaging technologists. More rigorous testing will still need to be carried out by accredited testers as required under Regulation 6 of the Radiation Protection Regulations 2016.

The nature of the testing required will depend on the type of radiographic equipment. Computed Radiography (CR) systems differ in the fundamental image acquisition and processing techniques from Digital Radiography (DR) systems. If unsure about the type of x-ray system you have, consult the user manual or seek manufacturer advice.

The majority of these tests are adapted from the RANZCR document *General X-ray QA and QC Guideline* [1] and the AAPM document *Ongoing Quality Control in Digital Radiography* [3].

Table 1- Summary of Quality Assurance Requirements

Test	Frequency[1]	Criteria
Detector calibration	Daily/ as required	Pass/Fail according to manufacturers protocol
Image plate erasure (CR only)	Weekly/ as required	N/A
Workstation image display	Reporting monitors - Monthly Operator monitors – Quarterly	See Section 3
Mechanical inspection	Quarterly	All mechanical functions operating correctly
Alignment: x-ray to light field/ detector	Quarterly	X-ray to light field (CR and wireless DR detectors): ±1% of SID X-ray to detector (integrated DR detectors): ±2% of SID
Consistency of Exposure Index (EI)	Quartely	EI within ±10% of baseline value
Image uniformity and artefact evaluation	Quarterly	Images uniform and artefact-free
Automatic Exposure Control (AEC) consistency	Quarterly	Post-exposure mAs within ±20% of baseline values
Reject image analyis	Annually or Quarterly	Adult imaging: 6% - 10% Paediatric imaging: 3% - 7%

[1] Where the frequency of the test is daily, this refers to each day the scanner is in use.

1. Detector calibration

Each manufacturer will have a detector calibration procedure that is prescribed to be performed regularly to ensure detector uniformity and stability. This will usually be done daily but the manufacturer may recommend a different frequency of calibration. It is recommended to follow the manufacturer's calibration protocol and any complications or failures should be escalated to service personnel [1].

2. Image plate erasure (CR systems only)

CR imaging plates are sensitive to scattered and naturally occurring sources of radiation and will store energy from these sources if left unused for long periods of time. A "primary" erasure procedure should be performed on all CR imaging plates on a weekly basis.

This frequency is based on the assumption that unused cassettes are stored in such a way that they will not receive a significant unintended exposure. If this is not the case, imaging plate erasure should be performed more frequently [1].

3. Image display quality

Background

This test is mandatory for radiologists reporting monitors, and for general x-ray operator monitors. This test may require a degree of radiologist cooperation. This test may be affected by user bias and so the test should be performed by the same person every time.

The test pattern contains:

- 18 incremental grayscale patches at the top with low-contrast bar patterns - to assess luminance response[2] and uniformity.
- Three large grayscale patches (black, mid-grey and white) - to assess maximum and minimum luminance and luminance uniformity.
- A continuous grayscale gradient at the bottom - used to assess luminance calibration errors and other artefacts.
- High-contrast bar patterns in the bottom right corner - used for qualitative spatial resolution measurements [2].

Equipment

- TG270-s QC Quality Control Test Pattern, from the AAPM report No. 270 [6] (see figure 1).
- TG-18 QC Quality Control Test Pattern, from the AAPM report No. 18.

Procedure

- Ensure the ambient light conditions are similar to those used for reviewing or reporting images.
- The window width and window level should be set using the full dynamic range of the display (eg. window width 4096, window level 2048) [1].
- View the test pattern on the radiologist reporting monitor or x-ray operators monitor.

[2] Luminance refers to the intensity of visible light emitted from the surface of a display. Luminance response refers to the change in luminance per change in grayscale value [4].

Analysis and performance criteria

- Review the three rows of small grayscale patches. The low-contrast bar patterns must be visible in at least 12 of the grayscale patches.
- Zoom and pan the three large grayscale patches across the display. These should be uniformly visible at all areas of the display (ie. no changes in brightness or contrast as they are moved across the display).

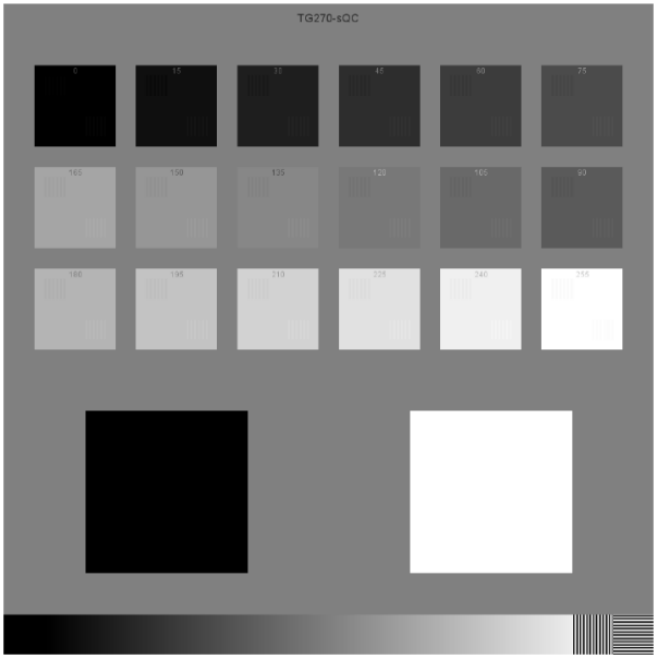

Figure 1: TG270-sQC test pattern for quality control of x-ray workstation displays and printed images. From reference 2.

- The grayscale gradient at the bottom should be displayed as a continuous change in grayscale values. There should be no obvious artefacts relating to incorrect display of grayscale values.
- The high-contrast bar patterns at the bottom right-hand corner should show alternating black and white bars one pixel wide in the horizontal and vertical directions.

Corrective action

If the required detail (low and high contrast bar patterns) are not visible in the image, or individual grey levels are not distinguishable, this may be due to a number of issues:

- ambient lighting conditions not ideal
- image window level and window width need adjusting
- monitor brightness and contrast need adjusting

If problems persist, contact the manufacturer of the monitor for remedial action.

4. Mechanical inspection

Background

A general mechanical inspection of the x-ray unit must be carried out at least every three months to ensure that there are no hazardous, inoperative, out of alignment or improperly operating components.

The service engineer may perform additional checks during servicing (for example, CR plate sensitivity matching). All service reports should be kept along with the site QC records [1].

Procedure

Perform an inspection of the system to ensure safe and optimal operation, using the checklist below [1].

- Check that all cables are free from kinks or knots. Cables should not be frayed or underneath any heavy equipment
- Verify that interlocks and breaks are working correctly
- Ensure that the table, x-ray tube and bucky move smoothly
- Ensure that control panel switches, indicator lights and meters are working properly
- Ensure that the field light is working, has adequate intensity under imaging conditions and collimator is free from dust
- Ensure that current technique charts are displayed near the control panel
- Ensure that there are no oil leaks around the x-ray tube and generator, and that these are free of dust
- Ensure that CR imaging plates are clean and free of artefacts (CR only)
- On the reporting workstation, display a recent clinical image and verify that the displayed time, date and facility identification are correct
- Check that the x-ray tube and generator model and serial numbers are clearly marked and readable (if labels are inaccessible, serial numbers must be displayed elsewhere)
- Visually inspect all personal protective devices (eg. lead aprons, thyroid and gonad shields) for shielding integrity. More thorough testing may be done by performing a test exposure of the device.
- Confirm that the operator's view of the patient from the control window is not obstructed by notices/charts
- Ensure the radiation warning sign on the door is intact and that the room warning lights are working (not applicable to mobile units)
- Ensure that cassette location /auto-collimation and locks are working (not applicable to mobile units)
- Check that centering and Source-to-Image Distance (SID) detents are working correctly. Verify the accuracy of the distance displayed on the collimator (not applicable to mobile units)

After each inspection, the following must be recorded:

- Date of inspection
- Inspection results
- Model and serial number of equipment
- Person performing test

Corrective action

Issues directly impacting the safety of patient and/or staff must be resolved as soon as possible.

5. Alignment: x-ray to light field/detector

Background

This test is performed to ensure accurate collimation and full coverage of image receptor while avoiding unnecessary radiation exposure of patients. This test should be performed on all x-ray units [1].

Procedure

CR and wireless DR detectors

These steps are to be followed for x-ray systems that use a CR cassette or a wireless DR detector [1].

- Ensure x-ray tube and table are level.
- Place CR cassette or wireless DR detector on table top.
- Set a source-to-detector distance of 100cm.
- Dim the room lights so that you can clearly see the edges of the light field.
- Collimate to an area greater than 10cm x 10cm – the exact area is not important as long as it is within the CR cassette or wireless DR detector.
- Use coins to mark the edges of the light field. It is good practice to place a coin within and outside the light field (see figure 2). Use an additional coin to mark the anode side.

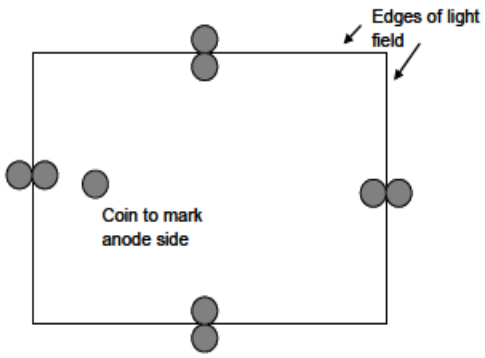

Figure 2: Coin placement to mark edges of light field and anode side. From [1].

- Make an exposure using 60 kV and 5 mAs.
- Open up the collimators fully and make an exposure using 60 kV and 1 mAs
- Readout the CR/DR image. Measure the difference between the x-ray field and the edge of the coin (light field).
- Repeat for broad and fine focus (if available).
- *Note that if the x-ray field is greater than the light filed, this is a positive difference.*
- Record the measurements. A helpful table for recording measurements is Record Sheet 5.2.a from the RANZCR *General X-ray QA and QC Guideline* [1].

Integrated DR detectors

These steps are to be followed for x-ray systems where the detector is built into the bucky. Markings on the top of the bucky show the position of the detector [1].

- Ensure x-ray tube and table are level.
- Set a source to detector distance of 100cm.
- Set auto-collimation.
- Dim the room lights so you can clearly see the edges of the light field. Visually confirm that the light field coincides with the markings on the bucky.
- Switch the room lights on. Align coins with the edges of the markings on the bucky. Use an additional coin to mark the anode side.
- Make an exposure using 60 kV and 5 mAs.
- Measure the difference between the edge of the image and the edge of the coin (light field).
- Repeat for broad and fine focus (if available).
- *Note that if the imaged filed is greater than the edges of the markings, this is a positive difference.*
- Record the measurements. A helpful table for recording measurements is Record Sheet 5.2.b from the RANZCR *General X-ray QA and QC Guideline* [1].

Performance Criteria

CR and wireless DR detectors

- X-ray field to light field alignment must be within ±1% of SID (For example, a maximum difference of 1cm at 1m)

Integrated DR detectors

- X-ray field to detector boundary alignment must be within 2% of SID. X-ray field should extend to all edges of the detector (ie. there should be no white bands around the edge of the image).

Corrective action

Any alignment outside of the stated tolerances shall be investigated as to the cause and discussed with the service engineer.

6. Consistency of Exposure Index

Background

This test is performed to ensure that the Exposure Index (EI) remains approximately constant under given exposure conditions [1].

This test requires you to set a baseline. This is done by performing the test on three separate occasions, separated by at least an hour.

If the results are consistent

- Set the average value as your baseline. Make a note of the day you set the baseline. All future results are compared to this value.

If results are not consistent

- Repeat the test checking that you have followed the correct procedure and used identical exposure conditions.

Following a major upgrade or repair, it may be necessary to set a new baseline value. Follow the steps outlined above and note the date the new baseline value was set and the reason for the change. A new baseline should not be set simply because the test fails, unless an investigation of the reason for the failure indicates that this is justified.

Procedure

Computed Radiography (CR)

A designated CR test cassette (freshly erased) and CR reader must be assigned for this test – this ensures consistency of measurement conditions. It is preferable to assign a cassette which is in clinical use as this will enable any deterioration due to wear and tear to be detected. Excessive deterioration of CR plates may indicate that plates are due for replacement. This test should be performed on all x-ray units [1].

In departments with multiple CR readers, it is considered good practice to repeat the test for all CR readers using one designated x-ray unit to make the exposures (there is no need to test all combinations of x-ray units and CR readers).

- Place the CR cassette on the imaging table.
- Set the focus-to-table distance to 110cm and centre the x-ray beam on the CR cassette.
- Ensure collimator position covers the full area of the CR imaging plate.
- Attach a 1mm copper sheet (or filters/attenuator supplied by the manufacturer) to the tube collimator, ensuring the beam is fully intercepted.
- Make a manual exposure using 70 kV and 4 mAs.
- Process the imaging plate using a consistent image processing algorithm (eg. L-spine).
- Record the EI (Note: according to the manufacturer, the EI may be given a different name eg. EXI or S Number).
- A helpful table for recording results is Record Sheet 5.3.a from the *General X-ray QA and QC Guideline* [1].

Digital Radiography (DR)

- If using a wireless DR detector, place this on the imaging table.
- Set the focus-to-table distance to 110cm and centre the x-ray beam on the detector.
- Ensure collimator position covers the full area of the detector.
- Attach a 1mm copper sheet (or filters/attenuator supplied by the manufacturer) to the tube collimator, ensuring the beam is fully intercepted.
- Make a manual exposure using 70 kV and 4 mAs.
- Use a consistent image processing algorithm (eg. L-spine).
- Record the EI (Note: according to the manufacturer, the EI may be given a different name eg. EXI or S Number).
- A helpful table for recording results is Record Sheet 5.3.a from the *General X-ray QA and QC Guideline* [1].

Performance Criteria

- Exposure Index should be within ±10% of the baseline value.

Corrective action

If the change in Exposure Index over consecutive periods follows a trend (eg. a continual increase or decrease in value), discuss the results with the service engineer.

7. Image uniformity and artefact evaluation

Background

This test is performed to ensure that images are uniform and free of artefacts. It is also used to ensure that the flat-field correction for DR receptors is working correctly.

Procedure

- Use the image acquired for the Consistency of Exposure Index test. Visually inspect the image for non-uniformity and artefacts. Note that CR images will suffer from the anode-heel effect.
- A helpful table for recording results is Record Sheet 5.4.a from the *General X-ray QA and QC Guideline* [1].

Performance Criteria

- The image should appear uniform and artefact-free.

Corrective Action

If artefacts are seen, they could be due to the monitor, the detector, x-ray beam non-uniformity or the copper sheet.

- If the artefact remains in the same place when the image is rotated or panned, it is due to the monitor. If the artefact moves with the image, it is due to the detector, x-ray beam or the copper sheet.
- The test may be repeated with the copper sheet rotated. If the artefact moves, it may be attributed to the copper sheet (dust, scratches or thickness non-uniformity). If the artefact remains in the same place, it is likely to be due to the detector or x-ray beam.
- Clean the equipment and repeat the test. If artefacts still appear, contact the service engineer of the equipment.

8. Automatic Exposure Control (AEC) Consistency

Background

This test is performed to ensure that the Automatic Exposure Control (AEC) operation remains stable over time. This should be checked using table and vertical buckies and by choosing examinations which encompass a range of AEC chambers.

This test requires you to set baseline values for mAs and Exposure Index (EI) for each examination. Follow the instructions for setting baseline values for the Consistency of EI test.

Procedure

- Select up to three frequently performed clinical examinations which are carried out using AEC. These should cover table and vertical buckies and a range of AEC chambers.
- Place designated CR test cassette/wireless digital detector in bucky (if applicable).
- Set the source-to-detector distance that would be used clinically and centre the x-ray beam to the centre of the bucky and the detector.
- Ensure collimator position covers the full area of the AEC chambers.
- Attach a 1mm copper sheet(or filters/attenuator supplied by the manufacturer) to the tube collimator, ensuring the beam is fully intercepted.
- Select the clinically relevant kVp and make an exposure using AEC
- Record the post-exposure mAs value and EI (Note: according to the manufacturer, the EI may be given a different name eg. EXI or S Number).
- A helpful table for recording results is Record Sheet 5.5.a from the *General X-ray QA and QC Guideline* [1].
- Repeat for all selected examinations

Performance Criteria

- Post-exposure mAs must be within ±20% of baseline values

Corrective Action

If post-exposure mAs is outside of the state tolerance or if the change in EI over consecutive periods follows a trend (eg. a continual increase or decrease in values), discuss the results with the service engineer.

9. Image Reject/Repeat Analysis

Background

Rejected and repeated images represent unnecessary radiation exposure of patients. They also result in inefficiencies in the imaging process owing to wasted time and resources [3]. Rejected and repeated images could be due to a number of causes, including but not limited to:

- Positioning
    - Rotation
    - Anatomy cut-off
    - Incorrect projection
    - Incorrect marker
- Exposure error
    - Overexposure
    - Underexposure
- Grid error
    - Cut-off
    - Decentering
    - No grid
    - Grid lines
- Artefact
    - Detector
    - Foreign object (jewellery, clothing, etc.)
    - Contrast media
    - Table/support/x-ray tube
- Patient motion
- System error
- Study cancelled

An analysis of the rate of rejected/repeated images in the department should be undertaken at least annually or ideally every 3 months. The result of this analysis may be communicated to the relevant quality control or radiation safety committee. This may lead to a review of the patient set-up or imaging protocol.

Procedure

The simplest method for reject/repeat image analysis is to divide the total number of rejected and/or repeated images for the analysis period and divide by the total number of images acquired for the same period:

$$Reject/repeat\ image\ rate\ (\%) = \frac{Total\ number\ of\ rejected\ and/or\ repeated\ images}{Total\ number\ of\ images\ acquired} \times 100\%$$

The reject/repeat images rate may be stratified by staff type, examination (eg. PA chest) and equipment or room. This would allow more accurate identification of the reason for rejected or repeated images and remedial action to take. For example, the reject/repeat imaging rate for trainee radiographers may be higher than for senior radiographers. This may indicate that more training is required. Information

necessary for reject/repeat image analysis may be obtained directly from the imaging modality or from the PACS.

Performance Criteria

The optimal image reject/repeat rate will vary between practices, being dependent on factors such as staff experience and difficulty of the examination.

Investigation and possible corrective action should be carried out if rejection rate is more than 10% for adult imaging and 7% for paediatric imaging. A lower limit for investigation may be set at 6% for adult imaging and 3% for paediatric imaging.

Achievable target should be less than 8% for adult imaging and 5% for paediatric imaging.

Corrective Action

The action to be taken will depend on the reasons for abnormally high or low repeat imaging rates. Abnormally high repeat imaging rates may indicate the need for retraining or equipment servicing. On the other hand, abnormally low repeat imaging rates can indicate poor compliance with the repeat analysis program or acceptance of poor quality images. In this case, a sample of images that have been accepted shall be reviewed to determine the level of image quality.

If abnormally high or low repeat imaging rates are found, the reason(s) for this and the corrective action taken must be recorded.

10. Record keeping

The results of all regular QA testing must be recorded either in writing or electronically. The records for the most recent three months must be available for inspection upon request.

In addition to the regular QC tests, records of patient dose metrics for each scan region and examination description, must be kept, including:

- Entrance Surface Dose (*ESD*) or Entrance Surface Air Kerma (*ESAK*) in mGy
- Dose-Area Product, *DAP* in mGy.cm^2
  Exposure Index(EI) for DR detectors.

Australian Diagnostic Reference Levels (DRLs) have not yet been developed for computed or digital radiography. However, practices may develop their own reference levels from a sample of examinations (minimum 10) and use this in an internal dose audit. Dose audits from other countries may also be used to establish reference levels for new or existing practices. One such audit is *Doses to Patients from Radiographic and Fluoroscopic X-ray Imaging Procedures in the UK – 2010 Review* [4], which is freely available on the internet.

Current Australian National Diagnostic Reference Level(DRL) can be found from the ARPANSA web page: www.arpansa.gov.au/research-and-expertise/surveys/national-diagnostic-reference-level-service/current-australian-drls/nm

References

[1] The Royal Australian and New Zealand College of Radiologists, *General X-ray QA and QC Guideline*, Version 1 (2013)

[2] American Association of Physicists in Medicine, *Display Quality Assurance,* The Report of AAPM Task Group 270 (2017)

[3] American Association of Physicists in Medicine, *Ongoing Quality Control in Digital Radiography*, The Report of AAPM Imaging Physics Committee Task Group 151 (2015)

[4] D Hart, MC Hillier and PC Shrimpton, *Doses to Patients from Radiographic and Fluoroscopic X-ray Imaging Procedures in the UK – 2010 Review,* Health Protection Agency, Centre for Radiation, Chemical and Environmental Hazards (2012)