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QC IN MAMOGRAPHY A SURVEY IN ITALY

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THE COMMISSIONING AND ROUTINE TESTING OF MAMMOGRAPHIC X-RAY SYSTEMS

A protocol produced by a Working Party of the Diagnostic Radiology Topic Group, **Institute of Physical Sciences in Medicine**

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CONTENTS

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The production of this protocol has been stimulated by the introduction of a programme of breast cancer screening in the United Kingdom, following publication of the Forrest Report (DHSS, 1986a). The Hospital Physicists' Association has already published a series of protocols (HPA, 1980-1985) to help establish uniform methods of assessing diagnostic X-ray equipment, but these are not specific to mammographic X-ray equipment. Accordingly, a Working Party of the Diagnostic Radiology Topic Group of the Institute of Physical Sciences in Medicine was established in October 1987 to produce a protocol for mammography. This document is the result.

The aim of the protocol is to provide methods for the commissioning and routine testing of mammographic X-ray systems which can be adopted nationally. It will be of use to medical physicists and medical physics technicians and also to X-ray engineers, radiographers, radiologists and other staff who have a responsibility for the testing of this equipment. However, it is recognised that at the present time, there is only limited knowledge of quality assurance applied to mammography and that the procedures described in this document will need revision in the light of experience.

The protocol gives guidance on the quality system and includes checks and measurements on the X-ray machine, automatic processing unit and screen-film receptor and the assessment of the overall performance of the mammographic X-ray system. Where relevant the commissioning tests are dealt with first, followed by discussion of which ones are pertinent as routine tests. All the tests, together with suggested frequencies are summarised in Appendix I. Throughout the text an attempt has been made to give a reasonable amount of practical detail and the style of a handbook has been adopted.

The Forrest Working Group stressed the importance of training of all the professions involved in providing the screening service. This protocol is an aid to the practical training of medical physicists, medical physics technicians, X-ray engineers, radiographers and other staff.

Although the need for guidance has arisen from the breast screening programme, it is hoped that this protocol will be used in the assessment of all mammographic X-ray units, whether they are used for screening or diagnosis and so help to achieve uniformly high standards of performance, both in the National Health Service and the private sector.

1.1 Mammography

Mammography is the X-ray examination of the breast. Low energy X-radiation is used to provide adequate contrast in the image because the various tissues of the breast have similar attenuation coefficients (Johns and Yaffe, 1987). At the present time, the majority of mammographic images are produced using a screen-film combination, exposed to X-rays generated at peak voltages in the range 25 to 32 kV. Xeroradiography is not commonly used in the UK and is not addressed in this document. The potential of ionography, computed tomography and digital radiography is still to be realised. Reviews of mammographic imaging, physics and technique have been given in NCRP (1980), Parsons (1983) and NCRP (1986).

1.2 United Kingdom Breast Cancer Screening Programme

A national breast cancer screening programme is being introduced in the United Kingdom at the present time, following the publication of the Forrest Report (DHSS, 1986a). The main conclusions of the Forrest Working Group that are pertinent to mammography were:

(i) Women aged 50 to 64y should be offered screening by mammography at 3 year intervals in the first instance.

(ii) High quality, single medio-lateral oblique view mammography should be used.

(iii) Adequate arrangements for quality control within and between centres is required to maintain an acceptable standard of mammography. Reference centres to control the quality assurance programme were suggested.

(iv) Mammography should not be undertaken without a high level of expertise.

(v) Training of staff is essential.

(vi) A basic screening unit could screen 12,000 women per year, serving a population of 41,500 women aged 50 to 64y within a total population of nearly half a million. This implies a requirement for about 120 basic screening units throughout the UK.

(vii) A substantial capital investment in equipment and buildings would be needed.

On publication of the Forrest Report the Government decided that at least one screening centre in each of the 14 Health Regions should be operating by March 1988 with the remainder by March 1990. Consequently there has been a great deal of activity at national level to deal with the many issues raised by the programme, and a National Breast Cancer Screening Advisory Committee has been formed. A sub-committee of the DHSS Radiological Advisory Committee has been set up to consider quality assurance in mammography (DHSS, 1988a).

Training is essential in maintaining high standards and to this end six national training centres have been established. The Royal College of Radiologists and the College of Radiographers have each drawn up a training syllabus (DHSS, 1988a).

1.3 Importance of Quality Assurance

Quality assurance is important to any radiographic examination (WHO, 1982), whether for screening or diagnosis and its application to radiology in its widest sense has been suggested (Hendra, 1986).

Quality assurance was seen by the Forrest Working Group as an essential element in the breast screening programme. It was considered vital, not just in relation to mammography, but to all aspects of the screening programme. It is particularly important in mammography because the examination is so demanding technically.

Guidelines on the establishment of a quality assurance system for screening mammography have been produced (DHSS, 1988a) but there is every reason to apply the same principles to all mammographic examinations. Quality assurance is discussed more fully in Chapter 2.

1.4 Importance of Safety

The importance of safety is emphasized by the Health and Safety at Work, etc. Act 1974 (HMSO, 1974). The more recent regulations governing radiation safety (HMSO, 1985) now place a legal obligation on an employer to be sure that X-ray equipment is radiologically safe. It is stated in the Guidance Notes for the Protection of Persons against Ionising Radiations arising from Medical and Dental Use (NRPB, 1988, para. 4.1) that diagnostic X-ray equipment cannot be considered safe from a radiation point of view unless it is in good order both mechanically and electrically. Thus maintenance and mechanical and electrical safety checks are complementary to radiation safety checks.

In the breast screening programme there will be both mobile and fixed units. The X-ray sets in the mobile units will be subjected to additional vibration and movement and this will have implications in the commissioning and routine testing of the X-ray machines. Guidance on the safe aspects of the use of trailers is given in DHSS (1987).

CHAPTER 2. QUALITY ASSURANCE

.1 Introduction

The term 'quality assurance' has been applied increasingly to diagnostic radiology, but not always with a consistent meaning. In the past it has often been regarded as being synonymous with quality control, although they are not the same. Quality assurance has often been taken to mean routine performance testing of X-ray equipment, but its meaning is much broader and this is recognised in the Forrest Report (DHSS, 1986a) and the DHSS Guidelines on a Quality Assurance System (DHSS, 1988a).

An effective quality system (IEC, 1988) will help to achieve and maintain:

a) Radiological information of adequate quality for medical diagnostic purposes.

b) Minimum radiation dose to the patient and medical staff, compatible with adequate quality of the radiological information.

c) Maximum cost containment by minimising wastage of time and resources (e.g. reduction of rejected films).

Benefits may also arise through the enhancement of the professional and public reputation of the department.

2 Definition of terms

Quality assurance may be defined (BSI, 1987) as all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality. Quality assurance has two components, namely (i) quality management which is that aspect of the overall management function that determines and implements quality policy and (ii) quality control which is the operational techniques and activities that are used to fulfil the requirements for quality.

In these definitions, quality refers to the total features and characteristics of a product or service that bears on its ability to satisfy stated or implicit needs and the quality policy is the overall quality intentions and direction of an organisation with regard to quality, as formally expressed by management.

These terms apply equally to radiology departments and the DHSS Guidelines (DHSS, 1988a) reflect this.

Quality management begins with the specification of an X-ray system and guidance has been given regarding mammographic screening equipment (DHSS, 1987). The specification forms part of the procurement contract, together with general technical requirements (DHSS, 1986b). At installation, the equipment must undergo acceptance testing. This is the process of verifying that the contractor has performed adequate tests to demonstrate that the specified requirements in the contract have been met (DHSS, 1985 and 1988b). The onus is on the contractor to undertake the tests. Acceptance may be a matter simply of completing a checklist. Any significant discrepancies should be notified formally to the contractor who should be required to undertake corrective action.

Commissioning is the set of tests carried out by the customer's representative to ensure that the equipment is ready for clinical use and to establish baseline values against which the results of subsequent routine tests can be compared. Some of the commissioning tests take the form of checks and measurements; others are the process of optimising the performance of the imaging system. Commissioning tests are also known as status tests (IEC, 1988), although the latter may also refer to baseline tests on equipment that has been in use for some time.

Routine tests are those tests which are undertaken either regularly, or after maintenance or repairs, to detect whether any change in the performance of the equipment has occurred. They are also referred to as constancy tests (IEC, 1988) and in-service tests (DHSS, 1988a). After major work on the equipment, the relevant commissioning tests may have to be repeated to establish new base-line values.

The sequence of the tests is shown diagramatically in figure 2.1.

Commissioning and routine tests together amount to the operating techniques of quality control. Both types of test and suggested frequencies are identified in Appendix I. However, it is stressed that the scope and frequencies of tests necessary to help maintain the performance of equipment are largely unknown at present and the Appendix should be regarded as a tentative guide only. The reader may wish to be selective regarding both the tests and their frequencies. The tests given in this protocol are specifically equipment tests and therefore such matters as film reject analysis are not included. Further details are given in e.g. Moores et al (1987) and BIR (1988).

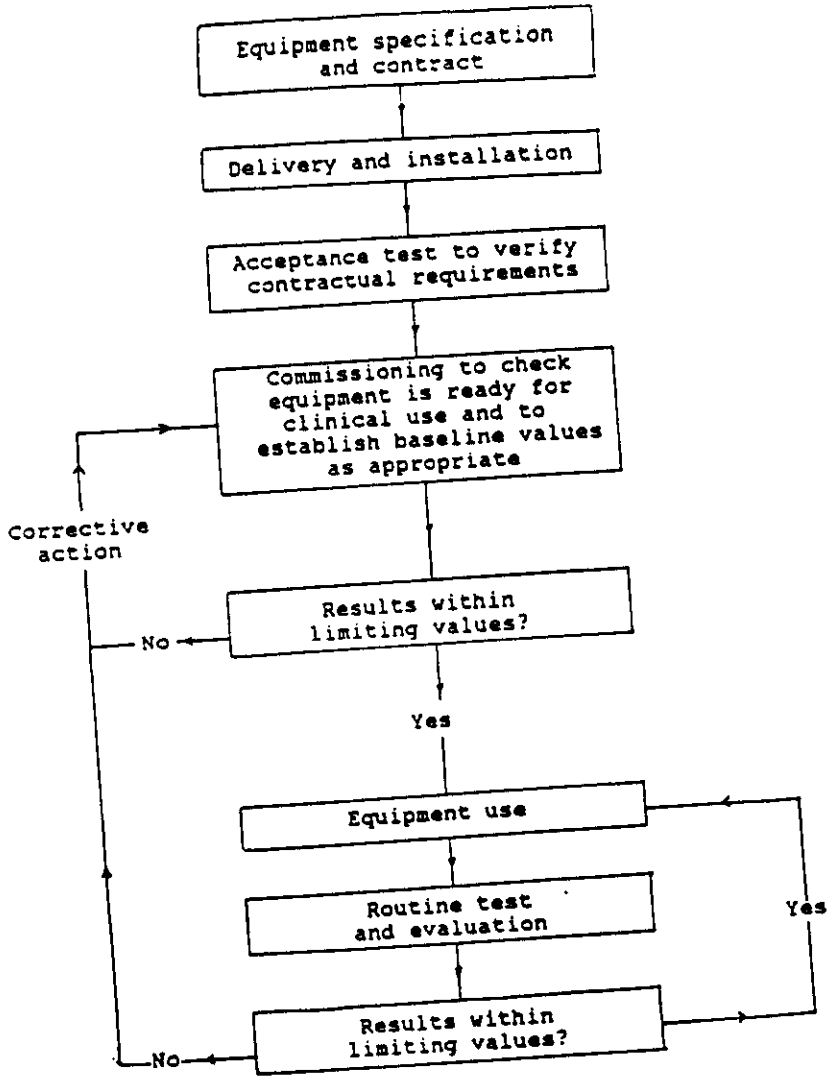


Figure 2.1 Flowchart of tests on X-ray Equipment

2.3 The quality system

The quality system is fully described in BSI (1979a). It should comprise the following features:

(a) Management. Quality assurance is a management tool and requires a Quality Assurance (QA) Manager (DHSS, 1988a). On a regional scale, the Forrest Report (DHSS, 1986a) envisaged, and the DHSS Guidelines (DHSS, 1988a) endorse, the establishment of Quality Assurance Reference Centres (QARC). The QA Manager is likely to be a senior member of the QARC staff who has the responsibility and authority for quality matters. The QARC would act as the focus within a region for the development, monitoring and revision of the quality system. Other duties would be to prepare a quality assurance manual, to ensure that there is liaison between inter- and intra-regional units in the breast screening programme, and to ensure that the quality system is reviewed and audited at appropriate intervals. At local unit level, a QA manager should be appointed to perform similar functions locally.

(b) Quality Assurance Manual. It is essential that the quality system is fully documented and that the manual reflects local conditions and organisation. The manual should include (DHSS, 1988a):

(i) the name of the person with overall responsibility for the quality system,

(ii) the names of those responsible for equipment procurement, test procedures, equipment maintenance and repair.

(iii) details of post-installation and acceptance tests and maintenance procedures.

(iv) details of commissioning and routine tests, limiting values, routine test frequencies and records of results, analysis and corrective actions.

(v) training programmes for all staff.

(c) Quality Assurance Committee. This may be formed from all staff participating in the quality system, including the local and regional QA managers. It should provide overall guidance for the quality system and should ensure that any necessary changes are made and that staff are kept informed.

(d) Quality Audit. This is a systematic and independent examination to determine whether the quality system is functioning effectively and whether the desired objectives are being achieved.

2.4 Responsibilities

Some of the responsibilities within the mammographic quality system are clear-cut; others are not so easy to define. Acceptance is normally undertaken by the Regional X-ray Engineer, except for the radiation safety aspects, which are the responsibility of the Radiation Protection Adviser. Commissioning tests are likely to be undertaken by the Regional X-ray Engineer and physicist or medical physics technician. Those routine tests that have to be done frequently are best done by the radiographic staff who use the mammographic X-ray system. Feedback of the results to the operator is an essential element of a quality system. Those routine tests that are necessarily less frequent, e.g. 3 monthly or longer, may be the province of the physicist or medical physics technician, especially as they may be more time-consuming and may require special test equipment and expertise.

2.5 Limiting Values

Limiting values may be defined as the acceptable variation of the parameter being measured (CEC, 1988). (Sometimes they are referred to as tolerances, e.g. BSI (1979a). Many of the parameters that are checked at the acceptance and commissioning stages will be specified by the manufacturer and limiting values may be quoted. If not, the limiting values given in this protocol may be helpful. For some of the quantities, limiting values will have to be established from knowledge of normal variations and measurement uncertainties. Limiting values also apply to the results of routine tests.

Limiting values are often represented by both positive and negative tolerances on the quantity in question, e.g. tube potential. However, this is not necessarily the case: some quantities have an upper limit only, e.g. breast dose, others have a minimum threshold value, e.g. lead equivalence.

2.6 Measurement Uncertainties

There are two categories of measurement uncertainty - systematic and random. Systematic uncertainties arise from physical effects which may influence or bias the result. Random uncertainties can be determined from an analysis of repeated measurements. Further details are given by, e.g. Campion and co-workers (1980).

The uncertainty associated with a measurement should be substantially less than the range represented by the limiting values and it is common to accept a measurement uncertainty of no more than one third of the range (CEC, 1988). However, the uncertainty associated with the estimation of some quantities, e.g. tube potential, may approach the limiting values that ideally should apply and it may be some time before technical advances enable the uncertainty to be reduced.

Accuracy is the closeness of an observed quantity to the true value and precision is the closeness of agreement between the results obtained by applying a defined procedure several times under prescribed conditions (BSI, 1979a).

In commissioning tests, good accuracy and precision are desirable to enable meaningful comparison with limiting values and to facilitate the intercomparison and compilation of data obtained from other systems or by different workers.

In routine tests, accuracy is not so important, provided that the initial routine test is carried out on the same occasion as commissioning is undertaken; it is the precision of the measuring instrument and method that is important for these tests.

CHAPTER 3. THE MAMMOGRAPHIC X-RAY UNIT

3.1 Introduction

Modern mammography units are designed to allow easy examination of the breast and have a dedicated high voltage generator to provide the required range of tube potential.

The X-ray tube assembly is mounted on a common support arm with the cassette table. At present the preferred target/added filter combination for screen film imaging is molybdenum/molybdenum which provides the required energy and spectrum of radiation. An alternative target/filter combination which has some popularity is tungsten with a range of filter materials such as molybdenum or palladium where the choice of filter and resultant energy and spectrum of radiation is dependent on the thickness of the breast being examined.

The nominal focal spot size is generally between 0.3 and 0.5 mm. If a magnification facility is provided, a dual focus X-ray tube is required with an additional fine focus.

The cassette table normally provides a cassette holder for direct exposure and a removable bucky assembly incorporating a secondary radiation grid. Modern mammography cassettes are constructed from hard plastic or carbon fibre materials (both of low attenuation) and have a single, back intensifying screen for use with single emulsion film, although double-screen mammographic systems have become available recently. The cassette table also incorporates the detector of the automatic exposure control system which is normally located below the cassette.

A device is provided for compressing the breast which is power driven on modern units. A number of accessories for magnification techniques, biopsy procedures and localised compression may be provided.

Many of the measurements described in section 3.5 need to be carried out at a standard setting of tube voltage. It is suggested that this be 28 kV, or as near as the available selections of tube voltage will allow. It is important that the instrumentation used for the measurements has an appropriate calibration.

3.2 Electrical Safety

The requirements for electrical safety are contained in British Standard 5724, Part 1 (BSI,1979b) and in the

Technical Requirements for the Supply and Installation of Apparatus for Diagnostic Imaging and Radiotherapy (DHSS, 1986b). The responsibility for testing in NHS hospitals normally lies with the Regional X-ray Engineer. No further details will be given here but further information may be found in DHSS (1985 and 1988b).

3.3 Mechanical safety and function

3.3.1 Introduction

The mechanical safety aspects of a dedicated mammography X-ray unit differ from those of other X-ray units. One difference is that a compression plate is fitted which may be power driven. There may also be power-driven height adjustment of the breast support table. The additional filtration may be adjustable or even removeable and there are usually rather more attachments than with other X-ray units. A protective screen generally forms part of the equipment.

Some of the checks in the following sections may be regarded as being part of acceptance testing but have been included here for completeness.

3.3.2 Safety Checks

(i) Check that powered movement of the table is prevented when compression is applied (DHSS, 1987, para. 1.4.3; DHSS, 1986b, para 3.10.1).

(ii) Check that the automatic release of the compression plate after an exposure functions correctly (if fitted).

(iii) Check that the auto release override is functioning (if fitted).

(iv) Check that the emergency compression release operates correctly.

(v) Check that the maximum compression force does not exceed 200 N (DHSS, 1987, para. 1.4.8) (see also the manufacturer's specification). (A compression balance or a set of bathroom scales may be used; their calibration should be checked before use).

(vi) Check that there are no sharp edges or surfaces on the cones, compression plates, support table, etc. which may harm a patient, or operator (DHSS, 1987, para. 1.4.9).

(vii) Check that the light stays on for no longer than 120s at a time (DHSS, 1986b, para. 3.2.1).

(viii) Check that, if the protective screen is completely transparent, the edges are marked (DHSS, 1987, para. 2.7.2).

3.3.3 Functional Checks

(i) Check that the equipment is complete by reference to the specification. Be particularly careful about attachments and optional extras such as cones, diaphragms, grid, biopsy plate and magnification tables.

(ii) Check that the following are marked:

- focal spot size and position (DHSS, 1986b, para. 2.12.2, BSI, 1981, para 5.1, NRPB, 1988 para. 4.3).
- inherent, added, total filtration in mm Al including that of adjustable/removable filters. (BSI, 1981, para 5.1, DHSS, 1986b, para 3.7, DHSS, 1987, para 1.3.5, NRPB, 1988, para's 4.4 to 4.7).
- position of AEC detectors on breast support table (DHSS, 1987, para. 2.2.5.b).
- magnification settings (if fitted).

(iii) Check that all movements are free-running and that the force required to be exerted by the operator to cause any equipment movement is less than 30 N (DHSS, 1987, para 1.7.4).

(iv) Check that all mechanical/electromechanical brakes function properly and without backlash (DHSS, 1987, para. 1.7.2).

(v) Check that scale markings are clear on all linear/rotational movements. The rotational scale markings should be at 10° intervals with 5° increments (DHSS, 1987, para. 1.4.4). Pay particular attention to the focus-film distance (FFD) marking if this is adjustable.

(vi) Check that the cones/diaphragms are marked with their field sizes at the relevant FFD (DHSS, 1986b, para 2.23.1).

(vii) Check that power driven vertical movement is still possible with a patient against the table (DHSS, 1987, para. 1.4.3).

(viii) Check that all foot switches operate.

(ix) Check that all the attachments fit properly and that the locks function.

(x) Check that the detector for the AEC moves properly into the predetermined positions (if available).

(xi) Check that the cassette can be inserted and removed easily without snagging and that the retaining force is sufficient to prevent movement of the cassette when it is in the vertical position.

(xii) Check that the light intensity from the X-ray field defining light is adequate.

(xiii) Check that the movement of the compression plate is smooth.

(xiv) Check the accuracy of the breast thickness indicator. (The slab phantom described in section 3.5.11(a) may be used for this).

3.4 Radiation Safety

3.4.1 Introduction

Radiation safety requirements are defined by the Ionising Radiations Regulations 1985 (HMSO, 1985), the accompanying Approved Code of Practice (HSC, 1985), the Guidance Notes for the Protection of Persons against Ionising Radiations arising from Medical and Dental Use (NRPB, 1988), and the Ionising Radiations (Protection of Persons undergoing Medical Diagnosis or Treatment) Regulations 1988, (HMSO, 1988). The Technical Requirements for the Supply and Installation of Apparatus for Diagnostic Imaging and Radiotherapy (DHSS, 1986b) also give guidance.

The differences between mammography units and general X-ray units, as far as radiation protection is concerned, stem from the use of lower X-ray energies and a specialised geometry.

The X-ray field is permanently aligned with a patient support table only slightly larger than the image receptor. The table should also act as a primary beam absorber. X-ray beam alignment is particularly important: the X-ray field should extend to the edge closest to the patient and may extend slightly beyond it, to ensure that the posterior wall of the breast is fully imaged. Not all existing machines have light beam delineators, although new ones should have (DHSS, 1987, para. 1.3.9). Some have a series of removable field defining diaphragms.

X-ray tube windows are generally made of beryllium, so it is <u>essential</u> that additional filtration is present, otherwise unacceptably high doses will be received by patients (Wright et al, 1971). However, the inherent filtration should not exceed 1 mm beryllium (DHSS, 1987, para. 1.3.4).

3.4.2 Inspection

The following checks relate to the safe operation of the X-ray set. The room in which the X-ray unit is situated is not considered except for the entrance warning light.

The checks should not be regarded as complete because some of the performance measurements in section 3.5 are complementary. For example, the filtration may not be marked and it may only be by measuring the half value layer that the filtration can be confirmed. In addition, Regulation 33 of the Ionising Radiations Regulations 1985 requires that X-ray equipment (which includes ancillary equipment having a bearing on patient dose and image quality such as grids, image receptors and processors) is such that the amount of radiation received by patients is the minimum consistent with the clinical requirements. Thus the performance measurements of section 3.5 are obligatory.

(i) Check that there is a mains isolator fitted (HSC, 1985, 2.1.8) accessible from the normal operating position (DHSS, 1986b, para. 2.5.2).

(ii) Check that there are clear and unambiguous markings of the controls (HSC, 1985, Part 2.1.9).

(iii) Check that there is a functioning mains-on warning light on the control panel. Note that this generally fulfills the requirement of having a device fitted which warns that one further action will generate X-rays. (NRPB, 1988, para 4.18).

(iv) Check that the "X-rays-on" light functions and that it remains on long enough to be seen even at short exposure times (NRPB, 1988, para 4.19). (An audible warning often is also fitted, but it is not a substitute for a visible warning).

(v) Check that the total filtration is at least equivalent to 0.5 mm Al or 0.03 mm Mo (NRPB, 1988, para 4.7).

(vi) Check that, if the added filtration is removeable or interchangeable, there is an interlock to prevent an exposure if the filter is removed or incorrectly inserted. (DHSS, 1987, para. 1.6.1).

(vii) Check that, if a field limiting diaphragm can be removed, there is an interlock to prevent an exposure unless the diaphragm is properly aligned (DHSS, 1987, para. 1.6.1).

(viii) Check that the exposure terminates when pressure on the exposure button is released prematurely. (NRPB, 1988, para 4.23).

(ix) Check that the exposure button is fitted to the control panel or is on a lead short enough to confine the operator to the protected area (NRPB, 1988, para 4.24a).

(x) Check that the design of the exposure switch prevents inadvertent production of X-rays (NRPB, 1988, para 4.25).

(xi) Check that the design of the exposure switch is such as to prevent a further exposure unless pressure on it is first released (NRPB, 1988, para 4.25).

(xii) Check that, if the X-ray set is permanently installed, there is a functioning red light at the entrance to the room warning when X-rays are being or are about to be generated (HSC, 1985, para. 2.1.5; NRPB, 1988, para's 3.12 to 3.13).

(xiii) Check that the lead equivalence of the (integral) protective screen is marked, on both the glass and the panel when appropriate, at a specified kilovoltage (DHSS, 1986b, para 2.2.5; NRPB, 1988, para 3.6).

(xiv) Check that the lead equivalence is at least 0.3 mm lead at 50 kV (DHSS, 1987, para 1.6.2).

(xv) Check that the gap between the screen and the edge of the control cabinet to which it is attached is minimal.

(xvi) Check that there is good visibility of the patient by the operator and vice versa. (DHSS, 1987, para. 1.6.2).

3.4.3 Leakage radiation

The measurement of leakage radiation is in two parts, firstly the location of leakage and secondly, its measurement (see also section 3.5.1 on tube rating).

Any deficiencies in the shielding of the tube housing or diaphragm assembly are best pin-pointed using film. Remove the cone if fitted and place a beam-stopper of 1 mm lead over the end of the diaphragm assembly such that no primary radiation is emitted. Leave any removable filter or diaphragm in place and do not cover the slot with lead. Position envelope-wrapped film (pre-packed or in industrial flexible cassettes) around the housing. Ordinary cassettes, fitted with intensifying screens, may also be used. Make sure that the films are marked so that their positions can be reconstructed. Expose at the maximum kilovoltage and a high mAs. Several exposures may have to be made. Process the films and pin-point any leakage.

Next, measure the leakage radiation using a suitable ionisation chamber/electrometer at the same tube voltage as before. Ideally the chamber should have an effective cross-sectional area that enables the leakage to be averaged over an area not exceeding 100 cm^2. Place the chamber close to the housing and in the positions corresponding to any significant leakage seen in the films. If no leakage is seen, measure the leakage in the cardinal axes and also at any filter/diaphragm slot. Correct the readings to mGy in 1 hour at 1 m from the focus at the maximum rating of the tube housing.

Equipment	Prepacked film/industrial flexible cassettes/ordinary cassettes, fitted with intensifying screens. Ionisation chamber and electrometer. Tube housing rating chart.
Limiting value	Not more than 1 mGy in 1 hour at 1 m from the focus at the maximum rating of the tube housing averaged over an area not exceeding 100 cm^2 (NRPB, 1988, para 4.2).

3.4.4 Lead equivalence of the integral protective screen (if supplied)

The measurement of lead equivalence is not straightforward but it may be deduced from the measurement of the transmission of primary or scattered X-rays. Alternatively, a low energy radionuclide source may be used (Hewitt, 1982).

The purpose of the measurement is to check that the radiation dose received by personnel behind the protective screen is not significant. Normally, a time-average dose rate not exceeding 1 $\mu Sv\ h^{-1}$ should be attainable and should not give rise to a significant dose (NRPB, 1988, para 3.6). A more practical approach may be to check that this figure is not likely to be exceeded.

3.4.5 Table transmission

The patient support table is normally regarded as being a primary beam absorber, but it is useful to check whether any radiation transmitted is significant.

3.4.6 Separation between film edge and table edge

The front edge of the film should be close to the front edge of the table so that as much of the breast as possible is imaged. The distance from the edge of the film to the front edge of the table, for the normal position of the cassette, should therefore be checked.

3.4.7 Alignment of X-ray field to film/cassette

The alignment of the X-ray field with the film/cassette should be checked for all the combinations of focus-film distance (FFD) and fixed field size available. Mark the identity of the film and its orientation. Measure the displacement between the X-ray field and the film along the front edge and the two sides. If the X-ray field overlaps the film along the front edge, measure the separation using a cassette placed such that it overlaps the table. Alternatively, use a fluorescent screen if this is more convenient.

Equipment	Cassette, markers, steel rule, fluorescent screen
Limiting value	Within the manufacturer's specification or, if not known - - 0 mm, + 3 mm along chest wall edge ± 5 mm along the other three sides

3.4.8 Alignment of light field to X-ray field

This should be checked for all the combinations of FFD and fixed field size available. Use a film/cassette and mark its orientation. Alternatively, use a fluorescent screen. Measure the displacement between the light field and X-ray field along the four edges.

Equipment	As above
Limiting value	Within the manufacturer's specification or, if not known - ± 5 mm (DHSS, 1987, para. 1.3.9)

3.5 Measurements

3.5.1 X-ray Tube Rating

Before commencing any measurements it is important to refer to the tube data in order to find a suitable exposure repetition rate within the rating of the X-ray tube. Some mammography units provide a delay period, during which a further exposure cannot be made. This may be a set time interval (typically 30 seconds) or an interval derived from the parameters and frequency of the previous exposures.

3.5.2 Alignment

Details of alignment checks are given in sections 3.4.5 to 3.4.7.

3.5.3 X-ray Field Non-uniformity

(a) Introduction

It is important to assess the variation in air kerma rate in the X-ray field because:

(i) The major cause of X-ray field non-uniformity is the heel effect. A mammographic X-ray tube is normally designed such that the part of the X-ray beam having the highest air kerma rate is directed towards the thickest part of the breast, i.e. closest to the front edge of the breast support table.

(ii) The thin foils used as beam filters may not be of a uniform thickness; perforations have also been reported (Barnes, 1988).

The method given below employs film and is similar to the British Standard for the determination of the maximum symmetrical radiation field (BSI, 1985) although this standard is not applicable to mammographic X-ray tubes. However, no attempt is made to calibrate the film density in terms of air kerma rate or to position the cassette and aluminium sheet perpendicular to the reference axis of the tube.

(b) Method

Place a sheet of aluminium (240 x 180 x 2 mm) on the breast support table with a loaded cassette in place. Expose at 28 kV and aim for a film density of between 1 and 1.5 above base plus fog. Measure the density in the centre of the field and at 20 mm intervals along the major axes. Inspect the film for any changes in density which might be indicative of imperfections in the filter.

Equipment	Aluminium sheet (240 x 180 x 2 mm) Densitometer
Limiting value	Parallel to the tube axis : according to manufacturer's specification, if given. Perpendicular to tube axis: within ± 10% of the density at the field centre.

3.5.4 Dimensions of Focal Spot

(a) Introduction

British Standard 6530 (BSI, 1984) describes three techniques that may be used to measure characteristics of the focal spot. Although this Standard refers in general to conventional diagnostic X-ray systems, much of the information may be applied to mammographic units.

The Standard recommends that the focal spot dimensions are measured using a slit camera but recognises that a star resolution grid and a pinhole camera are also useful. The results given by these three techniques may differ. Kimme-Smith et al (1988) have compared the slit and pinhole methods and Doi et al (1982) and Everson and Gray (1987) have compared all three.

It is suggested that on installation of a mammography system the dimensions of the focal spot should be checked using the slit camera method. However, this method may not be suitable for routine measurements as it requires precise alignment. An image of a pinhole or a star resolution grid should be recorded on the same occasion. Subsequently, as part of the routine tests, further images will demonstrate any appreciable change in the focal spot. There may be difficulties in the interpretation of star pattern images; further details may be found in BSI (1984) or, for example in Spiegler and Beckinridge (1972) and Burgess (1977).

The recommended tube voltage for focal spot measurements in British Standard 6530 is 75 kV. This voltage is not suitable for mammography units. The test should be performed at a tube voltage of 28 kV and at the most used value of tube current (further measurements may be made at other values of tube current).

(b) Measurement Geometry

A suitable support should be constructed to position the slit camera, star resolution grid or pinhole between the tube focus and the table. For accurate measurement of the dimensions of the focal spot it is important that the centre of the measuring device is centred on the reference axis of the beam and is normal (± 0.5°) to it. This may or may not be the central beam axis and may or may not be normal to the table (BSI, 1981).

The measuring device should be located close to the tube port to achieve adequate magnification. This may require the removal of the cone. The magnification may be determined geometrically or radiographically.

Information relating to beam geometry and the location of the reference axis should be given in the X-ray tube data or may be obtained from the manufacturer (BSI, 1981).

The focal spot value specified by the manufacturer will generally be smaller than the measured dimensions due to the generous limiting values allowed in British Standard 6530. In the following paragraphs the term 'nominal focal spot value' refers to that quoted by the manufacturer. It is important that the measuring method used by the manufacturer is known when comparing measured dimensions to quoted values.

Methods

(i) The Slit Camera

The focal spot dimensions should be determined using a slit camera with a 10μm slit. Two magnified images should be produced with the slit normal to and parallel to the X-ray tube anode-cathode axis. The measuring geometry should be such that the magnification is >=3 for a nominal focal spot value <=0.4 and >=2 for nominal focal spot valuesbetween 0.4 and 1.0. The film should be exposed to an optical density of between 0.8 and 1.2 above the base plus fog level. The use of a standard mammographic screen-film combination is acceptable but a non-screen film is preferred.

The dimensions of the focal spot are derived by examining and measuring the pair of images through a magnifying glass (5x to 10x, having a built-in graticule with 0.1 mm divisions) and correcting for the magnification factor.

(ii) The Star Resolution Grid

The focal spot dimensions can be estimated from the 'blurring diameter' on the image of a star resolution grid. This diameter refers to the distance between the outermost blurred regions on the image along each direction of evaluation (normal to and parallel to the X-ray tube anode-cathode axis).

Suitable spoke angles are 1.5° for focal spot values >=0.2 and 0.5° for focal spot values <=0.2. If only one star resolution grid is available, a compromise is 1° which should cover the range in focal values of 0.1 up to 0.5.

A magnified image (magnification >=3) of the star resolution grid is produced on a non-screen film. A standard mammographic screen-film combination can be used but it may be difficult to achieve a small enough exposure.

For a star pattern with a spoke angle of θ° the effective dimension f is given by:

$$f = \frac{\theta}{180} \quad \frac{D}{(M-1)}$$

where D is the blurring diameter on the image and M is the geometrical magnification of the image.

(iii) Pinhole Method

The pinhole method produces an image which in addition to dimensional information shows the orientation of and intensity distribution across the focal spot.

A gold/platinum alloy pinhole (30 μm in diameter) is supported in a similar manner to the slit camera. The image may be recorded using a non-screen film or a standard mammographic screen-film combination.

Equipment
Measuring device (slit, star or pinhole)
Supporting jig
Mammographic screen/film or non-screen film
Densitometer
Magnifying glass (5x to 10x) with graticule (0.1 mm divisions)

Limiting values

(i) Slit method

The results should be within the manufacturer's specification and it is important that the measuring method quoted by the manufacturer is taken into account. The limiting values for the slit method are given in BSI (1984) and are reproduced in Table 3.1 below.

TABLE 3.1

Limiting values of focal spot dimensions for nominal focal spot values

Nominal focal spot value	Limiting values of measured dimensions (mm)	
	Width	Length
0.1	0.10 - 0.15	0.10 - 0.15
0.15	0.15 - 0.23	0.15 - 0.23
0.2	0.20 - 0.30	0.20 - 0.30
0.3	0.30 - 0.45	0.45 - 0.65
0.4	0.40 - 0.60	0.60 - 0.85
0.5	0.50 - 0.75	0.70 - 1.1
0.6	0.6 - 0.9	0.9 - 1.3
0.7	0.7 - 1.1	1.0 - 1.5
0.8	0.8 - 1.2	1.1 - 1.6

~~Note that for nominal focal spot values of >0.3 the limiting values include the factor 0.7.~~ It is not certain whether this factor is applicable to mammographic tubes, as the Standard was written for general diagnostic tubes. In the absence of other guidance and in the interests of achieving uniform practice, it is recommended that this factor is applied according to Table 3.1.

Note also that, if it is necessary to check whether equipment complies with the DHSS Guidance Notes (DHSS, 1987, para 1.3.2 and 2.3.2), the factor 0.7 is <u>not</u> to be applied. The measured dimensions should be no greater than 0.2 x 0.2 mm (fine focus) or 0.5 x 0.5 mm (broad focus).

(ii) Star and pinhole methods (routine testing)

The results should be within ± 20% of the baseline value.

3.5.5 Kilovoltage Calibration

(a) Introduction

Two commonly used non-invasive methods of determining mammographic tube voltage are the digital kV meter and the penetrameter. The tube voltage can also be measured invasively but it is felt that such methods are unsuitable for commissioning and routine performance checks.

It is important that the measuring device has an appropriate calibration. Correction factors may be required for various target/filter combinations and high voltage waveforms.

(b) Measuring Instrument

(i) <u>Digital kV Meter</u> The digital instrument is easy to use and provides a direct readout of tube voltage for various target/filter combinations and high voltage waveforms. Suitable exposure factors should be given in the instruction manual.

(ii) <u>Penetrameter</u> The penetrameter (Ardran and Crooks, 1968; HPA 1977) should be designed for mammographic energies.

Exposure factors should be chosen such that the reference density produced on the film is approximately 1.0 above base plus fog. In general the required exposure will increase rapidly as the tube voltage is decreased and care should be taken not to overload the X-ray tube. It is recommended that films are evaluated using a densitometer.

(c) Range of Measurements

(i) Commissioning

Measurements should be made of at least four kilovoltage settings which should span the normal mammographic range. If two focal spot sizes and/or more than one tube current setting are available, these measurements should be performed on the larger focal spot size at the most commonly used tube current setting. Measurements of a single tube voltage setting at the other focal spot size and other tube current settings should also be made.

If the X-ray generator system incorporates a manual mains voltage control it may be of interest to examine the effect of mis-setting this control on the tube voltage.

(ii) Routine testing

Measurements should be made at one or two appropriate tube voltage settings

Equipment	Digital kV meter or penetrameter and densitometer
Limiting value	As tube voltage, can have a considerable effect on the mammographic image quality, it is desirable that the actual tube voltage be within ± 1 kV of the set value (DHSS, 1987). However, with the precision of current measuring equipment and the present difficulty of obtaining a valid calibration this may be difficult to achieve in practice. Therefore, a limiting value of ± 2 kV may be more realistic. If the limiting value is exceeded the calibration should be corrected (by the service engineer) before making any further measurements.

3.5.6 Half Value Layer and Filtration

(a) Introduction

The ICRP (1982) recommend that for mammography, the total permanent filtration should be equivalent to at least 0.5 mm aluminium or 0.03 mm molybdenum.

Details of the filtration will generally be shown on the X-ray tube assembly or given in the accompanying documentation. It is required (DHSS, 1986b, para 4.2.5) that every added filter shall be permanently and clearly marked with its filtration in mm of aluminium equivalent (see section 3.3.3 (ii)).

The total filtration of a mammographic X-ray tube assembly may be deduced from the half value layer of the X-ray beam at a specified tube voltage.

(b) Measurement of Half Value Layer

The half value layer should be assessed by adding thin aluminium filters to a collimated X-ray beam (narrow beam geometry) and measuring the attenuation.

Using an ionization chamber and electrometer a zero reading without any added aluminium is first established. Further exposure measurements are recorded for each added thickness of aluminium.

The aluminium foils must be of adequate purity, e.g. SIB grade or better, (HPA, 1977) and are positioned as close as possible to the tube focus. Normally four to six foils up to approximately 1 mm in <u>total</u> are sufficient to define the attenuation curve for the half value layer determination.

The measurements should be made at a tube voltage of 30 kV to be compatible with the data given in Appendix II. For a mammography unit with a molybdenum target and molybdenum added filtration, the half value layer will typically be between 0.3 and 0.4 mm of aluminium.

(c) Derivation of Filtration

The measured half value layer at a particular kilovoltage can be related to the total filtration employing published data (Wachsmann and Drexler, 1976). See Appendix II.

Equipment	Aluminium foils grade SIB Ionisation chamber/electrometer Suitable jig.
Limiting value	As total tube filtration can only be assessed by an indirect measurement, some additional uncertainty associated with this quantity should be applied to the estimation. However, if the half value layer is >0.3 mm of aluminium (at a measured 30 kV) it is unlikely that the total filtration will be less than the required 0.5 mm aluminium equivalent.

3.5.7 Exposure Time

(a) Introduction

Mammography will normally be performed using automatic exposure control (AEC). However, on occasions, manual control of exposure time may be required.

In the manual mode the duration of exposure is controlled by setting either exposure time or tube current exposure time product (mAs). In the latter case, if the tube current is known, the expected exposure time may be derived.

(b) Measuring System

The duration of exposure should be checked by use of a digital exposure timer suitable for mammographic X-ray energies.

It should be noted that with such instruments the exposure time is measured from the radiation waveform, whereas it is set (by the manufacturer) on the tube voltage waveform. Thus a consistent error may occur between the measured and set values (typically no more than 5 ms but possibly up to 20 ms). Alternatively a suitable detector connected to a digital storage oscilloscope may be used.

(c) Range of Measurements

Exposures should be made over a range of exposure times (or mAs values) and the measured time recorded.

Equipment	Digital timer or detector/ storage oscilloscope.
Limiting value	Manufacturers may be able to supply limiting values for the exposure times on each of their generator systems. Suggested values are ± 10% for times >=200 ms and ± 15% for times < 200 ms.

3.5.8 Tube Output

(a) Introduction

It is important to measure the radiation output of the X-ray tube (air kerma/mAs): too high a value may indicate inadequate filtration of the X-ray beam and too low a value may indicate problems with the high voltage waveform. Some typical values of output are given in Appendix II.

The consistency of X-ray output and its dependence on parameters should be examined.

(b) Measuring System

Tube output should be measured using a calibrated ionisation chamber and electrometer system. The chamber should have a flat response characteristic over the mammographic range of energies.

(c) Measuring Geometry

The chamber is supported in the X-ray beam at a suitable distance from the tube focus (40 cm to 50 cm) and at least 10 cm above the cassette table (to minimise the effects of backscatter). The measurements should be expressed as air kerma (μGy)/mAs corrected to a focus-detector distance of 1 metre.

(d) Range of Measurements

(i) Consistency of Output

Remove the compression plate. Select the most commonly used tube current and an exposure time to give a tube current-exposure time product of 30-50 mAs. Measure the tube output at one kilovoltage setting previously calibrated. Repeat four times.

Equipment: Ionisation chamber/electrometer
Suitable jig

Limiting value: The output should have a maximum deviation from the mean value of <10%.

(ii) Variation of Output with Tube Voltage.

Remove the compression plate. Select the most commonly used tube current and an exposure time to give a tube current exposure time product of 30 to 50 mAs. Measure the tube output at the same settings used in the calibration of tube voltage. From these measurements the tube output per mAs can be plotted against the kV . This should be approximately linear. Alternatively the log of output may be plotted against the log of kV which should again result in a near-linear plot (the gradient should be approximately 2).

The measurements should normally be made with the compression plate removed. However, it is necessary to repeat some of the measurements with the compression plate in place for the determination of breast dose (see section 5.1.3).

Equipment: As above

Limiting value: No limiting values may be specified but typical results are presented in Appendix II.

(iii) Variation of Output with Tube Current and Focal Spot Size

If other tube current values and/or focal spot sizes are available, measure the output at each of these settings at a single selected value of tube voltage (28 kV).

Equipment: As above

Limiting values: The output/mAs should have a maximum deviation from the mean value of <10%. Any variations may be due to problems in tube current calibration (assuming the tube voltage and exposure time to be correct).

3.5.9 Magnification and focus-film distance

Magnification is usually specified with respect to the surface of the breast support table. It should be checked at the normal setting and at each magnification setting using a thin marker of known dimensions. The focus-film distance may be checked by a similar method.

3.5.10 The Secondary Radiation Grid

(a) Introduction

At present, most mammographic examinations employing a screen-film combination are performed with a secondary radiation grid in the beam. Usually the grid is mounted in a bucky assembly and moves during the exposure. However, a stationary grid either inside or outside the cassette may also be used.

The grid ratio, line density and focal length will normally be shown on the grid itself or given in the manufacturer's data. For a moving grid DHSS (1987) recommends a grid ratio of 4:1 or 5:1 with a line density of approximately 30 lines/cm. Stationary grids have a higher line density, typically 80 lines/cm (Dershaw et al, 1985). The focal length should be appropriate to the focus-receptor distance of the mammographic unit.

The grid exposure factor gives the increase in exposure required when using the grid and in mammography is

typically about 2 and should not be greater than 3 (DHSS, 1987). It is defined as the ratio of the incident exposure with the grid in place to the incident exposure without the grid and is therefore a property of the grid itself and not of the grid system. The grid exposure factor is easily measured in systems where the grid alone can be removed but in the many cases where this is not possible, the grid system exposure factor may be measured instead. The grid system exposure factor is defined here as the ratio of the incident exposure with the grid system in place to the incident exposure without the grid system. For a moving grid, the grid and the grid system exposure factors will differ because of absorption in the cassette tunnel.

A method of assessing the performance of secondary radiation grids is described in British Standard 5913 (BSI, 1980) but this is not applicable to mammographic grids.

(b) Measurements

(i) Grid exposure factor/grid system exposure factor

The grid exposure factor should be determined at 28 kV with a 4 cm thick Perspex phantom (Section 3.5.11(a)) on the breast support table, above the plane of the grid, to produce scattered radiation. A film method employing a mammography cassette should be used. The grid exposure factor is estimated from the ratio of the tube current exposure time products (mAs) required to produce the same optical density on the processed film with and without the grid. The grid system exposure factor may be estimated in a similar way with the cassette being placed on top of the cassette tunnel for the exposure without the grid and a small inverse square law correction being applied to correct for focus-film distance.

(ii) Examination of the grid

It is useful to produce a plain radiograph of the grid at the focus-film distance at which it is used (see also section 3.5.3). This allows the line density to be estimated (through a magnifying lens) and the uniformity of air kerma rate across the radiation field to be assessed. Poor uniformity may be due to grid cut-off which indicates a misplaced grid or a grid of the incorrect focal length. (See also section 3.5.3).

The grid movement will have to be disabled for this examination.

Equipment: 4cm Perspex phantom
Densitometer

Limiting value: Grid ratio and line density: to manufacturer's specification.
Grid exposure factor: not to exceed 3.0

3.5.11 Automatic Exposure Control Systems

(a) Introduction

In screen-film mammography the radiation exposure is normally controlled by a radiation detector located after the image receptor. This detector monitors the X-rays transmitted by the receptor and the exposure is terminated when the radiation dose received by the detector reaches a predetermined level corresponding to the desired optical density on the film.

For many mammographic X-ray units, the position of the radiation detector can be varied between two or more predetermined positions to facilitate the exposure of breasts of differing size or density. A density control may be available which can be used to vary the exposure. There may be a further control used in conjunction with different screen-film combinations.

A guard timer will be fitted to prevent gross over-exposure of the breast if the automatic exposure control system fails. The guard time itself may be related to the maximum mAs available or to the manual setting of the machine, and in the latter case it is important to ensure that the value selected does not lead to premature termination of the exposure.

The performance of the automatic exposure control system will depend upon three major factors:

(i) The reproducibility of the system for repeat exposures under identical conditions.

(ii) The variation of the response of the system with radiation quality. (There will be quite large changes in radiation quality with breast thickness and composition due to variations in the X-ray spectrum transmitted by the breast).

(iii) The variation of the response of the system with dose rate.

In most cases, the radiation detector will be located behind the image receptor and the radiation dose it receives for fixed dose to the receptor will depend both upon the energy response of the detector and receptor and upon the transmission through the receptor. The AEC

system will therefore be energy-dependent and some form of electronic quality compensation may be desirable. (For example, LaFrance, Gelskey and Barnes (1987) have demonstrated that for a certain AEC system, the optical density on the film, varied between 1.4 and 0.5 for Perspex phantom thicknesses between 2.5 and 6 cm). If the radiation detector is located in front of the image receptor, the quality dependence will be reduced, although some automatic correction may still be appropriate. For those machines where quality variation remains of significance, it will be necessary to make small compensations using the density control, depending upon the patient and the choice of operating parameters (including adding or removing a grid and the use of magnification techniques).

The dose rate at the radiation detector will depend upon the tube current, voltage and filtration, as well as the size and composition of the breast being examined; the automatic exposure system may need to cope with dose rate variations of more than one order of magnitude.

The automatic exposure control should be tested using a phantom which can be used to simulate breasts of different thickness. It is suggested that the phantom be constructed from three slabs of Perspex, each 2 cm thick, and of semicircular cross section. A diameter of 16 cm is suitable, although the shape and area of the horizontal cross section through the phantom are not critical.

(b) Test Procedures

(i) Setting up the automatic exposure control

The automatic exposure control should be set up to give the desired optical density on the film. (This is normally done by the installation engineer). It is suggested that two slabs of the Perspex phantom are used to approximately simulate the exposure of an average-sized compressed breast, 4.5 cm thick. The phantom should be positioned as for a cranio-caudad projection and the standard chamber position should be used with the density control set in its central position (no density correction) and the compression device in place against the top surface of the phantom. The X-ray unit should be operated using the tube current and voltage which would be used in normal clinical practice. A tube voltage of 28 kV is suggested for the combination of screen-film receptor and a mammographic X-ray unit with a molybdenum target and molybdenum filter.

The screen-film combination normally used for mammography should be employed, with the films all taken from the same batch.

(ii) Overall consistency

Use two slabs of the test phantom to simulate the exposure of an average breast as described above. Position a suitable ionisation chamber above the phantom and compression device and in a location which does not shadow the exposure monitor but is within the radiation field. Make six exposures and record the reading of the ionisation chamber for each exposure. A loaded cassette should remain in place throughout the exposures.

Limiting value: The maximum variation of the ionisation chamber readings should not exceed ± 10% of their mean value.

(iii) Sensitive area of AEC detector

Do not disturb the chamber but remove the phantom and place a sheet of lead 0.5 mm thick on the table with a cut-out such that the AEC detector is not masked by lead (allowing a 10 mm margin). Replace the phantom and repeat the exposure as in (ii) above. The film may then be discarded.

Limiting value The chamber reading should be within 10% of the previous result

(iv) Consistency with change in phantom thickness

Use the test phantom with thicknesses of 2, 4 and 6 cm to simulate breasts of different sizes. For each phantom thickness, make one exposure and measure the optical density at a well-defined position on the resulting film (for example, at a point on the midline of the image and 2 cm from the edge of the film). The three exposures should all be made with the same cassette or using cassettes which have been previously matched.

Limiting value: It is desirable that the maximum density variation should not exceed ± 10% of the mean value. This may not be achievable, particularly on equipment manufactured prior to 1988 (see section (a) above).

(v) Consistency with change in tube voltage

Use two slabs of the test phantom to simulate the exposure of an average breast and measure the densities on the resulting films. If the X-ray unit has preset voltage stations, make one exposure at each voltage station. If there are no preset voltage stations, make exposures for at least four voltages which cover the range used clinically.

Limiting value: It is desirable that the maximum density variation should not exceed ± 10% of the mean value.

(vi) Consistency with change in tube current

Use two slabs of the test phantom to simulate the exposure of an average breast and measure the densities on the resulting films. Make exposures at each available tube current.

Limiting value: The maximum density variation should not exceed ± 10% of the mean value.

(vii) Consistency with change in other operating parameters

Use two slabs of the test phantom to simulate the exposure of an average breast and measure the densities on the resulting films. Make exposures which will test the effect of any other variable parameters on the function of the automatic exposure device. Parameters which may be tested include the effect of the position of the AEC monitor, magnification, standard or fine focus and the presence or absence of an anti-scatter grid.

Limiting value: It is desirable that the maximum density variation should not exceed ± 10% of the mean value.

(viii) Calibration of density control

It may be useful to calibrate this control. The experimental conditions described above for measuring overall consistency can be used. The ionisation chamber reading should be recorded for appropriate positions of the density control and the results expressed as a percentage of the readings for the central position of the control.

(ix) Guard timer

Before commencing this measurement, it is important to refer to the tube rating data to ensure that any exposure given is within the rating of the tube.

Remove the phantom and position a sheet of lead 0.5 mm thick on the top of the breast support plate so that it covers the whole of the patient support table including the monitor detector. Select the standard operating voltage and tube current and measure the time required for the exposure to be terminated by the guard timer.

The nominal cut out time for the guard timer must be ascertained before the exposure is made so that the exposure can be terminated manually should the cut out fail.

(x) Regular tests of the AEC system

The basic function of the AEC can be tested by exposing any phantom which approximately simulates an average-sized breast. The phantom used for frequent checks of image quality may be suitable for this purpose (section 5.2.5). The same cassette should always be used.

Position and expose the phantom with a loaded cassette in place. Measure the optical density at a defined position on the resulting film.

Limiting value: It is desirable that the maximum density variation should not exceed ± 10% of the mean density. This assumes that the processor is functioning consistently.

Equipment required:
Breast phantom(s)
Ionisation chamber and electrometer
Densitometer
Stopwatch or digital exposure timer
Lead sheet 0.5 mm thick.

CHAPTER 4. THE AUTOMATIC PROCESSING UNIT AND THE SCREEN-FILM SYSTEM

4.1 Introduction

The diagnostic value of a radiograph is affected by the type and condition of the film, intensifying screens and cassette and by the processing of the image after exposure. The information recording capability of any screen-film system is limited by its physical properties, and extra diagnostic information can usually only be obtained at the cost of increased patient dose. Once a particular system and standard of processing has been selected it is necessary to ensure that this standard is achieved and then maintained at an acceptable level throughout the working life of the system.

Optimum performance of automatic processing units (APU's) must be identified and maintained as this is of great importance in determining image quality. A processor which is not working properly will affect many films, therefore routine testing of processors must be an important part of any quality control programme. This is of particular importance in mammography where, ideally, a single processor would be dedicated to mammographic work and all mammography films would go through this processor. In departments with small workloads this may be impracticable, therefore a processor should be identified and as far as possible optimised for mammographic use.

A system of monitoring is described which uses test films drawn from departmental stock. These films are then exposed in a standard manner so that variations in the charted results will test both the processor and film stock/storage. In addition, film should be tested for consistency when new batches are used. However it would be unusual for loss of image quality to be caused by defective film. A more likely cause would be poor storage conditions leading to an increase in the fog level.

4.2 The Automatic Processing Unit

The performance of an APU depends on its design, the processing chemistry and the film used. In setting out a procedure to assess the performance it is necessary to establish, by reference to the manufacturer, the optimum conditions for an individual system and to have the processor set up accordingly. A review of the effect on overall performance of changing system parameters, e.g. developer temperature, shows that often a compromise must be accepted. This can be demonstrated by investigating the effect of such changes on the characteristic curve which is described in section 4.2.1.

The most valuable test of the APU is sensitometry (section 4.2.1), which is both a commissioning and routine test. Sections 4.2.2 to 4.2.7 describe further commissioning tests which provide baseline values.

4.2.1 Sensitometry

(a) Introduction

Three parameters can be derived from the film characteristic curve which provide a measure of performance:

speed contrast base + fog level

These parameters can be measured by using a sensitometric strip, which is a film that has been exposed under standard conditions, preferably using a stable light source, so that identical exposures can be achieved. A sensitometer combines such a light source with an optical step wedge to provide densities on film which enable the characteristics of the film to be determined (i.e. characteristic curve, base plus fog level, speed and contrast). In practice there will be slight variations due to film sensitivity but these can be minimised by using the same box of film to produce the sensitometric strips. If identical exposures are given then variations in the processed strips will be due to changes in the processing.

Some manufacturers supply pre-exposed strips. However, freshly produced sensitometric strips are preferred in order to avoid problems of image fade. Whatever system is selected it is important that it is simple to operate and reproducible.

Changes in speed, contrast and base + fog density reflect variations in the processor which could significantly affect the radiographic image quality.

A sensitometric strip should contain at least three density steps for evaluation of the three parameters identified above:

- an unexposed region of density, B, to measure base + fog
- a density step D_1 at an approximate density of 1 above B
- a density step D_2 at an approximate density of 2 above B

D_1 is used to monitor speed; $D_2 - D_1 = C$, the film contrast. When films are exposed clinically to a high density it may be useful to measure a density step at a density of approximately 2.5 above base + fog.

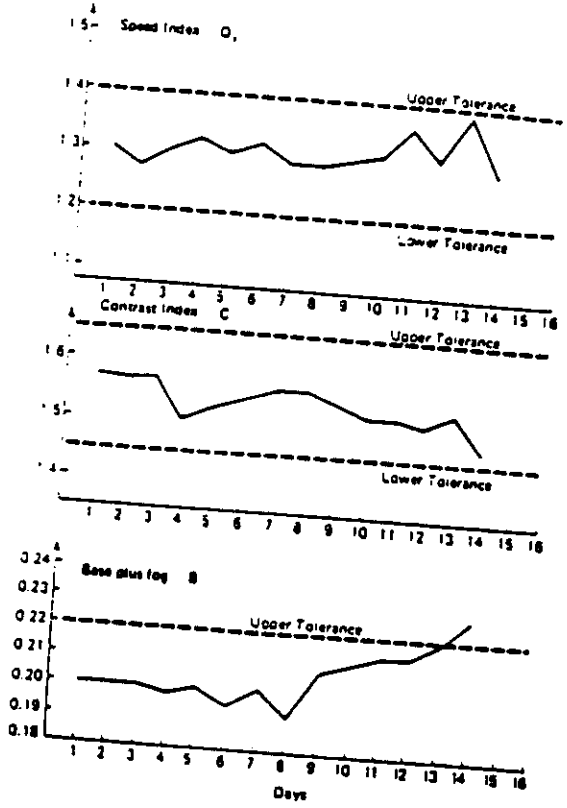


Figure 4.1 Typical sensitometric control chart for mammographic film

The values of B, D_1 and C may then be plotted on a control chart (figure 4.1) which is a simple graphical display of the parameters as a function of time. It is essential to establish limiting values and acceptable variations in these parameters.

When the parameters are displayed in this manner it is easy to detect trends which may be acted upon before the values recorded become important in terms of the quality of the radiographic image. Further simple measurements may then be required to identify the cause of these variations and these are described in sections 4.2.2 to 4.2.7.

It is assumed that in setting up the processor the manufacturer will have selected optimum conditions for the individual system. This can be verified by following the procedure laid down in HPA (1984).

(b) Method

After allowing time for the correct working temperature to be reached, several films should be passed through the system to clean the rollers. Next pass 5 sensitometric strips through the processor. Each strip should be fed through in the same position and orientation with the emulsion side down so that this is away from the rollers as it goes through the processor; this ensures that there is better circulation of the chemicals over the emulsion. The lowest density of the sensitometric strip should be at the leading edge of the film to prevent local depletion of the chemicals which might occur over high density areas.

This procedure should be performed at least daily for 3 to 5 days so that a reliable baseline can be calculated for each parameter. For each strip, measure the three densities B, D_1 and D_2 with a measurement uncertainty of ± 0.01 density units and calculate the contrast index C = $D_2 - D_1$. Mean values are then calculated to provide the baseline values for the control chart. Lines should be drawn on this chart corresponding to the upper and lower acceptable limits about the baselines.

It is important to calculate the standard deviation of these readings and to ensure that the magnitude of the standard deviation is smaller than the maximum variations of the parameters.

Equipment required: Sensitometer
Densitometer

Limiting Values: The variations in base plus fog level, B, speed, D, and contrast, C should not exceed ± 0.03, ± 0.1 and ± 0.1 respectively. The upper limit for B is 0.20. When the value of one of these parameters falls outside of these limits, the cause must be established; refer to manufacturer's or other literature, such as Moores et al (1987) for further details.

4.2.2 Temperature

If temperature indicators are fitted they should be calibrated periodically. The most critical temperature is in the development stage of the processing: each degree Celsius in temperature above normal would typically result in 0.1 increase in film density. The temperature is measured with an appropriate thermometer or thermocouple. A glass mercury thermometer should not be used because of the danger of contamination should there be a breakage. Most modern APU's should be capable of maintaining ±0.2°C. Variations in fixer and dryer temperatures are less critical.

Equipment: Digital or alcohol/glass thermometer

Limiting value: Developer - see manufacturer's specification
Fixer and dryer: ± 1°C

.2.3 Transport speed

The total transit time of a film through an APU can be measured using a stop watch.

Equipment: Stopwatch
Film (from stock)

Limiting value: ± 5% or manufacturer's specification

2.4 Replenishment rate

Replenishment rates should be measured as specified by the APU manufacturer. The correct rate will depend on area of film processed, type of film, average density of processed films and on workload. These rates are determined by the manufacturer.

Equipment: Plastic extension tube
Measuring jug
35 x 35cm film

Limiting value: The accuracy will vary with the age of the pump, but should be within ± 5%.

4.2.5 Specific gravity and pH

This measurement could be valuable in identifying the cause of faulty processing related to changes in chemistry or replenishment.

Equipment: Hydrometer
pH papers or probe and meter

Limiting value: To manufacturer's specification

4.2.6 Residual hypo

A residual hypo test is a simple chemical test designed to indicate whether all the sodium or ammonium thiosulphate has been removed from the processed film. Inadequate washing of the film would, in time, result in a stained and faded radiograph.

Hypo estimators are available from manufacturers which consist of a colour chart which is compared with unexposed processed film on which a drop of hypo test solution has been placed before processing.

Equipment: Residual hypo test kit

Limiting value: As given in the instructions with individual kits.
It will be in the form of an acceptable colour range.

4.2.7 Silver recovery

This measurement, performed at commissioning, gives an indication of the potential silver which may be recovered from the system. Silver estimating papers are available from manufacturers and these are rated from 0 - 10 g/l recoverable. Changes in the correct functioning of the system may affect the silver recovery rate e.g. changes in the replenishment rate.

4.2.8 Routine Monitoring

This may be restricted to the use of a sensitometric strip and to note the developer temperature when the strip is processed.

4.3 The Screen - Film System

4.3.1 Cassette and Screen Identification

Each cassette should be labelled with manufacturer, screen type and date of purchase. The screen should be numbered and details of any tests performed recorded.

4.3.2 Screen-Film Contact

The screen-film contact should be checked before the cassette is first used and annually thereafter. A suitable test grid should be used. The device described in BS 4304 (BSI, 1968) and by Ardran et al (1969), is suitable for mammography. Commercial devices are becoming available. Lay the grid flat, in contact with the top of the cassette and expose to produce a film density of about 2.

Regions of poor contact will be blurred.

4.3.3 Light-tightness of Cassette

Each cassette should be loaded with film and then exposed to X-rays to sensitise the film. An exposure resulting in about unit density should be sufficient. This ensures that any subsequent light exposure is on the linear and therefore the most sensitive part of the characteristic curve. The loaded cassette should then be held in front of a light source, e.g. a light box, paying particular attention to exposing areas around identification windows, hinges and clips.

4.3.4 Relative Sensitivity of the Screen-Cassette Combination

The relative sensitivity of the screen/cassette combination can be assessed with the phantom used for AEC measurements (see section 3.5.11).

Place the 4cm phantom on the table, with the cassette in position. Select 28kV and an mAs to produce about unit density on the processed film. Repeat for each cassette using films from the same batch. Measure the densities on each film at a specified point within the image of the phantom.

Limiting value: ± 0.1 ~~overall~~ optical density is desirable

4.3.5 The Characteristic Curve

(a) Introduction

Measurement of the screen-film characteristic curve may be required:

(i) when new types of film, screen or cassettes are introduced

(ii) when a change in the performance of screen or film is suspected

The characteristic curve can be used to determine the sensitivity, average gamma (contrast) and latitude of the screen-film system. The latter two of these parameters can be determined using a light sensitometer but it is usual to use one or more X-ray exposures. The standard methods are (ICRU, 1986):

(i) Time scale sensitometry.

(ii) Intensity scale sensitometry using absorbers, e.g. a stepwedge.

(iii) Intensity scale sensitometry using distance.

There are advantages and disadvantages to each of these, but the most convenient one is method (ii) utilising a calibrated step wedge.

If comparisons of different screen-film combinations, or of the same combination over a period of time are being made, the same method must be used.

The general condition of cassettes and screens may vary with age and may degrade the image. It is important that any artefacts which occur can be traced back to a specific cassette/screen. Therefore a marking system must be adopted (section 4.3.1).

(b) Method

The following method uses a Perspex step wedge to produce a series of densities on one film. The wedge should have at least 10 steps, each a minimum of 10 x 10 mm and increasing in thickness in increments of 5 mm. It should be calibrated in terms of relative exposure under each step.

Place the wedge on top of a loaded cassette on the patient support table and perpendicular to the anode-cathode axis. Select 28kV, or the nearest selection to this (the calibration should be checked). Choose exposure factors that will produce the required range of densities on the film (from base plus fog level up to density 3).

The film produced must be processed under standard conditions. A calibrated densitometer should be used to measure density in each region of the film, with a measurement uncertainty of 0.01 density units. From this, determine values of $E_{0.2}$, E_1 and E_2, as shown in figure 4.2.

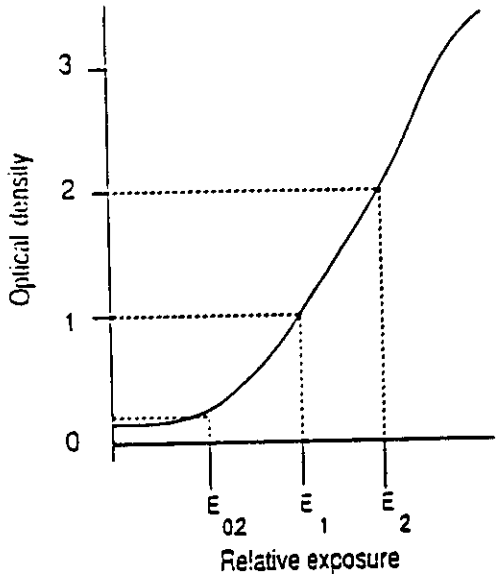


Figure 4.2 Typical mammographic screen-film characteristic curve

Calculate:

$$\text{sensitivity} = E_1$$

$$\text{average gamma} = \frac{1}{\log(E_2 - E_1)}$$

$$\text{latitude} = E_2 - E_{0.2}$$

Equipment: Perspex step wedge with at least 10 steps
X-ray tube and generator
Densitometer

Limiting value: ±10% of the mean value previously measured if no changes in the system have been implemented.

4.4 Darkroom and film storage conditions

The darkroom must be adequately light-tight to ensure that no extraneous light reaches the film before exposure. This should be assessed visually by dark-adapted eyes. The safelights must also be tested to ensure that they are not responsible for increased fog level. This can be carried out by a simple coin test.

Expose an X-ray film to produce a density of about unity. With all safelights off, place the film on the darkroom bench and lay 10 coins on the film in a row. Cover all but one coin with a piece of card, turn on the safelights and expose the first coin for five seconds. Then, at five second intervals, uncover another coin and repeat until all have been exposed. Turn off the safelights and develop the film. Visual inspection of the film will indicate any significant density on the film. If no coin outlines are visible repeat the exposures at longer times. This will enable the maximum safe handling time to be established.

Where darkrooms are used for storage of films it is important that excessive humidity and temperature are avoided. Manufacturers' recommendations for film storage should be followed. Generally, storage temperatures of 15 to 18°C and humidities of 50 to 60% are recommended. It is important that film is allowed to reach darkroom temperature before use.

A stock control system should be implemented by keeping an inventory. Film should be used in strict rotation, oldest first.

4.5 Illuminators and viewing room conditions

Illuminators and viewing room conditions should be checked at least annually and a simple visual check carried out quarterly. Before any check, the viewing boxes should be cleaned inside and out.

The visual check should be performed to detect mis-matches of fluorescent tubes in either brightness or colour.

A photometer or light meter is used to measure the brightness of each viewing box. The luminance should be at least 5500 lux (13eV at ASA 100) (HPA 1984).

Values less than this or with more than 10% variation across the viewing box indicate that the tubes should be replaced.

The ambient light level in the room should also be measured and should not exceed 86 lux (8eV at ASA 100) (HPA, 1984).

CHAPTER 5 ASSESSMENT OF OVERALL PERFORMANCE

5.1 Breast Dose

5.1.1 Introduction

There is a risk of radiation-induced carcinogenesis associated with the X-ray examination of the female breast, but with modern equipment and technique this risk is small, whereas the benefit of the examination is considerable (NCRP, 1986). It is important, nevertheless, to use appropriate equipment and technique so that the desired image quality is achieved at the lowest possible dose and the measurement of the dose to the breast forms an important part of the mammographic quality assurance programme.

The X-ray spectrum used for mammography is of low energy and the depth dose within the breast decreases rapidly with increasing tissue depth. For example, the exit dose measured by Hammerstein and co-workers (1979) for a 6cm thick breast phantom varied between about 1 and 13% of the surface dose, depending upon beam quality. It is important therefore to specify breast dose using a quantity which gives a measure of the dose to the whole organ.

Three such quantities have been suggested : mid-plane dose, mean breast dose and mean glandular dose (Hammerstein et al 1979). The surface dose to the breast does not give a good measure of the dose to the whole organ because of the large variation of depth dose with beam quality.

The dose will also be affected by the size and composition of the breast with the former varying both within and between populations and the latter throughout the life of the woman. This diversity of both dose specification and breast dimensions and composition makes dose comparisons very difficult and it is important for such purposes that doses be specified for a standard breast and in a standard way.

1.2 Dose specification

The dose specified in this document is the mean dose to the glandular tissues within the breast (Hammerstein et al, 1979; NCRP, 1986; ICRP, 1987). The term glandular tissue includes the acinar and ductal epithelium and associated stroma and it is the glandular tissues which are believed to be the most sensitive to radiation-induced carcinogenesis. In order to compare doses, it is necessary to define a standard breast with a standard composition.

The standard breast adopted has a central region comprising a 50:50 mixture by weight of adipose and glandular tissue and a superficial region of adipose tissue, 0.5 cm thick. The compositions of these tissues are given by Hammerstein et al, (1979) and are well simulated by the tissue substitute materials BR12 and AP6 formulated by White (1977) and White et al (1977). The standard breast is 4.5 cm thick. It has a semi-circular cross section in the horizontal plane of diameter 16 cm which gives a cross sectional area of approximately 100 cm^2. The exact area is not critical as the breast dose has only a small dependence on cross-sectional area (Dance, 1980). The dimensions of the standard breast are typical of those of a firmly compressed breast.

The mean glandular dose for phantoms similar to the standard breast used here has been measured (Hammerstein et al, 1979, Stanton et al, 1984) and calculated using Monte Carlo techniques (Dance, 1980 and Rosenstein, Anderson and Warner, 1985).

In the practical situation, a phantom constructed according to the above prescription may not be available amd even if it were, the measurement of the glandular dose throughout the phantom would be a tedious procedure. The method suggested here for estimating the mean glandular dose uses a 4 cm thick Perspex phantom and conversion factors which have been specially calculated (Dance, 1988) to relate a readily measured quantity for the Perspex phantom to the mean glandular dose for the standard breast. The procedure involves the determination of (i) the exposure time current product (mAs) for correct exposure of the Perspex phantom and (ii) the output (air kerma per mAs) of the unit with the phantom removed. These two quantities are then combined to give K, the incident air kerma (without backscatter) to the phantom. The mean glandular dose, D, for the standard breast is then estimated using the relationship:

$$D = Kpg \qquad \text{equation 5.1}$$

where p converts the air kerma for the Perspex phantom to that for the standard breast and g converts the air kerma for the standard breast to mean glandular dose. The conversion factors p and g are quality dependent and are given in table 5.1.

Table 5.1 The conversion factors p and g for calculating the mean glandular dose to the standard breast from measurements with a 4 cm thick Perspex phantom

The data are tabulated against half value layer and have been calculated (Dance, 1988) for a range of spectra from both a molybdenum target with a 30 μm molybdenum filter (HVL values 0.25 - 0.45 mm aluminium) and a tungsten target with either an aluminium or a K-edge filter (HVL values 0.45 - 2.00 mm aluminium). The conversion factor at 0.45 mm aluminium may be used for either target material. The variation of the factors with choice of spectrum at a fixed HVL is typically ± 3% on each data point. The factors can be used with or without a grid. The table contains data for use with the Xerox receptor.

HVL (mm Al)	p	g (mGy Gy^{-1})
0.25	1.12	155
0.30	1.10	183
0.35	1.10	208
0.40	1.09	232
0.45	1.09	258
0.50	1.09	285
0.55	1.07	311
0.60	1.06	339
0.65	1.06	363
0.70	1.06	384
0.80	1.05	422
0.90	1.04	473
1.0	1.03	497
1.2	1.03	550
1.4	1.03	594
1.6	1.02	632
1.8	1.02	666
2.0	1.02	696

5.1.3 Estimation of mean glandular dose for the standard breast

The mean glandular dose is estimated using a Perspex phantom as detailed in section 5.1.2. The phantom described in section 3.5.11 is suitable for this purpose. Except as otherwise noted, the phantom should be exposed using the settings normally used in clinical practice for a breast of size and composition similar to the standard breast. A loaded cassette should be in place.

The method involves a determination of both the incident air kerma for correct exposure of this phantom and the half value layer of the X-ray beam. Measurement of the former quantity is divided into two stages : a determination of the mAs required for the correct exposure of the Perspex phantom and a measurement of tube output per mAs. Methods for the measurement of tube output and of HVL are described in section 3.5.8 and section 3.5.6 respectively. Both of these quantities should be measured with the compression plate in place.

The mAs per exposure is determined using the Perspex phantom which is positioned as for a cranio-caudad exposure of the breast with the compression device in place against its top surface.

(i) For units where the mAs is indicated, i.e. those with manual control only or those with both automatic exposure control and post-exposure recording of mAs: expose and process a film and check that the resulting optical density is within the normal range. Alter the exposure time or density control if necessary. Record the mAs per exposure.

(ii) For units with automatic exposure control but without post-exposure recording of mAs: position a suitable ionisation chamber in front of the phantom and the compression device and in a location which does not shadow the radiation monitor. Expose and process a film and check that the resulting optical density is within the normal range. Make small alterations to the density setting if necessary. Note the air kerma recorded by the chamber. Switch the exposure control to manual and select an exposure time close to that obtained under automatic exposure control. Make an exposure and note the air kerma recorded by the chamber. From the ratio of the two chamber readings and the mAs used for the manual exposure, calculate the mAs per (automatic) exposure.

Measure the distance from the focal spot of the X-ray tube to the top surface of the breast phantom and calculate the air kerma incident on this phantom per exposure using the tube output (air kerma per mAs at 1 metre, from section 3.5.8), the mAs per exposure (from above) and the inverse square law.

Calculate the mean glandular dose to the standard breast using equation 5.1 and the above results. The correction factors p and q at the measured half value layer may be interpolated from the values given in table 5.1. When quoting measured dose it is essential to give both the dose specification and the breast size and composition.

Equipment:

Perspex phantom, 4 cm thick
Ionisation chamber/electrometer
Densitometer
Aluminium foils grade SI3
Suitable jig

Limiting value:

Mean glandular dose for the standard breast should not normally exceed 3 mGy per exposure with an anti-scatter grid or 1.5 mGy per exposure without a grid. (Other values have been suggested, e.g. in NCRP (1986) and DHSS (1988a)).

5.1.4 Routine monitoring of breast dose

The method described in section 5.1.3 above is appropriate at the commissioning of the X-ray set and for infrequent checks of breast dose.

For frequent checks of breast dose, however, it is sufficient to measure the constancy of the mAs per exposure of any phantom which approximately simulates an average sized breast. The phantom used for frequent checks of image quality may be suitable for this purpose (section 5.2.5, but see also section 3.5.11(x)). Position and expose the phantom using appropriate machine settings and with a loaded cassette in place. Determine the mAs per exposure. For units without post exposure recording of mAs, it is suggested that a jig be constructed to facilitate the reproducible positioning of a suitable ionisation chamber or other radiation monitor and that the reading of this monitor be recorded.

It is recognised that this procedure only gives an indirect indication of breast dose, but a more detailed method may not be practicable for a frequent test.

Equipment:

Simple phantom or the equipment listed in section 5.1.3

Limiting value:

± 10% is desirable

5.2 Image quality and test phantoms

5.2.1 Introduction

In diagnostic radiology the quality of the image is of prime importance. The consequences of poor image quality are twofold: firstly the radiologist may not have all the diagnostic information that should be available and secondly the patient may have received an unnecessary radiation dose, particularly if a repeat film is necessary. These comments are very relevant to mammography where, because of inherently low subject contrast, the desired image quality is close to the limits of performance of the system. In recent guidance (DHSS, 1988a) the first objective and standard for mammography is 'to achieve optimum image quality'. Therefore, in the commissioning or routine testing of a mammographic X-ray system an assessment of image quality is essential.

5.2.2 Clinical Image Quality

It is important to define what type of image is required and what information is required from the mammogram. This may vary from patient to patient and from radiologist to radiologist. It may also depend on whether the examination is for screening or for diagnosis when specific localisation or other mammographic information is requested. In the screening situation for example, image quality must provide high sensitivity for invasive adenocarcinomas under 1cm in diameter (Price, 1988).

All breast examinations are complicated further by the degenerative changes in breast composition and structure with age of the patient (Parsons, 1983). The normal breast consists of fibrous, glandular and adipose tissue. As the woman ages and following any pregnancies and the menopause, the fibrous and glandular tissue is replaced by fat. Cysts, fibrous tumours and dilated ducts are all benign conditions that may occur during these changes. The optimal image quality required for the visualisation of a large mass in a fatty breast may be very different from that required to show small calcifications in the more dense fibrous breast.

In general, lesions of the breast are indicated by masses, calcifications and distortions of breast architecture. A positive diagnosis will depend not only on their presence in the radiographic image but also on their number, size, shape and configuration. The following clinical features are important:

Calcifications: These are composed of calcium hydroxyapatite or tricalcium phosphate ranging in size from less than 0.1mm to 1.5mm with an occasional larger particle. They are most often irregularly shaped and present in clusters. Reports on the incidence of calcifications in carcinoma of the breast, as seen in pre-operative mammograms using screen film, range from approximately 30 to 40 per cent. However only a few per cent of

the mammograms exhibiting early tumours less than 1 cm in size reveal associated calcifications (Millis et al, 1976).

Masses: Soft tissue masses may vary in size from a few millimetres to several centimetres. They are irregularly shaped and often infiltrate with fine spicules into the surrounding tissues. Masses have approximately the same density as fibrous tissue and are slightly more dense than adipose tissue. A 3 mm infiltrating duct carcinoma in a 42 mm thick breast is calculated to have a subject contrast of only 1.3% (Johns and Yaffe, 1987).

Skin thickening, engorged ducts and distortion of breast structures: These are other signs that may be recognised in the breast radiograph as indicative of breast disease.

Image quality is therefore concerned primarily with the ability of the system to demonstrate the very small changes in soft tissue contrast and to detect the calcifications that are also often associated with breast disease. However by virtue of their size and contrast these critical features are difficult to detect in the presence of the structured noise associated with breast architecture. A good image is characterised therefore by the ease with which the critical feature can be seen in the presence of this noise.

.2.3 Image Quality Assessment

Image quality is the result of many factors and interactions between components of the imaging process. Important physical aspects that affect image quality include the target material and focus size, imaging geometry, X-ray tube potential and filtration, scattered radiation including the effect of compression and grids, image receptor speed, contrast and resolution and film processing.

Unfortunately there are no agreed standards for acceptable image quality nor any agreed protocols for predicting clinical performance based on the measurement of physical indices. It is anticipated that experience will allow standards on image quality to be set as the mammography screening service builds in the United Kingdom. The measurement of low contrast sensitivity and small detail visibility is important as a measure of the system's ability to image small masses and calcifications and the DHSS Guidelines (1988a) give suggested limiting values for these two parameters.

In addition to the measurement of physical indices discussed in Chapter 3, other quantities may be used as a measure of performance and image quality. For example, line spread function (LSF) and modulation transfer function (MTF) can give a useful measure of system performance (ICRU, 1986). MTF has been applied in mammography (Bencomo et al, 1982) but it is limited as a measure of overall performance and is unlikely to be applied in a routine quality assurance programme. Receiver operating characteristic (ROC) analysis, which includes observer performance in the assessment of overall performance, has also been used in mammography (Moores, et al 1979; Sabel et al, 1986). However, ROC analysis is impracticable for the assessment of image quality on a routine basis.

Although many individual physical parameters affecting image quality can be measured in a test situation, the practical approach that has traditionally been used in mammography is to use a test phantom simulating the clinical examination.

3.2.4 Image Quality Test Phantoms

An image quality test phantom is a device that simulates the shape and composition of the compressed breast and is sensitive to small changes in contrast and spatial resolution. It is used to provide a subjective or semi-quantitative assessment of image quality. It provides a standard which can be used as a quality control check on the performance of a particular mammography system with time, or to assess the performance of one mammographic system against another.

Test phantoms have been in use since the early days of mammography. Egan (1972) produced phantoms of breast tissue embedded in plastic and included pieces of material such as steel, lead, crushed marble and catgut. Other phantoms have been described by Stanton and Lightfoot (1966), Tonge and Davis (1978), DeWerd, Wochos and Cameron (1979) and White and Tucker (1980).

The ideal image quality phantom should be easy to use. It should reflect breast anatomy and be able to be used with the automatic exposure control to simulate the clinical exposure. Test detail should be clinically relevant and be sufficiently sensitive to register small changes in system performance. Quantitative measurement of image quality parameters should be possible and the test object should facilitate objective rather than subjective analysis so that image quality may be compared, irrespective of observer performance or experience.

Image quality phantoms can be divided according to the intended application:

(i) A phantom for frequent (e.g. daily to weekly) quality control checks. It should allow a rapid subjective check on low contrast sensitivity and small detail visibility. It should be sufficiently sensitive to detect the clinically significant changes in these parameters with time.

(ii) A more sophisticated phantom for commissioning and less frequent (e.g. 3-monthly to 6-monthly) checks. It may be suitable also for comparing different mammographic X-ray units or system components. This phantom should contain more detail and allow quantitative and, if possible, objective measurements.

Unfortunately, many of the phantoms that have been produced commercially do not relate well to the ideal, nor do they fit readily into one or the other of the above categories. A major difficulty with many of the earlier phantoms is a lack of suitable range and sensitivity when compared with the performance of a modern mammographic system. Image quality test phantoms continue to be developed (Gambaccini et al, 1988; Ramsdale et al, 1988). An anthropomorphic phantom for mammography has been described recently (Yaffe et al, 1986) and an improved version of such a phantom may be suitable for the daily checks on image quality.

In conjunction with the evolution of standards for image quality, it is expected that one or more particular phantoms will eventually become established as standards. Figures 5.1 to 5.8 show the details of the principal commercial phantoms which are described below in alphabetical order. (The figures have been re-drawn from manufacturers' or other literature: no responsibility can be taken for any errors).

(a) Agfa

The Agfa Mamoray phantom consists of a pair of lucite plates between which are sandwiched four types of detail. Superimposed on the lucite phantom is an aluminium graduated stepwedge. The phantom is 100 mm square and approximately 10mm thick. It does not simulate the size and thickness of the breast. Although the ten-step aluminium wedge allows a characteristic curve to be plotted it causes a large variation in contrast across the phantom image. The sandwiched details consist of four lines to measure low contrast sensitivity, additional areas containing glass beads and microcalcifications to measure high contrast resolution, together with grids of different mesh sizes.

The Agfa Mamoray phantom may provide a relative check on the performance of a mammographic system but it gives no quantitative measure of detail perceptibility. Care must be taken to ensure that the thickest part of the aluminium stepwedge does not obscure the sensitive area of the automatic exposure control.

(b) CIRS (USA)

This is a recent tissue-equivalent phantom manufactured by Computerised Imaging Reference Systems to a design and methodology developed by Fatouros et al (1985). The phantom is realistically-shaped even to the extent of having compression marks and the existence of a nipple. It is supported on a base plate acting as the chest wall. Various tissue compositions are available and the phantom includes fibres and specks of specified size. A pair of circular objects simulate breast tumours. There appears to be little experience in the use of the phantom (McCrohan, 1988).

(c) CGR

This test phantom is marketed by CGR as an accessory to their mammographic X-ray machines and is intended as part of their breast screening package. It is a D-shaped lucite phantom 45 mm thick and includes 0.1 - 0.3 mm simulated calcifications at two levels, two resolution test patterns, a contrast stepwedge with 6 steps, additional contrast steps and a contrast-detail section with contrasts of 0.6 - 3.4% at 20 kV.

It has a sophisticated design with potentially useful features, but a preliminary assessment (Ramsdale and Hiles, 1987) suggests that the phantom again suffers from a lack of sensitivity to both low contrast changes and small detail visibility. The phantom is being used as part of a quality control programme for breast screening in Sweden (Leitz, 1988) and is also to be used by the U.S. Emergency Care Research Institute (ECRI) in an evaluation of dedicated mammographic systems.

(d) Kodak

The Kodak ITO phantom has been available for some years and contains 7 sets of test detail embedded in a polyester resin disc, 140mm diameter and 15mm thick. Aluminium and vinyl chloride stepwedges are provided and nylon beads represent low contrast masses. Calcifications are simulated by ground and powdered chalk. Although providing a relatively wide range of different tests, the relevance of some of the details is considered inappropriate and the phantom has been reported as inferior to others (McCrohan et al, 1983). The phantom was used as a standard in the 'BENT' Programme (BRH, 1978).

(e) Leeds TOR [MAX]

A test object for mammography has recently been developed by FAXIL at Leeds who have considerable experience in the design and manufacture of test objects for diagnostic radiology. The test object comprises a thin breast-shaped Perspex plate to which additional scatter plates can be added and incorporates five different types of test detail. Two line-pair test objects placed at right angles are used to measure high contrast resolution. Simulated calcifications of different size and at different levels of contrast are provided to assess small detail visibility. An additional bar pattern together with three different sizes of circular detail provide a measure of low contrast resolution and low contrast sensitivity. A stepwedge provides the opportunity to obtain a characteristic curve.

A second, slightly less sophisticated version of the object without the line-pair patterns and named the TOR[MAS] is also available.

(f) Nuclear Associates/Victoreen

The Model 76-001-4 Mammographic Phantom comprises a 10cm diameter, 3.7cm thick acrylic block which surrounds a wax disc containing simulated calcifications in the range from 0.. - 0.27mm diameter and nylon fibres simulating soft tissue distortions. The phantom also contains a five-step air wedge to gauge image contrast. There is limited experience in the use of this phantom in the United Kingdom.

(g) RMI

The original RMI Random Phantom has been used extensively in the USA. It consists of a 100 cm square lucite base block and a cavity filled with 16 colour-coded wax blocks each containing test detail simulating tumour masses, fibrous structures and calcifications. The wax blocks which include one blank can be distributed randomly and this is a feature which is not available on other phantoms. In a survey of test phantoms (McCrohan et al, 1983), it was found that the RMI phantom had, among the four phantoms considered, the strongest correlation with clinical image quality. The report concluded that fibre and speck scores gave a good indication of film quality although the visibility of simulated masses was less satisfactory. In a comparative study of films and screens for mammography, the RMI phantom has been reported (Kirkpatrick and Law, 1987) as giving similar results to the "Barts" phantom (see (h) below).

A slightly modified version of the original Random Phantom has been introduced as the Model 152D Mammographic Detail Phantom. The random feature has been removed and a large single wax block contains the fibres, specks and masses, ranging in diameter from 0.4 - 1.6mm, 0.2 - 0.74mm and 0.25 - 2.0mm respectively. There is some suggestion that although the detail size now has elements small enough to challenge the best systems, and others sufficiently large to be imaged by the worst systems, there is an unfortunate decrease in sensitivity which impairs the phantom's discriminating ability (McCrohan, 1988).

Another version of the Model 152D, assigned as Model 156, has been adopted by the American College of Radiology in its new mammography accreditation programme. This phantom has identical detail but is slightly thinner.

(h) White and Tucker ("Barts")

This phantom was described by White and Tucker (1980) and is commonly called the "Bart's" phantom. The phantom is not currently available. It has been previously used as a

standard in a survey of mammography practice in Britain (Fitzgerald et al, 1981) and in more recent studies of mammography films and screens (Kirkpatrick and Law, 1987). Low contrast structures comprising cylinders, cubes and filaments varying in dimensions from approximately 0.4mm to 10mm are distributed in a 45mm thickness 50% fat/50% water substitute representing average breast. A stepwedge and simulated calcifications complete the phantom which has a total of 73 test details.

Although the phantom has been used with some success, results indicate that it may be insufficiently sensitive for modern mammographic systems. Objective comparisons from measurements made using different examples of the phantom also appear difficult because of some inter-phantom differences in manufacture and different methods of scoring.

.2.5 Test Phantom Use

Although the method of using a test phantom is essentially straightforward the type of phantom and its application may have some implications on the method adopted.

(a) Commissioning

Place the image quality phantom, preferably one suitable for commissioning, on the breast support table in the position normally employed for the craniocaudad view. If the phantom represents the attenuation provided by an average breast, use the automatic exposure control. If the phantom does not simulate an average breast or if automatic exposure control is not available, establish a suitable exposure to obtain an overall film density of 1.0-1.2. It is important to assess the image quality for the exposure conditions that are likely to be used clinically.

The following are relevant:

Tube voltage
Filtration
Focus-film distance
Magnification
AEC density control
AEC sensitivity
Compression plate and position
Grid
Cassette and screen
Film
Processing

Expose the phantom and process in the normal manner. Repeat to check for consistency of image quality between films. If necessary, produce a series of films at different exposure settings and compare them so as to establish optimum or clinically acceptable image quality; these are not necessarily the same.

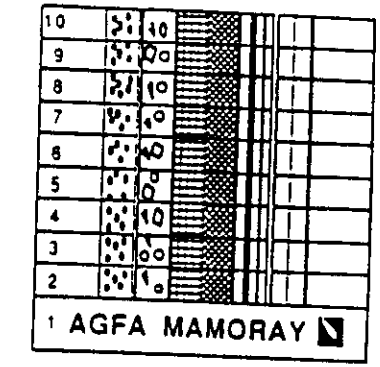
Where, possible compare the quantitative data with that obtained elsewhere on similar mammographic systems. Having STANDARDISED the exposure conditions, obtain a series of phantom films so as to establish base-line performance. Use a routine phantom if one is available.

(b) Routine Testing

Use the commissioning or routine phantom as available. Expose the phantom as above using STANDARD conditions. Compare the film and any quantitative information with previous films and data. Any deterioration in image quality will necessitate further investigation (see section 3.5).

Equipment: Image quality test phantom(s)
Densitometer

Limiting value: None at present



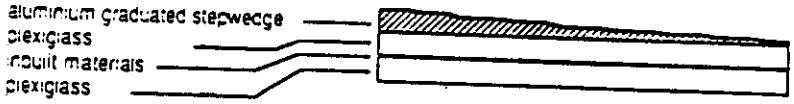


Figure 5.1 Main details of the Agfa Mamoray mammographic phantom

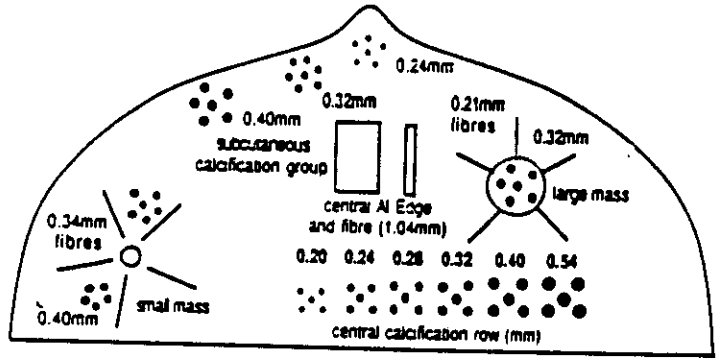


Figure 5.2 Main details of the CIRS (USA) mammographic phantom

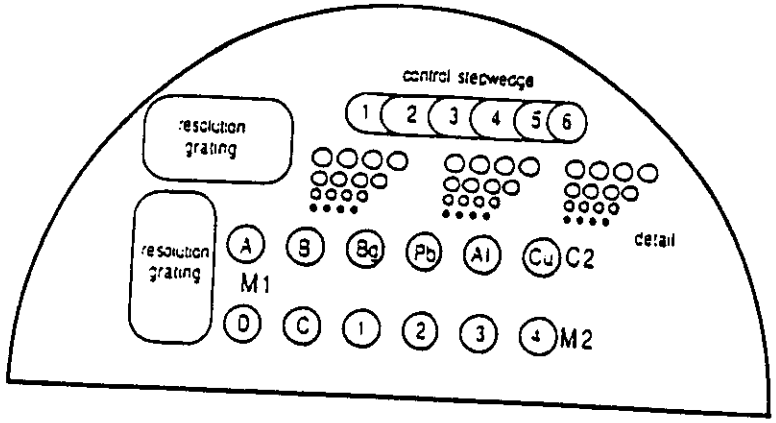


Figure 5.3 Main details of the CGR mammographic phantom

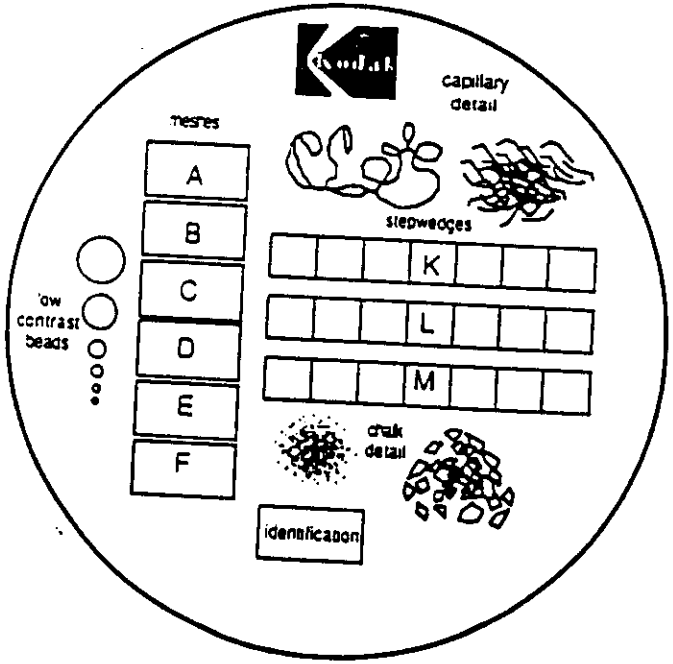


Figure 5.4 Main details of the Kodak [TO mammographic phantom

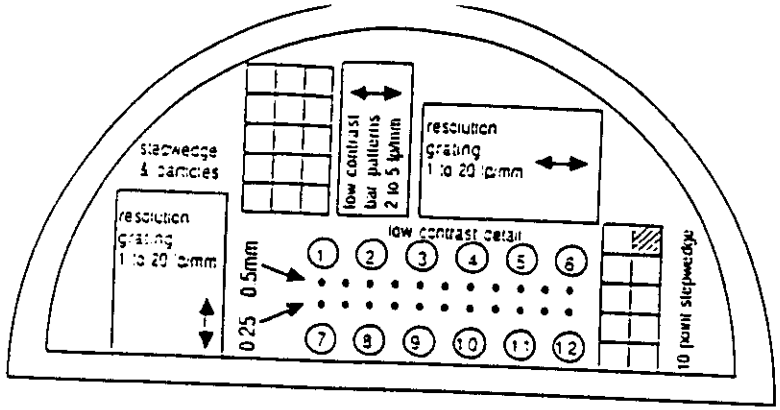


Figure 5.5 Main details of the Leeds TOR (MAX) mammographic phantom

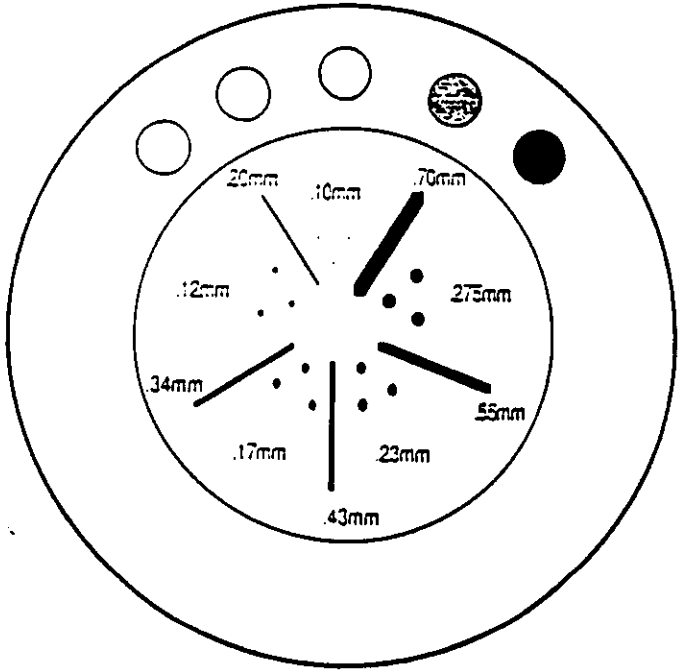
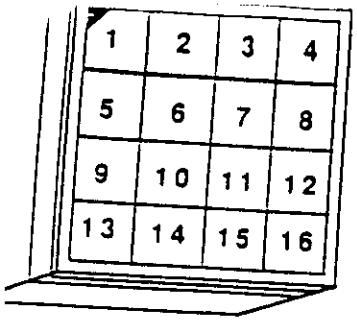


Figure 5.6 Main details of the Nuclear Associates/Victoreen Model 76-001-4 mammographic phantom



Fibres (mm. Dia.)		Specks (mm. Dia.)		Masses (mm. Dia.)	
1	1.56	7	0.74	12	2.0
2	1.15	8	0.54	13	1.0
3	0.96	9	0.32	14	0.75
4	0.75	10	0.24	15	0.5
5	0.54	11	0.20	16	0.25
6	0.40				

Figure 5.7 Main details of the RMI Model 1520 mammographic detail phantom

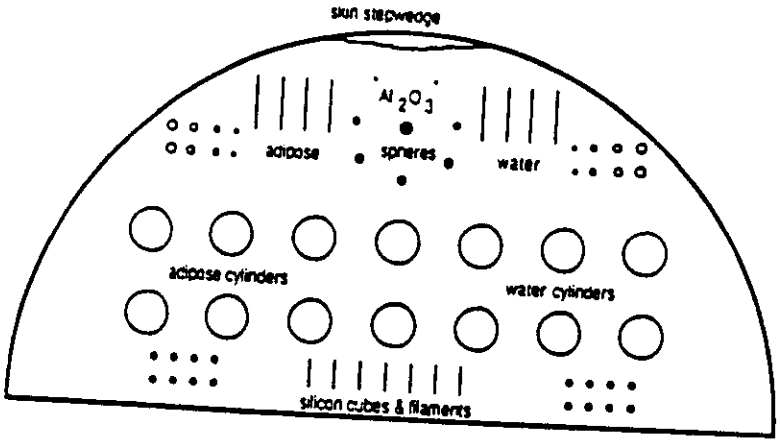


Figure 5.8 Main details of the White and Tucker ("Barts") mammographic phantom

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APPENDIX I - TEST FREQUENCIES

This Appendix lists all the tests in the order given in the protocol, together with the suggested frequencies at which they might be undertaken. The list may not be exhaustive, but will certainly be exhausting and readers may need to be selective! Frequencies should be regarded as tentative and may need to be altered in the light of experience. All the tests are regarded as being part of the commissioning process; a frequency is not shown if the the test does not need to be repeated. Some of the safety tests may need to be repeated more frequently for equipment fitted in mobile trailers (see section 1.4). Repairs and maintenance may necessitate additional tests.

(Key: D = Daily, W = Weekly, M = Monthly, A = Annually)

	D to W	3M to 6M	A
3.2 Electrical safety			X
3.3.2 Mechanical safety			
(i) table movement			X
(ii) compression auto-release		X	
(iii) auto-release override		X	
(iv) emergency release		X	
(v) maximum compression force		X	
(vi) sharp edges			X
(vii) field light			X
(viii) screen edges marked			
3.3.3 Mechanical functioning			
(i) equipment complete			
(ii) markings			
(iii) free movements			X
(iv) brakes		X	
(v) scale markings			

	D to W	3M to 6M	A
(vi) field sizes			
(vii) vertical movement			
(viii) foot switches			
(ix) attachments			X
(x) AEC detector			X
(xi) cassette movement			X
(xii) light intensity			X
(xiii) compression plate		X	
(xiv) breast thickness scale			X
3.4.2 Radiation safety inspection			
(i) mains isolator position			
(ii) clear control markings			
(iii) mains-on light			X
(iv) X-rays-on light			X
(v) total filtration			
(vi) added filter interlock			X
(vii) diaphragm interlock			X
(viii) exposure termination			X
(ix) exposure control position			X
(x) exposure control design			
(xi) exposure control function			X
(xii) entrance warning light			X
(xiii) + (xiv) lead equiv. markings			
(xv) protective screen gap			
(xvi) visibility			

	D to W	3M to 6M	A
3.4.3 Tube Leakage			
3.4.4 Lead equiv. measurement			
3.4.5 Table transmission			
3.4.6 Separation of film/table edge			
3.4.7 Alignment of X-ray field to film/cassette		X	
3.4.8 Alignment of light/X-ray field		X	
3.5.3 X-ray field uniformity			X
3.5.4 Size of focal spot			
slit camera			
star resolution grid		X	
3.5.5 Tube kilovoltage			
brief check		X	
full check			X
3.5.6 HVL/filtration			X
3.5.7 Exposure time			X
3.5.8 Output			
consistency		X	
versus kV		X	
versus tube current/ focus			X
3.5.9 Magnification			
3.5.10 Grid factor			
Grid film			X

	D to W	3M to 6M	A
3.5.11 Automatic Exposure Control			
sensitive area of AEC detector			X
phantom thickness		X	
tube voltage		X	
tube current			X
other parameters			X
calibration of density control			X
guard timer			X
regular test	X		
4.2 Automatic processing unit			
4.2.1 sensitometry	X		
4.2.2 APU temperature	X		
4.2.3 transport speed		X	
4.2.4 replenishment rate	X		
4.2.5 specific gravity/pH		As required	
4.2.6 residual hypo			X
4.2.7 silver recovery		X	
4.3 Screen-film system			
4.3.1 cassette & screen identification			
4.3.2 screen-film contact			X
4.3.3 light-tightness of cassette			X
4.3.4 relative screen sensitivity			X
4.3.5 characteristic curve			

	D to W	3M to 6M	A
4.4 Dark room and film storage			
light-tight darkoom			X
safelights			X
temperature			X
humidity			X
stock control	X		
4.5 Illuminators and viewing room			
visual check		X	
illuminator light level			X
ambient light level			X
5.1 Breast dose			
5.1.3 Full measurement		X	
5.1.4 Rapid check	X		
5.2 Image quality			
5.2.5(a) Optimisation			X
5.2.5(b) Routine check	X		

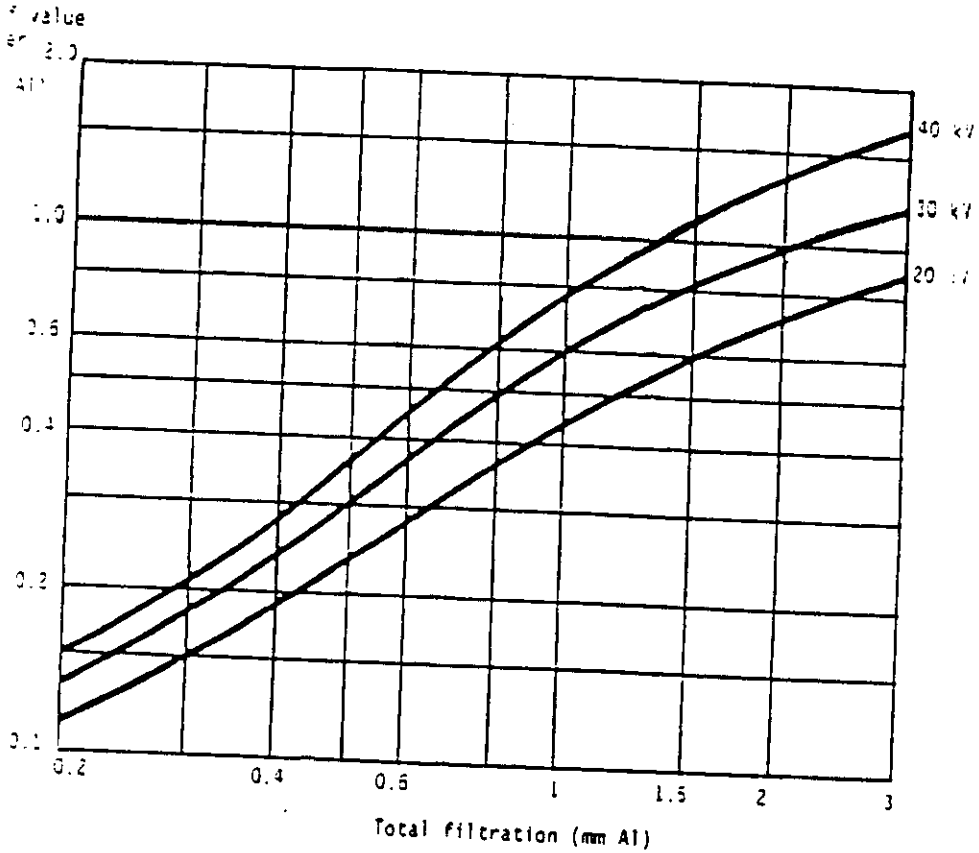

FIGURE AII.1. Relationship between tube voltage, filtration and half-value layer redrawn from the data given by Wachsmann and Drexler (1976, p 68).

Note that the graph was derived from results obtained on tungsten target tubes with beryllium windows, but it may be used as a guide for molybdenum target tube.

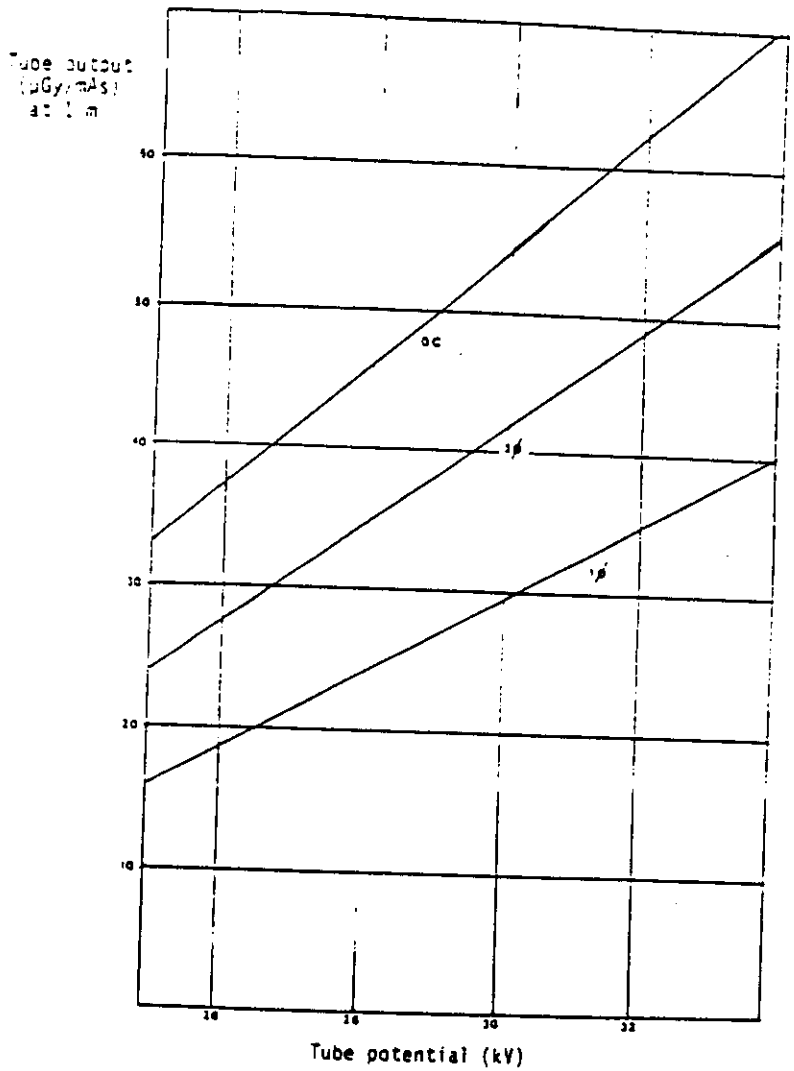

FIGURE AII.2. Typical outputs (air kerma/mAs at one metre) for molybdenum target mammographic X-ray tubes.

Note that the graph should be regarded as a guide only since it is based on data from a limited number of machines.

APPENDIX III : SUPPLIERS' ADDRESSES

This list may not be complete and should not be interpreted as a recommendation of any particular company or product.

NAME AND ADDRESS	PRODUCT
Agfa-Gavaert Ltd 27 Great West Road, Brentford, Middx TW8 9AX Tel: 01-560-2131	Sensi-densitometer Image quality phantom
Appleford Instruments Ltd P.O. Box 768, Abingdon, Oxon OX14 4UE Tel: 0235 510370	Test equipment
Computerised Imaging Reference Systems Inc. 2488 Almeda Avenue, Norfolk, Virginia, 23513, U.S.A.	Image quality phantom
Degussa Ltd, Paul Ungerer House, Earl Road, Stanley Green, Handforth, Wilmslow, Cheshire SK0 3RL Tel: 061-486-6211	Pinhole
Du Pont (UK) Ltd. Wedgwood Way, Stevenage, Herts SG1 4QN Tel: 0438-734546	Screen-film contact test tool
Faxil, ARNOLD CORRAN Dept. of Medical Physics, University of Leeds, Leeds General Infirmary, Leeds LS1 3EX Tel: 0532-432799	Image quality phantoms
Gammex-RMI Ltd., 4 Clarendon Chambers, Clarendon Street, Nottingham NG1 5LN Tel: 0602-483807	Focal spot slit camera/ test equipment/image quality phantom

NAME AND ADDRESS	PRODUCT
H. Hüttner, An der Schwedenschanze 1, D-8551 Heroldsbach/Thurn, West Germany, Tel: (09190) 428	Resolution test objects (also obtainable in UK from Siemens Ltd. and Vinten Instruments Ltd)
H. Miller Graphics Ltd., 8, Moody Street, Congleton, Cheshire CW12 4AP Tel: 0260-279988	Densitometers/ sensitometers
IGE Medical Systems, 260 Bath Road, Slough, Berks, SO1 4ER Tel: 0753-874000	CGR Image quality phantom
Industrieguter Import-Export GmbH, Steinkaulplatz 14, D-5100 Aachen-Kornelimunster, Germany Tel: 02408-4747	Focal spot slit camera
Kodak Ltd., Health Sciences Division, P.O. Box 66, Station Road, Hemel Hempstead, Herts HP1 1JU Tel: 0442-61122	Image quality phantom
Macbeth, Division of Kollmorgen (UK) Ltd. P.O. Box 178, Wolverhampton WV6 7TS	Densitometer
Physics Instruments Ltd., 21A Station Road, New Milton, Hants, BH25 6HN Tel: 0425-638055	Dosemeters/ test equipment
Radiatron Components Ltd., Crown Road, Twickenham, Middx. TW1 3ET 01-89-1221	Dosemeters

NAME AND ADDRESS	PRODUCT
R.Y. Parry P.O. Box 35, Newbury, Berks RG13 2NX Tel: 0635-46116	Densitometer
Siel Imaging Equipment Ltd., Unit 1, Orpheus House, Galleva Park, Aldermaston, Berks RG7 4QW Tel: 07356-71828	Test equipment/image quality phantom
Siemens Ltd., Siemens House, Windmill Road, Sunbury-on-Thames, Middlesex TW16 7HS Tel: 0932-785691	Resolution test objects
Vertec Scientific Ltd., 5 Comet House, Galleva Park Estate, Aldermaston, Reading, RG7 4QW Tel: 07356-77431	Dosemeters/test equipment
Vinten Instruments Ltd., Jessamy Road, Weybridge, Surrey KT13 8LE Tel: 0932-857711	Dosemeters/test equipment

QUALITY ASSURANCE

IN

MAMMOGRAPHY

A practical guide to radiographic quality control
produced by
Radiation Physics Group
Regional Department of Medical Physics and Bioengineering
Christie Hospital
Manchester M20 9BX
061 445 8123 ext 450

A G Brennan and A J Shaw

September 1988

Allegato B
Dispensa 4°

CONTENTS

INTRODUCTION:

This manual is intended to provide practical guidance on the implementation and operation of a routine quality assurance programme for mammography in the North Western Region. It is concerned solely with radiographic quality control and does not deal with the administrative structures necessary for the proper management of a quality assurance programme, radiological quality control and training. It is written as a practical users manual and it is intended that it be used as a companion publication to the IPSM protocol (IPSM, 1988).

It is assumed that comprehensive mechanical electrical and radiological safety commissioning has been performed on the unit to ensure that the standards of performance meet the conditions specified in the contract. Detailed status checks of all relevant parameters should also have been carried out to establish the baseline level of performance against which the extent of any future deterioration can be assessed. These are specified in Appendix 1.

It is assumed that the users will have had some experience and training in quality assurance and also have access to advice and support from a Physics Department with experience in quality assurance. The measurements are designed to detect any variation in the reproducibility of the components of the imaging process and the limiting values and associated actions are clearly specified for each measurement.

This document also includes the measurements that should be routinely performed by the Physics Department which are specified in Appendix 2. Finally, it must be acknowledged that this document may require revision in the light of further experience and developments.

Daily check

a. X-ray unit: Automatic exposure control: Reproducibility

1. Aim

To determine the reproducibility of the performance of the AEC facility. Also indicates the reproducibility of breast dose.

2. Equipment

2.1. Perspex phantom, 4 cm thick.

2.2. Designated cassette and film.

2.3. Calculator.

3. Method

3.1. Place 4 cm perspex phantom on tray, place the cassette in holder, select AEC chamber position 1 (nearest the chest wall) and apply compression.

3.2. Perform the normal warm-up exposures as specified in the manufacturers manual.

3.3. Using the normal AEC factors at 28 kV, perform a single exposure, recording the post-exposure mAs. Return the film with the screening radiographs for processing and inclusion in the reject analysis.

3.4. Calculate the mean post exposure mAs at the end of the week and calculate the overall mean for the 3 previous weeks.

4. Implementation

4.1. Frequency.

This should be performed daily before any screening examinations and after a routine service before engineer leaves.

4.2. Data record keeping.

All data should be recorded on the appropriate data sheet for future reference and comparison.

4.3. Limiting values.

mAs value should be within +/- 10% of the mean for the previous 3 weeks.

4.4. Action.

If the mAs reading is outside the limiting value, perform a repeatability measurement.

If the repeatability is unacceptable follow action specified in repeatability check (page 11).

If the repeatability is acceptable but the mean mAs of the repeatability check differs by more than +/- 10% from the mean mAs of the reproducibility measurements for the previous week, but by less than +/- 15%, perform a changing thickness measurement and follow action specified for this check (page 20).

If the repeatability is acceptable but the mean mAs differs by more than +/- 15% from the mean mAs of the reproducibility measurements for the previous week, notify the radiographer-in-charge, discontinue screening and arrange for a service engineer to correct the malfunction.

a. Daily check

b. Automatic film processing unit: Sensitometry

1. Aim

To ensure that optimum processing standards are maintained and to detect any changes by sensitometric methods. (It is assumed that the processor has already been set up at pre-determined optimum operating conditions).

2. Equipment

2.1. A box of 18 x 24 cm mammography film, dedicated specifically for sensitometry. This box should be from the most recent delivery and must be kept under the normal darkroom storage conditions.

2.2. Green light sensitometer and operating manual.

2.3. Densitometer and operating manual.

2.4. Graph paper, log book and coloured pens.

3. Method

3.1. A sensitometric strip is produced and fed through the processor, when it has warmed up, at the same time daily.

3.2. Always process the film in a reproducible manner, positioning the strip at the same place on the feed tray and with the least dense step at the lead edge of the film.

3.3. Record the date, time and development temperature on the processed sensitometric strip.

3.4. Perform density measurements on the sensitometric strip to determine values for speed index (SI), contrast index (CI) and base and fog density (BF). These measurements must be performed at 3 specific locations.

i) An unexposed area of the film. This is the value of base plus fog density (BF).

ii) A step which has a density of approximately 2.2. Use this step number for all subsequent measurements.

iii) A step which has a density of approximately 1.2. Use this step for all subsequent measurements. This is the speed index (SI).

To determine the value of contrast index (CI) subtract iii) from ii) above.

3.5. Record the values of SI, CI and BF on the data sheet and graph, noting any deviations and possible trends.

3.6. When there are about 5 sheets of film left in the dedicated box, implement a cross-over procedure. Obtain a second box of identical film from the most recent delivery and for the next 5 days process 2 sensitometric strips, one from each box, clearly identifying which is old and which is new.

3.7. Record SI, CI and BF, for both films.

3.8. It may be necessary to initiate the cross-over procedure earlier than indicated above if, due to storage conditions, the BF of the sensitometric strip becomes unacceptably high.

3.9. During the cross-over procedure, the differences in SI and CI should not vary by more than +/- 0.1 D and BF by +/- 0.02 D.

4. Implementation

4.1. Frequency.

This measurement should be performed daily or when a malfunction is suspected or after a routine service before the engineer leaves.

4.2. Data record keeping.

Establish a 'Sensitometry Log Book'. This should include the data sheets, graphs, strips, and all relevant information regarding sensitometry so that it can be easily understood by all radiographic and Physics Department staff.

4.3. Limiting values.

CI and SI should be within +/- 0.1 D of the mean for the previous month. BF should be within +/- 0.02 D of the mean for the previous month.

4.4. Action.

If either CI, SI, or BF is outside the limiting value repeat the measurement to verify.

If the variations are within the ranges +/- 0.1 to +/- 0.2 D for CI and SI and within the range +/- 0.02 to +/- 0.03 D for BF, continue processing but try to establish the cause and correct it before the situation worsens. Repeat the sensitometric check some time later. Although there is no substitute for real experience and knowledge, guidance on the interpretation of the sensitometric results is available in the referenced publications (BRH, 1977; HPA, 1984; Moores et al, 1987).

If all variations are greater than +/- 0.2 D for CI and SI and +/- 0.03 D for BF, discontinue processing and do not use the processor until the cause has been identified and corrected.

A. Daily check

C. Film: Reject rate

1. Aim

To quantify the amount of waste film as a % of the total film used for mammography - the reject rate. (This reject rate check is a component part of the continuous reject analysis and is performed daily to facilitate the early detection of changes in reject rates and the identification of causes.)

2. Equipment

2.1. 'Daily' boxes to collect waste film, 'weekly' boxes to store waste film.

2.2. 'Reject' data sheets.

3. Method

3.1. Discuss the project with all staff and explain the importance of performing the daily reject rate checks. Stress the importance of them using the correct box and 'reason' code.

3.2. Decide what categories of 'reason' are to be used in the analysis of the reject films.

e.g. too dark
too light
positioning
movement
processor
loader
blank film
test film
identification tag
absence of region of interest
fogged
other

3.3. Devise a coding system for each reason. Ask the staff, when discarding film, to mark each rejected film legibly with the correct reason code and put it in the correct box.

3.4. Provide a 'daily' box for each X-ray unit at appropriate sites, e.g. adjacent to the processor and reporting area.

3.5. Note the total number of radiographs from each unit before processing.

3.6. Collect, count and record the boxes' contents daily. Do not sort the contents into reason categories but store the contents safely in the weekly boxes for the weekly reject analysis check.

3.7. Collect all the data, calculate the daily reject rates for each unit and record the results.

3.8. If the reject rate for any one unit has changed significantly sort the reject films for that unit into 'reasons' and analyse the findings to identify the source of the change.

4. Implementation

4.1. Frequency.

This simple reject rate check should be performed daily to facilitate the early detection of problems.

4.2. Data record keeping.

All data should be recorded on the appropriate data sheet.

4.2.1. Information required from other records.

Total number of film processed from each X-ray unit.
Number of non-clinical films used.

4.2.2. Daily reject rate for each X-ray unit.
Daily overall total reject rate.

4.3. Limiting values.

This will be decided by the QA manager and will be dependent on local operational conditions.

4.4. Action.

Any sudden increase in reject rates indicates a problem that must be located and corrected. This information must be communicated to the users at the relevant screening unit as soon as possible and appropiate corrective action must be identified and implemented.

A. Daily check

d. Cassettes: Screen inspection and cleaning

1. Aim

To ensure that a high standard is maintained on the performance of the cassettes.

2. Equipment

Screen cleaning materials.

3. Method

The screens should be inspected for dust particles, marks and other contaminants and cleaned using a proprietary cleaner.

4. Implementation

4.1. Frequency.

This should be performed daily.

4.2. Limiting values.

If scratches or marks are present check that they do not impair or contribute (in a 'false-positive' manner) to the diagnostic quality of the mammograms.

4.4. Action.

If the diagnostic quality of the screen is impaired, it should be taken out of service.

B. Weekly check

a. X-ray unit

i. Automatic exposure control: Repeatability

1. Aim

To determine the repeatability of the performance of the AEC facility.

2. Equipment

2.1. Perspex phantom, 4 cm thick.

2.2. Designated cassette and film.

2.3. Calculator.

3. Method

3.1. Place 4 cm perspex phantom on tray, place the cassette in holder, select AEC chamber position 1 (nearest the chest wall) and apply compression.

3.2. Perform the normal warm-up exposures as specified in the manufacturers manual.

3.3. Using the normal AEC factors at 28 kV, repeat the exposure 5 times, recording the post-exposure mAs on each occasion.

3.4. Determine and record the mean and standard deviation of the post-exposure mAs readings. Return the film with the screening radiographs for processing and inclusion in the reject analysis.

4. Implementation

4.1. Frequency.

This should be performed weekly or when a malfunction is suspected (e.g. unacceptable reproducibility) or following correction of a repeatability malfunction.

4.2. Data record keeping.

All data should be recorded on the appropriate data sheet for future reference and comparison.

4.3. Limiting values.

All mAs values, should be within +/- 10% of mean.

4.4. Action.

If an mAs reading is outside the limiting value repeat the measurements to verify.

If an mAs reading is within the range +/- 10% to +/- 15% of the mean, perform the repeatability measurement daily to determine status and contact the mammogram reader/radiologist to ascertain whether or not reject rates have increased. If so and/or repeatability has worsened, notify the radiographer-in-charge, discontinue screening and arrange a service engineer to correct the malfunction.

If an mAs reading is greater than +/- 15% of mean, discontinue screening and arrange for a service engineer to correct the malfunction to ensure that the system operates within the limiting value.

B. Weekly check

a. X-ray unit

ii. Compression device: Reproducibility

1. Aim

1.1. To determine the reproducibility of the compression device.

2. Equipment

2.1. Large piece of hard compressible foam.

3. Method

3.1. Place the foam centrally under the compression plate and apply the maximum compression possible.

3.2. Record the pressure and the thickness of the compressed foam.

4. Implementation

4.1. Frequency.

This measurement should be performed daily or when a malfunction is suspected.

4.2. Data record keeping.

Record the data on the appropriate data sheet.

4.3. Limiting value.

A highly reproducible degree of compression is required, so recorded values should be within +/- 5% of the mean for the previous week.

4.4. Action.

If the data is outside limiting value, repeat the measurement to verify it. If possible adjust the compression device so that the compression is within the limiting value. If this is not possible notify the radiographer-in-charge, discontinue screening and arrange for the service engineer to correct the malfunction.

B. Weekly check

b. Image Quality: Reproducibility

1. Aim

To determine the reproducibility of the limiting resolution and threshold contrasts of the system.

2. Equipment

2.1. Leeds test object TOR (MAS).

2.2. Designated cassette and film.

2.3 Magnifier (5x or greater).

3. Method

3.1. Read the instruction manual before use to familiarise oneself with the principles and use of the test object. When examining the images, follow the procedures specified in the manual (Cowen et al, 1988).

3.2. Position the unit for the cranio-caudat projection and adjust the FFD to the maximum possible. Place the test object on top of the attenuator plates on the tray and expose automatically at 28 kV. Record the date, factors and unit on the film.

3.3. When the processed film has been returned and read, record the densities, the limiting resolution, the low contrast resolution limit, the threshold contrast of both the large detail low contrast objects and the small detail high contrast objects. Store the film for future reference.

4. Implementation

4.1. Frequency.

This measurement should be performed weekly or when a malfunction is suspected.

4.2. Data record keeping.

Record the data on the appropriate data sheets and store the films for future reference.

4.3. Limiting values.

mAs should be within +/- 10% of the mean for the previous 4 months.
Base+fog density should be within +/- 0.02 D of the mean for the previous 4 months.
Background density should be within +/- 0.1 D of the mean for the previous 4 months.

Absolute values of the resolution and threshold contrast will depend on the age and type of the equipment and other local conditions. Values should be reproducible to within +/- 1 increment of the baseline value for all the test object details.

4.4. Action.

A. If the base+fog and backround densities are outside the limiting values but within range +/- 0.04 D and +/- 0.2 D of their respective means and

i. If the mAs is outside the limiting value:
   1. Check that the correct exposure geometry and cassette have been used.
   2. Repeat the measurementto verify. If still outside,
   3. Check the daily AEC reproducibility results and perform a repeatability measurement.
   4. If the repeatability is unacceptable:
      Follow the action specified in the repeatability check (page 11).
   5. If the repeatability is acceptable:
      There may be a reproducibility problem, but this should be detectable by the daily AEC reproducibility measurement.

ii. If the mAs is within the limiting value:
   1. Check that the correct cassette has been used.
   2. Check the daily processor sensitometry measurements.
   3. If these are satisfactory, repeat the image quality measurements to verify that the densities are still incorrect.
   4. If the resolution and threshold contrasts are within the limiting values, there may be a film batch speed difference.
      Notify the radiographer-in-charge and perform a sensitometric film speed comparison with the present film and the processor sensitometry film.

B. If the base+fog and/or background are outside the range +/- 0.04 D and +/- 0.2 D of their respective means:
   1. Notify the radiographer-in-charge and discontinue screening.

C. If the resolution and/or threshold contrast measurements are outside +/- 1 increment of the baseline values:
   1. Check that the correct exposure geometry and cassette have been used.
   2. Repeat the measurement to verify, ensuring that the correct viewing conditions are used, If still outside
   3. Perform a film/screen contact measurement and follow the action specified (page 23).
   4. If the film/screen contact is acceptable:
      Notify the radiographer-in-charge and the Physics Department, who will perform focal spot size and kVp measurements.

B. Weekly check

c. Film:

i. Reject analysis

1. Aims

1.1. To establish the baseline for the QA programme and monitor its effectiveness.

1.2. To facilitate the detection of changes in reject rates and the identification of causes.

2. Equipment

2.1. 'Weekly' boxes in which to store waste film.

2.2. 'Reject' data sheets.

3. Method

3.1. Collect, count and record the 'weekly' boxes' content for each X-ray unit at the end of the week. Confirm that the numbers agree with those recorded daily on the 'reject' data sheets.

3.2. Sort the contents of each box into 'reasons' and record the findings before moving on to the next box.

3.3. Collect and total all the data for the week, calculate the reject rates per reason per X-ray unit and record results.

4. Implementation

4.1. Frequency.

4.1.1. It is of paramount importance that a full reject analysis be performed before commencing the QA programme to provide an initial baseline and to pinpoint problem areas.

4.1.2. It should be performed continuously to facilitate the early identification of faults and problem areas in the imaging chain. The attainment and maintenance of low reject rate is an invaluable indication of acceptably high quality and efficiency in the imaging process.

4.2. Data record keeping.

Record the data and reject rates on the appropriate data sheets.

4.2.1. Information required from 'reject' data sheets to include:-

Total films processed per unit.
Total rejects per unit.

4.2.2. Weekly reject rates for:-

(i) Each X-ray unit
(ii) Each reason at each unit
(iii) Each reason at for all units
(iv) Overall reject rate.

4.3. Limiting values.

This will be decided by the QA manager and will depend on local operational conditions.

4.4. Action.

4.4.1. Endeavour to keep rejects as low as can reasonably be achievable.

4.4.2. Be on the look out for changes that may be developing slowly through careless technique e.g. poor positioning or compression, or poor maintenance, e.g. scratches on film emulsion.

B. Weekly check

C. Film:

ii. Stock control/Film storage

1. Aim

To ensure that a high standard is maintained on the performance of the film.

2. Equipment

2.1. Maximum/Minimum thermometer.

3. Method

3.1. Stock control.

A strict control system should be implemented. The uniformity of batch number of film should be confirmed upon delivery and the delivery date should be clearly indicated on the box. Film and chemistry should be used in strict rotation, oldest first and no film or chemistry be used beyond it's expiry date.

3.2. Film storage.

Films should be stored at 15C to 18C and humidities of 50% to 60%. Films should be allowed to reach darkroom temperature before use.

4. Implementation

4.1. Frequency.

4.1.1. Stock control.

Should be conducted continuously. Checks should be made weekly or as often as necessary.

4.1.2. Film storage.

Film storage temperature should be checked periodically and daily during particularly hot and cold weather spells.

4.2. Data record keeping.

Detailed stock records of film and chemistry turnover should be kept as an aid to the administrative management of the work.

4.3. Limiting values.

4.3.2. Stock control.

On delivery check that the film is of the same batch and that its expiry date is not in excess of its estimated shelf-life.

4.3.3. Film storage.

Storage temperature should be maintainable to within +/- 2C.

4.4. Action.

4.4.1. Stock control.

If the film is not of the same batch confirm that it is of uniform sensitivity with the manufacturers and by sensitometric comparison. If its expiry date is in excess of its shelf-life return to manufacturer.

4.4.2. Film storage.

If temperature is consistently high, reduce the central heating temperature and/or install a fan or air conditioning system.

C. Monthly check

X-ray unit: Automatic exposure control: Changing thickness

1. Aim

To determine that the AEC performs correctly for changing phantom thicknesses.

2. Equipment

2.1. Perspex phantoms, 2 and 4 cm thick.

2.2. Densitometer.

2.3. Designated cassette and film.

3. Method

3.1. Place 2 cm perspex phantom on tray, record thickness on dedicated cassette and place in holder, select AEC chamber position 1 (nearest chest wall) and apply compression.

3.2. Using the normal AEC factors, perform an exposure, recording the post exposure mAs and the factors.

3.3. Repeat the above steps for thicknesses 4 and 6 cm, reloading the cassette each time.

3.4. When the films have been processed, read the densities in a reproducible area and record these on the films.

3.4. When the radiographs have been returned, record the densities. Return the films for inclusion in the reject analysis.

4. Implementation

4.1. Frequency.

This should be performed monthly or when a malfunction is suspected.

4.2. Data record keeping.

All data should be recorded on the appropriate data sheet for future reference and comparison.

4.3. Limiting values.

mAs values should be within +/- 10% of those for previous month. Range of densities should be within +/- 0.2 D of the average density and within +/- 0.1 D of that for an identical thickness for the previous month.

4.4. Action.

If the densities are outside the limiting value, repeat the measurements to verify.

If the mAs values differ by between +/- 10% and +/- 15% from those for the previous month, but the densities for different thicknesses are within +/- 0.2 D to +/- 0.3 D of the average, and the densities for the same thickness are within +/- 0.1 D to +/- 0.15 D of the previous months measurement, perform the measurements daily to determine status and contact the mammogram reader/radiologist to ascertain whether or not reject rates have increased.

If the mAs values differ by more than +/- 15%, or the density for different thicknesses differs by more than +/- 0.3 D, or for the same thickness differs by more than +/- 0.15 D, or the reject rates have increased, notify the radiographer-in-charge, discontinue screening and arrange for a service engineer to correct the malfunction.

D. Quarterly check

a. Breast dose: Reproducibility

1. Aim

To determine the long-term reproducibility of the breast dose.

2. Equipment

2.1. Perspex phantom 4 cm thick.

2.2. TLD material.

3. Method

3.1. Place the 4 cm perspex phantom on the tray, insert the cassette in the holder, and select AEC chamber position 1. Place the TLD material on the phantom in the indicated position and apply compression.

3.2. Using the normal AEC factors, perform one exposure and record the radiographic factors.

3.3. Return the TLD material and the recorded factors by post to:-

Personal Radiation Dosimetry Service
Palatine House
Palatine Road
Withington
M20 9BX

Return the exposed film for inclusion in the reject analysis.

4. Implementation

4.1. Frequency.

This should be performed 3 monthly.

4.2. Data record keeping.

All data should be recorded on the appropriate data sheet for future reference and comparison. Additionally the Physics Department will also keep a record of the breast dose measurements.

4.3. Limiting value.

This will be determined by the Physics Department.

4.4. Action.

This will be investigated by the Physics Department.

D. Quarterly check

b. Cassettes: Film/screen contact

1. Aim

To ensure that any deterioration of the screens is identified thereby avoiding inferior quality mammograms and unnecessary dose to the population.

2. Equipment

2.1. Film/screen contact test tool.

2.2. Cassette log book.

3. Method

3.1. Ensure that the cassettes have been cleaned and reloaded.

3.2. Read the manufacturers literature for the contact test tool.

3.3. Place the cassette on a flat surface and position the test tool on top of it.

3.4. Adjust the focus-film-distance to that specified in the manufacturers literature and collimate the field size to the cassette size. (If these steps are not possible on a dedicated mammography unit, a conventional X-ray unit should be used.)

3.5. Using fine focus, perform an exposure to give a density of approximately 2.0 D.

3.6. Repeat the above procedure on each cassette, clearly identifying each cassette using a marker system prior to processing.

3.7. Examine the resultant films on a viewing box at a distance of 4 m.
Areas of increased density are indicative of areas of bad film/screen contact.
Areas of decreased density are indicative of chemical damage to the screen or dirt.

3.8. Examine and clean any offending screens and repeat the above procedure to confirm the findings.

4. Implementation

4.1. Frequency.

Quarterly and when degradation of the image indicates that film/screen contact may have deteriorated.

4.2. Data record keeping

Record in the cassette log book:-

Cassette number, screen type and age
Physical state of cassette and screen (visually)
Results of tests and date

and store the films for future reference.

4.3. Limiting value.

When viewed at 4 m, the films should appear to be of uniform density. Areas of increased density are indicative of poor film/screen contact and the cassette should be removed from clinical use. Areas of decreased density are indicative of chemical damage ot dirt. If, after cleaning and repeating the test, the area of decreased density remains, the cassette should be removed from clinical use.

4.4. Action

Each cassette removed from clinical use should be evaluated to determine the extent of screen damage and due consideration should be given to either replacing the screen or discarding the cassette and screen.

E. Routine checks

Automatic film processing unit: Simple maintenance

1. Aim

To obtain and record baseline data on the performance of the processor as an aid to the diagnosis and detection of faults.

2. Equipment

2.1. Thermometer either alcohol or digital (not mercury!). If digital, a long measurement probe is essential.

2.2. pH meter or pH indicator papers (range 9 to 13 for dev., 3 to 7 for fix.).

2.3. Stopwatch.

2.4. Two graduated measuring cylinders (250 ml), accurate to within 5 ml, one for developer and one for fixer. These should be long enough to hold the hydrometer.

2.5. Residual hypo test kit for archival permanency.

2.6. Silver estimating paper.

2.7. Hydrometer.

2.8. Lengths of plastic hose, cleaning materials and a sink sufficiently large to hold the roller racks.

2.9. Processor manuals and manufacturers information for film and chemistry.

2.10. Service records and details of modifications.

3. Method

3.1. The rollers and tanks should be kept free from chemical deposits by frequent regular cleaning.

3.2. The roller racks should be removed and all moving parts should be inspected for signs of wear. The circulation of the solutions in the tanks should then be rechecked with the racks removed and the processor switch on.

3.3. All drains and pipes should be inspected for holes, leaks and blockages. The proper function of the water flow valves should be also checked.

3.4. The roller racks should be replaced and the film transportation times checked and recorded.

3.5. The processed film should be examined for scratches, roller marks, streaks and evidence of inadequate washing or drying.

3.6. The solution temperatures should be checked and recorded and the filter checked for cleanliness and presence of blockages.

3.7. The replenishment rates of the developer and fixer should be checked and recorded using the graduated measuring cylinders using the manufacturers specified procedures.

3.8. The efficiency of the fixing and washing should be checked and recorded using the hypo test kit.

3.9. The pH and specific gravities of the solutions should be checked and recorded.

3.10. The silver content of the fixer and the silver recovery tanks should be checked and recorded using silver estimating paper.

4. Implementation

4.1. Frequency.

4.1.1. The rollers should be cleaned daily, and all the tanks quarterly or whenever solutions are changed.

4.1.2. The roller racks should be cleaned weekly and all moving parts and circulation inspected weekly or when a fault is suspected.

4.1.3. The drains and pipes should be inspected weekly or when a fault is suspected.

4.1.4. The film transportation times should be checked 3 monthly.

4.1.5. The films should be examined weekly or as indicated.

4.1.6. The solution temperatures should be checked monthly although the developer temperature should be checked and recorded daily during the sensitometric measurement. This should be compared with the displayed value to confirm its long term accuracy.

4.1.7. The replenishment rates should be checked 3 monthly or as indicated by the sensitometry.

4.1.8. The hypo-test should be performed 6 monthly or as indicated by the sensitometry.

4.1.9. The pHs and specific gravities should be checked 6 monthly or as indicated by the sensitometry.

4.1.10. The silver content should be checked 6 monthly.

4.2. Data record keeping.

Establish a 'Processor Log Book' in which all data is clearly recorded and dated.

4.3. Limiting values.

These are clearly specified in the referenced publications (BRH, 1977; HPA, 1984; Moores et al, 1987).

4.4. Actions.

These are best borne of experience but some are specified in the referenced publications (BRH, 1977; HPA, 1984; Moores et al, 1987).

References:

1. BRH, 1977. Photographic Quality Assurance in Diagnostic Radiology, Nuclear Medicine and Radiotherapy. Vol. II. Photographic Processing, Quality Assurance and the Evaluation of Photographic Materials. 77-8018 (Bureau of Radiological Health, Maryland 20852).

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3. HPA, 1984. TGR32, Measurement of the Performance Characteristics of Diagnostic X-Ray Systems used in Medicine, Part IV (IPSM, York).

4. IPSM, 1988. The Commissioning and Routine Testing of Mammographic X-Ray Systems. (IPSM, York).

5. Moores et al, 1987. Practical Guide to Quality Assurance in Medical Imaging. BM Moores, ET Henshaw, SA Watkinson and BJ Pearcy. (John Wiley, Chichester).

Appendix 1:

Measurements performed at commissioning:

These are listed below and the list is not intended to be exhaustive.

1. Electrical Safety

2. Mechanical Safety and Function

3. Radiological Safety

   Radiation protection operational procedures and local rules
   Operation of controls and warning devices
   Tube leakage
   Beam limitation and alignment
   Lead equivalence

4. Radiological Performance

   kVp accuracy
   Output repeatability and reproducibility
   Output variation with kV, mA and time/mas
   Accuracy and repeatability of exposure timer
   Total filtration
   Focal spot sizes
   Grid: alignment, bucky factor and contrast improvement factor
   Automatic exposure control: repeatability, variation with kV, thickness, magnification and density correction.

5. Automatic Film Processing Unit

   Processor Optimisation
   Processor Sensitometry
   Baseline Performance Measurements

6. Film/Screen System

   Identification
   Uniformity of batch sensitivity
   Film/screen contact
   Characteristic curve

7. Darkroom and film storage conditions

8. Illuminator and viewing room conditions

...dix 2:

Routine tests performed by the Physics Department:

Routine tests are undertaken regularly and/or after repair to determine if any change in the performance of the equipment has occurred and to update the baseline data, if appropriate. The tests performed and their frequency will depend on local operational conditions and should include the following:-

Operation of emergency release

Operation of controls and warning devices

Beam limitation and alignment

kVp accuracy

Output repeatability and reproducibility

Focal spot sizes

AEC repeatability

Sensitometric processor comparison

Cassettes, uniformity of batch sensitivity

Illuminator performance

Appendix 3:

Sample data sheets

Sample data sheets for all the measurements are included in this appendix. Some additional 'reject analysis' data sheets with sample data and calculations are also included.

Automatic exposure control: Daily Reproducibility

X-ray unit:

__ kV, 4 cm perspex, chamber position 1, cassette no.__

Date	mAs	Weekly mean	Rolling 3 wk mean	UL	LL	Comments

UL = 1.10 x 3 week mean LL = 0.90 x 3 week mean

Automatic film processor: Daily Sensitometry

Processor:

Date	Temp C	BF	SI step __	step __	CI	Comments
U Limit						
L Limit						

Automatic film processor: Daily Sensitometry

Processor:

Date	BF	SI step __	step __	CI	Comments
U Limit					
L Limit					

Automatic exposure control: Weekly Repeatability

X-ray unit:

__ kV, 4 cm perspex, chamber position 1, cassette no.__

Date	mAs 1	2	3	4	5	Mean +/-S.D.	UL	LL	Comments
	,	,	,	,	,				

UL = 1.10 x mean mAs LL = 0.90 x mean mAs

Compression device: Weekly Reproducibility

X-ray unit:

Date	Pressure (bars)	Thickness (cm)	UL P	LL P	UL T	LL T	Comments

UL = 1.0_ x last week mean LL = 0.9_ x last week mean

Image quality: Resolution Weekly Reproducibility

X-ray unit:

28 kV, Cassette no.__

Date	mAs	Density Base+Fog	Density Background	Limiting Resolution	Low contrast Linear detail	Comments
U Limit						
L Limit						

Image quality: Threshold Contrast Weekly Reproducibility

X-ray unit:

28 kV, chamber position 1, cassette no.__

Date	Large Detail Low Contrast 6 mm	Small Detail High Contrast 0.5 mm	Small Detail High Contrast 0.25 mm	Comments
U Limit				
L Limit				

Film: Daily Reject rate

Processor:

Date	X-ray unit	Films processed	Rejects Processor	Rejects Reporting	Daily reject rate	Comments
					%	
					%	
	Other					
	Overall TOTALS				%	

Film: Weekly Reject analysis, individual units

Processor:

Dates:

X-ray unit								
Total films processed								
Reason	Rejects per reason	Reject rate per reason			Rejects per reason	Reject rate per reason		
1. Dark		/	=	%		/	=	%
2. Light		/	=	%		/	=	%
3. Posn		/	=	%		/	=	%
4. Move		/	=	%		/	=	%
5. Proc		/	=	%		/	=	%
6. Blank		/	=	%		/	=	%
7. Test		/	=	%		/	=	%
8. ID tag		/	=	%		/	=	%
9. No ROI		/	=	%		/	=	%
10. Fog		/	=	%		/	=	%
11. Other		/	=	%		/	=	%
Total rejects								
Weekly reject rate	/	=	%		/	=	%	
Comments								

Film: Weekly Reject analysis, all units

Dates:

X-ray unit					Other	TOTAL, All units	
Total films processed							

Reason	Number of rejects					TOTAL all units	Reject rate
1. Dark					-		/ = %
2. Light					-		/ = %
3. Posn					-		/ = %
4. Move					-		/ = %
5. Proc					-		/ = %
6. Loader					-		/ = %
7. Blank					-		/ = %
8. Test					-		/ = %
9. ID tag					-		/ = %
10. No ROI					-		/ = %
11. Fog					-		/ = %
12. Other					-		/ = %
TOTAL All reasons					=		/ = %

Comments

Automatic exposure control: Monthly Changing thickness

X-ray unit:

__ kV, chamber position 1, cassette no.__

Date	Thickness (cm)	mAs	UL mAs	LL mAs	Density	UL D	LL D	Comments
	2							
	4							
	6							
	Average Density =							

UL mAs = 1.10 x last mAs LL mAs = 0.90 x last mAs
UL D = last Density + 0.1 D LL D = last Density - 0.1 D
Density range = last average Density +/- 0.2 D

Breast dose: Quarterly Reproducibility

X-ray unit:

28 kV, 4 cm perspex, chamber position 1, cassette no.__

Date	mAs	TLD dose (mGy)	Comments