**WHO Chest Radiography in Epidemiological Studies**

**Part C – Quality Control**

**Contents**

Introduction

Objectives

1. Personnel and reviewing results
2. Equipment maintenance
   1. Daily tasks
   2. Weekly tasks
   3. Monthly tasks
   4. Quarterly tasks
   5. 6-monthly tasks
   6. Yearly tasks
   7. As required tasks
3. Monitoring patient doses
   1. Dose reference levels
   2. Exposure indicators
4. Image analysis
   1. Image critique
   2. Image reject analysis
5. Conclusion and additional resources

Acknowledgements

Glossary

References

Appendices

**Introduction**

Quality Control (QC) is activities created to ensure the ongoing monitoring and evaluation of equipment and procedures (1). The collaboration of these activities into an overall management program is known as Quality Assurance (QA) and this ensures that the range of activities work effectively (1).

A QA programme in diagnostic imaging aims to ensure quality during all phases of the service operation, including radiation protection and safety, and that the standard of procedures and the final products are maintained at the highest level (1-4). One aspect of QA programmes focuses on the operation of equipment and is not only recommended by numerous professional bodies, but is a requirement of the European Union amongst many governments (2). It is important to ensure that equipment is not only working properly, but to its optimum level (2). For example, a good QA programme should determine whether the X-ray exposures that are set is what are delivered.

The importance of a QA programme whereby regular QC activities are established will allow for the timely detection of any image quality degradation (2). This can be achieved through quality audits of the safety rules and procedures outlined in Part B – Study Guidelines, and may require education and training of relevant staff. Effective quality control improvements involve taking the following steps (5):

1. Determine the issue and conduct an audit to define its cause. This can be conducted internally by the facility or externally by an independent body.
2. Discuss the problem and decide on solutions
3. Take action to correct the problem. Any action should be reported and documented within a reasonable timeframe, taking into account the cost of proposed corrective actions.
4. Conduct a follow-up audit after an interval to ensure the corrective action is effective and has been maintained

The scope of activities for the X-ray systems used in these guidelines include (6):

1. Routine QC of equipment
2. Other recommended QA systems for X-ray imaging, such as computed radiography (CR), digital radiography (DR) and film printing
3. Radiation protection and radiation monitoring, such as optimization of radiation dose and image quality, with structured reports and the establishment of diagnostic reference levels (DRLs)
4. Clinical image review and image reject analysis

This section of the guidelines includes the recommended QC measures and documentation of these measures throughout a study. The QA programme described in these guidelines is a collaboration of recommended resources for quality management from the Royal Australian and New Zealand College of Radiologists (RANZCR) the World Health Organisation (WHO), the European Commission and the International Atomic Energy Agency (IAEA). Additional resources have been gathered from currently established best practice techniques. The QC measures described outline the adherence to the protocols described in Part B – Study Guidelines in addition to the monitoring of safety practices.

**Objectives**

In the World Health Organization definition of QA as it pertains to diagnostic imaging, it is recognized that high quality images with consistently adequate diagnostic information are produced as a result of an organized effort by the staff operating the facility (2). The emphasis here is on the diagnostic quality and not necessarily the best quality images. Whilst all facility staff should strive towards the best quality images, it should be recognised that an image that is not of best quality but of sufficient diagnostic quality should not be repeated.

These guidelines aim to ensure that a QA programme is developed for researchers and facility staff, with the intent of maintaining a standard of radiographic procedures, allowing for consistently high quality chest X-rays. More specifically, the inclusion of QC in these guidelines will ensure that there are fewer equipment failures, resulting in reduced downtimes and overall costs, that a record and audit trail will exist as proof of these high standards, and that repeat images are kept to a minimum, resulting in less radiation to patients (1).

The development of a QA program will ensure that the radiology equipment can yield the desired information in keeping with any of the site’s applicable country accreditation standards (2). This includes any QC techniques, as well as administrative procedures to verify that these techniques are performed properly, that the results are promptly and accurately evaluated, allowing for any necessary corrective measures to be undertaken (2). The persons responsible for each QC action should be established at the beginning of the program, where that person is sufficiently trained to carry out those actions. Furthermore, the appropriate equipment required for each action should be available, as well as the establishment of the standard of quality.

A summary of the tasks and their frequency from these guidelines is described in Appendix 1, with a checklist provided in Appendix 2. A final list of required equipment outside of standard X-ray equipment within a facility is provided in Appendix 14.

1. **Personnel and reviewing results**

Some QC actions as part of the QA programme will need to be carried out by a regulatory authority or qualified personnel. However, it is recommended that at least one staff member at each facility is identified as the responsible person for ensuring that quality checks are undertaken at specified times. This person should also provide strategies for corrective and preventative action in a timely manner and formulate quality improvement strategies within the department (6).

All QC activities should be recorded so that they are easily identifiable and trends can be easily tracked. These records should be kept alongside the routine service reports provided by the service engineer. The results of QC tests should be made available immediately to both the facility and researchers. Where the results of the QC tests are out of tolerance, corrective action must be decided upon. This may involve the contact of a service engineer, who will determine the urgency of any corrective action. For example, minor intolerances may be able to be addressed at the next routine service, whilst other intolerances may need immediate action.

1. **Equipment Maintenance**

The outcome of good image quality in the acquisition and subsequent processing of a chest X-ray involves optimal performance of many pieces of equipment. Whilst equipment requirements to meet this outcome have been described in Part B – Study Guidelines, it is the essential maintenance through a QA programme that is the basis for good, dose-effective practice (1,7,8).

Equipment maintenance involves conducting QC activities that measure specific technical parameters and their tolerances at regular intervals to monitor equipment function over time and detect any issues that may be contributing to a decrease in optimal performance. Limiting values for these parameters and tolerances on the accuracy of their measurement is required to ensure that good radiographic technique is appropriately applied (7).

These limiting values should not be too liberal, as equipment of moderately poor performance may be seen as being optimal. Neither should the parameters be too tight, as this will result in untenable expectations of performance (5). Furthermore, limiting values should take into account the age of the equipment and the original equipment specifications (5). When a problem is discovered, yet a cause cannot be identified, an engineer should be notified (1).

There are many equipment QC activities that could be implemented as part of a QA programme. However, only those that are deemed pertinent to the optimal performance of equipment are described here. The periodic intervals required throughout this maintenance will vary depending on both the type of equipment and manufacturer recommendations. It is expected that the technical parameters are established at the time of equipment commissioning, or at least verified prior to the commencement of a study (2).

In the purchasing of equipment, arrangements for regular maintenance should be included in the contract and it should be made clear to facility staff which tasks can be carried out by facility staff and which tasks require a service engineer (5). If a warranty for the equipment is to be issued, the time-period and cover of the warranty, as well as the personnel responsibilities will need to be established (1). Equipment servicing and compliance testing schedules should consider the following factors (5):

* The frequency of the servicing and compliance testing
* Who conducts these activities
* How these activities are recorded
* The proximity of servicing personnel to the facility

The recommended QC activities and their frequency for each piece of equipment will vary depending on the vendor and where possible, these recommendations should be followed. However, for ease of implementation, the following described QA programme consists of generic QC activities that are categorized into recommended periodic frequency. It is expected that results of all QC activities are recorded so that ongoing monitoring of equipment and workflow efficiency can take place. Where required, suggested worksheets have also been included as appendices.

* 1. **Daily tasks**

Unless otherwise specified, it is expected that the following daily checks are performed at the beginning of and preferably at the same time of each day.

* + 1. **General checks**

*Facility Cleanliness (5)* – This is not only to maintain a level of professionalism within the facility, but to ensure efficient workflow and minimize the risks of occupational injury. In the X-ray examination room, this includes ensuring clean linen on the examination bed, positioning aids and sponges away in cupboards or on shelves and the floor free of any obstacles and tripping hazards.

For the X-ray control room, the floor should be clear of any tripping hazards, the console clean, with all display fields readable and the line of sight to the patient maintained.

In the darkroom, benches should be tidy and cleaned of any dust that may contribute to film artifact. Any film or chemical storage should be in a safe place and the floors clear of any obstacles.

* + 1. **Automatic Film Processor**

Many issues can occur regularly with an automatic film processor, necessitating the daily checks described below. It is important to be aware of these potential issues during use and inspections. Examples of some of these issues include (1):

* Mechanical failures, for example film jams and film damage
* Electrical failures, for example replenishment pump failures
* Chemical problems, for example incorrect mixing of developer and fixer or blocked replenishment hoses
* Inadequate supply of water or water contamination

Correct maintenance and use of the processor will ensure that there is little downtime and thus higher efficiency and increased cost effectiveness (1).

The procedures described below are adapted from the World Health Organization Quality Assurance Workbook (1). A checklist for these tasks is provided in Appendix 3.

*Before start-up*

1. Remove the crossovers and wash them in warm water. (Note: always wash the developer crossover first to avoid developer contamination)
2. Wipe over the deep rack rollers that are above the solution levels
3. Clean all interior exposed surfaces
4. Check the replenishment hoses for bends or leaks
5. Turn on the water and check that the tank is filling
6. Replace the crossovers and the tank lids

*Start-up*

* 1. After switching the processor on, listen for any abnormal noises or vibrations
  2. Remove the processor lid
  3. Check the replenishment system is working
  4. Replace the processor lid
  5. Feed in one unprocessed 35x43 film, and then inspect it for any artifacts or residual chemicals once processed. This process will also clean any deposits from the rollers. This film is known as the ‘clean-up’ film
  6. Clean the exterior surfaces, especially the feed tray
  7. Wipe over all darkroom surfaces (if applicable)
  8. When the developer temperature has stabilized, check the developer temperature:
     1. Place a thermometer (preferably a digital thermometer, but not a mercury thermometer) into the developer
     2. Once the thermometer reading has stabilized, record the temperature
     3. Check this temperature with the processor readout temperature (if there is one). Otherwise, compare this with the manufacturer guidelines
     4. Plot a graph of temperature vs date, looking for any fluctuations. Anything more than 1-2 degrees’ difference should be investigated as to whether they are caused by aspects such as different testing times or testing before the developer has reached its stable temperature

*Shut-down (at the end of the day)*

* 1. Remove the processor lid
  2. Switch off the processor
  3. Look for any leaks
  4. Inspect and wash the roller-drive cogs and mechanisms
  5. Turn off the wash water (if appropriate)
  6. Wash off any chemical splashes on the interior exposed surfaces and exterior surfaces
  7. Replace the lid leaving it slighty raised to avoid fume build-up
  8. Leave the darkroom door open (if applicable)
  9. Restock chemicals and films
     1. **X-ray Equipment and film**

*X-ray tube warm-up –* This is a series of X-ray exposures that are conducted after the X-ray unit has been switched on. X-ray tubes consist of the internal components suspended in a vacuum to prevent tube “arcing” between the cathode and the anode due to any air that may have leaked into the tube. The purpose of the warm-up procedure is to slowly raise the X-ray tube current and voltage to slowly burn off any of the available oxygen. Overall, this will maintain the life of the X-ray tube.

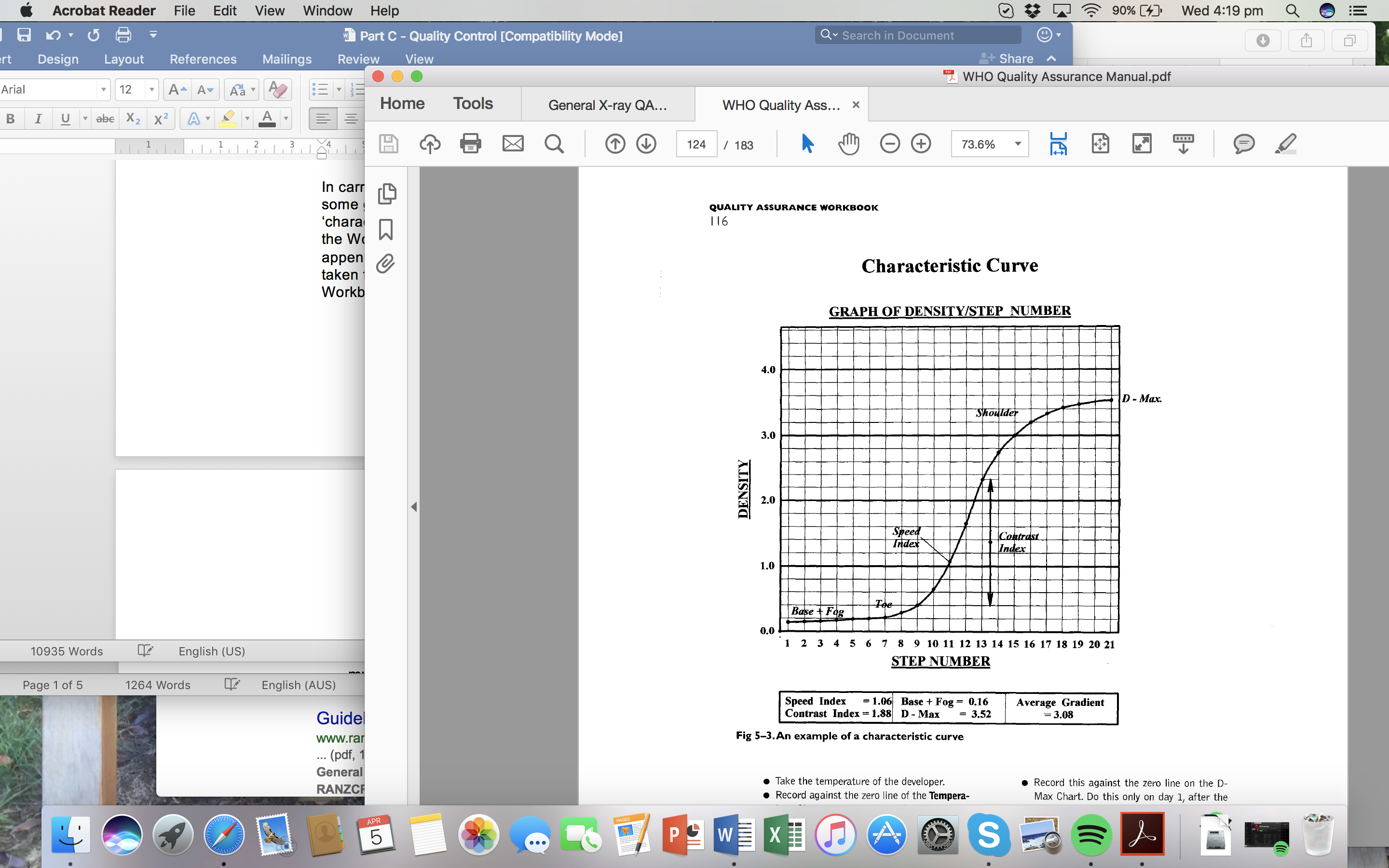
The specific X-ray tube warm-up procedure is strictly manufacturer specific and should be checked with the manufacturer as to which exposures are deemed appropriate.

*X-ray film sensitometry –* Sensitometry is the study and measurement of the relationship between the films, the intensifying screens, the X-ray exposures and the processing of films. In the cases of diagnostic imaging using film, the main interest is in the performance of the processor. This can be achieved by standardizing the exposure, as well as the types of film and screens, leaving the processor performance as the variable (1).

Sensitometry needs to be conducted each day once the processor has reached the correct operating temperature and after the ‘clean-up’ film has been processed. This test should also be carried out at the same time each day, when the developer temperature is tested. For the test procedure, you will need a step-wedge image, which is an image with a number of columns, each of decreasing brightness. Each column is numbered, with the lightest column as number 1. The step-wedge image can be obtained using one of the following methods as outlined in the World Health Organization’s Quality Assurance Workbook (1):

* Method 1 – Using a sensitometer (if accessible)
  + Use a dedicated box of film of the type used for chest imaging
  + Using the sensitometer, select the light colour relevant to the film colour sensitivity (blue or green)
  + Under safelight, insert a sheet of film into the sensitometer until it reaches the backstop
  + Press the cover down and hold until the light or audio signal have stopped
  + Process the film
* Method 2 – Marking an X-ray image of an aluminium step wedge under standard conditions (if an aluminium step wedge is accessible)
  + Place a 18x24cm cassette with a standard film face-up on the X-ray table
  + Place the step wedge on the face of the cassette
  + Use 100cm FFD, place the central ray of the X-ray beam in the centre of the cassette and collimate to include the step wedge in the X-ray field
  + Select an exposure that will produce a full range of step wedge densities and make an exposure. This exposure should be the same used each time this test is completed
  + Process the film
* Method 3 – Producing a standard range of densities using X-ray without the step wedge
  + Place a 18x24cm cassette with standard film face-up on the X-ray table
  + Divide the face of the cassette into 11 strips
  + Cover all but the end strip with lead rubber
  + Set 100cm FFD, centre and collimate the X-ray beam to the end strip (strip 1)
  + Select an exposure that is low enough to barely produce a visible density
  + Move the lead rubber so that strips 1 and 2 are uncovered
  + Again, centre and collimate to the uncovered area (strips 1 and 2) and expose using the same exposure
  + Move the lead rubber so that strips 1, 2 and 3 are uncovered
  + Again, centre and collimate to the uncovered area (strips 1, 2 and 3) and expose using the same exposure
  + Repeat this process until all strips have been exposed, then process the film
* Method 4
  + Purchase a pre-exposed sensitometry film produced by the film manufacturer
  + Process the film

In carrying out the sensitometric test, you will need a densitometer and some graph paper. The use of the graph paper will assist in creating a ‘characteristic curve’. A typical characteristic curve is demonstrated in the World Health Organisation’s QA Workbook (1) and is shown in figure 1.



**Figure 1** *An example of a typical characteristic curve that can be created using the sensitometric test**(source: World Health Organisation QA Workbook (1))*

Instructions on carrying out the sensitometric test are taken from the World Health Organisation’s Quality Assurance Workbook (1) and include the following:

* + - Switch on the densitometer and set the readout to zero (calibration)
    - Place the centre of the density to be read directly over the aperture and under the reading arm
    - Lower the reading arm to the film, press the “read” switch and hold for a few seconds, until the readout stabilizes
    - Read the density of each step on the test film image and record the densities against their step numbers
    - Using the graph paper, plot a graph of step numbers on the horizontal axis against densities on the vertical axis and join up the plots to create a ‘characteristic curve’
    - Compare the curve with the control characteristic curve, which is either provided by manufacturer or when the processor is installed. If there is a large variation, the processor is not functioning correctly
    - Calculate the “Speed” index by selecting the step number that has a density within the range of 1 and 1.3.
      * Compare this to the control speed index
      * The allowable variance of the speed index is plus or minus 0.15
    - Calculate the “Contrast” index by recording the densities that correspond with the step numbers that are 2 above and 2 below the step number used to calculate the speed index
      * The contrast index is the difference between these 2 densities
      * Compare this to the control contrast index
      * The allowable variance of the contrast index is plus or minus 0.15
    - Calculate the “Base plus fog” by measuring the density of the film that received no exposure. On the graph, the base plus fog is also known as the “D-min”
      * Compare the base plus fog to the control base plus fog
      * The allowable variance of the base plus fog is plus or minus 0.02
    - Calculate the “D-max” by measuring the density at the maximum density step on the step wedge image (the darkest step). The D-max corresponds with the top of the characteristic curve.

Whilst conducting the measurements for the characteristic curve as described above, it is inevitable that some variation in measurements will occur. However, if these variations are large and sudden, or if there is a continual increase or decrease in the variations, action will need to be taken. This will involve immediate ceasing of use of the processor, informing other users of the issue, then reporting the problem to the researchers. The cause of the variation will then need to be determined by following the chart in table 1 as taken from the World Health Organisation’s Quality Assurance Workbook (1).

**Table 1** *An example of the possible interpretation of sensitometric charts and recommended action**(1).*

|  |  |  |
| --- | --- | --- |
| **Chart changes** | **Possible cause** | **Action** |
| * Speed and contrast increase * D min acceptable * Speed and contrast up * D min increases | *First stage of over development*   1. Developer temperature high 2. Excessive replenishment 3. Developer too concentrated 4. Check processing time | 1. Adjust temperature 2. Adjust replenishment 3. Change developer 4. Developing time too long add starter |
| * Sudden increase in Speed, D min & D max after service | *Excessive over development*  Starter omitted or insufficient  Starter in developer | Add starter to developer |
| * Speed decreases * Loss of image contrast * D min normal * Image density low over whole image * Speed and contrast low * D-min also low | *Under development*   1. Developer temperature low 2. Developer exhausted 3. Insufficient replenishment 4. Replenisher used up 5. Developer too dilute 6. Developing time too short | 1. Check and adjust temperature 2. Check and adjust replenishment 3. Check and refill replenisher tank 4. Replace replenisher 5. Check processing time |
| * Sudden decrease in speed and D-max after service * Small decrease in D-min | *Excessive amount of starter in developer* | Replace developer, add correct amount of starter |
| * Increase in speed * Shoulder decreases * Loss of contrast * Increase in fog | 1. Aerial oxidation 2. Contaminated developer | Replace developer after washing out tank  Add correct amount of starter |

For ease of tracking any variations, it is recommended that the graphs shown in appendix 4 as taken from the World Health Organisation’s QA Workbook are used to plot the values each day (1).

For a given radiographic projection, there are many factors that can affect the “blackening” of the film, including (7):

* + - * The radiation dose
      * The radiation quality
      * Patient size
      * The radiographic technique
      * Image receptor sensitivity
      * Film processing

The amount of film blackening in different areas of the film determines the optical densities of the film. The optical densities of the base plus fog on a film should not exceed 0.25. Within the image, the diagnostic relevant part of the film should have a density range between 0.5 and 2.2, with a mean optical density range between 1.0 and 1.4. However, nowadays the judgment of optical densities is based on global impressions rather than measurements (7). It is therefore unnecessary to determine the optical densities on an image and rely on your own observations and feedback from researchers.

* 1. **Weekly tasks**

To ensure efficiency of the QC activities and enable appropriate comparison of results, it is recommended that the following tasks are completed on the same day of each week and at the same time on each of these days.

* + 1. **Automatic film processor**

*Cleaning and inspection -* In conjunction with the daily activities for the automatic processor as outlined above, the deep rack rollers should be washed once a week. This can be completed by placing the rollers in warm water, then rinsing and reinstalling. The rollers should also be inspected for any damage.

*Check replenishment rates –* The replenishment rates of the developer and fixer are important to ensure that the film is being appropriately chemically processed. An excess or shortage of replenishment on a film can have disastrous consequences. The following method is based upon that described by the World Health Organisation’s Quality Assurance Workbook, which outlines how to check the replenishment rates (1). For this method, you will need a graduated 100ml cylinder or graduated measuring jug:

* + - * Check the replenishment hoses for any bends that may restrict the flow of the chemicals
      * Switch on the processor, remove the lid and activate any micro-switches that will allow you to feed film with the lid off
      * Place the end of the developer replenishment hose in the cylinder or jug
      * Feed a film into the processor. This will automatically pump a pre-set amount of developer into the cylinder or jug
      * Record the amount of developer that has been pumped
      * Empty the cylinder or jug and repeat the process for the fixer
      * Compare the recordings with the manufacturer’s recommendations. If the results do not compare, adjust the quantity regulator (if possible) so that it is in line with the recommendations. Otherwise, contact the service engineer and the researchers to inform them of the issue
    1. **X-ray equipment and film**

*Image receptor, cassette and intensifying screen cleaning –* Regular image receptor and cassette cleanliness is essential to avoid unnecessary artifacts appearing on the image. All cassettes (for both film and CR) should be clearly numbered on the outside so that the radiographer can identify which cassette was used when an artifact is discovered (1). Cassettes should also be marked on the outside, which identifies the type of intensifying screen used (1).

During the weekly tasks, cassettes should be inspected for cleanliness, as well as for appropriate function of any hinges, catches or casings (1). The condition of the surface of the intensifying screens should also be inspected in bright light. The cassettes and image receptors should then be cleaned on the outside using either standard hospital disinfectant or alcohol wipes.

Similarly, the intensifying screens should be cleaned weekly, however the process should be as per manufacturer instructions, such as using anhydrous alcohol and a lint-free cloth. Intensifying screen cleaning will minimize artifacts caused by static electricity between the film and the intensifying screen. These artifacts are seen on film as small areas of blackening, such as a “lightning strike” appearance and occur when charges build up due to friction between the surfaces, with the frequency increasing with a lower humidity. Other ways of avoiding these artifacts are to decrease the film sliding across the intensifying screen during loading and unloading and potentially using a humidifier to increase air humidity (1).

*CR Image plate erasure –* CR imaging plates are sensitive to scattered and naturally occurring radiation sources. They store any absorbed energy, particularly when the plates have not been used for long periods of time (6). It is therefore recommended that a primary erasure of all the imaging plates as per manufacturer guidelines is conducted weekly.

*Cassette light leakage test* – The integrity of an imaging cassette may diminish over time due to wear and tear. A cassette with slightly decreased integrity may allow small amounts of light to enter, thereby causing unwanted blackening of the film. Cassettes should therefore be tested for any leakage of light. This can be achieved by placing a closed cassette with a fresh film inside under a bright light for 15 – 30 minutes and then processing the film (1). Inspection of the processed film will determine if any light has leaked into the closed cassette.

* 1. **Monthly tasks**

Similar to the weekly tasks, good practice of conducting monthly QC activities is that they are performed on the same day of the week and at the same time of day to ensure that any tests can be accurately compared.

* + 1. **Automatic Film Processor**

*Cleaning and inspection -* In conjunction with the daily activities for the automatic processor as outlined above, all racks and component parts of the automatic processor should be inspected for damage during cleaning. The filters should also be cleaned. If economically possible, all tanks should be drained of chemicals, cleaned and then re-filled with fresh solutions (1).

*Fixer retention rate analysis –* Residual fixer on processed X-ray films will eventually turn the films brown, severely decreasing the image quality of the film and reducing the capacity for comparison. The fixer retention rate analysis determines the amount of residual fixer on the processed image (5). The test to determine the fixer retention rate is specific to the manufacturer of the processor and it is recommended that the manufacturer’s guidelines are followed.

* + 1. **X-ray equipment and film**

*Physical and mechanical inspection –* There is much activity that can occur in an X-ray facility over the course of a month. Consequently, equipment will be moved and some can become inadvertently damaged. The following are suggested methods of inspecting equipment, with results recorded on the record sheet in appendix 5. Please note that this appendix can also be used for any portable machines as outlined below. Anything out of the ordinary should be reported immediately to both the service engineer and researchers:

* + - * Check all cables are free from breaks, kinks or knots and electrical connections are secure (1,6)
      * Check that cables are not under other heavy equipment (6)
      * Ensure all interlocks and brakes on the equipment is working correctly and that the tube is securely fixed to the support (1, 6)
      * Check that the X-ray table and X-ray tube move smoothly (6)
      * Ensure that the light beam diaphragm is functioning, is free from dust and has an adequate intensity so that it can be easily identified from the surrounding room light (6)
      * Check that there is no dust around the X-ray tube and generator and that they are free from oil leaks (6)
      * Ensure that the operator’s view of the patient from the control area is not obstructed by any notices or charts (6)
      * Check the control panel for the following (1, 6):
        + Working and attached meters, indicator lights, knobs, switches and buttons
        + Visible and accurate read-outs of exposure factors
        + Proper operation of undamaged hand switch
      * Using a spirit level or bowl of water, check that the table top is horizontal (1)
      * Using a spirit level or a string and weight, check that the vertical column is vertical (1)
      * Test the accuracy of a digital FFD scale using a tape measure (if required) (1)
      * Check that the X-ray tube and generator model and serial numbers are clearly marked and readable. If the labels are inaccessible, serial numbers must be displayed somewhere (6)
      * Record the date of inspection, results and X-ray equipment identification (6)

*Portable X-ray unit –* For facilities that use a portable X-ray unit as a back-up unit in cases of equipment breakdown for research purposes, the following checks are as essential as for the stationary unit (1):

* + - Check all locks, brakes and tube arm movements are working correctly
    - Check cables are free from breaks, kinks or knots and electrical connections are secure, including the electrical plug
    - Check that the hand switch is in good condition and that it exposes when the switch is used
    - Check any control panel lights and switches, as well as the exposure factor meters to ensure they are working
    1. **Other equipment**

It is important that QC activities extend to other equipment within the facility that contributes to the quality and appearance of images. Additionally, where possible, specialist checks and analysis of warning lights and signs by medical physicists should occur monthly (5,6).

*Film printer QC –* Facilities will not need to print films for research purposes, nor will they necessarily need to print films for primary reporting. However, even if facilities use CR or DR as their mode of image acquisition, many will need to print films as a medical record or for viewing by a referring clinician. The film printer QC will determine whether the quality of the images on the film is sufficient for its purpose. In these cases, a visual check may be sufficient if the facility does not have access to a densitometer, but the service engineer should check the optical density range during the routine service (6). The following QC procedure for the film printer is based on the Royal Australian and New Zealand College of Radiologists General X-ray QA and QC Guidelines (6). Results can be recorded using the record sheet in appendix 6:

* + - * Print the TG18-QC test pattern from the printer
      * Check for any disturbing artifacts on the image
      * Ensure that the rollers of the printer are clean and in good working order
      * Evaluate the following image quality factors:
        + Visible borders
        + Straight lines
        + Appearance of squares
        + Squares of different shades from black to white are distinct
        + The finest horizontal and vertical line pairs are visible in the high contrast pattern in all 4 corners and in the centre
        + The 5% and 95% grey squares are clearly visible within the 0% and 100% backgrounds
        + At least 11 letters are visible in the phrase “QUALITY CONTROL” for the dark, mid-grey and light renditions
      * Record the date, the printer identification and the test results

*Viewing box* – The viewing box used to view images directly after processing should be safely fixed to a wall or a stable mobile structure. It should have an even light all over and be clean and electrically safe, with a sufficient light output. The screen to which the films attach for viewing should be cleaned both inside and outside. However, any electrical checks should be performed by a qualified electrician (1, 2).

* 1. **Quarterly tasks**

QC activities that are performed quarterly mainly relate to the X-ray equipment. For a simple QA programme to function and to avoid confusion of tasks, it is recommended that all quarterly tasks be completed on the same day.

If not economically possible on a monthly basis, the drainage and cleaning of the film processor tanks, followed by the refilling of tanks with fresh chemicals may be more viable every 3-months (1).

Additionally, depending on the agreement with the local regulatory body, most personnel radiation dosimeters are required to be analysed every 3-months.

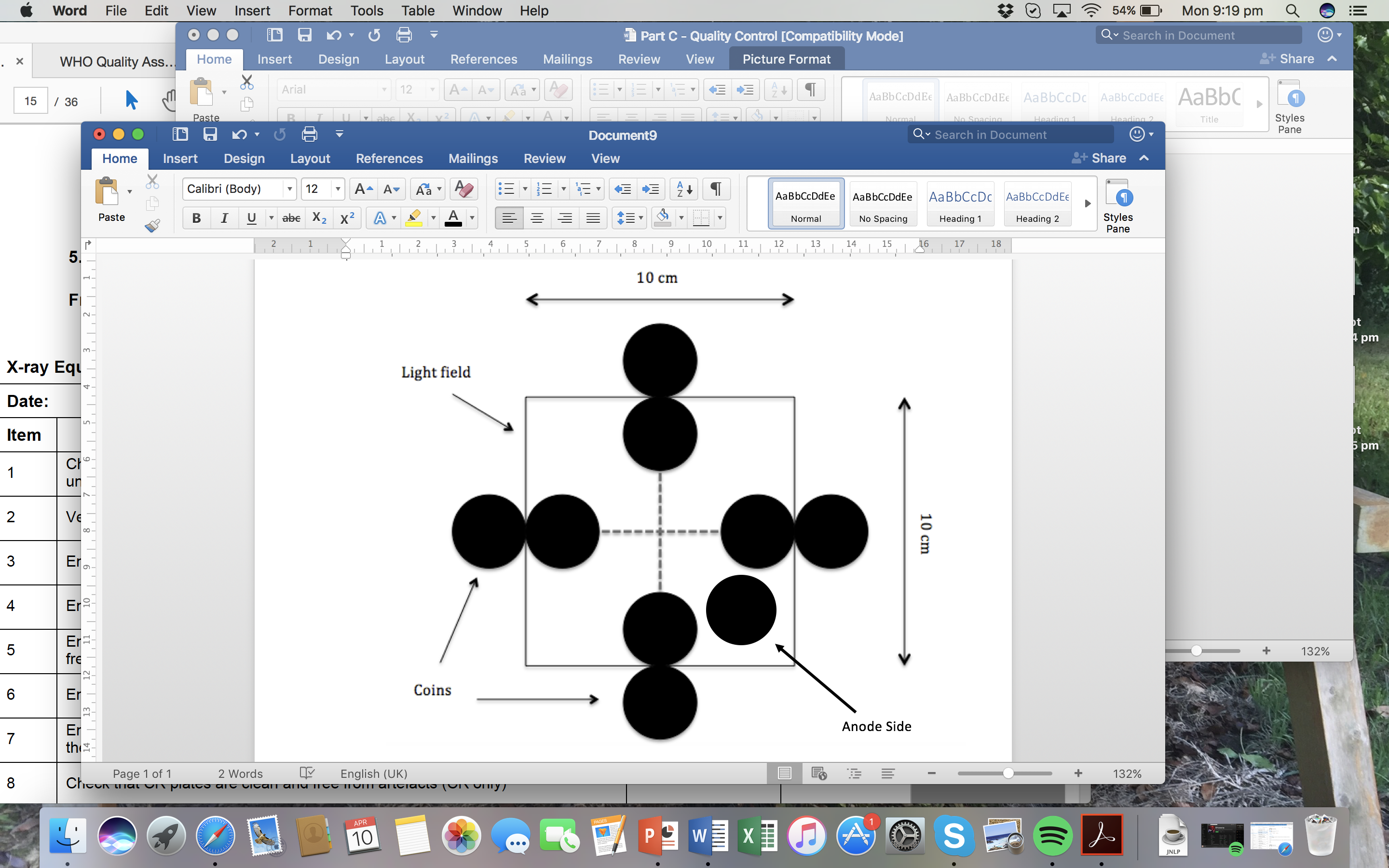
* + 1. **X-ray equipment and film**

During the routine service, the service engineer may perform a mechanical check of a DR system and its associated components (if applicable), as well as a check of CR plate sensitivity matching (if applicable) (6).

*Alignment of X-ray field to light field (1,3,4) –* Part B – Study Guidelines discussed the importance of beam limitation to the region of interest through the use of beam collimation. To ensure accurate and consistent collimation of the X-ray beam, there should be precise alignment of the light beam with the X-ray field (5). This will also ensure that there is no unnecessary exposure of radiation to the patient (6).

The recommendations for congruency of the light beam to the X-ray field vary between countries (6, 9) However, the recommended requirement is that the light field must be within ±2% of the X-ray field (9). There are 2 methods of testing the light field correspondence to the X-ray field that are based on the Royal Australian and New Zealand College of Radiologists’ General X-ray QA and QC Guidelines (6). Results of these methods can be recorded using the sheet in appendix 7, which is also based on these guidelines (6).

* + - * Method 1 – For film and CR detectors
        + Ensure the x-ray tube and table are level
        + Place the cassette or detector on the table top
        + Set a SID of 100cm
        + Collimate to an area of 10x10cm
        + Place a coin on the inside and outside of the light field on all 4 sides to mark the edges of the light field (see figure 2).
        + Place another coin on the anode side of the tube to allow results to be easily compared
        + Expose using the factors of 60kV and 5mAs
        + Open the collimators fully and expose using the factors of 60kV and 1mAs
        + Process the film or readout the CR / DR image and measure the difference between X-ray field and edge of coin (light field)
        + If the difference between the X-ray field and the light field using these factors is greater than 2cm, contact the service engineer



**Figure 2** *An example of the set-up for testing the light field with the X-ray field for film, CR and wireless DR detectors*

* + - * Method 2 - For wireless and integrated DR detectors
        + Ensure tube and table are level
        + Set a SID of 100cm
        + Collimate to an area of 10x10cm on the detector
        + Place a coin on the inside and outside of the light field on all 4 sides to mark the edges of the light field (see figure 2).
        + Place another coin on the anode side of the tube to allow results to be easily compared
        + Expose using the factors of 60Kv and 5mAs
        + Measure the difference between the edge of the image and the edge of the coin (light field)
        + The X-ray to detector must agree to within 2% of the SID
        + Record the date, deviation of X-ray from the detector and the X-ray equipment ID

*Consistency of Exposure Index (EI) –* For CR and DR, the exposure index is a measure of the amount of exposure received by the image receptor. Indirectly, it is an indication of the image quality. The use of the term EI is manufacturer specific and may be given other names, such as “S-number”, “SAL” or “LgM”, however the concept for its use is consistent (6). The EI value is dependent on many factors, such as the irradiated area, the beam attenuation by an object in the X-ray field and the exposure factors used. Therefore, the EI value is not absolute and will differ depending on the anatomical region that is imaged. Additionally, for a given body area the EI value may differ from other images of the same area due to variations in exposure factors, patient position and collimated area. Nevertheless, analysis of EI values over time is useful for QA purposes to monitor patient radiation doses for a given body area.

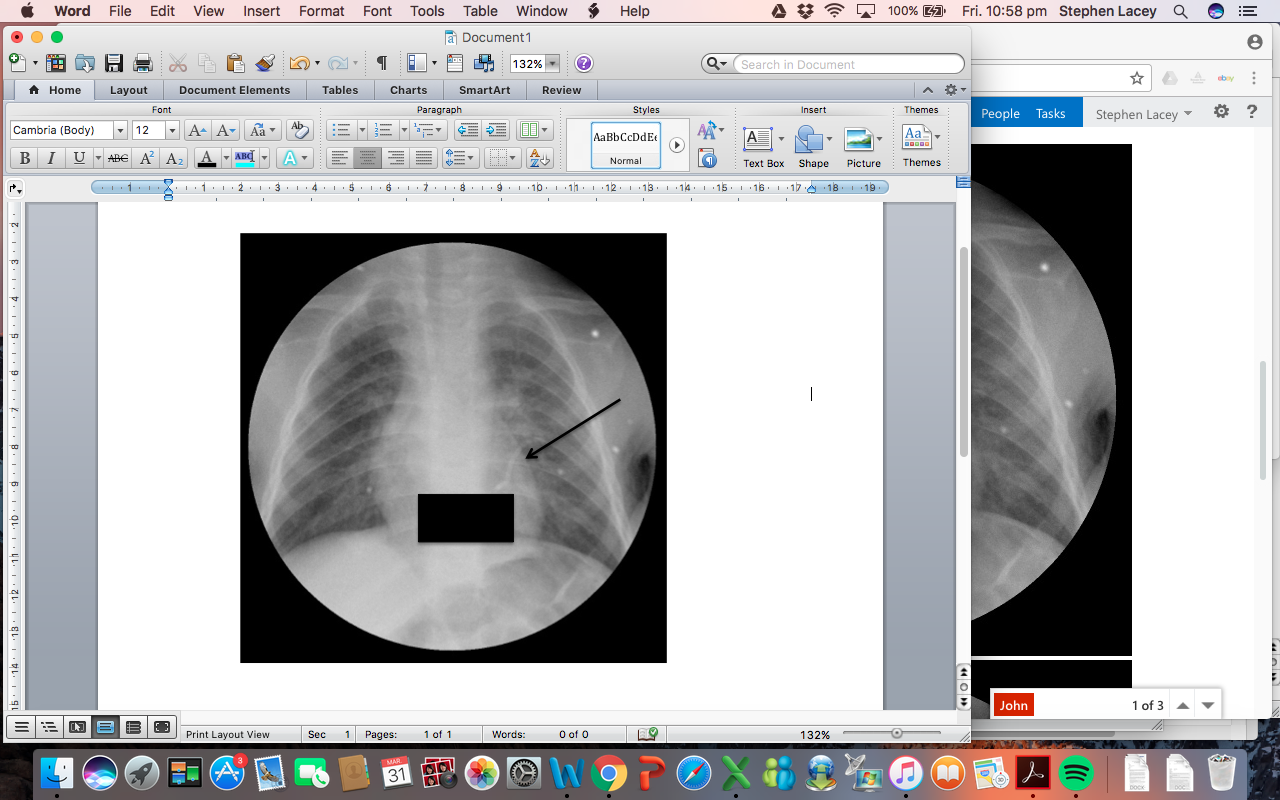
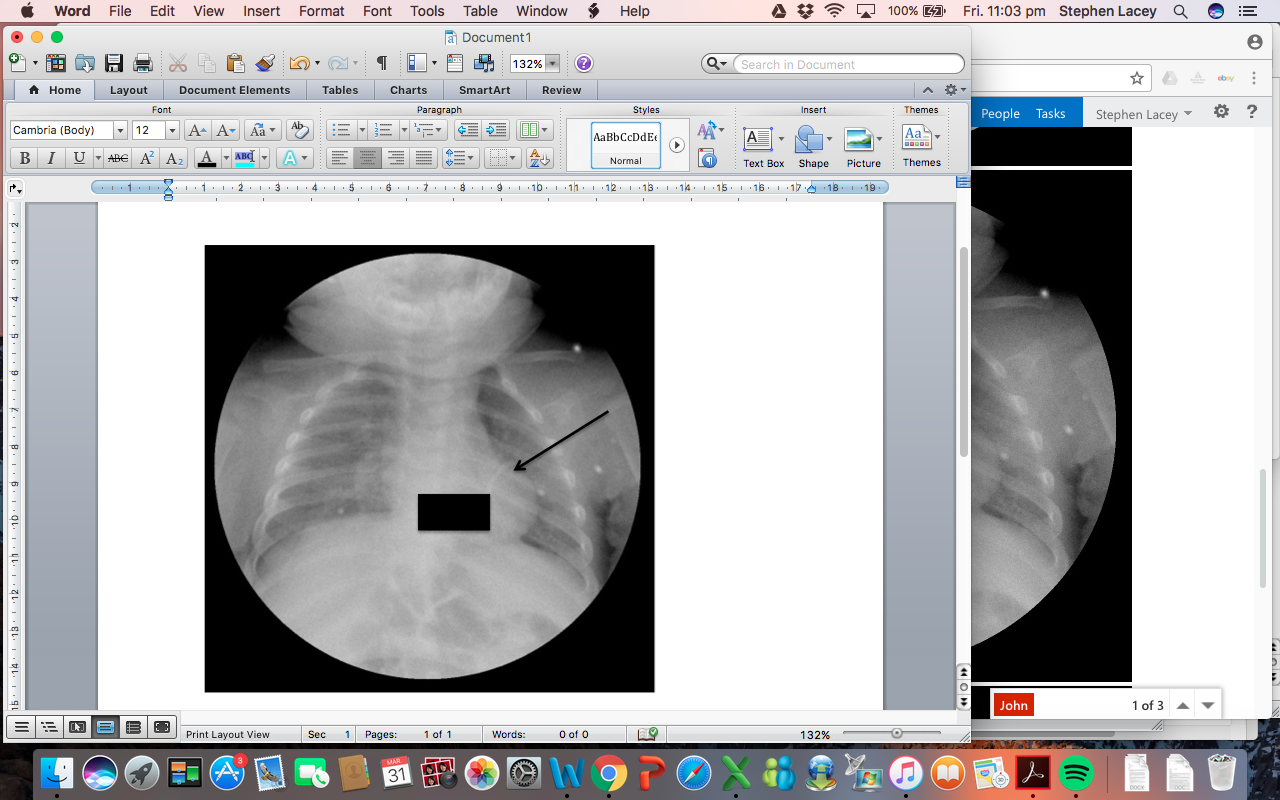
For a given exposure condition with no object to attenuate the field and with a consistent collimated area, the EI should remain approximately constant. This EI value should therefore be able to be replicated, with the consistency of the EI determining either whether the output of the X-ray unit or the detector system is malfunctioning. To analyse this possibility, a baseline EI needs to be set, with all future EI tests being compared to this baseline (6).

To set the baseline, the procedure outlined below should be followed on 3 occasions and separated by at least an hour. If the results of the 3 tests are consistent, the average value of the tests should be set as the baseline (6). If not consistent, repeat the test ensuring that the correct procedure is followed and contact a service engineer if problems persist. The baselines will need to be reset when upgrades to software and X-ray tubes occur as the baseline EI value may change. Once a baseline has been set, any EI consistency test results should be within 1% of the baseline value. If small (<1%) changes over consecutive periods follow a trend, contact the service engineer.

The following procedure to determine the EI baseline is based on the Royal Australian and New Zealand College of Radiologists’ General X-ray QA and QC guidelines (6). Results of the procedure can be recorded using the sheet in appendix 8. Baselines are generally determined with a heavily filtered X-ray beam to ensure removal of the lower energy radiation that contribute to scatter, which would ultimately affect the consistency of the EI baseline. Please note that a separate test for each X-ray unit is required, as EI values will differ between X-ray units:

* + - * For CR systems:
        + Use a designated, freshly erased test cassette and CR reader to ensure consistency. The test cassette should be in clinical use so that deterioration due to general wear can be detected. If there are multiple readers, test each reader using the same cassette but with different X-ray units
        + Place the CR test cassette on the X-ray table
        + Use a SID of 110cm, with the central ray on the cassette
        + Ensure that the collimated field covers the full area of the CR plate
        + Attach a 1mm copper sheet to the collimator, ensuring that the beam is fully intercepted
        + Expose using 70kV and 4mAs then process the plate using a consistent processing algorithm
        + Record the date, algorithm, EI value and X-ray equipment ID
      * For DR systems
        + If wireless, place the detector on the X-ray table
        + Use a SID of 110cm and centre the X-ray beam on the detector
        + Ensure the collimated field covers the full area of the detector
        + Attach a 1mm copper sheet to the collimator, ensuring that the beam is fully intercepted
        + Use a consistent processing algorithm
        + Expose using 70kV and 4mAs
        + Record the date, algorithm, EI value and X-ray equipment ID

*Image uniformity and artifact evaluation –* Using the correct X-ray equipment and image receptors, it is expected that a non-attenuated image would have a uniform appearance. Image artifacts may occasionally appear, but can be a result of many factors, including equipment error. Image artifacts caused by non-uniformity can occasionally be identified during routine imaging of patients (see section 4.1 - “Image Critique” for more detail) and an example of this is shown in figure 3.



**Figure 3** *Two separate X-ray images acquired using the same X-ray unit. The same artifact is present in both images (arrows), indicating that the artifact is equipment related, based on a non-uniformity of the image. The artifacts were discovered during routine imaging of the patients.*

However, some artifacts are much subtler and therefore not all artifacts and non-uniformity can be determined through the image critique process. The process for determining imaging uniformity and artifact detection as outlined below is based on the Royal Australian and New Zealand College of Radiologists’ General X-ray QA and QC guidelines (6). Results of the procedure can be recorded using the sheet in appendix 9. In addition to these benefits, this test is also useful for determining whether the flat-field correction for DR systems is functioning correctly:

* + - * Method:
        + Use the image acquired for the ‘Consistency of EI’ test. If using film, create an image using the method outlined for the CR systems section of the ‘Consistency of EI’ test
        + Visually inspect the image for non-uniformity and artifacts, noting that CR images and film will suffer from the ‘anode-heel effect’
        + Record the date, comments on uniformity and artifacts and the X-ray equipment ID
        + If artifacts are seen, determine if it is due to the monitor, the detector, X-ray beam non-uniformity or the copper filter

To eliminate the possibility of display artifacts (e.g. from the monitor or light-box), rotate or pan the image. If the artifact moves with the image it is due to the imaging system (i.e. copper filter or image receptor). However, if it stays in the same place, it is due to the display system

To eliminate the possibility of artifacts on the copper filter, such as dust, scratches or thickness non-uniformity, rotate the copper and repeat the test. If the artifact stays in the same place, it is most likely to be due to the image receptor. In this case, clean the image receptor and repeat the test. However, if the artifact moves, it may be attributable to non-uniformity on the copper filter.

* + - * + Clean the image receptor and repeat the test
        + If the artifact persists, contact the service engineer and the researchers to inform them of the artifact
    1. **Image viewing monitors**

*Monitor testing –* As discussed in Part B – Study guidelines, viewing monitors used by study researchers should meet standardised brightness and resolution requirements to ensure maximum consistency of monitors in multiple locations. This can be achieved with regular monitor testing, which is outlined below.

For clinical purposes in tele-radiology, monitor testing is typically performed monthly. However, as reading images for study purposes does not have the same clinical detail requirements, it is recommended that testing is performed prior to the commencement of a study to ensure monitors are appropriately calibrated, and quarterly thereafter.

Monitor testing should be performed by a reader regularly using the monitor. The reader should obtain the Society of Motion Picture and Television Engineers (SMPTE) test pattern in appendix 10. They should then follow the method below and complete the checklist in appendix 11 by indicating whether each criterion is adequate or inadequate.

* Method:

1. **Overall appearance**
   1. Confirm that the shapes, lines and grey percentage steps are clear and evident
2. **No blurring or bleeding**
   1. Using the long, high contrast rectangles towards the sides of the test pattern, confirm that there is no blurring or bleeding between the black and white areas
3. **Dynamic range – 5% and 95% contrast areas from adjacent 0% and 100% areas**
   1. Distinguish whether the stepped density squares can be compared with the surrounding grey squares
4. **Dynamic range – 5% squares visible at both ends of the greyscale**
   1. In addition to step 3, distinguish whether you can just perceive between the 0% and 5% square, and between the 95% and 100% square
5. **Dynamic range – each greyscale square shown from 0-100%**
   1. Check that there are 12 squares showing grey scale from 0% to 100% at 5% increments
6. **Spatial resolution and aliasing – high contrast bars appear distinct black and white**
   1. Compare the black and white sections on the high contrast rectangles towards the sides of the test pattern, ensuring that there is clear distinction between 0% and 100%
   2. There should be no banding in the shaded white-grey-black rectangles at the sides of the test pattern
7. **Spatial resolution and aliasing – horizontal and vertical lines appear clearly differentiated**
   1. Using the small squares of multiple lines in the centre and each corner of the test pattern, compare the small details differentiation

If any of the criteria are deemed as inadequate, this should be immediately reported to the study researchers and the monitor removed from use for the study, until any problem can be repaired.

* 1. **6-monthly tasks**
     1. **Darkroom**

The sole purpose of the darkroom is to ensure that film handling can occur safely, without being exposed to light that would ultimately cause film fogging. Consequently, efficient light omission and effective safelight use needs to be regularly tested (1,5).

6-months is also a good time to check on the conditions of the darkroom to ensure that the film handling is occurring at an appropriate temperature (between 10°C and 20°C) and humidity (between 40% and 60%) (1). A general room cleanliness, conditions of areas such as any bench-tops and inventory of chemical protective equipment such as gloves, aprons and goggles should also be assessed at this point.

*Darkroom white light leakage test –* The darkroom must be completely free of any white light during film handling, yet over time with movement in and out of the darkroom, some white light may be able to enter the room. The following method is based on the World Health Organisation’s QA Workbook, which outlines how to test for white light leakage (1):

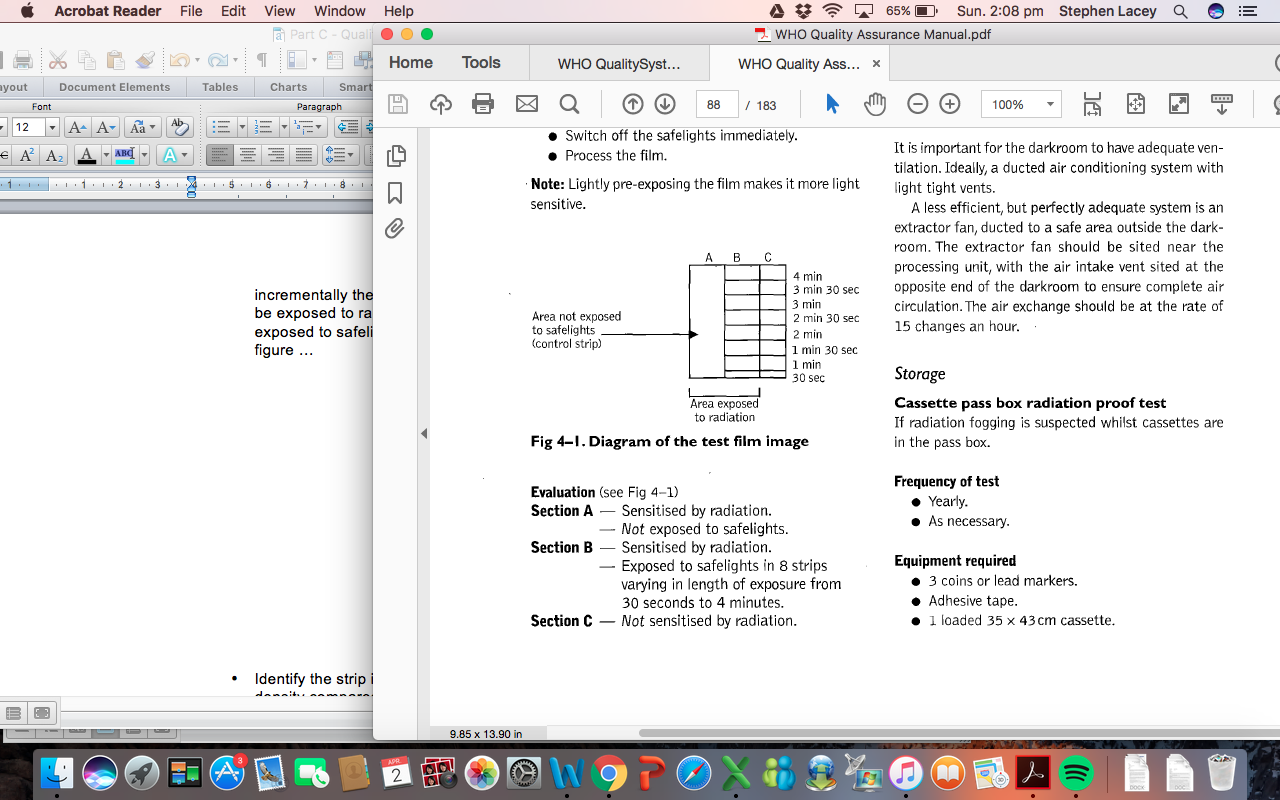
* + - * Method
        + Turn on all lights in areas adjacent to the darkroom
        + Turn off all darkroom lights
        + Close all doors and remain in the darkroom for 10 minutes to allow your eyes to properly adjust to the light
        + Look around the room for signs of white light leaks
        + Seal any leaks
        + To test if any light fogs the film in the darkroom, place a film on the workbench and cover half of the film with a sheet of card
        + Leave the film for 3 minutes, then process the film
        + If fogging has occurred, there will be a difference in densities on the film as a result of the card

*Safelight efficiency test –* The safelight in the darkroom uses filters to suit the light sensitivity of the film that is used in the facility. Safelights may also contribute to film fogging for the following reasons:

* + - * Incorrect filter type
      * Inappropriate levels of filtration
      * Incorrect light bulb wattage
      * Positioned too close to the workbench
      * Allow leakage of white light

The safelight efficiency test as outlined below is based on the World Health Organisation’s QA Workbook (1):

* + - * Place a 24 x 30cm cassette on the x-ray table
      * Set a SID of 100cm and collimate the beam to the area of the cassette
      * Cover one third of the cassette with lead rubber. This area will be “area C”
      * Expose at 45kV and 2mAs
      * Unload the cassette in the darkroom in total darkness, without the safelight on
      * Place the film on the workbench
      * Cover one third of the exposed film with sheet of card. This area will be “area A” and is at the other end of the film to area C. The area between area A and area C is now “area B”
      * Cover areas B and C with a second sheet of card except for a 3cm strip at the top of the film
      * Switch on the safelights and wait for 30 seconds
      * Move the second sheet of card down 3cm and wait another 30 seconds
      * Repeat this process until the bottom of the film is reached
      * Switch off the safelights, remove the cards in complete darkness and process the film
      * Note that area A will be exposed to radiation and not the safelight, area B will be exposed to radiation and incrementally the safelight over 4 minutes and area C will not be exposed to radiation but will have incrementally been exposed to safelight over 4 minutes. This is demonstrated in figure 4.



**Figure 4** *A diagram of the test film image for the safelight efficiency test (Source: World Health Organization QA Workbook (1))*

* + - * Identify the strip in area B which has a noticeable increase in density compared to its equivalent strip in area C
      * Note the safelight exposure time of this strip. This is considered the extreme limit of film handling time
      * 3 minutes is considered the limit of acceptable film handling time
      * If the safe handling time is considered to be too short, consider one or more of the following modifications, then retest after the modification:
        + Increase the safelight height above the workbench
        + Reduce the bulb wattage
        + Replace the safelight filter
        + Further prevent white light leakage from the safelight
        + If there is more than one safelight, remove one safelight
    1. **X-ray equipment and film**

*Image Quality Test -* As X-ray units become older, image degradation may occur. The image quality for each X-ray unit within a facility should be regularly assessed for issues that may be specific to equipment problems (5). Image quality and any image degradation should be regularly assessed during the “image critique” of images (see section 4.1). However, it is also a good idea to ensure that any issues that may be specific to an X-ray unit can be identified through a specific image quality test (6). The following procedure and associated record sheet (see appendix 12) is based on that from the Royal Australian and New Zealand College of Radiologists’ General X-ray QA and QC Guidelines (6). Ideally, it should be carried out by the on-site radiologist, or one of the researchers in conjunction with the person acquiring the images:

* + - * Select 5 chest X-ray images per X-ray unit
      * Perform image quality assessment for each film (appendix 12)
      * Record the date, X-ray equipment ID, person(s) carrying out the image quality assessment
      * Any reasons for images being deemed not clinically acceptable should be investigated in conjunction with a service engineer

*Film-screen contact test –* Radiographic detail can be diminished if there is insufficient contact between the film and the screen within a cassette. The amount of film-screen contact for each cassette should therefore be regularly tested (5). The film-screen contact test requires a sheet of wire mesh that has a distribution of 8-wires per inch, which is generally encased in acrylic for ease of handling (10). Alternatively, some paperclips may be used which are placed in an even distribution over the cassette. The following procedure for the film-screen contact test is based upon that by the Minnesota Department of Health (10):

* Load a film into the cassette and wait for 15-minutes to allow for any trapped air to dissipate
* Place the cassette on the X-ray table and place the wire mesh (or paperclips) on top of the cassette
* Set a SID of 100cm, centre the X-ray beam to the centre of the cassette and collimate to the edges of the cassette
* Expose using 65kV and 5mAs. This should be sufficient to give a density reading of about 2.0 using the densitometer. If the density reading is significantly higher or lower, adjust the exposure factors accordingly
* Label and process the film
* View each film on a view box in a dimly lit room from a distance of approximately 1.8 metres
* Look for areas that are obviously darker and/or blurrier. These areas indicate poor film-screen contact. There will always be small areas of blurriness on the film, which may not necessarily indicate poor contact. Areas of poor contact need to be evaluated based on their land size.
* If the area of poor contact could obscure important information on the X-ray, remove the cassette from service
* Record the date, exposure information and cassette identification
  1. **Yearly tasks**
     1. **X-ray equipment and film**

*Routine servicing and medical physics checks -* With respect to the equipment used, many of the yearly QC tasks should be carried out by service engineers as part of the routine servicing contracts, or by specialist medical physicists (5). These tasks include, but are not limited to:

* Total filtration of the primary X-ray beam (5)
* Tube leakage performance (this can also be conducted whenever X-ray tubes are replaced) (5)
* Source-to-image distance calibration (5)
* X-ray generator and tube kVp output and linearity measurement (this can also be conducted whenever parts are replaced) (1, 5)
* Radiation output reproducibility (1)
* Constancy of radiation output (1)
* DR detector calibration, flat field test and dark noise test. The frequency of the detector tests varies depending on the manufacturer, although should occur during routine maintenance. These tests generally either pass or fail, with failure requiring equipment replacement (6)

Upon completion of these tasks, the equipment should be labelled indicating the status of the equipment. Furthermore, any equipment that does not meet the performance requirements should be removed from service until repairs can be carried out. Researchers should be informed of any issues with equipment, particularly if the equipment will be out of service.

* + 1. **Other equipment**

*Lead apron testing –* As lead aprons and thyroid shields age, they become prone to damage due to wear and tear. Lead aprons can also be easily damaged due to mishandling or incorrect storage. To assist in the maintenance of their integrity, appropriate lead apron storage methods are that they are hung or stored flat and not close to a heat source. Additionally, they should never be folded as this will cause the lead to crack (1).

Regular testing for any damage to the lead that may cause radiation leakage should also occur annually (5, 11, 12). All lead aprons and thyroid shields should be individually labelled so that they are easily identifiable and continual inspection trends can be documented. Results of the following inspections can be documented using the record sheet in appendix 13:

* Visual check of lead apron and thyroid shield cleanliness, including effectiveness of fasteners and hanging loops, and any tears (1, 6). Any unclean lead should be thoroughly cleaned using soap and warm water. Ineffective fasteners and hanging loops should be mended appropriately
* X-ray test the lead aprons and thyroid shield to determine if there are any significant cracks (1, 5, 6). This is ideally achieved by screening the lead using a fluoroscopy unit with an image intensifier (11, 13). However, if there is no fluoroscopy unit at the facility, the lead can be tested using the following method:
  + Place the largest sized cassette with loaded film (or largest image receptor size for CR and DR) on the X-ray table
  + Place the lead apron or thyroid shield on the cassette, ensuring that there is no overlap of lead on the cassette.
  + Centre the X-ray beam to the centre of the cassette or image receptor and collimate to the cassette size
  + Expose using an exposure that will demonstrate some small penetration of the lead, yet clearly show any tears
  + Process the film (if applicable)
  + Inspect the image for any non-uniformity of the lead due to tearing. Tears will be demonstrated as significantly lighter areas within the darker lead
  + It is likely that the entire lead apron will not be able to be tested in one X-ray exposure. Therefore, repeat the process above, placing different areas of the lead over the cassette or image receptor, until all the lead has been exposed
  + Record the date, lead apron or thyroid shield identification, condition of the item, whether the item is acceptable or non-acceptable

For any lead that is damaged, the choice to replace it may be dependent upon the level of funding of the facility. It is suggested that the damaged lead is removed from service and replaced with new lead if the defect is greater than 15mm2 (11-13). However, defects that are not clearly over highly radiosensitive organs can continue to be used, provided the location and size of the defect, as well as the date the defect was discovered is clearly marked on the lead. Lead that falls under the following criteria will need to be replaced if the defects are greater than 670mm2 (11-13):

* Defects are not in close proximity of critical organs
* Defects are along the seam of the lead
* Defects are in part of the lead that is overlapped with another part of the lead (e.g. wrap around lead skirt)
* Defect is on the back of the lead apron

For any thyroid shields that are used, these should be replaced if the defect is greater than 11mm2 (11, 13).

* 1. **As required task**
     1. **Film**

*Accidental light fogging of film test –* There may be times where accidental exposure of unprocessed film to white light may occur. An example of this is where the white lights are turned on in the darkroom while a film hopper (or film box) is left open. During these cases, the following degree of fogging test can be performed (1):

* Under safelight conditions, remove the front film, the rear film and a film from the middle of the affected packet or hopper
* Identify which film is from which part of the packet or hopper
* Process the films
* Assess the degree of fogging on each film to determine if it is within acceptable limits
* If not, either use the film as the morning ‘clean-up’ film (see 2.1.2 – Daily Automatic Processor Tasks) or discard the film

1. **Monitoring patient doses**

For the same patient size and the same radiological examination, there is a disparity between operators and facilities on the exposures that are used. This inconsistency can lead to a substantial variation in the dose delivered to the patient. Patient radiation dose and its affects have long been researched in the literature. More recently however, it has captured worldwide attention, particularly for pediatric patients with interest published in guidelines by various international organizations, including the United Kingdom National Radiological Protection Board (NRPB) (14), the International Atomic Energy Agency (IAEA) (15), the International Commission for Radiological Protection (16), the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (17) and the European Commission (EC) (7).

This interest has led to the establishment of dose reference levels (DRLs) across many countries and regions, with the aim for facilities to monitor the radiation doses to their patients for specific examinations and strive for further optimization (18). The implementation of digital systems has also enabled facilities to monitor doses through exposure indicators, which will be discussed in more detail below (see 3.2). DRLs and individual dosimetry all contribute to radiation protection and quality in practice (19).

Within the scope of these documents for research purposes, it is not a mandatory requirement for facilities to abide by any specific DRLs or exposure indicator. DRL and exposure indicator calculations require specific calculation equipment that may not be readily available in some areas. Furthermore, the accuracy of the calculation equipment is questionable, with as high as 40 % allowable variation for X-ray equipment dose meters, which is in line with current International Electrotechnical Commission (IEC) standards for dose meters (20,21). However, it is highly recommended for those facilities that have access to the required equipment to gather such data. Adherence to the guidelines as outlined in Part B – Study Guidelines will assist in the optimization of patient doses, with DRLs and exposure indicators being recommended methods to establish whether the practice at the facility is achieving satisfactory images at appropriate dose rates.

It is also recommended that prior to the production of any dose evaluation program, facilities record an inventory of their medical radiological equipment, with technical specifications, for example filtration or anti-scatter grid use. This will allow any required changes to practice due to dose increases to be recorded and monitored.

* 1. **Dose Reference Levels (DRLs)**

DRLs are used in facilities to monitor performance and improve optimization (19). They are “a form of investigation level, applied to an easily measured quantity, usually the absorbed dose in air, or tissue-equivalent material at the surface of a simple phantom or a representative patient” (22). DRLs are applicable to groups of similar patients, rather than individuals (4, 18). They are derived from a regional or national survey of the doses for a specific examination and are represented as the 75th percentile or 3rd quartile of the spread of median doses from the survey (19). This ensures effective recognition of any outliers that have occurred during data collection (23).

For a specific country, DRLs that are set by a national regulatory body are known as NDRLs, whilst for a facility or group of facilities that measure their own median doses over a number of patients, this is known as the local dose reference level (LDRL) (4).

LDRLs can be adjusted to correspond with the level of technology and local optimization achievements. It is then periodically compared with the NDRL, which is the reference dose value. If the LDRL exceeds the NDRL, the method of image acquisition is investigated and adjusted to improve the optimization process (18). For example, in adult chest X-rays, a consistently higher dose might be caused by the use of the automatic exposure control (AEC), which could then be deemed as unnecessary. However, NDRLs do not signify optimum performance and facilities should continue to strive for doses that are well below NDRLs, whilst recognizing the potential loss of clinical information due to the dose reduction (23). Similarly, LDRLs that are set should not be applied as a dose limit, but as a guidance for radiology staff to assist in achieving high quality examinations at reasonable dose levels (4, 24).

At the 68th World Assembly for the World Health Organization, a side event titled “Imaging for Saving Kids – the Inside Story about Patient Safety in Pediatric Radiology” was held where it was recommended that a strategy for improving patient safety in pediatric imaging is to work on dose optimization and foster the establishment and use of DRLs in children (25). Furthermore, the Framework of the IAEA’s Radiation Protection in Pediatric Radiology use DRLs for patients and dose limits to outline their principles of Justification and Optimization (15).

For patient safety, dose monitoring through DRLs is highly recommended as it can improve the optimization of radiation dose by reducing the frequency of unjustified high (or low) dose values (4). Furthermore, adherence to the recommended technical factors outlined in Part B – Study Guidelines will also ensure that dose is optimized (15). Studies performed by the European Commission demonstrated that where there was adherence to recommended technical factors, patient doses were less widely distributed and within acceptable limits (7).

***3.1.1 How to acquire dose data and create LDRLs***

Most dose data for use of dose comparison with DRLs should be easily obtainable from the X-ray equipment console. This can be achieved manually, with separate dose data recorded for each X-ray unit in the facility. Dose quantities should allow for comparison between these units and data collected should consider both the technical settings and characteristics (23).

The most appropriate dose quantity for chest X-rays is the Air-Kerma product (PKA or KAP), also known as the Dose-Area Product (DAP). This is a measure of the total radiation delivered to the patient and is the product of the radiation concentration delivered to a point on the patient (in Grays or Gy) and the area that is exposed (in cm2). This quantity is available in all X-ray equipment of present technology and considers the full radiation exposure to the patient. It can be easily recorded in daily practice, and is determined either by built-in or removable PKA (DAP) meters, or by computational systems in X-ray units that calculate the PKA value from the imaging parameters (23).

In addition to the Air-Kerma Product quantity, the Entrance-Surface Air Kerma (ESAK) is recommended as it allows follow-up of patient doses and enables further comparisons with DRLs, as many DRLs are expressed by the ESAK. ESAK is the air-kerma measured on the central beam axis at the position of the patient, with consideration given to the backscatter that occurs because of the interaction of the X-ray beam with the patient and surrounding structures. The ESAK is therefore the product of the measured X-ray beam output and an appropriate backscatter factor (usually around 1.3). However, the X-ray beam output measurement requires the use of a calibrated ionization chamber, which may be difficult for most facilities due to their limited availability (23). Modern systems are overcoming this through automatic recording of exposure factors into the image data, but are seldom available in rural and remote regions (26).

As discussed above, the LDRL is the median dose over several patients for a facility or group of facilities. The representative dose samples should be taken from all X-ray units that are used for chest X-rays. Larger sample sizes will provide more reliability to the results. For example, a sample size of about 100 patients per age group per room will allow for a 10% confidence interval at a 95% level of confidence. However, considering the relative throughput of patients in a facility, a sample size of as little as 10 patients per age group to determine the median values will be sufficient (23).

There is a wide variation of patient sizes across all ages for children, however this is more pronounced for children under 5-years of age. For example, within the child’s first 6 months of life, their weight doubles, and triples within the first year (23). It is therefore imperative that consideration is given in the grouping of these patients for DRLs.

Although for a single age-group, there can be a spectrum of patient weight (24), it is recommended that patients are grouped based on patient age. This is due to most of the current NDRLs being given in terms of patient age (see 3.1.2). There are, however, some more recent NDRLs that are weight based. Therefore, as an approximation, the weight to age range equivalence outlined in table 2 is recommended (23).

**Table 2** *Weight and age ranges for patient groupings for the purposes of DRL establishment* (23)

|  |  |  |  |
| --- | --- | --- | --- |
| **Group** | **Weight range** | **Age range** | **DRL age** |
| Neonate | Less than 5kg | Less than 1 month | **0 years** |
| Infant / toddler | 5kg to less than 15kg | 1 month to less than 4 years | **1 year** |
| Middle childhood | 15kg to less than 30kg | 4 years to less than 10 years | **5 years** |

For each of the above groups, it is recommended that where possible, at least the PKA / DAP is determined, with ESAK values also beneficial. Once an appropriate sample size of values is obtained, the median (50th percentile) dose value for each age group per facility or group of facilities can be calculated, which will then form the LDRL for that age group. This process should be repeated annually or when new equipment is installed to ensure accurate, consistent monitoring of dose values and to determine if active attempts of dose optimization is successful (23-25).

When carrying out the patient dose surveys, the following process is recommended, with consideration given to each parameter’s effect on patient dose so that variations are identified and appropriate adjustments can be made (23):

* Use a KAP/DAP meter to collect PKA or DAP readings (in μGy.cm2) for each patient
* Measure beam output and multiply by backscatter factor to obtain the ESAK (in mGy) for each patient
* Collect a sample size of at least 10 patients per age group per X-ray unit
* Record the equipment type for each X-ray unit (Film / CR / DR / Manufacturer)
* Record the technical factors used for each image (SID / filtration / grid use / exposure factors)
* Calculate the median (50th percentile) doses for each age group for the facility or group of facilities. This will act as the LDRL
* Record the number of facilities and X-ray units participating in the survey
  + 1. ***How to compare LDRLs with NDRLs***

With significant differences in image acquisition methods between countries, where possible it is ideal for LDRLs to be compared with NDRLs that are based on dose surveys from the same country. NDRLs are determined with sufficient coverage of all institutions for which they are intended. In most cases, the authoritative body that provides the NDRLs for that country will have also issued detailed guidance on how to compare the LDRLs with the NDRLs.

It is recognized that NDRLs do not exist for every country and pediatric NDRLs are even less often established. In these cases, it is sufficient for the LDRLs to be compared with international recommendations or NDRLs from other countries. For example, as a minimum approach, the European Commission have a set of “European DRLs” that can be used as a comparison (see table 3). These are regularly updated to reflect the development of optimization in Europe. However, these comparisons should only be used as preliminary values until relevant NDRLs are established (23).

When primarily comparing the LDRL with the NDRL, if the LDRL for the facility or group of facilities is higher than the NDRL, the NDRL value should then replace the LDRL unless the higher LDRL value can be justified. However, for any subsequent comparisons, the cause of a higher LDRL should be thoroughly investigated (4). For example, higher values could be caused by equipment malfunctions, changes in practice or insufficient training of new users (4, 23).

To ensure appropriate relevance of the comparison, it is recommended that the same dose quantities and patient grouping is applied as the NDRLs for which the LDRLs are being compared. Additionally, the significance of any difference between the NDRL and the LDRL can be more exactly studied through statistical means, for example a student t-test (23).

Table 3 outlines the European DRLs (EDRL) for pediatric chest X-rays. A DRL study from a representative European country (Austria) has also been included for comparison to demonstrate the variation between patient dose surveys and imaging techniques (7, 23, 27).

**Table 3** *PKA / KAP / DAP and ESAK DRLs for paediatric AP/PA Chest X-rays in Europe and Austria* (7, 23, 27)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Age (years)** | **PKA / KAP / DAP (mGy.cm2)** | | **ESAK (μGy)** | |
| **Europe** | **Austria** | **Europe** | **Austria** |
| 0 | 14 | 17 | 80\* | 55 |
| 1 | 20 | 23 | 100\* | 69 |
| 5 | 39 | 26 | 80 | 82 |

\*ESAK values for age groups 0 and 1 years have been taken from (7), which was created in 1996. Current values are expected to be lower.

In a further comparison, a patient survey in India to determine DRLs demonstrated much higher ESAK values than those described above. For the age groups of 0, 1 and 5 years, the ESAK values were 180μGy, 280μGy and 170μGy respectively. The likely reason for these higher values is due to the technical factors used to acquire the images, with between 55 and 60kVp, and 4 and 7mAs. As discussed in Part B – Study Guidelines, factors such as these will increase the surface entrance dose to the patient due to the decrease in X-ray beam penetrability (28).

* 1. **Exposure Indicators**

Modern CR and DR systems employ an exposure indicator value that is automatically recorded for each image. The exposure indicator determines the radiation incident on the imaging plate, which can provide a method of optimizing image quality and dose monitoring (15). Although in CR and DR imaging, images with an increased dose can often demonstrate optimal image quality, the use of exposure indicator values can ensure that the dose range is also optimal. However, the disadvantage is that this process does not consider images that have been rejected due to over or under exposure (29).

It must be noted here that the exposure indicator is not a direct indication of patient dose as many technical factors can affect the exposure indicator for a given image. For example, for the same kV and mAs values, an image with a larger field size will show a different exposure indicator value than an image with a smaller field size (29). Additionally, the exposure indicator value relies on the user selecting the correct body part and patient size algorithm prior to the exposure, otherwise it is inaccurate. However, overall tracking of the exposure indicator values will give an indication as to the correct use of equipment and optimal radiation techniques. It is therefore not recommended that the exposure indicator is used solely to evaluate the image quality for individual images, rather the mean exposure indicator over many chest images is evaluated for trends in increased or decreased dose.

The “exposure index” or “EI” refers to the exposure indicator of specific manufacturers, for example Kodak or Canon. As described in the Consistency of EI Test in section 2.4.1, a variety of other terms can be used to describe this indicator depending on the manufacturer (see table 4). Furthermore, whilst in most cases a higher exposure indicator generally denotes an increased image receptor dose, care must be taken when evaluating these values as some manufacturer indicators will decrease as the dose increases (15). Nevertheless, the exposure indicator range is optimal irrespective of patient size and technical factors.

Table 4 is taken from the IAEA publication “Radiation protection of children in digital radiography” (29) and is an example that describes the exposure indicator values for specific mean receptor doses across a range of manufacturers. Note that for Fuji systems, the exposure indicator (S number) decreases as the receptor dose increases. When an image is not over or under exposed, exposure indicator values will be considered within acceptable limits. These limits are determined by the manufacturer, relating to the receptor doses.

**Table 4** *Exposure indicator values, specific to manufacturer terms for different mean receptor doses* (29)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Manufacturer** | **Exposure Indicator** | **Mean Receptor Dose** | | |
| 5**μGy** | 10**μGy** | 20**μGy** |
| Fuji | S | 400 | 200 | 100 |
| Kodak | EI | 1700 | 2000 | 2300 |
| Agfa | IgM | 1.9 | 2.2 | 2.5 |

When using the exposure indicators for monitoring patient doses, collaboration with manufacturers to determine the target exposure indicator values for each examination type is recommended. Monitoring can be achieved by following the steps below. Once optimization has been reached, the frequency of this dose monitoring process should be annual to allow for appropriate evaluation and possible adjustments of practice:

* Select a sample of at least 10 patients per age group (as per DRLs above) per X-ray unit
* Record the exposure indicator values for each image, as well as the corresponding kVp, mAs and filtration (if possible)
* Calculate the mean exposure indicator per age group per X-ray unit
* If the mean exposure indicator demonstrates an overall over-exposure, the imaging technique should be evaluated and adjusted. Once adjustments are made, this process should be repeated.
* If the mean exposure indicator demonstrates and overall under-exposure, use the image critique tool outlined in section 4 below to determine if the images are of sufficient quality. If image quality is sufficient, practice does not need to be adjusted. If image quality is insufficient, the imaging technique should be evaluated to attempt to increase the dose. Once adjustments are made, this process should be repeated.

Whilst the main aim for dose monitoring is to strive for the lowest possible dose, the overriding criterion is an acceptable image quality. In normal imaging practice, image quality must still be sufficient irrespective of dose (23). A system to judge image quality sufficiency is described in section 4.1 “Image Critique” below.

1. **Image analysis**

Image analysis involves the determination of whether images are either acceptable for diagnosis, or unacceptable requiring rejection and repeat. During the implementation of a QC program, acceptable standards of image quality for this threshold should be established. In the evaluation of image acceptability, images may be rejected for one or more of a number of factors. For the chest X-ray, these factors include, but are not limited to the patient position or the visibility of lung fields.

If it has been determined that an image must be rejected, the rejected image must be combined and analyzed with other rejected images to determine any common trends in reject rationale. These rationales may be the result of equipment and / or imaging technique and a regular analysis will ensure that any required changes to practice can occur appropriately.

The following sections outline both a process for analyzing images for acceptability and determining trends in reject rationale. Determining the acceptability of an image will almost always be a subjective process. However, this method aims to reduce the subjectivity in an attempt to maintain consistency of diagnostic images.

* 1. **Image critique**

There are two main aims of the image critique process; to determine if an image is diagnostic, and to improve and maintain an acceptable and safe standard of imaging. Whilst many factors need to be evaluated in the critique of images, not all of these factors will require an image to be repeated. For example, the absence of a lead side-marker will reduce the certainty of the difference between the left and right side of the patient, but it will not warrant a repeat image for diagnostic purposes.

The aim of image acceptability standards is to ensure that they are objective. This is achieved by introducing parameters that characterize image quality and omit the opinions of professional personnel (24). Although the final decision of image acceptability is always subjective, the subjectivity can be minimized for individual criteria for the image critique process. This is important for the operator when assessing their own images and when receiving feedback from radiologists or researchers.

The criteria used to critique an image is similar in many parts of the world. However, the weighting factors of importance applied to each criterion is widely variable, with subjectivity in almost all criteria. In studies where evaluated images are acquired from multiple operators at multiple facilities, this subjectivity will lead to a large variation in the acceptability standards of imaging.

The diagnostic requirements for the chest X-ray in the European Commission’s “European guidelines on quality criteria for diagnostic radiography images in paediatrics” (7) require the following criteria to be evaluated:

* + - Peak inspiration
    - No rotation or tilting of the thorax
    - Inclusion of the chest from just above the lung apices to the 12th thoracic vertebra
    - Reproduction of the vascular pattern in the central two-thirds of the lungs
    - Reproduction of the trachea and proximal bronchi
    - Sharp diaphragm and costo-phrenic angles
    - Visualization of the spine and paraspinal structures, and of the retrocardiac lung and mediastinum

In 2017, an image critique set of criteria that minimizes the subjectivity was created by Adam Steward, Tutor Radiographer at Western Health in Melbourne, Australia, and Stephen Lacey, Tutor Radiographer at The Royal Children’s Hospital in Melbourne, Australia. The criteria encompass each of the diagnostic requirements from the above European Guidelines and applies numerical values from 1 to 4 for each criterion, with associated guidelines to the definition of the numerical values. An assessment rubric of the criteria and scoring definitions are outlined in appendix 15 and each criterion with its ideal feature (i.e. a score of 4 out of 4) is included in table 5.

**Table 5** *Criteria for a quantitative image assessment with ideal feature descriptions*

|  |  |
| --- | --- |
| **Criterion** | **Ideal feature description** |
| Use of lead side-markers | Must be permanent, not obscure relevant anatomy and on the correct side of the patient |
| Collimation comprising inclusion of relevant anatomy and exclusion of irrelevant anatomy | All required anatomy is included **and** four borders of collimation are evident with collimation tight to the area of interest |
| Image artifacts and aesthetics | No artifacts are present or are removed from the relevant anatomy as best as possible **and** the long axis of the body plane is aligned to long axis of the image receptor |
| Exposure | No quantum mottle (noise) on the image. There is a visually adequate exposure that is within the acceptable exposure indicator range or is slightly outside, indicating underexposure |
| Contrast | Demonstration of vertebral bodies through the mediastinum **and** good evidence of peripheral vascular markings |
| Movement Unsharpness | Cortical bony margins **and** lung detail are sharp indicating no patient movement |
| Patient rotation | No patient rotation as evident by the equidistant clavicular heads from the spinous processes |
| Projectional correctness | Clavicular heads are projected between the third and fifth thoracic vertebrae |
| Consideration of other structures | The scapulae are retracted from the thorax **and** the chin is projected above the lung apices |
| Patient functional state | Full inspiration. There are 10 or more posterior ribs visible above the diaphragm |

Ideally, the criteria outlined in appendix 15 is applied informally to every acquired image by the operator. This gives the operator an important indication as to whether the image should be rejected and repeated.

The formal use of these criteria can be adopted by the operator, radiologists and researchers as a method of providing feedback for overall image quality. For example, the operator may use the criteria to conduct periodic audits of image quality, whilst radiologists and researchers may use it to monitor and provide feedback on image quality and its adherence to the requirements of a study.

For maintenance and improvement of optimal image quality, it is therefore recommended that a radiologist and / or researcher use these criteria to provide feedback on a least one image per facility per week throughout a study period. Furthermore, each facility should use the criteria to establish an ongoing review of their images. It is recommended that a sample of at least 10 images per month is reviewed, with an average value for each criterion established to allow common issues in image quality to be identified, thereby improving trends.

* 1. **Image reject analysis**

The image reject analysis is a basic component of any QA program (24). The benefits for the analysis process include (1):

* Reducing any unnecessary doses to patients
* Increasing facility efficiency
* Reducing overall costs to facilities
* Providing ongoing comparative data
* Providing a possible source of statistics to support claims for more funding to replace, modify or repair faulty equipment

The main consequences of image rejection are that patients may be receiving unnecessary radiation doses and/or there is an unnecessary cost to a facility in rejected films. Meanwhile, an image that is rejected before the exposure (e.g. film artifact) indicates that changes to practice may need to occur.

Films can be rejected prior to an exposure taking place, indicating that an error in workflow or equipment maintenance has occurred. For example, fogging of films may be occurring regularly due to light leakage into a darkroom. After exposure, image rejection should occur when deemed not to meet the standards required for diagnosis. Although operators should strive for excellent quality images every time, sub-optimal images can sometimes be sufficient for their diagnostic purpose. However, retaining such images does not allow proper identification of some major issues in practice.

Whilst there are many specific reasons that images are rejected, each of these can be classified into one of three main causes (24):

* Equipment issues
* Technical competence
* A combination of equipment issues and technical competence

The analysis of the rejected images can then be completed during regular periodic audits, with trends in rejections being identified (7). Understanding the main reasons for rejection allows the operator to correct faults, thereby reducing future rejection rates (1).

During the rejection process, images should be categorized into one of a pre-determined set of rejection reasons. Since images rejected after exposure will be because of the image critique process, good practice is to categorize rejection reasons into the criteria used for image critique. The following categories are suggested examples for image rejection reasons:

* Required anatomy is not included
* Patient artifacts (e.g. jewelry, buttons, ECG leads etc)
* Film artifacts (e.g. scratches, static, film processing problems etc)
* Exposure (over or under)
* Contrast (too high or too low)
* Film fogging (film only)
* Patient movement
* Patient rotation
* Projectional incorrectness
* Overlying structures (e.g. patient’s chin)
* Expiratory images

A recommended image rejection analysis worksheet is demonstrated in appendix 16. In cases where images are rejected for multiple reasons, each reason should be noted on the worksheet to allow for a proper comparative analysis of rejection trends. A separate rejection analysis should be conducted for each X-ray unit so that any issues with specific equipment can be easily identified. Therefore, particularly where film is used, it is ideal to keep rejected images for each unit separate from other units. Furthermore, the total number of rejected images should be compared against the total number of images per x-ray unit so that percentage trends of rejected images can be identified.

To appropriately identify issues, take corrective action and analyse improvement trends in practice, it is recommended that the image analysis is conducted monthly (1, 5). Additionally, if equipment malfunction is identified as a major issue, parallel analysis with other QC tests such as sensitometry or exposure indicator consistency tests is recommended to easily identify specific causes (1).

1. **Conclusion and additional resources**

With the correct equipment and resources, and consideration of funding constraints, the procedures outlined in the sections above are considered necessary to ensure the consistent high quality of pediatric chest radiographs. A successful QA program is where the QC activities are ongoing and these activities will have the added benefit of maintaining a high standard for all aspects of radiography within a facility. Whilst many QC activities are not mandatory, the implementation of a QA program is in the best interests of both the patient and facility as the use of radiation and ongoing costs to the facility will be optimized.

In addition to the described QA program, other QA resources are available through many international organizations. For example, the International Atomic Energy Agency (IAEA) developed its Basic Safety Standards (BSS) as a means of protection to people and the environment from the harmful effects of radiation. The BSS consists of a series of requirements that include statements which specify the activities that must be completed and the recommended personnel. Additionally, the BSS contains a requirement for special consideration in pediatric patients. There are requirements for all X-ray systems to be calibrated and their performance to be monitored through a QA program. The BSS are not mandatory standards, but are publically available for countries to adopt if they wish (29).

It must be noted here that countries using the BSS to receive IAEA technical assistance or assistance from a co-sponsor of the BSS will need to comply to the standards (29). To assist facilities to further understand the BSS and demonstrated compliance, the IAEA run a training program, which also provides a regulatory framework for qualified professionals to work as a radiation safety officer for their facility. This can significantly boost a country’s radiation protection and radiation safety infrastructure by providing an ongoing needs assessment, practice standard development, policy implementation and system evaluation (31).

The World Health Organization has produced a “Global Initiative” with an intent to improve the implementation of international radiation safety standards in patient care and promote safe and more effective use of medical radiation. Additionally, the initiative aims to improve a country’s capacity to assess health risks and develop policies that consider costs and benefits as well as potential health impacts (32).

The benefits of a quality assurance program extend beyond maintaining and improving appropriate quality and optimization in imaging. Through adopting the Global Initiative described above the Australian Quality Use of Diagnostic Imaging (QUDI) program is an example of a national system-based quality improvement initiative (32, 33). Commencing in 2004, this program offers a comprehensive package of activities to promote sustainable quality diagnostic imaging services in Australia. It has been designed to incorporate the following priorities (33):

* QA and accreditation
* Uniform standards and consistent regulation
* Education of referrers and providers
* Education of consumers and providers about appropriate referral
* Management of new technology
* Professional supervision
* Role evolution

The QUDI program has highlighted specific challenges that are relevant to any QA program, particularly in developing countries. For example, differing priorities and philosophies of various stakeholders will affect the importance and relevance of activities, thereby altering the quality of imaging. Furthermore, the recruitment and retention of appropriately qualified, experienced and dedicated personnel to co-ordinate such a program, as well as the initial costs may be extremely challenging (33).

Whilst challenges in implementing a QA program will inherently exist, these will be amplified in facilities that do not currently have any such program. However, not only is a program’s development crucial to improving and maintaining optimal image quality, it is highly likely to have long-term cost benefits to the facility through minimizing faults and upholding continuity of imaging.

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**Glossary**

*AEC* Abbreviation for Automatic Exposure Control. Ionization chambers positioned behind the image receptor that allow an amount of radiation sufficient to produce a pre-determined good quality image

*Air-Kerma* The sum of kinetic energy released per unit mass of air. The unit is the Joule per kilogram, or Gray (Gy)

*Anode-Heel Effect* The variation of the intensity of X-rays emitted by the anode depending on the direction of emission

*Anti-scatter grid* A device consisting of alternate radiopaque and radiolucent strips, designed to allow the primary X-rays to pass through, but absorb scattered radiation

*AP* Abbreviation for antero-posterior, which describes the projection whereby the x-ray beam path travels from the anterior to posterior parts of the patient

*Arcing (tube)* Momentary losses of X-ray output due to short circuits within the tube due to small amounts of gas within the tube vacuum.

*Artifact* An artificial appearance on a radiograph that is not natural and can be caused by a variety of means, including structures or mishandling of film

*Base plus fog* Density of a processed film without the effects of light or radiation, caused by the manufacturer and storage of the film. This is also the density at which the characteristic curve starts

*Beam (X-ray)* A spatial distribution of X-rays emanating from the X-ray tube

*Bucky* A commonly used abbreviation of the Potter-Bucky moving grid system, which is designed to reduce the amount of scattered radiation reaching the film

*Calibration* The quantitative assessment of the errors in equipment performance when compared to reference or true values

*Cassette* Light tight holder that contains a pair of intensifying screens (for film), between which is placed the film

*Characteristic curve* A measure of the varying relationship between an applied exposure over a range of film densities

*Collimator(s)* A device used to control the coverage of the x-ray beam and determine the x-ray field size. Also known as the light beam diaphragm (LBD)

*Contrast* Difference between 2 or more densities on an image. High contrast is where there are few shades of grey between the lightest and darkest areas of the image. A high contrast film curve will lie toward the left of the characteristic curve.

*CR* Abbreviation for computed radiography, where transmitted X-rays are converted to light via a solid-state imaging device, such as a photostimulable phosphor plate, and recovered and processed using a digital computer

*DAP* Abbreviation for Dose Area Product. The product of the amount of radiation output from the X-ray tube and the total area irradiated

*Darkroom* Light tight room in which the processing of radiographs is carried out

*Densitometer* A device used to measure the optical density on of any spot on a radiograph by measuring the light that can pass through it

*Detail (image)* The amount and quality of information contained in a radiographic image, which is determined by image sharpness, contrast and density

*Developer* The chemical treatment that converts the latent film image into a visual image

*Distortion* Misrepresentation of a body part outline in the image due to changes in X-ray beam/body part alignment or unacceptable object-image distance

*Dose* A general term denoting the quantity of radiation or energy absorbed in a target

*DR* Abbreviation for digital radiography, where transmitted X-rays are converted directly into a digital image using an array of solid-state detectors

*Effective dose* The sum of the products of the absorbed organ dose and the respective tissue-weighting factor for each specified organ as outlined by the ICRP. The sum for all organs in the body should be 1

*Erect* Term used to describe the upright position of the patient

*ESAK* Abbreviation for Entrance Skin Air Kerma. The air kerma to air on the X-ray beam axis at the point where the X-ray beam enters the patient or a phantom. This includes the contribution of backscatter

*Exposure* The amount of radiation produced from the X-ray tube by a pre-determined set of exposure factors (voltage, current, time). The term ‘exposure’ is usually used to mean exposure factors

*Exposure indicator* A measure of the radiation incident on the imaging plate

*Exposure latitude* The range of exposure factors, within which the resultant radiograph is considered to be acceptable. A film that is said to have a “wide latitude” can accept large changes in exposure, without excessive density changes

*FFD* Abbreviation for focal-film-distance, the distance from the focal point (origin) of the X-ray beam to the image receptor. Also known as the source-image-distance (SID)

*Film density* Degree of blackening on a film. This increases as exposure to the film increases. It can be radiographic, where the degree of blackening is caused by the deposit of metallic silver, or tissue, where the greater density of the tissue causes more attenuation of the x-ray beam and thus appears lighter on the radiograph

*Filter (safelight)* A specialized, coloured glass window, fitted to a safelight in a darkroom that enables the safe handling of X-ray film

*Filter (X-ray)* A sheet of metal (usually aluminium) fitted to the port of an X-ray tube to filter out the low wavelength X-ray photons

*Fixer* Dissolves off all unwanted film emulsion and makes the image permanent

*Fog* Unwanted blackening of a film, which is commonly caused by scattered radiation reaching the unprocessed film or light fog caused by unwanted white light reaching the unprocessed film

*Gradient (curve)* The steepness of an incline at a specific point on the characteristic curve. Determines the contrast of a film at a given density.

* + - * Average gradient – A line drawn between the 0.25 and 2.00 density levels on the characteristic curve
      * Top gradient - A line drawn between the 0.25 and 1.00 density levels on the characteristic curve
      * Mid gradient - A line drawn between the 2.00 and 3.00 density levels on the characteristic curve

*Grid* See “Anti-scatter grid”

*Gy* Abbreviation for Gray. The absorption of one joule of radiation energy per kilogram of matter

*Image receptor* A device that is used to capture the difference in X-ray beam energies after passing through an object and then converting it to an image. It may be a film and cassette, phosphorescent screen (for CR) or a flat-panel detector (for DR)

*Intensifying screen* Radiation sensitive screens, placed inside a cassette on either side of the film, which fluoresce when struck by radiation, the light emitted significantly contributing to the blackening effect on the film

*KAP* Abbreviation for Air-Kerma Product. Equivalent to the DAP, this is a measure of the total radiation delivered to the patient and is the product of the amount of radiation output from the X-ray tube and the total area irradiated

*kV* Abbreviation for kilo-voltage, it is an X-ray exposure factor that controls the penetrating power and thus quality of the X-ray beam. It also affects the image contrast (higher kV = lower contrast)

*Light beam* Light emanating from the X-ray unit that has multi-leaf collimators

*Diaphragm* allowing for the correct positioning of the X-ray beam over the patient

*mA* Abbreviation for milli-amperes, it is an X-ray exposure factor that controls the intensity of radiation and therefore film density and patient dose (higher mA = higher film density = higher patient dose)

mAs Abbreviation for milli-ampere seconds, it is the multiple of the mA and the exposure time (in seconds) and refers to the quantity or density of radiation to which the patient is exposed. The density can be controlled by setting either the mAs as one factor or setting the mA and time separately

*Oxidation* A weakening of the developer strength caused by prolonged exposure to air

*PA* Abbreviation for postero-anterior, which describes the projection whereby the x-ray beam path travels from the posterior to anterior parts of the patient

*Penetration* The ability of the X-ray beam to penetrate structures, as determined by the energy of the beam (controlled by kV)

*Primary beam* Radiation emitted from the X-ray tube that has not reached the patient or object being imaged

*Processing* The chemical treatment of an exposed X-ray film that results in the production of an X-ray image

*Quality (image)* The appropriate level of contrast, definition and patient positioning in the demonstration of the required body parts of an image to allow the image to be appropriately read

*Quality Assurance* The overall management program, put in place to ensure that a comprehensive range of quality control activities work effectively

*Radiolucent* The property of a structure to wholly or partially allow the passage of X-rays

*Radiopaque* The property of a structure to wholly or partially stop the passage of X-rays

*Scatter (radiation)* Secondary radiation that has been changed in direction from the primary beam

*Sensitometer* A consistent light source that produces a standard range of densities when exposed on film

*SID* Abbreviation for source-to-image distance, the distance from the focal point (origin) of the X-ray beam to the image receptor. Also known as the focal-film-distance (FFD)

*Sievert* The unit of equivalent dose and effective dose, equal to 1 J/kg in the international system of units

*Supine* A term used to describe a patient lying horizontal on their back

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**Appendices**

1. Summary of quality control tasks and frequencies
2. Review of QC test results - Daily and weekly
3. Daily processor maintenance checklist
4. Quality control processing chart
5. Physical and mechanical inspection of X-ray equipment record sheet
6. Film Printer QC record sheet
7. Alignment of X-ray field to light field record sheet
8. Consistency of exposure index (EI) record sheet
9. Image uniformity and artifact evaluation record sheet
10. SMPTE test pattern
11. Monitor testing checklist
12. Image quality record sheet
13. Lead apron testing record sheet
14. Required equipment for QC tests
15. Quantitative chest X-ray image critique scoring definitions
16. Reject analysis record sheet