

NRL
National Radiation Laboratory

Guidelines for Quality Assurance in Radiation Protection for Diagnostic X-Ray Facilities: Large X-Ray Facilities

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**GUIDELINES FOR QUALITY ASSURANCE IN
RADIATION PROTECTION
FOR DIAGNOSTIC X-RAY FACILITIES:
LARGE X-RAY FACILITIES**

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ABSTRACT

The Code of safe practice for the use of x-rays in medical diagnosis (NRL C5¹) requires that each x-ray facility has an appropriate quality assurance (QA) programme in radiation protection. The objective of the quality assurance programme is to ensure accurate diagnosis and to ensure that doses are kept as low as reasonably achievable. In addition the quality assurance programme should ensure compliance with NRL C5¹ at all times. This requires an in-house system of regular checks and procedures.

These guidelines are intended to assist x-ray facilities to comply with the NRL C5 requirement, by outlining the features considered to be appropriate for a QA programme. The concepts involved in QA programmes are described, and details are given of the types of tests to be performed. An indication of QA equipment required is given, and suggested test frequencies are outlined.

1 INTRODUCTION

For the purposes of these guidelines, a large x-ray facility is defined as having at least one of the following (in addition to general radiography rooms):

- *More than one fluoroscopy room*
- *More than one film processor*
- *A mammography machine*
- *A digital fluoroscopy system*
- *A CT scanner*

The use of ionizing radiation in New Zealand is controlled by the Radiation Protection Act (1965). Licences under this Act may be granted for a number of purposes, including medical diagnosis. All licences for the use of x-rays for medical diagnosis include a condition that the requirements of *the Code of safe practice for the use of x-rays in medical diagnosis (NRL C5¹)* are met. Among the requirements of *NRL C5* are a quality assurance programme in radiation protection.

The objective of the quality assurance programme is to ensure accurate diagnosis and to ensure that doses are kept as low as reasonably achievable. In addition the quality assurance programme should ensure compliance with *NRL C5¹* at all times. This requires an in-house system of regular checks and procedures as detailed in these guidelines.

In addition, and completely independent from the quality assurance programme, each facility is required to have a complete radiation protection survey performed at least once every four years. For those facilities with image intensifier systems, a CT scanner or mammography machine, these must be done every two years. The radiation protection survey is intended to focus on radiation safety and checks for compliance with the appropriate requirements of *NRL C5*. As part of this, the radiation protection survey acts as an external independent audit of the quality assurance programme. The tests and measurements made during a radiation protection survey cannot be considered to be part of the quality assurance programme. The radiation protection survey is currently performed free of charge to the facility by NRL staff. A qualified health physicist is also permitted to do radiation protection surveys, provided that the protocol and equipment used are acceptable to NRL.

A comprehensive radiation protection quality assurance programme requiring some test equipment is appropriate for large facilities (as defined above). The general requirements for a quality assurance programme in radiation protection, as given in *NRL C5* and of relevance to large x-ray facilities, are summarised as follows: (Note that **should** and **shall** have specified meanings within *NRL C5*, but not elsewhere in these guidelines.)

- 1 The principal licensee for any facility that uses x-rays for medical diagnosis **shall** ensure that a suitable programme of quality assurance (with respect to radiation protection), is instituted and maintained.

- 2 The programme **shall** ensure as a primary goal, accurate and timely diagnosis. As secondary goals the programme **shall** ensure minimisation of radiation exposure and risk and of discomfort and cost to patient and community. These secondary goals **shall** always be balanced against the primary goal.
- 3 The programme **shall** comprise such routine checks and procedures as are required to give reasonable confidence in the continuing compliance with this Code of Practice. The programme **shall** be approved by a qualified health physicist, to ensure that the quality control procedures are sufficient to ensure compliance with this Code. The programme **shall** include quality control of x-ray film processing facilities. Note: A programme is not to be confused with a radiation protection survey.
- 4 There **shall** be a well-defined responsibility and reporting structure, appropriate to the size and scope of the facility. Each staff member **shall** routinely review the results of checks for which they are responsible and report summary results to their superior. Any anomalous check **shall** be reported immediately. Each staff member **shall** be responsible for the maintenance of the programme by any personnel under his/her control.
- 5 Procedures **should** be standardised and set down in protocols or local rules (a quality assurance manual) wherever possible.
- 6 All equipment **shall** be checked at suitable regular intervals to ensure it is operating within suitable tolerances of accuracy and consistency. The tests performed and their frequency **shall** be approved by a qualified health physicist. All measurements and maintenance **shall** be recorded in an equipment log. As well as routine tests any faults or breakdowns **shall** be logged and reported to superiors.
- 7 Acceptance tests **shall** be performed on all new equipment to
 - (a) ensure that it meets the manufacturer's specifications;
 - (b) ensure that it complies with this Code;
 - (c) establish baseline data for subsequent quality assurance.
- 8 Control charts **shall** be established for all parameters measured. Control limits **shall** be established for all parameters. If a measured value of any parameter exceeds a control limit, action **shall** be taken to correct the parameter.
- 9 A retake analysis **shall** be performed at regular intervals to monitor the effectiveness of the programme.
- 10 The frequency with which a particular parameter is tested **should** be determined by both the likelihood and the consequences of an error beyond the acceptable tolerances.

- 11 The programme **should** conform to the procedures and tolerances given in *NCRP report 99* (National Council on Radiation Protection and Measurements, 1988)² or *Assurance of quality in the diagnostic x-ray department*³.
- 12 The programme for CT facilities **should** include the recommendations given in *IEC 1223-2-6*⁴.

It should be noted that a properly implemented QA programme will result in significant benefits. These will include reduced costs due to reduced repeat rates, increased accuracy of diagnosis, reduced equipment down-time and increased morale and job satisfaction for staff^{5,6,7,8}.

2 IMPORTANT CONCEPTS FOR QA PROGRAMMES

Acceptance testing

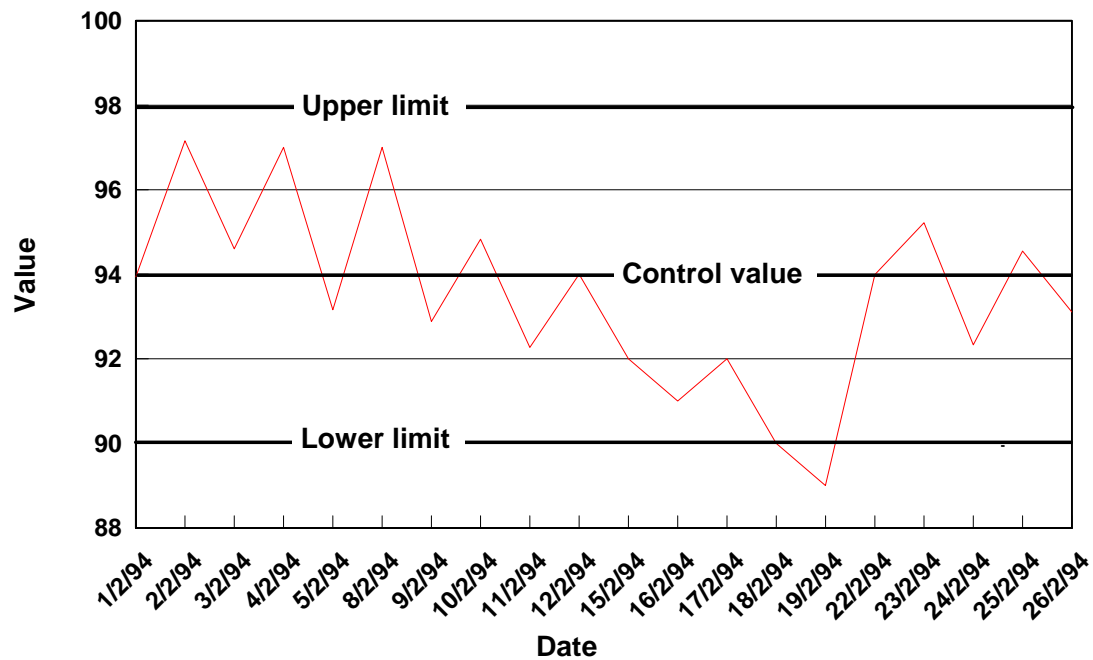
Whenever a new piece of equipment is installed, acceptance tests should be performed. This may take a few days for complex equipment⁹. The purposes of the acceptance tests are three-fold.

- First it is important to check that the equipment meets the specifications set out in the purchase contract with the supplier. (For this reason it is important that purchase contracts clearly state the requirements for the equipment.)
- Second, the acceptance tests establish baseline values for the parameters that are to be monitored during the QA programme.
- Third, the acceptance tests will show whether the machine complies with the requirements of *NRL C5*, at installation.

Control charts

Once baseline values for the QA parameters have been established a system has to be set up to ensure that these parameters are maintained to within acceptable tolerances. Control charts are an essential part of the system⁷. A control chart is a plot of the measured parameter with time. A typical control chart is shown in figure 1. The control chart has three horizontal lines, giving the desired value of the parameter and the allowable limits. The desired value is determined from the acceptance tests, or from tests made at the start of the QA programme (first ensuring that the equipment is performing correctly). Allowable limits may come from many sources, such as published protocols, regulatory requirements, or the effects on other parameters that may be affected.

Figure 1. An example of a control chart



Each time a measurement is made the result is plotted on the control chart. Whenever a parameter goes outside the control limit, the measurement should be repeated. If no mistake has been made and the parameter is still out of control, then immediate action must be taken to correct the parameter. If this is not done, then the entire QA programme is a waste of time. It is sometimes possible to observe trends in the data that suggest that a parameter will become out of control in the near future (as in the example above). It is advisable to take corrective action at this stage, rather than to wait until the parameter is out of control.

Reject/retake analysis

A reject is defined as any film rejected by the department as scrap for any reason^{7,10,11}. A retake is a patient film that has to be retaken because of an error. Retakes are only a part of all rejected films. Rejects may be due to three main causes.

- 1 Retakes
- 2 Films wasted due to other causes, such as fogging, equipment breakdowns, etc
- 3 Trial films to establish exposure settings that are not viewed by a radiologist as part of the diagnosis. (For example, some films in a tomographic series.)

Analysis of the rejected films over a period of time will enable causes of rejects to be determined and improvements to be made. The more detailed the analysis performed, then the more information will be obtained. The simplest approach is just to collect all rejects and to express the rate as a percentage of all films used. This gives a baseline value for the reject rate for future reference.

This may be done continually, or for shorter periods on a regular basis. The minimum period should be at least six weeks. The first two weeks' results are generally discarded to eliminate the "startup effect".

If the rejects are sorted by work area or room, then corrective action may be directed to where it is most needed.

If they are categorised by reason for rejection, then effort may be directed at reducing the most common errors. Further subdivision by anatomical region may help determine which examinations are causing the most difficulty. Finally, analysis by staff member may be used to direct training to staff with difficulties in particular areas.

Equipment logs

Each x-ray room should have an equipment log⁷. To be recorded in this log are the dates and details of all QA corrective action, breakdowns and routine servicing. This should include, if possible, an estimate of the downtime.

Responsibility for the QA programme

In every department, a particular person should be assigned the overall responsibility for the QA programme⁷. Clearly, this person should be familiar with all the x-ray equipment and with the principles of radiology quality assurance. Where appropriate, it is well worthwhile to establish a committee to oversee the programme. This committee should include representatives of all the areas involved, MRTs, radiologists, medical physicists, service personnel and management. (Note that *NRL C5* requires that the QA programme be approved by a qualified health physicist or directly by NRL.)

The QA manual

The procedures involved for the entire QA programme must be recorded in a manual¹². This is to ensure that all tests are carried out in a consistent and reproducible manner. If not, then parameters may appear to be out of control, where in fact the change was due to differences in the measurement technique. Clearly the manual should be readily available to all personnel concerned.

Staff training

At the start of the QA programme, staff will need to be given sufficient training to carry out the QA procedures for which they are responsible. Periodic refresher training will be required also during the programme to keep staff up to date with development of the programme and to provide feedback on its effectiveness and acceptability to staff.

3 SPECIFIC REQUIREMENTS FOR LARGE FACILITIES

All equipment and accessories need to be included in the QA programme, although the frequencies may be very different for each item. This chapter describes the parameters that need to be tested for each item of equipment and gives the suggested frequency of tests. Where appropriate, recommendations for

test equipment are given. Specific step-by-step descriptions and tolerance values of all the tests are not given. Such detailed information may be found in many of the publications listed in the bibliography. In many cases the tolerances required may be determined from the requirements of *NRL C5*. In any case the qualified health physicist may choose appropriate frequencies where specific guidance is not given elsewhere.

Note that QA measurement instruments or systems are available from a number of manufacturers. These generally combine kVp, dose and time measurement capabilities, and in some cases are computer interfaced and have QA reporting software. The cost of such instrumentation is small compared to the cost of the x-ray equipment and is well justified.

It is essential that all test equipment be calibrated on a regular basis. NRL may be consulted if necessary for details of equipment calibration.

3.1 Automatic film processors

Of all equipment in x-ray departments, film processors cause the greatest proportion of rejects^{7,10,13,14}. Consequently, QA of film processors will give the greatest improvement in reject rate. Therefore, film processor QA should be the first priority of any QA programme and will probably form a major share of the work of the programme. Processor QA must be performed daily to be fully effective.

The principles of processor QA are simple and well described in many documents^{2,3,15,16,17,18,19,20}. The first step is to ensure that the processor is operating correctly at the start of the programme, usually by cleaning, replacing chemicals and checking the replenishment rates and developer temperature. A light sensitometer should then be used daily to expose test films that are processed without delay^{20,21}. Measurements of the densities with a densitometer are then made to give base+fog, mid density (speed) and contrast indexes which are plotted on the control charts. Systems that automate much of this procedure are commercially available. (Note that special measures are required for modern low-crossover films, or films with different emulsion speeds on each side.)

If any parameter is found to be out of control, corrective action must be taken. The appropriate action may often be determined by consulting trouble-shooting charts. (Charts are generally supplied by x-ray film or film processor manufacturers.) These show the action to be taken, for example, if contrast and speed are down but fog is up. Control charts and test films should be stored for future reference, and a log book should be kept for each processor.

Two further items are important for processor QA. The first is that the test films must always come from the same box of film, to eliminate variations between film batches. Second, when the box is almost empty, a new box should be started in parallel, to check for differences. It may be necessary to adjust the control chart values if the new batch is slightly different or even to reject the batch of film, if it is too far out of control. (It has happened!)

3.2 X-ray generators

Peak kilovoltage

The most important parameter to monitor is the peak kilovoltage, since small drifts in the kVp can significantly alter the film density. Large x-ray facilities should have some form of kVp instrument. Either an inferential digital kVp meter or an Ardran and Crooks type penetrometer^{22,23} may be used. Alternatively, a qualified health physicist may be contracted to make kVp and other measurements requiring expensive equipment.

Depending on the age and stability of the generator, kVp measurements should be made at least annually, and in addition, after servicing, and if a drift in kVp is suspected for any reason.

Linearity with mA/mAs

Good linearity will ensure that the same film blackening can be obtained for the same mAs, regardless of the mA/time combination used. To assess linearity a dosimeter is required⁷, although results of reduced accuracy may be obtained using film²⁴. Depending on the age and stability of the generator, linearity measurements should be made at least annually, after servicing, and if unpredictable results are being achieved with changes in mA.

Reproducibility of mAs

It is clearly important that the film blackening should always be the same for a given machine setting. Good reproducibility is therefore essential for consistent radiography. Reproducibility may be assessed using a dosimeter⁷, although results of reduced accuracy may be obtained using film²⁴. The standard deviation should not exceed 5% of the mean dose¹.

Exposure timer accuracy and reproducibility

These contribute to mAs linearity and reproducibility. Many instruments are available with time measurement capabilities, while a spinning top may be used for one- and two-pulse machines^{7,17}.

Waveform monitoring

Increasing numbers of test devices are capable of displaying the x-ray output and/or the kVp waveform. It is strongly recommended that the waveform be checked at a range of generator settings whenever the full set of tests is done²⁵.

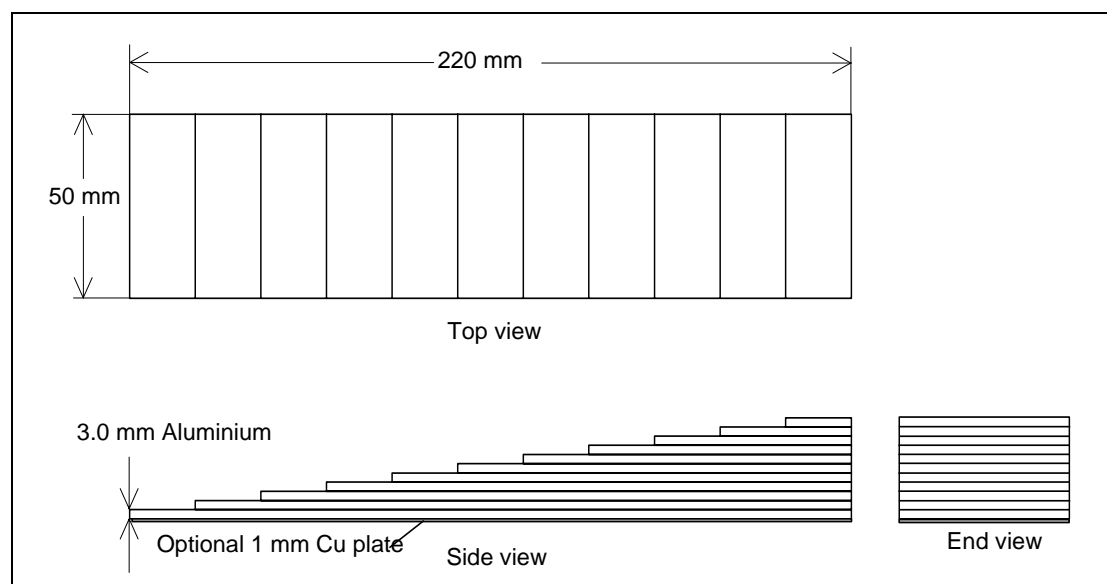
Regular x-ray generator tests

All of the above tests for kVp, linearity, reproducibility and exposure timer require the use of test equipment and in many cases will require the services of a qualified health physicist²⁶. Therefore, in order to provide a quick check on the entire radiographic system that is easily performed by radiography staff, it is recommended that a stepwedge exposure test be performed periodically. Although such a test is not likely to be able to provide a diagnosis for any equipment problems, it will show whether there have been any changes since the previous test. The stepwedge exposure frequency should be as determined by a qualified health physicist, depending on the age and stability of the equipment.

Weekly tests may be appropriate for older machines, while monthly to quarterly may be more appropriate for modern equipment.

The design of a suitable stepwedge is given in figure 2. This may easily be constructed from layers of 2.5 mm aluminium. (NRL may be able to supply suitable wedges should there be sufficient demand.) This should be radiographed using an mAs for which the image of the thickest part of the wedge is just discernible above the base+fog density. For single phase machines with 2.5 to 3.0 mm total filtration, 80 kVp should be used, while for three-phase and medium frequency machines 70 kVp should be used. An 18 x 24 or 24 x 30 cm cassette may be used. (If a higher kVp is typically used for a particular room, then a 1 mm Cu plate added to the wedge may be appropriate.) The cassette, each side of the wedge, must be shielded with lead or lead rubber. The kVp, mAs and FFD required for this should be recorded in the QA manual and should be used for all subsequent tests, unless there is some change to the x-ray machine or film processing. In this case a new mAs should be determined for subsequent tests. The first image should be kept in a safe place and used as a reference image to compare with the subsequent images. While the images may be assessed by eye the use of a densitometer is preferable.

Figure 2. Design for a stepwedge suitable for QA of x-ray machines



In the event that the image differs markedly from the reference image, then the reason should be sought. If there has been no change in processing conditions, as determined by the daily processor QA, then there could be a fault in the x-ray machine.

3.3 X-ray tubes

Filtration

The filtration must comply with the NRL¹ requirement for greater than 2.5 mm Al equivalent in the primary beam. To measure the total filtration, a set of high purity aluminium filters and a dosimeter are required. The half value layer should be measured at a known kVp and the total filtration inferred from an appropriate

chart²⁷. It may be possible to inspect the tube assembly to establish that filtration complies, by adding up the equivalent filtration of each component, plus any added filtration. Filtration needs to be measured at acceptance testing and then only after servicing or modification to the tube assembly.

Labelling

NRL C5 requires that the focal spot position be marked, to enable radiation protection survey measurements to be made accurately and consistently. A label is also required, giving the specifications of the tube. This should be checked at acceptance testing and after major servicing.

3.4 Automatic exposure controls (AEC)

Significant reductions in the retake rate may be achieved through consistent use of AEC for all exposures²⁸. However, this can only be achieved if the AEC device itself is correctly adjusted and is included in the QA programme. A simple device for streamlining the AEC QA was described recently²⁹. QA involves taking films for various phantom thicknesses, kVp and mA settings, and for each combination of AEC detectors. A measurement protocol appropriate to the type of AEC system should be determined by a qualified health physicist.

3.5 Light beam diaphragms (LBD)

There are four aspects to LBD performance to be considered^{7,17}. These are accuracy, delineation (centring), brightness and edge sharpness. Requirements for these are given in *NRL C5*. LBDs need to be checked regularly as they are prone to being knocked out of alignment. They should be checked at least twice yearly, and more often if found to be necessary. The LBD may be tested using a commercial test tool or the "eight pennies method"¹⁷.

It is important also to check the alignment of the x-ray beam with the grid and the image receptor for wall and table buckys.

3.6 X-ray cassettes

X-ray cassettes must be kept in good condition. They should be cleaned and checked regularly. All cassettes of the same type should be of the same speed. This should be checked periodically^{7,17,24}. Film/screen contact should be checked using a wire mesh or similar test object. Light leaks should be checked for, by processing a film that has been kept in a cassette exposed to light for an hour or more without x-ray exposure. Intensifying screens must be replaced when they are worn out, or if they become damaged.

3.7 X-ray image intensifier systems

General considerations

Image intensifier systems are generally complex, with a number of separate components that all have to be in good condition and correctly adjusted for image quality and patient dose to be acceptable³⁰. The image intensifier insert is one of the few components in diagnostic radiology that has a clearly limited life, and

which deteriorates in a relatively predictable manner during its life. Because of this deterioration, the dose rate to the patient required for satisfactory image quality will increase during the life of the II, to two or even three times the value when new.

A properly budgeted replacement programme for II inserts is essential for all x-ray departments with fluoroscopy equipment. A large department with ten image intensifiers should budget to replace (for example) one or two inserts each year on average.

Regular maintenance and adjustment of all components are essential for all image intensifier systems, while a full assessment by a qualified health physicist should be made at least annually. A full radiation protection survey is required by *NRL C5* at two year intervals.

Maximum entrance surface dose rate

The maximum dose rate permitted by *NRL C5* at the position of the patient's skin is 50 mGy per minute. To test this, a dosimeter is required. For systems with automatic brightness control, sufficient lead (>2 mm) should be placed on the II face to drive the technique factors to maximum. For systems with manual control, the maximum technique factors should be set. This test should be performed at least annually and after servicing. Note that for modern systems it may be more appropriate to use about 5.0 mm of copper to represent the largest patient likely to be examined, to check the maximum dose rate likely to be reached in practice.

Average patient dose rate

Because the performance of the II insert deteriorates with time, the dose to patients should be regularly monitored^{30,31}. At acceptance testing and radiation protection surveys the dose rate for a patient equivalent phantom (see below) should be determined, and the technique factors (kVp, mA, focus-II distance and TV monitor brightness and contrast settings) should be recorded in the QA manual. For systems with automatic brightness control, the phantom should be screened regularly and the technique factors checked. If these have changed significantly, the reason should be sought, and the system serviced if necessary. For manual systems, the technique factors recorded in the QA manual should be set, and the image of the phantom should be checked. If the brightness seems to have changed then again the reason should be sought, and the system serviced if necessary.

Patient equivalent phantom

Each facility must have a patient equivalent phantom to enable QA tests to be made. The actual phantom used is not critical³¹. However, the phantom must be reproducible. The phantom should measure at least 300 x 300 mm. The thickness will depend on the material used. Suitable phantoms could consist of 250 mm of water in a container, 200 mm of perspex, 250 mm of oil tempered hardboard, 2.5 mm of copper or 45 mm of aluminium. Note that "thick" phantoms that are approximately tissue equivalent are preferable in most circumstances, as the exit beam quality and scatter levels are more typical of those that occur in actual examinations.

Automatic brightness control (ABC)

The ABC system is responsible for maintaining constant brightness at the TV monitor, regardless of patient attenuation. ABC systems operate in many different ways, including control of some or all of the kVp, mA and video gain. It is crucial that the ABC system be well maintained and adjusted at all times, as ABC system faults may cause excessive dose rates and/or poor image quality. In the worst case, an ABC fault may cause the generator to run at maximum kVp and mA. The parameter that the ABC system ultimately controls is the II input dose rate. Therefore ABC system performance can be monitored by regular measurement of the II input dose rate. This should be done with a range of phantom thicknesses, at least twice per year^{7,17,30}.

3.7.1 Image intensifiers

II input dose rate

The II input dose rate is a key parameter to monitor, as it gives a guide to the condition of the image intensifier and it can indicate the presence of other problems with the system^{30,32}. *NRL C5* gives limits for the II input dose rate. In general most intensifier systems should give satisfactory image quality at dose rates much lower than the limits. To measure the II input dose rate a relatively sensitive electrometer is required, fitted with a pancake ionization chamber of at least 50 cc volume. The grid (if fitted) should be removed for this test, or alternatively the chamber should be positioned between the grid and the II face. If the grid cannot be removed then an allowance must be made for the grid attenuation, typically 50% for primary beam (no scatter).

If the II input dose rate has changed significantly since the previous tests then adjustments to the system may be required. Any II that is found to require input dose rates greater than the limits in *NRL C5* should be replaced.

Image contrast and resolution

At acceptance testing, a set of measurements should be made using approved II test objects^{32,33}. These tests should be repeated at least annually.

Where approved test objects are not available for routine testing, an image quality QA phantom should be devised³¹. This will set threshold values for contrast and resolution. This should be used regularly, to check that no deterioration in the image quality has occurred.

Conversion factor

The best guide to the condition of an image intensifier is obtained by a measurement of its conversion factor. This requires specialised equipment and generally can only be done by a qualified health physicist or by the manufacturer. For some systems it is not practicable to do it at all. Where the conversion factor can be measured, replacement of the II insert is generally recommended when the conversion factor has reduced to a third of the value when the II was new. The conversion factor should be measured annually where possible.

Where the conversion factor cannot be measured, indirect methods need to be applied to assess the condition of the II insert, as described above³⁰.

Focus

The focus controls for the II should be regularly checked and adjusted if necessary, using a line pair test plate or fine grid. The best compromise between central and peripheral resolution should be achieved^{7,17}.

3.7.2 Fluoroscopic television chains

Generally, television chains have a number of adjustable parameters that all have to be within tolerance for optimum image quality. For example, these parameters may include peak white and black level voltages, blanking circle diameter, II vignetting correction, etc. The adjustments provided and the optimum voltage values depend on the individual manufacturer. Therefore, the manufacturer's test protocols and recommended test frequencies should be adhered to.

Assessment of most of the TV system parameters may be made using a test object placed on the II face³⁰, and a storage oscilloscope with single TV line facility. The measured parameters should be compared to the manufacturer's specifications, although general recommendations that apply to the majority of systems may also be applied³⁰.

Among the most important parameters is the noise produced by the TV system. The peak-to-peak TV camera noise should be less than the quantum noise at normal II input dose rates and should be less than 10% of the peak white voltage.

3.8 Fast film changers

Angiographic film changers require several tests to be made periodically to ensure that the film transport is synchronised to the x-ray exposures, that the film/screen contact is satisfactory and that the screens are clean and in good condition³⁴.

To properly check the film transport and synchronisation, a dual trace oscilloscope should be used³⁴.

Film/screen contact can be tested using a mesh as for conventional x-ray cassettes. The grid should be removed from the film changer for this test.

The intensifying screens should be carefully cleaned and checked for damage.

3.9 Cine systems and small format cameras

The crucial parameter for both cine systems and small format cameras^{35,36} is the dose per frame at the II input face. Generally a dose of 0.1 to 0.2 μGy per frame is recommended for cine depending on the II field size. For small format cameras, the dose for correct operation should be determined at acceptance testing. The dose per frame should be checked using a dosimeter at regular intervals, at least twice per year, and more often for intensively used systems.

For cine systems, jitter of the camera and or projector can be a problem. The Society of Motion Picture and Television Engineers (SMPTE) test films can be used to check for projector jitter. If the projector is found to be OK, and jitter is observed in the clinical films, then the cine camera is at fault³.

The cine camera, spot film camera and cine projector optics should be carefully cleaned regularly, and inspected for deterioration. Any optical elements in poor condition must be replaced.

3.10 Digital subtraction imaging (DSI) systems

Before any quality assurance measurements can be made on DSI systems, the x-ray and image intensifier systems must be tested as described above.

Most measurements on DSI systems require specialised phantoms and test equipment, and should be made by a qualified health physicist^{37,38,39}. The tests should be carried out every three months. A typical series of tests would follow the protocol provided with the DSI test objects supplied by Leeds University³⁷. The discussion below is based on the use of the Leeds test objects.

II input dose per frame

Fundamental to the tests is a measurement of the dose per frame at the entrance surface position of the patient and at the input face of the image intensifier. A sensitive electrometer and a large (>50 cc) pancake chamber are required for the latter measurement. The dose per frame at the patient entrance surface is recorded for comparison purposes. The II input dose per frame is needed to determine that the system is correctly adjusted and that the image intensifier is still in satisfactory condition for DSI requirements.

Operating headroom

It is important for digital subtraction systems, that the dose rate (dose per frame) at the image intensifier input face be set sufficiently low to prevent saturation of the video signal in the brightest parts of the image. If saturation should occur then clinical information may be lost in the subtracted images. Saturation is avoided by setting the dose rate at a level that gives a video signal that is less than the maximum. The percentage that the operating level is set below the maximum is termed the headroom. However, if the headroom is too great, then the actual useable part of the video signal (the dynamic range) will be too small. The automatic dose rate/dose per frame is therefore a compromise between dynamic range and headroom.

The Leeds "jig test object" is designed to measure the headroom for peak sensing systems. It gives a subtracted image of a stepwedge. The headroom is assessed by counting the number of steps of this stepwedge that are visible. As each step corresponds to 4% above the operating video level, the headroom is the number of steps visible, times 4%.

There is now available an analogous Leeds test object designed to be used with average sensing systems.

The jig test object also contains a low contrast square. If this square is not visible, then the electronic noise of the system is excessive.

Dynamic range

A further test of dynamic range is made using the Leeds "quadrant test object". This has four sets of low contrast details. Each set is in a sector of differing x-ray intensity, obtained by different thicknesses of copper filter. The relative x-ray intensities of the four sectors (quadrants) are 100%, 33%, 10% and 3.3%. Clearly, as the x-ray intensity is reduced the details will become more difficult to see. Detectability of the details in each quadrant is therefore a test of the dynamic range.

Contrast-detail performance

The Leeds "contrast-detail test object" is very similar to the NRL CD test object used for conventional IIs, as reported above. However, the contrasts for each detail size are lower, reflecting the greater capability of DSA systems. A contrast-detail assessment should be included in the quarterly tests.

Misregistration

The Leeds "Dalmatian" test object may be used to assess the accuracy of registration of the mask and subtraction images. This has a large number of 11 mm details spaced in a uniform matrix over the test object. The test object remains in place for both the mask and subtraction images and therefore should disappear in the subtracted image. Any misregistration results in halos in the subtracted images.

Monitors and hard copy devices

The viewing monitors and the hard copy film device for DSI need to be checked at least weekly, as drifts in performance can significantly reduce image quality^{40,41}.

3.11 Computed tomography scanners

CT scanners are generally covered by a service contract that includes calibrations and some form of regular preventative maintenance (often monthly). This is essential to ensure satisfactory calibration of the machine at all times. Generally the sorts of tests made are invasive and can only be made by the service agent. However, a maintenance contract does not relieve the facility from the responsibility for regular quality assurance measurements^{42,43}.

At the very least the CT number of air and water and the noise level at the centre of a uniform phantom should be assessed weekly. Regular checks of the modulation of a bar pattern phantom should be done at least monthly (using the ROI standard deviation function) to check the resolution⁴³. The CTDI in air should be measured annually and after major servicing (such as x-ray tube replacement), in order to monitor patient dose levels. The multi format camera and the video display units must be checked regularly, at least weekly^{40,41}.

3.12 Mammography machines

Mammography is the area of radiology requiring the greatest effort in quality assurance. Mammography can only be effective with a comprehensive quality assurance programme⁴⁴. A complete programme for mammography QA would require more extensive description than is appropriate here. Only the types of tests to be performed are outlined here, while the recommended frequencies are included in section 4. There are several excellent published QA programmes^{45,46,47}. It is strongly recommended that all mammography facilities obtain at least one of these publications.

The greatest priority for mammography QA should be the film processor. Careful daily quality control of film processing is a pre-requisite for satisfactory mammography. All of the relevant items for general x-ray machines and automatic exposure controls should also be monitored regularly. These generally need to be monitored more often than in general radiology and to have tighter control limits. In addition, specialist features of mammography should be checked. These include the focal spot size, beam quality, compression device, regular assessments of an imaging phantom, daily exposure of a perspex phantom to check the AEC device, and a regular check on the dose level.

3.13 Tomography machines

The x-ray generator and x-ray tube should be checked in accordance with the recommendations above before tests on the tomographic system are applied. Items to check for tomography are stability, resolution, layer selection and angle of swing^{7,17}. BIR³ give a good explanation of the tests to be used.

Stability is assessed visually by watching the tomographic motion during an exposure from a distance of about 2 m. This should be done without x-ray exposure if possible, or with the LBD closed. (Otherwise the operator should wear a lead apron.) The movement should be continuous, smooth and at a regular speed.

Smoothness of swing may also be tested using a pinhole in a lead sheet to produce an image of the tube movement. The image should be regular and of even density.

Resolution is tested using a wire mesh test object, with a selection of meshes from 1 up to 2 holes mm⁻¹. Resolution should be at least 1.2 mm⁻¹.

Layer thickness and layer height should be assessed using an angulated scale.

These tests should be done at least annually, and more often if found to be necessary.

3.14 Mobile radiographic equipment

The same requirements apply to mobile equipment as to equivalent fixed machines. However, because of the harsher treatment often afforded to mobile

machines, the quality assurance tests may need to be done more frequently⁷. In particular the LBD alignment should be checked often. Additional items to check include the mechanical features, such as tube locks, wheel brakes, safety of electrical cables, etc.

3.15 Mobile image intensifier equipment

Mobile image intensifier systems should meet the same requirements as fixed II systems. However, because of the harsher treatment often afforded to mobile machines, the quality assurance tests may need to be done more frequently. In particular the alignment of the x-ray tube with the II should be regularly checked to ensure that the primary x-ray beam is completely intercepted by the II.

3.16 Grids

Grids should periodically be checked for warping and damage and should be radiographed to check for uniformity¹⁷.

3.17 Protective equipment

Lead aprons and lead gloves should be thoroughly checked at least annually for any signs of wear or damage. If they appear to be suspect, then they should be tested using x-ray film or a fluoroscopy machine.

3.18 Darkrooms

A well laid out darkroom that is clean and free from light leaks is essential for satisfactory radiography.

The entrance should be light tight, either a maze or well-sealed door. Safelights should be the correct colour for the film type being used and should be no more than 25 watts. (Note that "novelty lamps" are not suitable.) A check for light leaks should be made at least annually. A film fog test should also be done at least annually^{1,7,48}.

3.19 Viewboxes

The viewbox(es) should be in an area shielded from direct sunlight or bright artificial light. It should be possible to dim the lighting. The viewbox should be cleaned inside and out at least annually. The fluorescent lamps should be replaced if they become too dim. The lamps should all be the same colour and the same wattage⁴⁹. Inexpensive light meters can be obtained, to simplify QA of viewboxes. *NRL C5¹* gives brightness values for viewboxes. Locally derived tolerances for uniformity should also be applied. Note that the brightness of viewboxes tends to increase by 20 to 30% as they warm up and also note that the brightness of the fluorescent tubes reduces with age.

There is evidence that the colour temperature of viewboxes is important also⁴⁹. This should be checked periodically as appropriate.

3.20 Technique charts

It is essential that all radiographic technique factors are recorded and displayed on a technique chart^{28,50}. This should include the kVp, mA and exposure time to set (or AEC detector, density and speed settings) the cassette type and size to use, the focus to film distance, and any important centring points and angulations. These technique charts must be kept up to date and must be clearly legible.

3.21 Dose measurements

As part of the QA programme, *NRL C5* requires that all x-ray facilities periodically assess the dose to patients for a number of common examinations (skull, chest, thoracic spine, abdomen, lumbar spine and pelvis and the more complex procedures barium enema, barium meal and IVU). Patient dose estimates generally require the assistance of a qualified health physicist or NRL. Three methods may be used for these dose assessments. All three methods rely on the use of organ dose data obtained from computer simulation of x-ray examinations of an average patient^{51,52}.

The simplest method is to calculate the doses from the technique factors used for average patients, using x-ray output calibration data for each x-ray tube. The second method is to use thermoluminescent dosimeters to measure the entrance surface doses for a number of average patients. Finally a dose area product meter can be fitted to the x-ray machine for a number of examinations. This is the most practical method for fluoroscopy examinations.

3.22 Approval of the QA programme

NRL C5 requires that the QA programme be approved by a qualified health physicist. For large x-ray facilities, a programme following the guidelines herein should be satisfactory. However, NRL or a qualified health physicist must give overall approval to the programme and should be consulted concerning any details of the programme that are in doubt. All documentation for the QA programme should be kept in a safe place, so that the details may be checked during NRL radiation protection surveys.

4 AN OUTLINE QA PROGRAMME FOR LARGE FACILITIES

Each x-ray facility is required by *NRL C5* to institute a QA programme in radiation protection that is appropriate to its size and scope. In essence the QA programme involves the implementation of procedures to ensure that all of the items of equipment are tested at the appropriate frequency, and that corrections are made when parameters are found to be outside the permitted tolerance. Besides the actual QA measurements, essential components of the QA programme are acceptance tests and reject/repeat analysis. The programme should be set down in a QA manual. Responsibility for the QA programme should be assigned to one person and where appropriate, should be overseen by a QA committee. These concepts are discussed in section 2 above.

Notes

- It is intended in the programme below that for each category, the tests in the previous category should be included. For example the weekly tests would include all of the daily tests, plus those to be done weekly.
- The frequencies are those typically required for average equipment. The frequencies may be modified in the light of experience, to be more frequent or less frequent as necessary.
- Clearly, it is assumed below that corrective action will be taken immediately, should any tests reveal that QA parameters are out of control.

Equipment

To perform a satisfactory QA programme, each facility should have (or have access to) the following test equipment.

- A light sensitometer, with single/double emulsion and blue/green capability.
- A densitometer.
- A basic QA dosimeter.
- A kVp meter, or kVp penetrometer.
- An inexpensive light meter (Luxmeter).
- A good quality thermometer.
- An aluminium stepwedge.
- A set of aluminium (type 1100) filters.
- Some form of resolution test object or set of meshes.
- Basic II image quality phantom.
- Patient equivalent phantom.
- Specialised phantoms for DSA, CT, mammography, etc as appropriate.
- Some equipment may require specialised test jigs, attachment or imaging objects.

(The total cost of this equipment would be in the range \$10,000 to \$15,000, not including specialised DSA/CT/mammography phantoms.)

Daily tests

For each film processor in the department, a film exposed to a sensitometer should be processed, the densities read and the results posted on the control chart. This test should be done at the same time each day, after the processor has been in use for an hour or so.

The mammography machine AEC should be checked with a standard (40 mm) perspex phantom, and the mAs should be recorded.

Video displays and hard copy devices should be checked.

Weekly tests

A stepwedge should be radiographed for each x-ray tube in the department and the density parameters should be plotted on a control chart. If any measured parameters are found to be out of control, then corrective action must be taken. (This may be done monthly if weekly tests show no variations.)

A mammography QA phantom should be imaged and the details detected should be recorded.

If not done daily, video displays and hard copy devices should be checked.

CT scanners should have the CT numbers of air and water and the noise at the centre of the water phantom measured. The modulation of a bar pattern phantom could also be checked using the ROI software.

For fluoroscopy systems, the patient equivalent phantom should be screened, using a standardised machine setup, and the technique factors noted.

Monthly tests

The intensifying screens should be carefully inspected each month and cleaned if necessary. A reduced cleaning frequency may be possible in the light of experience. They should be cleaned at least every six months.

The mammography machine AEC should be thoroughly tested.

For mobile machines fitted with an LBD, the alignment should be checked. Wall and table buckys should have the beam alignment checked.

A stepwedge radiograph should be produced for all of the x-ray tubes at the facility, if not required weekly. These should be compared to the reference stepwedge for each tube. Any differences should be investigated and corrective action taken if necessary.

Checks of patient dose rate and image contrast and resolution as described above should be made at facilities with image intensifiers.

Quarterly tests

DSA machines should be tested quarterly as described above.

For mammography machines the mean glandular dose should be checked, by comparing the mAs required to image a 40 mm perspex phantom.

For machines fitted with an LBD, the alignment should be checked.

Annual tests

Protective aprons and gloves should be given a careful visual inspection. If suspect, then they should be referred for more careful checking.

The viewbox should be cleaned, including the internal reflectors, and the lamps replaced if they have become dim.

Film/screen contact should be checked using a mesh. Cassettes should be checked for light leaks and damage. The screens should be carefully inspected for scratches, blemishes or other damage. Old or worn out screens should be replaced.

A light-leak and light-fog test should be done in the darkroom.

The technique chart should be checked to ensure that it is up to date.

The films in the reject/retake bin should be sorted by category¹⁰. The number in each category and the total number should be counted. The reject/retake rate should then be calculated as the percentage of all films used. The reject categories with the greatest numbers of films should be investigated to determine whether any improvements can be made.

It is strongly recommended that the peak kilovoltage, total filtration, linearity and reproducibility of the x-ray machine(s) be checked at least annually.

For image intensifier systems the II input, patient and maximum dose rates should be measured. Where possible, the II conversion factor should be measured. Tests with approved II test objects should also be made.

The accuracy of any focus to film readout devices should be estimated

For mammography machines, all parameters should be checked, including compression device and paddles, generator kVp, linearity and reproducibility, focal spot size, AEC device, x-ray cassettes, darkroom and viewbox. In addition the mean glandular dose for an average breast should be checked. The mAs required for the 40 mm perspex phantom should be noted for use as a quarterly test that the mean glandular dose has not changed.

Two-yearly tests

All of the annual tests should be done. In addition a full radiation protection survey should be performed, either by NRL or by a qualified health physicist (approved by NRL). This will include quantitative tests on the x-ray generator(s), image intensifier and any mobile x-ray equipment and will also include assessment of doses to patients.

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