Radiation Guideline

6

Registration requirements & industry best practice for ionising radiation apparatus used in diagnostic imaging

Part 6

Test protocols for parts 2–5

NSW EPA
ENVIRONMENT PROTECTION AUTHORITY

Department of
Environment and Conservation (NSW)

These are the prescribed Test Protocols for Parts 2 –5 of *Radiation Guideline 6*, defined in clause 3 of the Radiation Control Regulation 2003 (except the Mammography Radiation Guideline). This edition supersedes the Test Protocols published in June 2000.

From 24 September 2003 the Department of Environment and Conservation (DEC) incorporates the Environment Protection Authority (EPA), which is defined in section 4 of the *Radiation Control Act 1990* as the Authority responsible for administering the Act and Regulation. Statutory functions and powers in the *Radiation Control Act 1990* continue to be exercised in the name of the EPA.

For technical information about this Guideline contact the Radiation Control Section of the DEC on (02) 9995 5959.

Published by:

NSW Environment Protection Authority
59–61 Goulburn Street
PO Box A290
Sydney South 1232
Ph: (02) 9995 5000 (switchboard)
Ph: 131 555 (information & publications requests)
Fax: (02) 9995 5999 (general)
TTY: (02) 9211 4723
Email: info@epa.nsw.gov.au
Web: www.environment.nsw.gov.au

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INTRODUCTION

This Guideline is for the information of owners, licensed users of ionising radiation apparatus and persons accredited under section 9 of the *Radiation Control Act 1990* (the Act) as Consulting Radiation Experts (CREs). The Guideline sets out the basic test protocols that must be followed by CREs in the assessment of radiation apparatus for compliance with the mandatory requirements of Parts 2–5 of *Radiation Guideline 6: Registration requirements & industry best practice for ionising radiation apparatus used in diagnostic imaging*.

Compliance testing for the mandatory requirements of the Mammography Radiation Guideline (*Radiation Guideline 6: Part 1*) must be conducted by following the Royal Australian and New Zealand College of Radiologists' *Mammography Quality Control Manual* (2002).

This Guideline may also be used by persons performing quality control testing of diagnostic imaging apparatus to standardise their test procedures. Quality assurance (including quality control) is widely recognised as an essential element of good radiological practice. The primary objective in performing quality control of radiation apparatus is to ensure that it is functioning to a prescribed minimum standard.

In the event of amendment to the Act or the Radiation Control Regulation 2003, references to the legislation in this document shall be deemed to refer to the current legislation. In the event of an inconsistency between the Guideline and the current legislation, the requirements of the legislation prevail to the extent of the inconsistency.

From 24 September 2003 the Department of Environment and Conservation (NSW) incorporates the Environment Protection Authority (EPA). The EPA is defined in section 4 of the *Radiation Control Act 1990* as the Authority responsible for administering the Act. Therefore, statutory functions and powers in the Act and the Radiation Control Regulation 2003 continue to be exercised in the name of the EPA.

The Guideline was developed by the Radiation Control Section of the Department of Environment and Conservation (NSW) in consultation with the Radiation Advisory Council.

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SECTION 1—TEST EQUIPMENT

1.1 Calibration of instruments

A CRE must ensure that any radiation monitoring device used for compliance testing is:

- suitable for the type of measurement for which it is to be used
- used only when it is fully operational and properly calibrated
- capable of measuring the type of radiation being assessed over the range of energies and dose rates required
- subject to periodic maintenance to ensure its continued accurate operation
- calibrated to an Australian or international primary or secondary standard satisfactory to the manufacturers' requirements.

1.2 Test equipment

The following items are required to carry out compliance testing:

- a dosimeter with appropriate ionisation chambers
- a non-invasive beam analyser or kVp meter and electronic timer
- aluminium filters (Grade 1100 or equivalent)
- masking tape
- a collimator alignment test grid or lead markers/paper clips
- a perpendicularity test tool
- a light meter
- lead sheets
- a tape measure
- radiographic cassettes & film/fluorescent screen
- non-screen film
- a calculator with statistical functions
- a resolution gauge
- a Westmead test object (or equivalent)
- a 20 cm water phantom
- 6 sheets of perspex, each 24 cm x 30 cm, 1cm thick
- 2 mm copper sheet
- a pinhole camera/star test pattern (0.5° or 1°)
- appropriate phantoms for CT and bone mineral densitometry
- a densitometer.

SECTION 2—GENERAL

2.1 Protection of the x-ray tube

Prior to commencing testing the manufacturer's warm-up procedure should be followed. Alternatively, three exposures at 50 kVp, 50 mA, and 2 seconds should be made. For dental apparatus the lowest kVp, low mA, and 1 second exposure time should be used.

Consult tube heating/cooling curves to avoid damage to the x-ray tube. If curves are not available, allow 30–60 seconds between each exposure. Where the testing of panoramic units requires a full cycle exposure allow 5 minutes between exposures if cooling charts are not available.

To protect the x-ray tube tests should be conducted simultaneously where possible.

2.2 Line voltage

Variations in line voltage from 240 V may cause equipment to fail the kVp requirements specified in this Guideline. Compliance testing should be carried out at 240 V, which is the optimal line voltage at which diagnostic imaging apparatus should be used. If equipment has failed kVp requirements the owner should have a qualified person monitor the line voltage.

2.3 Radiation units

Quantity	SI Unit	Old Unit	Conversion
Exposure	coulombs per kilogram (C/kg)	roentgen (R)	1 C/kg = 3876 R
Absorbed Dose	Gray (Gy)	rad (rad)	1 Gy = 100 rad
Equivalent Dose	sievert (Sv)	rem (rem)	1 Sv = 100 rem

Note: Equivalent Dose = absorbed dose x radiation weighting factor (weighting factor for x-rays = 1)

All measurements should be in SI units. All radiation output measurements should be recorded as absorbed dose in air [1 R = 8.73 mGy in air].

(Source: ICRP60)

2.4 Certificate of Compliance

A Certificate of Compliance must be completed by the CRE and provided to the owner of the apparatus within 21 days of the date of compliance testing for the purpose of certification for registration, regardless of whether the apparatus has passed or failed. In addition, the CRE must, within a reasonable period after the inspection, issue the owner with a report. The report must include readings and calculations, details of non-compliance with mandatory requirements of *Radiation Guideline 6* and may include recommendations relating to matters outside mandatory requirements in the Guideline (for example, recommended best practice). The report should note any mandatory requirements that are not applicable to the apparatus.

2.5 Minor non-compliance issues

Where an apparatus fails to comply with a mandatory requirement of *Radiation Guideline 6* but may be safely used while the fault is corrected, a CRE may, at their discretion, certify the equipment as compliant. In exercising this discretion a CRE should specify a deadline (not exceeding three months) for the apparatus to be brought to full compliance and may impose restrictions on the use of the apparatus until it is repaired.

SECTION 3—AUTOMATIC EXPOSURE CONTROL

3.1 Backup timer

Aim:

- To ensure that the backup timer is functioning and backup time does not exceed the specified time.
- Where positions of AEC chambers are marked, all chambers are to be individually tested.

Equipment:

- 2 mm lead sheet
- Electronic timer or non-invasive beam analyser

Factors:

- 50 kVp

Method:

- Place the lead sheet between timer and AEC chamber.
- Set automatic exposure control density to 0.
- Expose and note the backup time from the electronic timer.
- Use low mA setting to test time cutoff.
- Use high mA setting to test for mAs cutoff.

Analysis:

- Exposure should terminate before 6 seconds or 600 mAs, whichever occurs first.

3.2 Reproducibility

Aim:

- To assess the variation in radiation output, average kVp and exposure time for a number of exposures of the same object in AEC mode.

Equipment:

- 20 cm water phantom or 2 mm copper
- Dosimeter (small volume chamber) and electronic timer or non-invasive beam analyser
- Three loaded radiographic cassettes
- Densitometer

Factors:

- 80 kVp, 200 mA

Method:

- Position phantom on film receptor.
- Set AEC density to 0.
- Set SID and focal spot to clinical conditions.
- Place dosimeter and electronic timer on tube side of phantom.
- Expose cassette and process film.
- Repeat twice.

Analysis:

- Record density of each radiograph.
- Calculate average and standard deviations for optical density, input exposure and exposure time.
- Coefficient of variation must not exceed 0.05.
- Variation in optical density must not exceed ±0.1 at a density of 1.2.

Note:

- Taping a metal washer, or similar, to the cassette provides a consistent point for density measurements.

3.3 Response time

Aim:

- To measure the minimum response time of the AEC.

Equipment:

- Dosimeter (small volume chamber) and electronic timer or non-invasive beam analyser
- Six sheets of perspex, each 24 cm x 30 cm x 1cm thick

Factors:

- High kVp, high mA (e.g. 120 kVp, 200 mA)

Method:

- Position dosimeter/timer or beam analyser on image receptor.
- Place perspex sheets in front of detector.
- Note exposure time and output.
- Repeat exposures, decreasing perspex thickness each time.
- Keep decreasing perspex thickness until minimum time is reached, i.e. when the time no longer changes as perspex is removed.

Analysis:

- Minimum response time must not exceed 0.02 seconds.

Note:

- Ensure AEC chamber is not obscured by beam analyser.

3.4 Exposure timer

(a) Accuracy

Aim:

- To determine how the exposure time compares with the selected time.

Equipment:

- Digital timer or non-invasive beam analyser

Factors:

- Fixed kVp, fixed mA, (e.g. 70 kVp, 200 mA) variable time

Method:

- Position digital timer or beam analyser at the distance recommended by the manufacturer.
- Collimate to size of detector.
- Make a series of exposures commencing at the shortest exposure time, then across the range of the timer at commonly used settings up to 1 second.

Analysis:

- For intra-oral dental apparatus, measured times must be within ±10% or 20 milliseconds of the indicated value, whichever is the greater, for times within normal working range.
- For all other apparatus measured times must be within ±5% of nominal values.

Notes:

- For half-wave rectified dental apparatus the exposure time must be determined from the time the kV waveform first rises to 75% of the kVp until it falls below this value.
- This test is not required for apparatus where mAs is selected as a single component.

(b) Reproducibility

Aim:

- To determine the variation in exposure time over a number of exposures at the same generator setting.

Equipment:

- Digital timer
- Lead backing sheet

Factors:

- 70 kVp, 20 mAs

Method:

- Position digital timer in primary beam at the distance from the focal spot specified by the manufacturer.
- Place lead sheet under digital timer to absorb backscatter.
- Collimate beam to size of detector.
- Make a minimum of five exposures.
- Check commonly used times.

Analysis:

- Use statistical function on calculator to calculate average and standard deviation.
- Calculate coefficient of variation (C):

$$C = \frac{\text{standard deviation}}{\text{average}}$$

- All values must be within ±5% of average (coefficient of variation <0.05).

Notes:

- If a unit fails output reproducibility other measurements may be meaningless.
- If an appropriate calculator is not available an approximation may be obtained using the formula:

$$C = \frac{(\text{max. value} - \text{min. value})}{2} \div \text{average}$$

- For older apparatus with mechanical switching, turn controls from set positions between exposures and then return to original settings.
- This test is not required for apparatus where mAs is selected as a single component.
- This test may not be necessary if reproducibility of radiation output is acceptable.

3.5 Dead-man exposure switch

Aim:

- To ensure that the exposure is terminated by removing pressure from the exposure switch.

Equipment:

- Electronic timer or non-invasive beam analyser

Factors:

- Low kV, mA, long exposure time (e.g. 1 second)

Method:

- Position timer in the primary beam at 50 cm from focus.
- Initiate exposure and release switch before exposure is terminated.

Analysis:

- Radiation emission must cease when switch is released.
- Measuring instrument will indicate time when exposure is terminated.

SECTION 4—KILOVOLTAGE

4.1 Accuracy

Aim:

- To determine how the measured kVp compares with the generator setting.

Equipment:

- Digital kV meter

Factors:

- Variable kVp, fixed mA, fixed time

Method:

- Position kV meter at the distance recommended by the manufacturer.
- Collimate to size of detector.
- Observe radiation waveform at 70 kVp and obtain hardcopy if possible.
- Make a series of exposures across the clinically used range.

Analysis:

- Check radiation waveform for any unusual characteristics that may affect subsequent measurements.
- Measured kVp_{avg} must be within ±5% of the nominal value.
- For capacitor discharge apparatus kV_{max} must be within ±5% of nominal value.
- For dental apparatus the measured KVp_{avg} must be within ±5KVp of nominal value.

Notes:

- Do not use times below 0.1 seconds.
- If using a non-invasive beam analyser use low sensitivity unless results dictate otherwise.

4.2 Reproducibility

Aim:

- To determine the variation in average kVp over a number of exposures at the same generator setting.

Equipment:

- Digital kV meter
- Lead backing sheet

Factors:

- Clinical setting, for example – 70 kVp, 20 mAs

Method:

- Position kV meter in primary beam at the distance from the focal spot specified by the manufacturer.
- Place lead sheet under meter to absorb backscatter.
- Collimate beam to size of detector.
- Make a minimum of five exposures.

Analysis:

- Use statistical function on calculator to calculate average and standard deviation.
- Calculate coefficient of variation (C):

$$C = \frac{\text{standard deviation}}{\text{average}}$$

- All values must be within ±2% of average (coefficient of variation <0.05).

Notes:

- If a unit fails output reproducibility other measurements may be meaningless.
- If an appropriate calculator is not available an approximation may be obtained using the formula:

$$C = \frac{(\text{max. value} - \text{min. value})}{2} \div \text{average}$$

- For older apparatus with mechanical switching, turn controls from set positions between exposures and then return to original settings.
- This test may not be necessary if reproducibility of radiation output is acceptable.

SECTION 5—RADIATION OUTPUT

5.1 Linearity

Aim:

- To determine the linearity of the radiation output over a range of mA or mAs settings.

Equipment:

- Dosimeter (small volume chamber) or non-invasive beam analyser
- Lead backing sheet

Factors:

- 70 kVp, variable mA, 0.1 s or 70 kVp, variable mAs

Method:

- Position ion chamber in primary beam at 75 cm from focal spot (record actual distance) or beam analyser at distance specified by manufacturer.
- Set dosimeter to Exposure mode (Total or Integrate).
- Place lead sheet under chamber to absorb backscatter.
- Collimate beam to size of chamber.
- Measurements should be made at as many mA or mAs stations as practicable.

Analysis:

- Calculate μGy/mAs (X) by dividing output by the nominal mAs.
- Determine X_{max} and $X_{min.}$
- Calculate linearity coefficient:

$$\text{linearity coefficient} = \frac{X_{max} - X_{min}}{X_{min} + X_{max}}$$

- Linearity coefficient must not exceed 0.1.

Notes:

- kVp should be measured at each mA station to assess kVp compensation.
- Linearity should be measured for both/all focal spot(s) sizes as μGy/mAs may vary.
- This test does not directly check if mA stations have been correctly calibrated.
- For mammography, appropriate kVp and distance factors should be used.

5.2 Programmed timer

Aim:

- To determine the linearity of the radiation output over a range of clinically used timer settings.

Equipment:

- Dosimeter (small volume chamber) or non-invasive beam analyser

Factors:

- Full range of clinically used timer settings

Method:

- Make a minimum of five exposures.
- Calculate coefficient of linearity using the formula in 5.1 above (if time is not displayed on control, use time chart supplied by manufacturer).

Analysis:

- Coefficient of linearity must not exceed 0.1.

Notes:

- Readings should be taken on the different patient type settings with all other factors constant, to ensure satisfactory operation.
- Readings should be taken on each film type setting with all other factors constant, to ensure satisfactory operation.

5.3 Reproducibility

Aim:

- To determine the variation in radiation output over a number of exposures at the same generator setting.

Equipment:

- Dosimeter and appropriate ionisation chamber or non-invasive beam analyser
- Lead backing sheet

Factors:

- 70 kVp, 20 mAs
- for intra-oral dental: fixed kVp, fixed mA, 0.1 seconds.

Method:

- Position the ion chamber in the primary beam at 75 cm from focal spot (record actual distance) or beam analyser at the distance specified by the manufacturer.
- Set dosimeter to Exposure mode (Total or Integrate).
- Place lead sheet under chamber to absorb backscatter.
- Collimate beam to size of chamber.
- Make a minimum of five exposures.

Analysis:

- Use statistical function on calculator to calculate average and standard deviation.
- Calculate coefficient of variation (C):

$$C = \frac{\text{standard deviation}}{\text{average}}$$

- All values must be within ±5% of average (coefficient of variation <0.05).

Notes:

- If a unit fails output reproducibility other measurements may be meaningless.
- For older apparatus with mechanical switching turn controls away from set positions between exposures and return to original settings.
- If an appropriate calculator is not available an approximation may be obtained using the formula:

$$C = \frac{(\text{max. value} - \text{min. value})}{2} \div \text{average}$$

SECTION 6—COLLIMATION

6.1 Radiographic apparatus

Aim:

- To ensure coincidence of the radiation field with the light field.
- To assess the perpendicularity of the primary beam with the image receptor.

Equipment:

- Loaded cassette
- Collimator alignment test tool or metal markers to delineate edges of light field
- Perpendicularity test tool

Factors:

- 50 kVp, 10 mAs or similar low factors depending on film/screen combination

Method:

- Position cassette at 1 m SID, adjust light field to alignment marks on test grid, or collimate to approximately two-thirds of cassette size and mark the edges of the light field.
- Mark cathode end of tube for orientation.
- Place perpendicularity test tool in centre of the light field.

Analysis:

- The irradiated area should be within ±1% of the distance from the focus-to-image receptor in all directions.
- The image of the upper bead in the perpendicularity test tool should fall within 5 mm of the lower bead or ring.

Notes:

- Repeat with collimator rotated 90°.
- Repeat for each focus.
- This method can also be used to assess alignment of primary beam with bucky tray by placing a second cassette in the bucky tray and exposing simultaneously using an exposure time greater than 0.1 seconds.
- X-ray assembly and collimator should be visually inspected to assess perpendicularity before starting alignment test.

6.2 Fluoroscopic apparatus

Aim:

- To ensure that the primary beam is confined to the image receptor area.

Equipment:

- Loaded radiographic cassette or non-screen film
- Masking tape
- Tape measure

Factors:

- Low or ABC

Method:

- Maximise SID.
- Ensure collimators are fully open.
- Place cassette or non-screen film as close as possible to image intensifier (II) input surface.
- Expose cassette under ABC for 1–2 seconds to produce an optical density of approximately 1.0.
- Process film and measure dimensions of the x-ray field.
- Record dimensions of image on TV monitor.
- Repeat for all II field sizes.
- Repeat with minimum SID.
- Compare area exposed on film with area viewed on the TV monitor at both maximum and minimum SID for all II field sizes.

Analysis:

- The primary beam must not fall outside the image receptor under any circumstances.
- The collimator must automatically limit the primary beam to the field size selected regardless of SID.
- The field size viewed on the TV monitor should be within ±10% of the selected field size.
- The primary beam must be centred to the II field; the centre of the II field must appear as the centre of the image on the TV monitor.

6.3 Intra-oral dental apparatus

Aim:

- To assess the diameter of the primary beam at the end of the cone.

Equipment:

- Radiographic film of appropriate size

Factors:

- Low

Method:

- Place cone in direct contact with film surface and expose.

Analysis:

- Beam diameter must not exceed 60 mm.
- If beam is not circular, maximum diagonal dimension must not exceed 60 mm.

Notes:

- Where processing facilities are not available a fluorescent screen may be used to assess beam size.

6.4 Panoramic apparatus

Aim:

- To ensure that the dimensions of the primary beam at the secondary collimator do not exceed, yet adequately cover, the dimensions of the slot of the secondary collimator.

Equipment:

- Two pieces of radiographic film of a size large enough to cover the slot in the secondary collimator

Factors:

- Low

Method:

- Place one film behind the slot of the secondary collimator and the second film in front, ensuring the entire slot is covered and the film cannot move during exposure; mark each film for identification.
- Expose film (a full scan is not necessary).

Analysis:

- Superimpose the processed films, aligning the slit images; the dimensions of the slit on both films should be equivalent.

Notes:

- Where it is difficult to perform this test on an apparatus, it is sufficient to measure the radiation field with the front film only, provided the film can be directly related to the slit, via the use of orientation markers.

6.5 Cephalometric apparatus

Aim:

- To ensure that the dimensions of the primary beam at the image receptor plane do not exceed the prescribed dimensions.

Equipment:

- 350 mm x 350 mm film or larger

Factors:

- Low

Method:

- Place film at receptor plane and expose.

Analysis:

- Where possible the dimensions of the image should not exceed 180 mm x 240 mm and in all cases must not exceed 240 mm x 300 mm. In certain circumstances use of a larger field may be approved after the apparatus has been assessed by a CRE and the details of that assessment have been provided to the Authority. The Authority must be satisfied that such a practice does not cause a safety risk to any person.

6.6 Intensity of collimator light source

Aim:

- To measure the intensity of the light output of the collimator.

Equipment:

- Light meter

Method:

- With collimator fully open, turn on light.
- Position light meter detector at 1 m from focal spot.
- Take reading in each quadrant of light field to determine uniformity.

Analysis:

- The illuminance of the light field must be not less than 100 lux at 1 m.

Notes:

- Ensure detector is parallel to anode-cathode axis.
- Ambient room light should be as low as possible.

6.7 Dark shutter (condenser discharge apparatus)

Aim:

- To assess function of the dark shutter and measure any leakage.

Equipment:

- Dosimeter (large volume chamber)

Factors:

- Maximum kVp, minimum mAs

Method:

- Position chamber 5 cm below face of collimator with shutters fully open.
- Take one reading immediately on charging the unit.
- Take one reading immediately after discharge.

Analysis:

- Neither reading must exceed 0.02 mGy/hr.

SECTION 7—TEST PROTOCOLS: HALF-VALUE LAYER

7.1 Half-value layer

Aim:

- To assess the x-ray beam quality and determine the adequacy of filtration.

Equipment:

- Dosimeter (small volume chamber) or non-invasive beam analyser
- Lead backing sheet
- Aluminium filters (Grade 1100)
- Tape for positioning filters

Factors:

- 70–100 kVp, fixed mAs

Method:

- Remove all optional or easily removable filtration.
- Position ion chamber in primary beam at least 75 cm from focal spot or beam analyser at distance specified by manufacturer.
- Set dosimeter to Exposure mode (Total or Integrate).
- Place the lead sheet under the chamber to absorb backscatter.
- Collimate the beam to the size of the chamber.
- Make three exposures with no filters added (free in air), then take the average.
- Tape 1 mm of the aluminium filter on the face of the collimating device.
- Repeat exposures with 2, 3 and 4 mm aluminium filters.

Analysis:

- Plot exposure against thickness of filter.
- Halve the average free in air exposure and determine corresponding thickness of aluminium from graph.
- The HVL must not be less than the values indicated in Table 7.1.

Notes:

- kVp should be checked before HVL assessment.
- If using a non-invasive beam analyser only two measurements are usually required. The HVL will be calculated following the second measurement, provided the tube voltage and exposure time have not varied significantly.
- Any removable filters should be removed prior to HVL determination.

- For undertable fluoroscopic tubes, position the chamber midway between table top and image receptor and place aluminium filters on the table top under the chamber.
- Ensure entire beam is intercepted by filters.
- For intra-oral dental apparatus, aluminium filters should be taped over the open end of the cone.

TABLE 7.1 HALF-VALUE LAYERS

X-ray tube voltage (kVp)	Minimum HVL (mmAl)
<50	*
50	1.5
60	1.8
70	2.1
80	2.3
90	2.5
100	2.7
110	3.0
120	3.2
130	3.5
140	3.8
150	4.1
>150	*

*These half-value layers should be obtained by linear extrapolation.

SECTION 8—TEST PROTOCOLS: RADIATION OUTPUT

8.1 Leakage radiation

Aim:

- To measure any leakage radiation through the x-ray tube assembly and beam limiting device.

Equipment:

- Dosimeter (large volume chamber)
- Fluorescent screen or non-screen film

Factors:

- Maximum kVp, 100 mAs (time should not exceed 1 second). Ensure tube rating is not exceeded.

Method:

- Collimator should be fully closed or covered with 20 HVL of lead.
- Position chamber 1 m from focal spot and make exposures at positions, including cathode, anode and front of tube assembly.
- Calculate time averaged leakage using tube duty cycle or cooling curve data.

Analysis:

- For dental apparatus used with intra-oral image receptors, leakage radiation must not exceed 0.25 mGy in an hour at a distance of 1 m from the focus.
- For all other apparatus, leakage radiation must not exceed 1.0 mGy in an hour at a distance of 1 m from the focus, taking into account the tube duty cycle.

Notes:

- An incorrectly positioned x-ray tube insert or flaws in the lead shielding in a housing may give rise to narrow but intense beams of leakage radiation which fail to ionise the entire chamber and therefore appear not to exceed the specified limit; such beams are highly undesirable and the cause should be remedied.
- Pinhole leaks or ‘hotspots’ can be detected by the use of a fluorescent screen or non-screen film wrapped around the x-ray tube assembly.

8.2 Maximum absorbed dose in air

Aim:

- To measure the maximum radiation output from an x-ray tube in the fluoroscopic mode.

Equipment:

- Dosimeter (small volume chamber) or beam analyser

Factors:

- Maximum kVp and mA

Method:

- Minimise SID.
- Place chamber at the position appropriate for that apparatus (see Table 8.1).
- Set dosimeter to Rate mode.
- Ensure chamber is central to the x-ray field (use ABC to check).
- Protect image intensifier by covering with at least 2 mm of lead.
- Irradiate chamber at maximum kVp and mA until dosimeter reading stabilises.

Analysis:

- For all systems where Automatic exposure control (AEC) is not provided, and for systems used exclusively for paediatric aims, the absorbed dose in air must not exceed 50 mGy/min.
- Where AEC is provided the absorbed dose in air must not exceed 100 mGy/min.
- Where a boost or high dose facility is activated the absorbed dose in air must not exceed 150 mGy/min.
- Where a boost or high dose facility is activated it must be restricted to a maximum of 20 seconds, after which it must return to normal fluoroscopic mode

Notes:

- Ensure that the II is completely covered with lead to avoid damage.

TABLE 8.1 DETECTOR POSITIONS FOR MEASUREMENT OF MAXIMUM ABSORBED DOSE IN AIR

	Condition	Detector Position
1	X-ray tube permanently UNDER table	ON the table
2	Image Intensifier permanently UNDER table	300 mm ABOVE table top
3	C or U arm apparatus (no permanent table)	300 mm from image intensifier but not less than 400 mm from focal spot
4	X-ray tube and image intensifier moveable around table	400 mm from focal spot

8.3 Scatter radiation

(a) Radiographic/fluoroscopic apparatus

Aim:

- To determine that sufficient shielding is provided for all occupied areas.

Equipment:

- Dosimeter (large volume chamber)
- 20 cm water phantom

Factors:

- 100 kVp, 100 mAs (or similar factors)

Method:

- Collimate primary beam to phantom size.
- Position chamber at 1 m horizontally from centre of phantom and take measurement (use this as a reference).
- Take a measurement immediately outside control area.
- Take a measurement inside control area.
- Repeat for other areas where adequacy of shielding is to be determined.

Analysis:

- Determine weekly dose based on workload.
- Shielding should ensure that radiation dose does not exceed the limits prescribed in Schedule 2 of the Radiation Control Regulation 2003.

Notes:

- Beware of backscatter. Ensure that the dimensions of the protective shield are adequate to fully intercept leakage radiation from the x-ray tube assembly and scattered radiation from the patient.

(b) Computed tomography and bone mineral densitometers

Aim:

- To determine that sufficient shielding is provided for occupied areas.
- To determine accuracy of isodose curves supplied by manufacturer.

Equipment:

- Dosimeter (large volume chamber)
- Appropriate body phantom

Factors:

- Maximum kVp, mA and scan time
- 10 mm CT slice thickness

Method:

- Position phantom centrally within scan field.
- Position chamber 1 m from centre of field at 45° to phantom and take measurement.
- Take a measurement at the end of the couch.
- Take a measurement immediately outside control area.
- Take a measurement inside control area.
- Repeat for other areas where adequacy of shielding is to be determined.

Analysis:

- For measurement of scatter radiation in CT facilities a phantom with minimum diameter of 360 mm must be used; clinical abdominal scanning parameters should be employed.
- Determine weekly dose based on workload and average scans per patient.
- Shielding should ensure that radiation dose does not exceed the limits prescribed in Schedule 2 of the Radiation Control Regulation 2003.
- Measurements should approximate isodose curves supplied by manufacturer.

SECTION 9—TEST PROTOCOLS: RESOLUTION

9.1 High contrast resolution

Aim:

- To assess the ability of the fluoroscopic imaging system to display high contrast information.

Equipment:

- Line pair gauge
- 20 cm water phantom

Factors:

- ABC or 70 kVp, 1 mA

Method:

- Place line pair gauge directly onto centre of image receptor surface at 45° to the grid and to the raster lines.
- Collimate to gauge, place the water phantom in the beam and note the number of line pairs visible on the monitor.
- Monitor should be viewed from a distance of 4 times the screen diameter, in ambient light.

Analysis:

- The high contrast resolution of the live image must not be less than the following values:

TABLE 9.1 HIGH-CONTRAST RESOLUTION

Apparatus	Field size (cm)	Resolution (line pairs/cm)
New	11 to < 18	18
	18 to < 26	16
	26 to <30	14
	30 to 36	12
	>36	10
Existing	≤ 25	12
	> 25	10

Notes:

- This is a subjective test that can be affected by room lighting, monitor contrast and brightness settings and orientation of test gauge.
- This test must be performed without any time integration or image enhancement.

9.2 Low contrast resolution and image distortion

Aim:

- To assess the ability of the fluoroscopic imaging system to display low contrast information.
- To assess any image distortion.

Equipment:

- Westmead test object (or equivalent)
- 20 cm water for acceptance testing of new apparatus
- 2 mm copper for routine QA

Factors:

- ABC or 70 kVp, 1 mA

Method:

- Set SID at normal operating distance or 100 cm.
- Place test object directly onto centre of image receptor at 45° to the raster lines.
- Place water or copper in the beam on the table top or on the test object.
- Monitors should be viewed from a distance of four times the screen diameter in ambient light.
- Adjust monitor brightness and contrast settings to optimum *(see Notes below)*.
- View all field sizes and record the following:
  (a) field size
  (b) distortion – note any 'S' or pin cushion distortion
  (c) contrast threshold: the number of large circles detectable on the live image
  (d) contrast detail – the number of hole sizes visible from the contrast detail portion of the test object on the live image.

Analysis:

- Field size should be within ±1 cm of nominal size.
- The low contrast threshold must not be less than 4%.
- Minimum contrast detail for the clinical field size used should not be less than the following:
  (a) general fluoro – 6 holes (1.5 mm)
  (b) interventional application – 7 holes (1.0 mm).

Notes:

- These are subjective tests which can be affected by room lighting, monitor contrast and brightness settings and orientation of test object.
- This test must be performed without any time integration or image enhancement.
- If possible, hard copy images should be taken.
- Optimal adjustment of TV monitor is best done using the following method:
  (a) turn contrast to zero
  (b) turn brightness until image is just not visible
  (c) adjust contrast until both circles are visible.
- As most image intensifiers do not display an area as large as quoted, the manufacturer should be consulted for the exact size.

SECTION 10—MEAN CT NUMBER, NOISE AND UNIFORMITY

10.1 Mean CT number, noise and uniformity

Aim:

- To determine the mean CT number, noise and uniformity of an image.

Equipment:

- CT phantom

Factors:

- Appropriate clinical factors

Method:

- Position phantom in centre of gantry within scan field.
- Scan phantom.
- Select a region of interest (ROI) at the centre of the image and determine the mean CT number and standard deviation of pixels in ROI (noise).
- Compare the mean CT numbers of the ROI in the central position with those in the outer ROI.
- Repeat at three other positions within ROI.

Analysis:

- Noise should not deviate from baseline values by more than ±10% or 0.2 Hounsfield unit (HU) whichever is larger.
- Mean CT number in the central region of interest should fall within ± 4 HU of the baseline value.
- The difference between the mean CT numbers of the central ROI and the outer ROI should not vary by more than 2 HU from those of the baseline values.

Notes:

- All significant settings of radiation apparatus and accessories should be recorded to ensure duplication in future testing.
- Select positions in the ROI corresponding to 3, 6, 9 and 12 o'clock to allow for easy duplication.
- A decrease in noise may be the result of an unnoticed increase in dose.
- Most CT systems have in-built software which performs the above tests using a special calibration phantom.

SECTION 11—TEST PROTOCOLS: PATIENT DOSE EVALUATION

11.1 Radiographic examinations

Aim:

- To evaluate the patient dose for typical radiographic examinations to typical patient sizes.

Equipment:

- Dosimeter (small volume chamber)
- Lead backing sheet

Factors:

- Nominal factors for standard size patient (70 kg)

Method:

- Position chamber in centre of beam at appropriate focus-to-skin distance.
- Place lead backing sheet under chamber.
- Use standard collimation.
- Initiate exposure and record results.

Analysis:

- The skin entrance dose should not exceed the reference values in Table 11.1.

Notes:

- The skin surface entrance doses in Table 11.1 are in air with backscatter for conventional film-screen combinations up to 200. For faster film-screen combinations (400–600) the values should be reduced by a factor of 2–3.
- Doses in excess of the guidance levels should be based on sound clinical judgement.

TABLE 11.1 DIAGNOSTIC REFERENCE LEVELS FOR RADIOGRAPHIC EXAMINATIONS FOR A STANDARD SIZE PATIENT (70 KG)

Examination	Surface entrance dose per radiograph with backscatter (mGy)	
Lumbar Spine	AP	10
	Lat	25
	LSJ	30
Chest	PA	0.4
	Lat	1
Pelvis	AP	8
Abdomen, IV urography & cholecystography	AP	8
Skull	AP	5
	PA	5
	Lat	3

PA Posterio–anterior

AP Anterio–posterior

Lat Lateral projection

LSJ Lumbo–sacral joint projection

11.2 Fluoroscopic examinations

Aim:

- To evaluate the patient dose for typical fluoroscopic examinations.

Equipment:

- Dosimeter
- Standard patient equivalent phantom (20 cm water)

Factors:

- ABC or manual factors commonly used

Method:

- Position chamber on table in centre of field.
- Using appropriate supports, place phantom above chamber.
- Adjust collimator so edges are just visible on monitor.
- Set dosimeter to Rate mode.
- Activate image intensifier long enough for dosimeter reading to stabilise.
- Record exposure rate in all modes.

Analysis:

- Dose rates should not exceed the guidance values in Table 11.2.

Notes:

- Values in Table 11.2 include backscatter and relate to a 23 cm field size.
- Record indicated mA and kVp, collimation, carriage height, etc. for future reference.
- For overtable tubes or C-arm systems the chamber should be positioned as per Table 8.1 and source-to-chamber distance should be noted.

TABLE 11.2 DOSE GUIDANCE LEVELS FOR FLUOROSCOPIC EXAMINATIONS

Mode of operation	Surface entrance dose rate* (mGy/min)
Normal II field size >17cm	17
Normal II field size ≤ 17cm	25
High Level	100

* in air with backscatter

11.3 CT examinations

Aim:

- To evaluate the scanner output for typical CT examinations by measuring the CT Dose Index (CTDI)[1]

[1] EC, Report EUR 16262, *European Guidelines on Quality Criteria for Computed Tomography*, 1999.

Equipment:

- Pencil ion chamber with at least 10 cm length of active volume
- CT dosimeter phantom (see Notes)

Factors:

- Appropriate clinical factors for the procedures to be tested, including pitch

Method:

- Centre and align the appropriate CTDI phantom in the gantry with long axis within 2 mm of scanner centre line in both horizontal and vertical planes and CT scan plane in the centre of phantom.
- Scan to check alignment.
- Insert the ion chamber in the centre of phantom and repeat at peripheral locations.
- Scan a single axial CT rotation without movement of the table.
- Calculate the CTDI, $CTDI_w$ and $CTDI_{vol}$

$$CTDI = \frac{c.L.D}{T}$$

where c = ion chamber calibration factor
L = length of chamber active volume
T = CT slice thickness
D = measured dose from single scan (mGy).

Analysis:

- The CTDI should not exceed the guidance values in Table 11.3.

TABLE 11.3 SOME DIAGNOSTIC GUIDANCE LEVELS FOR CT PROCEDURES[2]

Examination	CT Dose Index$_w$ (mGy)	Dose Length Product (mGy cm)
Routine Head	60	1050
Routine Chest	30	650
Routine Abdomen	35	780
Routine Pelvis	35	570

[2] Nagel HD, ed. Radiation Exposure in Computed Tomography: Fundamentals, Influencing Parameters, Dose Assessment, Optimisation, Scanner Data, Terminology. 4th ed. Hamburg: CTB Publications, 2002.

Notes:

- A CTDI phantom is a 14–16 cm long acrylic (polymethyl methacrylate) cylinder with diameter 16 cm (head), 32 cm (body) or 8 cm (paediatric). Holes are drilled for placement of the pencil ion chamber. One hole is at the centre and four others located at a depth of 1 cm below the surface of the phantom at the 3, 6, 9 and 12 o'clock positions. Acrylic rods are inserted into all holes except at the position where the dose is to be measured.
- $CTDI_c$ is the CTDI measured at the central location while $CTDI_p$ is the average CTDI measured at the peripheral locations.
- $CTDI_w = 1/3\ CTDI_c + 2/3\ CTDI_p$.
- $CTDI_{vol} = CTDI_w/p$ where p = pitch.
- Dose length product (DLP) = CTDI x scan length (mGy.cm) for an examination.
- An alternate measurement, the CTDI in air, does not require a phantom as the dose is measured using the pencil ion chamber placed in-air at the gantry centre of rotation. This method may be used in conjunction with software to determine the effective dose, provided the scan regions of the patient are accurately known.
- Because of the expense of the CTDI phantom, CTDI air should be adequate for baseline constancy tests.

11.4 Intra-oral dental examinations

Aim:

- To determine the radiation exposure at the skin surface for a typical examination.

Equipment:

- Dosimeter (small volume chamber) or beam analyser

Factors:

- Bite-wing exposure

Method:

- Position chamber in primary beam at 10 mm from end of cone and expose.

Analysis:

- Skin entrance exposure for a bite-wing should be in the range of 2–3 mGy and must not exceed 5 mGy for any intra-oral radiograph.

Notes:

- Ensure entire active volume of chamber is irradiated.

SECTION 12—QUALITY ASSURANCE

12.1 Focal Spot

Aim:

- To ensure that image resolution is not degraded by enlargement of the focal spot.

Equipment:

- Pin-hole camera (focal spot > 0.3 mm) or star test pattern (focal spot ≥0.3 mm)

Factors:

- 75 kVp, 10 mAs

Method:

- As per test tool manufacturer's instructions.

Analysis:

- Determine apparent focal spot size as per instructions.
- Tolerance limits are given in Table 12.1.

Notes:

- Measurement should be performed for each focus.

TABLE 12.1 FOCAL SPOT TOLERANCES

Nominal size of focal spot (mm)	Tolerance minus	Tolerance plus
<0.8	0	50%
0.8 – 1.5	0	40%
>1.5	0	30%

12.2 Image viewing

Aim:

- To ensure the level of light intensity emitted by the viewing box is adequate and sufficiently uniform.

Equipment:

- Light meter with luminance detector

Method:

- Visually check for any inconsistencies in colour or brightness.
- Place detector over centre of viewing box and record luminance.
- Repeat in each quadrant of viewing box.

Analysis:

- The minimum luminance in the centre and each quadrant of the viewing box should be >1000 nit (candela.m^{-2}).
- The five luminance levels should be within ±10% of mean value.
- The colour of the viewing box should be white or blue and should be consistent throughout a complete set.

REFERENCES AND FURTHER READING

Australian Radiation Protection and Nuclear Safety Agency & National Occupational Health & Safety Commission, 2002, Recommendations for Limiting Exposure to Ionizing Radiation (1995) (Guidance Note [NOHSC:3022(1995]) and National Standard for Limiting Exposure to Ionizing Radiation [NOHSC:1013(1995)], Radiation Protection Series Publication No. 1, ARPANSA, Yallambie, Victoria.

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Note: The Australian Radiation Protection and Nuclear Safety Agency is publishing the Radiation Safety Series to replace over time the documents comprising the National Health & Medical Research Council Radiation Health Series.

DEFINITIONS

In this Guideline:

ABC means automatic brightness control

Act means the *Radiation Control Act 1990*

AEC means automatic exposure control

Absorbed dose means energy delivered from radiation per unit mass of absorbing material, measured in Gray (Gy) or mGy. One Gray equals one joule per kilogram

Added filtration means quantity indicating the *filtration* affected by added filters in the useful beam, but excluding *inherent filtration*

Air kerma means *kerma* measured in a mass of air

Authority means the NSW Environment Protection Authority

Coefficient of variation means the standard deviation divided by the mean of a set of numbers

Coefficient of linearity equals $((X_{max}-X_{min})/(X_{max}+X_{min}))$ where Xi = μGy/mAs for exposure setting 'i'

CRE means consulting radiation expert

CT means computed tomography

CTDI means CT dose index, the integral of the dose profile along a line perpendicular to the tomographic plane from *7T* to *+7T* (where *T* is the nominal slice thickness), divided by the product of the nominal slice thickness and the number of tomograms (N) produced in a single scan

Filtration means modification of the spectral distribution of an x-ray beam as it passes through matter by the differential absorption of poly-energetic photons

Fluoroscopic apparatus means radiation apparatus that emits ionising radiation, as defined in the Act, used for the purpose of fluoroscopy or radioscopy. (It should be noted that Standards Australia and the International Electrotechnical Commission have adopted the term 'radioscopic', but for the purposes of this document the term 'fluoroscopic' is used.)

Focal spot means the area of the *target* from which x-rays are emitted

Half-value layer (HVL) means the thickness of a specified material that reduces the exposure rate of a given x-ray beam to half its original value

Inherent filtration means the *filtration* affected by the irremovable materials of an *x-ray tube assembly* (i.e. glass, oil and port seal), through which the radiation beam passes before emerging from the x-ray tube assembly. It is expressed in terms of thickness of a reference material that, at a specified potential difference and waveform, gives the same radiation quality in terms of *half-value layer*

Kerma (K) means Kinetic Energy Released in a material by ionising radiation and is determined as the quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all the charged ionising particles liberated by uncharged ionising particles in a material of mass dm ($K = dE_{tr}/dm$). The unit of kerma is the gray (Gy), or joule per kilogram

Kerma rate means kerma per unit time and is determined as the quotient of dK by dt, where dK is the increment of kerma in the time interval dt

Optical density (OD) means the degree of film blackening produced during development, where optical density is the log of the reciprocal of the fraction of light transmitted through the blackened film

Operator means a person licensed under Section 6 of the Act to use ionising radiation apparatus

owner means the owner of the radiation apparatus to which Section 7 of the Act applies

Phantom means the test object that simulates the average composition of various structures

Primary beam means all ionising radiation that emerges through the specified aperture of the protective shielding of the x-ray tube and the collimating device

Radiographic apparatus means ionising radiation apparatus, which emits ionising radiation, used for the purpose of radiography

Radiation leakage means ionising radiation transmitted through the protective shielding of a radiation source other than the primary beam

Radiation quality means a characteristic of radiation determined by its spectral distribution that controls its penetration. It depends on the magnitude and waveform of the tube's potential difference and the *total filtration*, and is described in part by its *half-value layer*.

Regulation means the Radiation Control Regulation 2003

Scattered radiation means ionising radiation produced from the interaction of electromagnetic ionising radiation with matter. It has a lower energy than or a different direction from that of the original incident ionising radiation.

SID means source-to-image receptor distance. This is the same as focus-to-image receptor distance and focus-to-film distance.

Target means the area of the anode which is struck by the electrons from the cathode

Total filtration means the sum of *inherent filtration* and *added filtration* between the radiation source and the patient or other defined plane

X-ray tube assembly means the *x-ray tube housing* with an *x-ray tube insert*, but not including a collimating device

X-ray tube housing means a container in which an x-ray tube is mounted for normal use, providing protection against electric shock and against ionising radiation except for an aperture for the useful beam. It may contain other components.

X-ray tube insert means a highly evacuated vessel for the production of x-radiation by the bombardment of a *target*, usually contained in an anode, with a beam of electrons accelerated by a potential difference

X-ray tube potential difference means the peak value of the potential difference applied to the *x-ray tube,* expressed as kilovolts peak (kVp)

Unless otherwise defined, all words in this Guideline have the same meaning as in the Act and the Regulation