Australian Radiation Laboratory

Radiation Doses from Mammography in Australia

by

Julian E. M. Thomson, Beverley F. Young, Joseph G. Young and David R. C. Tingey

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ABSTRACT

During 1989-90 the Australian Radiation Laboratory conducted a postal survey of at least 90% of the mammographic facilities in Australia. The primary aim of the survey was to measure the mean glandular dose (MGD) and the X-ray beam half value layer (HVL) for a typical mammograph. The MGD and HVL were measured with a specially designed tissue equivalent monitor which was inexpensive and robust enough to withstand the rigour of the postal service. In all, 258 mammographic centres were surveyed. It was found that for centres using film-screen imaging, the average mean glandular dose was 1.83 mGy for centres using grids and 0.84 mGy for centres not using grids. In addition to the MGD and HVL, comprehensive statistical information was collected and data is presented on the types of equipment and techniques used, the number and age of patients and demographic distribution of centres. The use of dedicated equipment using film-screen techniques was almost universal (98%). Most mammography was performed using X-ray tubes with molybdenum anodes (97%) and the use of grids was popular (80%). One unexpected result was that, of approximately 300,000 examinations performed annually, 162,000 (54%) of women were under 51 years old. Statistical correlations between MGD and mammographic techniques and equipment have been investigated. Results indicate that the use of a grid is the major factor determining dose and several other factors appear to have minor effects. In view of the distribution of MGD, it is recommended that the mean glandular dose per image, for a 5 cm compressed breast thickness, should not exceed 2.0 mGy when a grid is used and 1.0 mGy without a grid.
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1. INTRODUCTION AND AIMS.

Present medical opinion is that mammographic screening is the best available method of reducing mortality from breast cancer (Ta89a, Ta90, Fe88). For several years, national screening programs have operated in several countries including Sweden and Great Britain. In most states of the USA routine screening is available to women upon request.

In Australia at present, mammography is performed as part of the Medicare system only by referral of 'symptomatic' women to radiologists. It is generally recognised that many of these referrals are for minimal symptoms or have resulted through family history or anxiety or the like. The number of mammographs performed has increased dramatically over the last few years to approximately 300,000 per annum. A screening program for truly asymptomatic women is expected to commence in Australia in the near future and its implementation will take the number of women mammographed annually to well over one million.

Although mammography is the best available method of early detection of breast cancer, it may not be without risk. The possible risk arises from radiation induced breast cancer. Studies of women whose breasts have been exposed to high doses of radiation, indicate an increased incidence of breast cancers (UN88). In view of little evidence to the contrary, it would seem reasonable and prudent to extrapolate these results from high doses, and infer a possible risk from low doses delivered by screening mammography. Many such estimates have been made (La87, Va88, Mc88 La89). It is therefore important that the radiation dose delivered by a screening mammograph be minimised and that the possible risk/benefit ratio be constantly reviewed. To achieve this, the average radiation dose delivered by mammography equipment in a screening program should be continually monitored.
During 1989-90 the Australian Radiation Laboratory (ARL) surveyed every centre known to be performing mammography in Australia. Since the glandular tissue is the tissue most at risk to radiation carcinogenesis (IC87), the main aim of the survey was to measure the mean glandular dose (MGD). The survey, which was conducted entirely by mail, involved the measurement of the beam half value layer (HVL) and the MGD delivered for a typical mammograph at each centre. In addition, information was collected on current resources, types of equipment, mammographic techniques, geographic distribution of facilities and the number and ages of patients. An Australian screening program may utilize substantial resources from existing radiological facilities and it is hoped this information will be helpful in its planning.

One of the aims of the survey was to determine the average and spread of MGDs amongst the various centres. This information enables risk estimates to be made, practical dose limits to be recommended and mammographic doses to be compared with those of other countries. In addition, centres whose doses are either much higher or lower than average would have this information reported back to them so that they might take appropriate action (see Appendix 3).

It has been well established that for mammography to be efficacious it needs to be carried out by dedicated equipment. Surveys in the United States (Ja79a, Ja79b, Ru87) indicated a significant number of non-dedicated equipment being used for mammography. By surveying all centres performing mammography in Australia, rather than just a representative sample, those using non-dedicated equipment could be identified and advised confidentially that their techniques are not recommended.

There are many factors that may influence MGD in mammography. Some of these which were considered are the use of grids, type of grids, use of automatic exposure devices, X-ray tube voltage, anode type, method of breast compression, film processing, and brands of film, screen and X-ray unit. Part of the purpose of the present work was to investigate which of such factors statistically correlates with dose and which may, by manipulation, lead to dose reduction.
2. SURVEY DESIGN.

Due to the large number of mammography facilities which are widely distributed throughout Australia and because of the limited resources of the Laboratory, the survey was conducted entirely by mail. This method has been successfully used in both the USA (BE77, Je78, Wo78, Ja79a, Ja79b and Ru87) and Italy (Ri87). The measurement of physical parameters such as radiation dose and beam quality was achieved by using a specially designed radiation monitor using thermoluminescent dosimeters (TLDs). The survey was designed to consist of three phases.

In the first phase, an initial inquiry was sent to all Radiologists for whom a patient had made a recent claim through Medicare for a mammographic procedure, and to all hospitals in Australia (see Appendix 1). This was done in order to establish which centres in Australia were performing mammography at the start of the survey in March 1989. The term 'centre' includes public and private clinics, hospitals and mammographic screening centres. In all 3000 initial questionnaires were sent out.

In the second phase, a kit was sent to each centre from which a positive response had been received. The kit consisted of a comprehensive questionnaire on the equipment and techniques used, a monitor to be exposed, an instruction sheet on how to expose the monitor and a control TLD (see Appendix 2). Upon receipt back at the laboratory the questionnaire responses were recorded and doses and half value layers were computed from the TLD readouts.

In the third phase, reports were sent to the participants which gave the results of the dose and HVL measurements, together with appropriate comments and suggestions (see Appendix 3). Each centre also received a national summary indicating the distribution of MGD and HVL, enabling a comparison of its own results with the national ones.

All phases of the survey were managed on a PC using a single database and processes developed with Ashton Tate's dBase IV software. These processes included such things as maintenance of mailing lists,
production of questionnaires, storage of questionnaire responses, computation of physical parameters (e.g. HVL, MGD, Entrance Exposure) from the TLD readouts and production of the reports for each centre.

3. MAMMOGRAPHIC DOSIMETRY.

3.1. Parameters to be Measured.

Early studies of patient dose from mammography (BE77, Wo78, Je78) relied on measurements of the entrance skin exposure. These methods were chosen primarily because of the ease of measurement, for example, by placing a single TLD monitor on a patient's breast. Because of the differences in beam qualities used in various mammographic techniques it is not possible to relate accurately these exposures to dose to the glandular tissue. Some studies (Ja79a, Ja79b, Co84) made estimations of the midline dose. Mean glandular doses can be inferred from midline doses, but again because of the differences in beam qualities substantial inaccuracies can occur (Mu79).

To clarify the situation relating to the description of radiation dose in mammography, the International Commission on Radiological Protection (ICRP), at their meeting in Como in 1987, recommended:

"...that the usual reference terms for radiation dose estimation from X-ray mammography be the average absorbed dose in the glandular tissue (excluding skin) in a uniformly compressed breast of 50% adipose, 50% glandular tissue composition. The reference breast thickness should be specified." (IC87)

This recommendation was based on the work of Hammerstein et al., (Ha79) which in turn has been incorporated by the National Council on Radiological Protection and Measurements (NCRP) in their Report No. 85 "Mammography - A User's Guide" (NC86).

The ICRP recommendations have been adopted in the present study with the primary quantity of interest being the mean glandular dose (MGD) for a compressed breast of the recommended composition and 4.8 cm
thick. The reason for this choice as a reference thickness is discussed in section 3.2 on breast sizes.

A simple method of evaluating the MGD is described in the NCRP Report No. 85. The method requires that only the beam HVL and the free air exposure at the entrance surface of the breast need to be measured. An alternative method of determining the MGD is by measuring depth dose profile within the breast and integrating to obtain the required MGD.

An inexpensive and robust monitor was developed at the Laboratory which allowed the estimation of the MGD by both of these methods. In addition to the HVL and MGD, the monitor enabled the midline dose, entrance and exit exposures for the reference breast to be measured. All doses measured by the survey have been determined in units of gray and all exposures in Roentgen. In reporting to centres, exposure has also been quoted as Air KERMA, which for practical purposes has the same properties as exposure at mammographic energies.

3.2. Breast sizes.

It has been established by Stanton et al. (St87) and Prado et al., (Pr88), that the MGD increases rapidly with breast thickness. Their work suggests that for film-screen mammography, using a beam from a molybdenum anode, there is a doubling of the dose for each additional 1.5 cm of breast thickness. Thus by increasing breast thicknesses from 2 to 8 cm the dose would be expected to increase by a factor of about 16. For the present study to produce a true estimation of population doses, it is important that the measurements be made of doses that would be received by an average thickness breast in Australia.

Very little information has been published on the size and composition of the breasts of women undergoing mammography in Australia. Colgan and O'Reilly (Co84) surveyed women at a large Sydney hospital in the early 1980's and reported an average compressed breast thickness, for the cranio-caudal view, of 5.8 cm with a standard deviation of 1.1 cm. This study was for only a small number of women, at one centre and using compression techniques in vogue over a decade ago.
In order to obtain a more reliable estimate of average breast size measurements were made of the breast of 900 women, 300 of whom presented for mammographic examination at each of the Redfern Breast Clinic in Sydney, the Wesley Breast Clinic in Brisbane and the Royal Brisbane Hospital. The women were chosen at random. One of the quantities measured was the compressed thickness for the cranio-caudal view. Analysis of this data showed a normal shaped distribution of thickness at each centre. The average thickness at the Redfern Clinic was 5.7 cm whereas much smaller values of 4.4 and 4.5 cm were found at the Royal Brisbane and Wesley Clinics respectively. The larger average breast size found at Redfern was attributed to the large number of southern Europeans living in the area. These findings suggest that breast sizes may vary significantly with location and that a statistical study of many centres is required to obtain an accurate estimate of the average breast size in Australia.

In selecting the breast thickness for the survey, measurements from the three centres were combined. Figure 1 shows the distribution of compressed breast thicknesses for the cranio-caudal view. This has a mean of 4.8 cm and standard deviation of 1.3 cm. Thus a reference breast thickness of 4.8 cm was chosen for the present study.

3.3. Mammographic X-ray Spectra.

Radiological imaging of the breast has always been difficult because in most cases there is very little differential absorption between normal and abnormal tissue. For optimum imaging, a low energy beam and sensitive imaging medium are required. All mammography equipment manufacturers currently supply X-ray tubes with molybdenum anodes, although some firms will supply alternative tubes with tungsten anodes. The molybdenum spectrum produces $K\alpha$ and $K\beta$ characteristic lines at 17.9 and 19.5 keV. The predominance of these K-shell lines is further enhanced by the use of a molybdenum filter to suppress energies greater than 20 keV. A feature of these pseudo-monochromatic beams is that the HVL does not vary significantly in the energy range from 24 to 30 kVp. At these low energies there is a substantial difference in attenuation between different types of soft tissue (adipose, glandular) as well as
for various other light elements which may be used in the construction of radiation measurement devices. This creates difficulties in dosimetry associated with mammography and great care needs to be taken in the selection of any phantom materials and measuring devices.

4. ARL MONITOR.

4.1. Requirements.

It was the intention of the survey to measure the MGD at each centre under the conditions which would normally be used for a middle aged woman with average breast composition and a nominal compressed thickness of 5 cm. The NCRP technique requires a monitor capable of measuring the HVL and the free air exposure at the top surface of the breast. Previous postal surveys (Ja79a, Wo78, Ri87) have measured these quantities with a monitor which contained TLD dosimeters and aluminium filters. In these surveys, the monitors were exposed with the kVp and mAs of the X-ray equipment set manually.

At present in Australia a very large percentage (87%) of mammography centres use automatic exposure control (AEC) devices to terminate the exposure at the correct film density. With these devices, termination of the exposure is automatically controlled by an electronic sensor placed on the exit side of the film cassette. In many cases it is difficult, if not impossible, to manually reproduce the exposure given by the AEC for a typical mammograph. In these cases the type of monitor used in previous postal surveys would not be satisfactory.

An inexpensive monitoring device was required which simulates breast tissue of the required thickness so that automatic exposure control would terminate the beam at the correct exposure.

In this report, the term 'monitor' refers to our complete measuring device which is constructed of material which simulates breast tissue (phantom material).
4.2. Monitor Composition (Phantom material).

Many materials, for use as substitutes for breast tissue, are described in the literature (Ha79, Wh77, Wh80, Fa85) and many commercial phantoms have been produced for use in quality assurance testing of mammographic equipment (CIRS\(^1\), Leeds Test Object, RMI). White et al. (Wh77) described two breast substitutes, nominated as BR10 and BR12. The work of Hammerstein et al. (Ha79), which is fundamental to the NCRP formulation, discussed three phantom materials intended for use as breast tissue substitutes. The material chosen by these authors as being most suitable for their work was BR12. The cost and labour of producing a large number of phantoms made of this material was unacceptable for the present study.

The similarity of the elemental composition of cellulose and 50% adipose/50% glandular breast tissue led us to believe that cellulose may have merit as a breast tissue substitute. Table 1 shows the composition of breast tissue (Ha79), BR12 (Wh77) and cellulose in the form of paper from a telephone directory. The chemical analysis of the telephone book paper was performed by AMDEL Limited, Frewville, SA (AM88). The major components that effect the attenuation of soft X-rays is the ratio of Carbon:(Oxygen + Nitrogen). Good agreement of this ratio for the telephone book paper and breast tissue is found. At the low energies used in mammography, very small proportions of elements with an atomic number above that of Calcium (20) will have a noticeable effect on the attenuation. None of these elements were found in the paper. In addition it is noted that the calcium content of the paper is far closer to breast tissue than in the BR12 material.

Figure 2 shows the mass attenuation coefficients, as a function of photon energy, for telephone book, adipose tissue, glandular tissue and 50% adipose/50% glandular tissue. These were derived using appropriate mixtures of the elemental attenuation coefficients of Hubbell (Hu82). The mass attenuation coefficients for the telephone book closely follow

\(^1\) The CIRS phantom material is manufactured by Computer Imaging Reference System, Inc., to comply with the requirements of NCRP Report No 85.
those for the 50/50 tissue throughout the mammographic energy region from 10 to 40 keV.

The suitability of telephone book paper as a phantom material was further demonstrated by direct measurement of the attenuation of paper and equivalent thicknesses of 50/50 CIRS phantom material. This was done using monochromatic K-shell fluorescence X-rays, from 13.5 to 45 keV, from an Americium-241 fluorescence source. The measurements consisted of collecting X-ray spectra using a germanium detector, with (1) no attenuator, (2) a slab of telephone book and (3) the equivalent thickness of CIRS phantom material. The ratio of counts in the fluorescent peaks with and without the attenuator (CIRS or paper) yielded the attenuation ratio for the material at that particular energy. Figure 3 shows these attenuation ratios as a function of X-ray energy. As can be seen, the attenuation properties of the materials were essentially the same for thickness of 1, 3 and 5 cm of phantom material, throughout the mammographic energy region.

4.3. Design of the Monitor.

The ARL monitor consisted of a block of paper cut from the 1988 edition of the Melbourne Yellow pages telephone directory. The nominal density of the telephone book material was 0.62 g.cm\(^{-3}\). A thickness of 7.5 cm of paper was used to provide the equivalent mass per unit area of a 4.8 cm thick 50% adipose/50% glandular breast of density 0.98 g.cm\(^{-3}\). A schematic diagram of the monitor is shown in Figure 4. The overall size of the block was 15 x 13 x 7.5 cm. TLD sachets were placed on the top and bottom as well as at 1/4, 1/2 and 3/4 of the way through the block. The sachets were placed in a row across the monitor so that none was directly above another and in such a way as to minimize beam variation due the heel effect of the X-ray tube.

The apparatus for measuring the HVL was positioned along the edge of the block so that, when the monitor was exposed, it would be on the opposite side to the usual position of the chest wall. In this position, the apparatus does not occlude the beam passing through to the AEC device and heel effects would be minimised. The apparatus
consisted of a thin strip of lead, to remove the effect of backscatter, and a series of thin aluminium filters of various thicknesses. A TLD sachet was placed under each strip of aluminium as well as on top of the lead backing close to the aluminium filters.

The HVL of beams from molybdenum anode X-ray tubes were all expected to be close to 0.3 mm Al. In these cases only two aluminium filters, of 0.3 and 0.6 mm thickness, were required for accurate measurements. For tungsten anodes, additional filters of 0.9 and 1.2 mm Al were used to provide for the greater range of HVLs expected.

5. TLDs AND THE EVALUATION OF EXPOSURE, MGD AND HVL.

5.1. TLD Material.

The thermoluminescent (TL) phosphor used in this study was lithium fluoride powder doped with magnesium and titanium (Harshaw, TLD-100). The powder was loaded into opaque PVC sachets which had a wall thickness of approximately 0.2 mm and a density of approximately 1.4 g.cm$^{-3}$. Each sachet was filled with about 130 mg of powder which was sufficient for five readouts.

Before each issue, the powder was sieved using 180/75 micron mesh sieves, washed with research grade ethanol, allowed to dry at room temperature, annealed for 1 hour at 400°C, shock cooled on copper blocks for 15 minutes and given a final heat treatment at 80°C for 20 hours. The powder was loaded into the sachets within 48 hours of being annealed.

5.2. TLD Reader.

Two Pitman 654 TOLEDO TLD readers were used to read out the TLD-100 powder. Both readers had identical heating cycles, namely; a pre-heat stage of 135°C for 14 seconds followed by a readout stage of 275°C for 14 seconds, with both the pre-heat and readout stages having temperature ramp rates of approximately 30°C s$^{-1}$. 
A powder dispenser which was fitted to each reader enabled accurate volumetric dispensing of the TLD-100 powder directly onto the heating pan. Each dispensing deposited 20 mg of powder with a reproducibility of better than 3%.

During readout sessions the sensitivity of the TLD readers were checked on a regular basis using internal and external light sources. The sensitivity control of each unit was fixed for the duration of the survey.

5.3. Fading Tests.

Measurements were undertaken to determine to what extent the TL dosimetry glow peaks decayed with time. Dosimeters were given a single exposure to \(^{137}\)Cs gamma rays and then read out over a period of seven weeks. After an initial decay of approximately 5% in the first 4 days no significant reduction was observed thereafter.

5.4. TLD Energy Response.

TLD-100 powder is nearly tissue equivalent over the energy region from 40 keV to 2 MeV. The energy of the X-ray photons used in mammography is generally in the range from 10 keV to 30 keV. The energy response of the powder, when encapsulated in PVC sachets, has significant variations in this energy range which needed to be taken into account. The response of the encapsulated powder was measured relative to \(^{137}\)Cs gamma rays using X-ray beams commonly employed in mammographic examinations. Three dedicated mammography units were used for these measurements, two with molybdenum targets and one with a tungsten target, as well as a Seifert ISO DEBYEFLEX 2002 X-ray diffraction unit connected to X-ray tubes with either molybdenum or tungsten targets.

The output of the X-ray units was measured using an MDH model 1015 X-ray monitor with a 20X5-6M low energy ionization chamber which had been calibrated to an absolute accuracy of better than 2% against the Australian Standard of Exposure.
The response, per unit exposure, of the encapsulated TLD-100 powder relative to that from $^{137}$Cs gamma rays is shown in Figure 5 for HVLs between 0.1 and 4.0 mm of aluminium. These data were fitted with a function of the form $(a-(b/(HVL+c)))$ which is shown as the solid curve. This function was used for $R_f(HVL)$ in Equation 1 below to correct the TLD readouts for the energy sensitivity of the TLD dosimeters.

5.5. Controls.

An unexposed TLD sachet was sent with each monitor with instructions that the control was not to be exposed and that it be returned with the monitor. This sachet was used to estimate background radiation received by the monitor in transit and while at the radiological practice. Unexposed TLD sachets were also held with the $^{137}$Cs standards at ARL. These were used to estimate the background for the $^{137}$Cs standards used to calibrate the TLD readers (see Section 5.6).


Prior to the readout of each monitor the TLD readers were, in effect, calibrated in units of exposure using TLDs which had been given a known exposure to $^{137}$Cs gamma rays. The exposure to a TLD sachet was evaluated from an average of the readouts, using the following relationship:

$$X = (N - N_c) \cdot \frac{(X_{cs}/(N_{cs}-N_{ccs})) \cdot R_f(HVL)}{R_f(HVL)} \quad \ldots(1)$$

where,

- $X$ - the exposure derived from the TLD readout (Roentgen),
- $N$ - the average of the TLD readouts (counts),
- $N_c$ - the average of the readouts of the control sent with the monitor (counts),
- $N_{cs}$ - the average of the $^{137}$Cs standard readouts (counts),
- $N_{ccs}$ - the average of the control for the $^{137}$Cs standard readouts (counts),
The HVL apparatus incorporated in the monitor provided what shall be referred to as the TLD half value layer ($HVL_{TLD}$). This quantity is the thickness of aluminium which would reduce the TLD readout to half that produced by the incident beam. This was evaluated from a least squares fit of a quadratic function to the logarithm of the TLD readout data from the aluminium filters. This method of obtaining the $HVL_{TLD}$ was thoroughly tested and proved to be remarkably accurate even when data was available for only three points.

A series of measurements were made, using beams of known HVL, in order to calibrate $HVL_{TLD}$ against true HVL. These measurements were made using beams from the same X-ray units which were used for TLD energy response measurements, whose true HVL had been accurately measured by standard techniques using an MDH monitor. Figure 6 shows a plot of the $HVL_{TLD}$ against the true HVL of the X-ray beam. The relation is seen to be almost linear and is shown fitted with a quadratic. This quadratic was used as a calibration function to determine true HVL from the $HVL_{TLD}$ determined from the monitors exposed at each centre.

The error in the HVL for a given centre was estimated from the propagation of the uncertainties in the fit which determined the $HVL_{TLD}$ together with a component resulting from systematic errors inherent in use of the calibration function. This latter component was estimated from the relative standard deviation in the residuals to the fit for the calibration data. In other words from the spread of the data that was used to determine the calibration function (Figure 6). For a typical measurement the above analysis gives an overall standard error (66% confidence) of about .03 mm of aluminium.
5.8. Evaluation of Mean Glandular Dose - NCRP Method.

A simple method of evaluating the mean glandular dose (MGD), by using the HVL of the beam and the free air exposure at a position corresponding to the entrance surface of the breast, is described in the NCRP Report No. 85 (NC86). It produces excellent results providing that the beam HVL is accurately known and sufficient care is exercised to determine the free air exposure for identical radiographic technique factors which would be used with the breast in place. This method circumvents the difficulty in performing a depth dose measurement and, in general, is quite straightforward to implement. Because of these features it has received wide acceptance as a standard method of measuring the MGD. The MGD is evaluated using the following equation,

\[ D_g = D_{\infty}(HVL,\text{Thick}) \cdot X_a \]  \hspace{1cm} \text{(2)}

Where,

- \( D_g \) - the MGD to the breast in mGy,

- \( D_{\infty}(HVL,\text{Thick}) \) - the MGD in mGy resulting from a free air exposure of 1 Roentgen. This is a function of both the beam HVL and the breast thickness, and

- \( X_a \) - the Free Air Exposure in Roentgen at the position of the entrance surface of the breast, when the same exposure factors are used as if the breast were present.

The value of exposure, \( X_a \), was obtained from the readout of the TLD at the top central position. The readout was converted to an exposure in the manner described in the previous section (Equation 1) and reduced by 3% to account for backscatter from the top of the paper block. This backscatter correction was derived from experimental measurements and
was in good agreement with the work of Harrison et al. (Ha90a). $\overline{D}_{\text{HVL,Thick}}$ was evaluated as a function of HVL, for a 5 cm thick breast, from the curves presented in the work of Stanton et al. (St84). Separate functions were used for molybdenum and tungsten anode tubes. Recent work by Dance (Da90) is in good agreement with that of Stanton et al. and supports the functional representations of $\overline{D}_{\text{HVL,Thick}}$ used in the present study.

Errors associated with the MGD determined by this method have been evaluated from the errors associated with $X_0$ and HVL assuming that there is no error associated with the function $\overline{D}_{\text{HVL,Thick}}$.

5.9. Evaluation of MGD - Depth Dose Method.

The use of a breast tissue equivalent monitor in the form of a block of paper allowed TLDs to be placed at the 1/4, 1/2 and 3/4 thicknesses as well as on the top and bottom. This enabled the depth-dose profile to be evaluated. An independent estimate of MGD could then be made by appropriate integration of this depth-dose profile.

Readouts from the TLD dosimeters distributed through the monitor, were first converted to exposure using the method as described previously. These exposures were then converted to glandular doses by multiplying by the exposure-to-absorbed dose conversion factor for glandular tissue of $f_x=7.9$ mGy/Roentgen (Ha79, St84). A quadratic curve was fitted to the logarithm of these depth data to produce a function which represented the depth-dose profile. The MGD is then given by,

$$\overline{D}_{\text{HVL,Thick}} = \frac{1}{4} \int_{0.5}^{4.5} D_0 \exp(ax^2+bx+c) \, dx \quad \ldots\ldots(3)$$

where $x$ is the depth in tissue and $D_0$, $a$, $b$ and $c$ are evaluated by the least squares fit to the depth dose data.

It should be noted here that the integration has been carried out from 0.5 cm to 4.5 cm rather than from 0 to 5 cm. This is done to exclude the dose to the surface layers of the breast which is predominantly
adipose tissue and will not contribute to the glandular dose of the breast (NC86).

Errors in the MGD evaluated by this technique have been estimated by taking into account errors associated with the fit to the depth-dose curve, accuracy of the factor $f_g$ and accuracy of the TLD energy calibration. It was assumed that the beam quality was invariant through the monitor.

5.10. Best Estimate of MGD.

The MGD evaluated by the NCRP method plotted against the MGD evaluated using the DD method for all centres measured is shown in Figure 7. These data shows a scatter of points quite tightly surrounding a line at 45° to the axis and passing through the origin, indicating that the agreement between the two methods of evaluating the MGD is excellent. The average MGD for all centres, as determined by each method, differed by less than 3%.

There is no a priori reason to believe that one method of evaluation of MGD would be more accurate than the other. It is therefore reasonable to assume that the best estimate of the mean glandular dose for a particular centre would be given as the average between the results of the two methods. It is this value which has been reported to the individual centres.

Assuming the two methods are independent and have similar standard deviations, the standard deviation associated with the average of a pair of MGDs can be estimated by analysing the relative difference between pairs of results from all centres. Such an analysis gives a relative standard deviation of 4.2% for the average of a pair of MGDs for a given centre. This standard deviation does not include an estimate for systematic uncertainties (associated with absolute scale etc.) of each method. When these are added in quadrature to the standard deviation quoted above, the overall standard deviation for the MGD reported to a given centre was approximately 7%. In some cases where the exposure to the monitor was particularly small, the accuracy
of evaluating the exposure from the TLDs became the dominant error. In these cases a significantly larger standard deviation than the above was reported to the centre.

6. RESULTS.

6.1. Response to the survey.

The overall response and support for the survey was extraordinarily good. Of the 3000 initial inquiries sent out, more than 98% responded. Only one reply was received indicating an unwillingness to participate. Affirmative replies to the initial questionnaire yielded 262 X-ray mammography units currently in use and 5 units awaiting commissioning. It is estimated that this represents at least 90% of the mammography equipment in Australia at the beginning of 1990. Of the centres which were sent the second questionnaire and a monitor, only 4 either did not reply or did not expose their monitor correctly. Successful measurements were made on 258 X-ray units. A summary of some of the statistics on participation and mammographic techniques is given in Table 2.


Almost without exception mammography is performed in Australia using dedicated, special purpose X-ray equipment. Only 4 centres reported using general purpose X-ray equipment. Three of these used Xerographic image processing for which non-dedicated X-ray units were appropriate. Only one centre reported using non-dedicated equipment with film-screen techniques and had discontinued its use upon delivery of new equipment.

With the exception of the three centres using Xerox imaging, all centres reported using film-screen imaging techniques. No centres used plain film imaging techniques.

Most mammography was performed on units using X-ray tubes with molybdenum anodes. There were only 7 units (3%) with tungsten anodes compared to 249 (97%) with molybdenum anodes. The X-ray tubes with
molybdenum anodes were most commonly used with beam filtration of between 0.025 mm and 0.03 mm of molybdenum. A significant number stated that additional filters of aluminium were used at kilovoltages below 30 kVp for an average sized breast. It has generally been recommended (Sä86, Be83) that only a molybdenum anode be used for kVp's less than 30 keV.

The use of an automatic exposure device is also widespread with 86% responding that it is used all or most of the time.

There has been debate about the use of grids to improve image quality in mammography (Ni86, Si86), particularly when related to a screening program. The use of grids appears to be popular with 203 centres (80%) replying that a grid was used on more than 90% of their patients. Only 31 centres (12%) indicated that no grid was used. A few centres (<3%) stated that a grid was only used for large and/or dense breasts.

The use of dedicated or modified film processing is an area where it is believed substantial dose reductions and improved image quality may be achieved. Only 62 centres (24%) used dedicated processors and a further 49 (19%) indicated the use of a modified development cycle.

Firm breast compression, using a plastic paddle, appeared to be universal. The degree of compression was generally determined by patient comfort. Responses to the survey questionnaire revealed that pressure was variously indicated in terms of 'bar', 'kilopascals', 'Newton' or an unidentified numerical scale. There is obviously no standardisation of pressure indication on mammographic equipment and hence no simple way in which comparisons can be made.

6.3. Geographic Distribution.

The geographic distribution of mammography facilities throughout Australia is shown in Figure 8. As expected, there is a concentration of X-ray units in and around the major capital cities and coastal regions, with few units in the sparsely populated country areas.
A breakdown of the number on a State-by-State basis is given in Table 3. There is a fairly even number of X-ray units on a per capita basis with the exception of Western Australia which has about half the number of machines per capita of the other States. Table 3 also shows the number of mammographs performed per year and the number of mammographs per 1,000 people in each State. It is noted that the per capita number of mammographs is remarkably constant (21-26 per 1,000) with the exception of the Northern Territory where the sample size was small.

6.4. Equipment Brands.

Tables 4a, 4b and 4c give numbers of X-ray units, film and screen brands being used in Australia. CGR X-ray units are used by 40% of the centres. Film and screens manufactured by Kodak appear to be strongly preferred.


A histogram of the number of women being mammographed per year per machine is shown in Figure 9. The distribution is heavily skewed with only 15 X-ray units being used to examine more than 3000 women per year and 76 being used for less than 500 examinations per year. The average number of examinations per machine per year was 1175 and the median was 875. In centres where screening was known to be performed, the number of examinations was generally more than 3000 per year but none reached 10,000 exams/year which is common in overseas screening programs (Fo86).

In order to estimate the growth of mammography services, two questions were asked - "How many mammograms were performed in the last 3 months?" and "How many mammograms were performed in the same 3 months last year?". For centres which answered these questions, the totals were 88,500 and 56,000 respectively. It would appear that, even without an officially supported screening program, the number of mammographic examinations is increasing rapidly.
6.6. Patient Ages.

One unexpected result of the survey was the distribution of age groups of women receiving mammograms (Table 5). It was noted that 54% of all mammographic examinations were performed on women under the age of 51. The reasons were not apparent from the survey data. If, as one might expect, a significant amount of mammography in Australia is pseudo screening, it is not being directed at the age group which is intended to be targeted in a mass screening program (AI90a, Fo86).


The distribution of HVLs for X-ray units using film-screen imaging, is shown in Figure 10. The mean HVL for these units is 0.32 mm of aluminium. Most of the half value layers cluster tightly about the mean and are in the range from 0.26 mm to 0.38 mm of aluminium. There are a few outside this range and this information has been reported to the centres concerned with a comment that further investigation should be undertaken.

The Australian Standard 2398 (SA80), which is currently under review, specifies a minimum HVL of 0.3 mm of aluminium for a tube potential of 30 kVp. A similar standard has been adopted by most State authorities. As most mammography equipment is used below this potential, it is clear from the present work that practically all of the equipment measured would comply with the Australian Standard.

The three X-ray units which used Xerox imaging had HVLs around 2 mm of aluminium which is within an acceptable range for this type of equipment.

6.8. Mean Glandular Dose (MGD).

The use of a grid is clearly associated with an increase in patient dose. For this reason the data has been analysed for all centres collectively, as well as for centres using and not using grids. A summary of the results relating to MGD is given in Table 6. The
average MGD determined by the two methods of evaluation of dose were in agreement to better than 4%. In the following discussion, all values quoted for the MGDs are the average from these two methods.

For all centres the average MGD was 1.70 mGy. For centres using grids the average MGD was 1.83 mGy whereas for those not using grids it was 0.84 mGy (excluding Xerox). A comparison of these values indicates that the use of a grid increases the dose by a factor of about 2.2. This is consistent with the results of other studies (Ni86, Ha90b).

Overall, the minimum MGD was 0.09 mGy and the maximum was 6.8 mGy, a ratio of 70. Even when considering only centres using grids, there is still a ratio of about 30 between the maximum and minimum MGD. A similar spread is found within the group not using grids. The distributions of the doses for centres using grids and not using grids are shown in Figures 11 and 12 respectively. The MGDs for the centres using grids, appear to be log normally distributed. Although the overall spread is quite large, the results cluster fairly closely about the average with about 66% lying between 1.2 and 2.5 mGy.

The average MGD for the three centres using Xerox imaging techniques, was 2.3 mGy. Although larger than the average, they were still well within the range found for film-screen techniques using a grid.

6.9. Entrance and Exit Exposures.

The distribution of entrance exposures on the monitor is shown in Figure 13. This illustrates the very high skin doses delivered in mammography. Figure 14 shows the distribution of exit exposures which can be related to the sensitivity of the imaging system. The distribution of the ratio of entrance to exit exposure is shown in Figure 15. The mean value of 58 for this ratio would appear to be consistent with production of an optimum image. It has been postulated that ratios of less than 45 would produce images of unsatisfactory contrast, whereas those greater than 62 would be delivering an unnecessarily high skin dose. A more detailed survey of image quality would be required to provide further information on these aspects.
6.10. Collective and Population Weighted MGD.

The discussion on Mean glandular Dose (Section 6.8), dealt with the distribution and average of doses on a 'by machine' basis. Risk studies often require a knowledge of the collective population dose and/or the average dose per exposed person. This information is given in Table 7 and was obtained by multiplying the MGD for each X-ray unit by the number of women examined with it, and summing over all units. The total collective population dose, assuming two views per examination, was 992 gray and the weighted average to a patient for a cranio-caudal view was 1.70 mGy.

7. DISCUSSION.

7.1. Comparison with Other Studies.

Table 8 show the MGDs measured in present survey together with those from measurements done in the USA, Canada, New Zealand and Italy. The only previous Australian study was done by Colgan and O'Reilly in 1983 (Co84) who measured the mid-line dose. For comparison purposes, the NCRP method has been used to calculate the MGD from this data. Xerox machines have been excluded and the film-screen imaging group have been separated into those which use a grid and those which do not.

Direct comparison with the original BENT study in the United States (BE77, Ja79a) is difficult as results are quoted in terms of midline absorbed dose for a 6 cm breast. However the NEXT 1985 (Mammography) results (Ru87) are quoted in terms of average glandular dose which are given Table 8. Overall there is good agreement between the MGDs measured by the various surveys with a range of between 1.4 and 2.3 mGy for imaging using a grid. An average MGD of 1.83, given by the present study, appears to be only slightly above the average of the overseas studies.

In the USA in 1978, 10% of units were using direct exposure film, 45% film-screen combinations and 45% Xerography (Ja79a). In 1984, a limited survey of 38 practices in NSW showed that 66% were using
film-screen techniques and 34% Xerography (Co84). In Manitoba, Canada, as recently as 1988, 60% of the mammographic examinations were being carried out with Xerox equipment (Hu 90). In the Canadian study, which gives the most up to date data on Xerox, a MGD of 3.3 mGy was found. Although the introduction of film-screen techniques lowered the radiation dose compared with plain film radiography and Xerography, there was a concomitant degradation of the image quality. Recent improvements in film-screen technology coupled with the use of a grid now provides images of much higher quality and has led to the Xerox process being superseded.

In contrast with the above surveys, the present study revealed that no centres were using plain film radiography and only 3 of the 258 centres were still using Xerox. As the manufacturer of this equipment has now ceased production, none will be used in future.

7.2. Factors Which Affect Patient Dose.

One of the aims of the present study was to determine which factors in the mammographic process have an effect upon patient dose. One such factor, which has been discussed above, is the use of grids. Other factors that may be considered are equipment brands, geographic location, HVL, use of automatic exposure devices, grid parameters and film processing techniques. A statistical analysis was undertaken to establish which, if any, of these factors were associated with higher or lower MGD. The analysis was limited to those machines using molybdenum anodes. A regression analysis evaluated the dependence of the log(MGD) on likely factors using the GLM procedure from the program SAS (SA85). This was done as the factors were considered to enter multiplicatively. A significance level of 5% was adopted throughout. Factors contributing to significant differences in MGD are the use of a grid, the brand of the X-ray unit, the use of automatic exposure devices and the use of dedicated or modified film processing. Factors that could not be shown to have an effect on MGD, within the available statistics, included brand of film, State of Australia, measured HVL, development time and temperature, film to focus distance, and grid parameters.
By far the largest influence on MGD was the use of a grid. The analysis revealed that the grid elevates the MGD by a factor of about 2.4, which is similar to a value of 2.2 given by simply dividing the average doses with and without grids (see Table 6). (The former result takes into account the effect of other confounding factors which correlate with grid usage.)

Although the statistical analysis indicated a correlation between brand of X-ray unit and MGD, the influence is at most quite small. Table 9 shows the MGD when grids are used for the most common brand of X-ray units. There is little variation in the MGD between the different brands but those delivered by the Bennett and Siemens units appear to be lower than the overall average. This result is of marginal statistical significance.

Table 10 shows the MGD for centres using and not using automatic exposure devices. For centres using grids, the statistical analysis indicates that the use of automatic exposure is correlated with an increase of dose by a factor of about 1.6. It is difficult to find a causal explanation for this.

Film processing is a factor which might be expected to affect the dose. Tabar (Ta89b) and Haus (Ha90b) caution that extended processing should be carefully tested and monitored as many film types do not give optimal speed and contrast if not processed under conditions recommended by the manufacturer. Table 11 shows the average MGD obtained for those centres using modified or dedicated processing. There is a statistically significant reduction in dose for centres using a grid and dedicated or modified processing. Although this result is not apparent for centres not using grids, the small sample numbers do not allow any conclusion to be made in this case. It is interesting to note that although the use of dedicated or modified processing was statistically correlated with dose, a finer analysis to determine whether developer time or temperature was correlated with dose yielded a null result.
8. RISK.

The possible risk from mammography arises from radiation induced breast cancer. All known associations between radiation and induced cancer come from women exposed to high radiation doses. These include the Japanese atomic bomb survivors (To84, UN88), multiple fluoroscopy examinations of TB patients in Massachusetts and Canada (Ho84, Bo77 & My74), women treated for mastitis in Rochester NY (Sh77) and Swedish women treated for benign breast conditions (Bo77). In view of the absence of any significant evidence to the contrary, risks from the lower doses used in mammography are generally estimated from these high dose data, assuming a linear risk dose relation.

The risk estimates presented here are based on a simple absolute risk model. In this model it is assumed that, following irradiation, there is a lead time of 10 years before the risk becomes apparent. After this period, a constant risk-per-year of induced cancer, is manifest for the remaining life. This risk of inducing breast cancer is determined by the absolute risk coefficient which is usually expressed as the number of induced cancers per 10,000 women.gray.year.

Evaluation of absolute risk coefficients from the above data spans the range from 3 to 10 induced cancers per 10⁴ W.Gy.yr (BE80, UN88, La80, La87, Fe84, Le77, Bo79). There is some evidence from the high dose studies that the risk coefficient decreases quite rapidly with age at exposure. A controversy still remains as to whether this is true. An NCI working group (Up77) suggested that whereas the risk coefficient for younger women is 7.5 per 10⁴ W.Gy.yr, it should be reduced to 3.5 per 10⁴ W.Gy.yr for women over the age of 35. Recent studies (BE90, NI85, Fe90) have included a variation of risk with age at irradiation. For 45 year old women the BIER V report (BE90) gives about 10 per 10⁴ W.Gy.yr whereas that interpreted by Feig from the NIH report (Fe90, NI85) is 1.3 per 10⁴ W.Gy.yr. The reasons for these large discrepancies is not clear but it is noted that the BIER report is based on the most recent DS88 Japanese bomb survivor dosimetry whereas the NIH report uses older Japanese dosimetry. In the present work a value of 6 per 10⁴ W.Gy.yr is used for all ages at which irradiation occurs.
The average population mean glandular dose for all centres is given in Table 7 as 1.7 mGy per film resulting in 3.4 mGy for a two film examination to a compressed breast thickness of nominal 5 cm. Appendix 4 gives the lifetime risk of an induced cancer resulting from a single examination at age 40, 50 and 60. These results are in good agreement with a similar calculation by Law (La87, La89). At 50 years of age, the possible risk of inducing a breast cancer is 40 per million examinations. This may be crudely compared with expected detection rates from a screening program, of about 6000 per million upon initial examination and 2000 per million on re-examination.

The relatively small increase in the biological effect of low energy X-rays used in mammography, compared to higher energies, has not been considered in any of the above calculations. The ICRU (IC86) has recommended quality factors greater than 1 for X-rays below 30 keV. This results from the higher LET from the electrons produced by low energy photons compared to those produced at higher energies. It has been suggested by Brenner and Amols (Br89) that a quality factor of about 1.3 should be used for mammography, which uses energies below 20 keV. This in effect will mean that all risk estimates based on a quality factor of 1, should be increased by about 30%.

Risk calculations in the present study are based on doses to an average compressed breast thickness of 5 cm. Dose to the breast increases rapidly with thickness (St84). For an 8 cm glandular breast the dose will increase by a factor of at least 5. It is reasonable to suggest that risk should also depend upon the mass of tissue irradiated as well as the dose. An 8 cm breast will be at least triple the mass of a 5 cm breast so the risk may be increased by a factor of about 15. For a 40 yr old woman with large glandular breasts, the lifetime risk, from a single examination, may be as high as 900 per million examinations. For women with large glandular breasts, the ability of mammography to detect malignancies is significantly reduced compared to those with smaller less dense breasts. Therefore the benefit/risk ratio for young women with large glandular breasts, will be much smaller than for the rest of the population and it is for this group that further work needs to be done to establish the true efficacy of mammography.
9. RECOMMENDATIONS.


In Australia, at present, the maximum dose that should be delivered during a mammographic examination has been implicitly set by the National Health and Medical Research Council (NH&MRC) when at their 97th session they endorsed the "Report of the Working Party on Screening for Breast Cancer" (NH84). Appendix IX of this report states:

"11.3 The probable benefit of mammography would be dependent on the following conditions being met:
(i) use of modern low-dose screen-film combination or xeroradiographic equipment designed for mammography and restricting the mid dose to the breast from the examination to less than 10 milligray (1 rad). Regular monitoring of the X-ray outputs is essential."

These recommendations have a number of deficiencies. A mid dose to the breast of 10 milligray may not be relevant to mammography techniques used at present. More importantly, in the light of the ICRP recommendations, the mid-dose to the breast is no longer considered to be a suitable measure of risk. The term 'examination' needs to be more specifically defined. An examination could be interpreted as being just one image, or four images - two of each breast. Finally, Xerox imaging is no longer being used and so special reference to it need not be made.

The ICRP recommendation (IC87) states that "the usual reference terms for radiation dose estimation from X-ray mammography be the average absorbed dose in the glandular tissue (excluding skin) in a uniformly compressed breast of 50% adipose, 50% glandular tissue composition. The reference breast thickness should be specified." This recommendation provides a basis for comparison with other studies, both overseas and local and it is felt that the current recommendations should reflect this.
Measurements of breast thicknesses (see Figure 1) indicated that the average breast size for women being mammographed was close to 5 cm and this forms the basis for recommending this as a reference thickness for mean glandular dose.

The MGDs determined by this survey were evaluated using two techniques; one based on the NCRP (NC86) and the other from integration of the depth dose measurement. Both methods are capable of producing accurate results, and in the present study were in good agreement. The NCRP is generally the simpler method to use and requires a measurement of the free air exposure for a typical mammograph. For some machines using automatic exposure controls, this may be impossible to obtain without using a breast phantom. The DD method will perform well providing the depth dose profile can be accurately measured within a phantom which accurately simulates the required breast tissue. It is only recommended where a suitable phantom and dosimetry facilities, such as TLD, are available.

The calculations presented on risks, together with the ALARA (As Low As Reasonably Achievable) principle, are sufficient to make the minimization of dose of significant importance in performing mammography. However, the true benefits of mammography will only be obtained from images of the highest quality. In making recommendations on the mean glandular dose, care must be taken not to compromise possible image quality by recommending an excessively low maximum mean glandular dose. The strategy for making recommendations has been to select dose limits below which a substantial majority of Radiologists are currently achieving quality images. The present results indicate that over 65% of those using grids have a MGD of less than 2 mGy, and over 65% of those not using grids have a MGD less than 1 mGy. These form the basis of the maximum doses recommended below.

Once a satisfactory standard has been achieved, it is necessary to maintain that standard and monitoring at regular intervals is required to achieve this (He89, He90, NH84). Whilst internal checks are an important part of quality assurance monitoring, a check by an independent body is desirable to show that standards are being maintained.
9.2. Recommendations.

In view of the data presented by this report the following recommendations are made.

1. The ICRP recommendations (IC87) that "the usual reference terms for radiation dose estimation from X-ray mammography be the average absorbed dose in the glandular tissue (excluding skin) in a uniformly compressed breast of 50% adipose, 50% glandular tissue composition. The reference breast thickness should be specified." be used as a standard within Australia.

2. The maximum mean glandular dose (MGD) from X-ray mammography in the glandular tissue (excluding skin) in a uniformly compressed breast of 50% adipose, 50% glandular tissue composition of 5 cm thickness for a single image of the breast, should not exceed 2.0 mGy when a grid is used and not exceed 1.0 mGy when a grid is not used.

3. Calculation of the MGD should be made using the method recommended by the NCRP (NC86) or by direct depth dose integration.

4. Regular quality assurance monitoring of X-ray equipment and processing, as recommended by the Australian Institute of Health (AI90b) should be undertaken by each centre conducting mammography.

5. The MGD for each mammographic unit should be measured annually by an independent body.
Acknowledgments

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Fischer Imaging (Meeco Holdings Pty Ltd) for the use of an Athena Mammographic Unit over a period of 6 weeks.

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Mr Peter Wykes for manufacture of the monitors required.
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TABLE 1

COMPARISON OF BREAST TISSUE AND SUBSTITUTE MATERIALS
FOR A BREAST COMPOSITION OF 50% ADIPOSE/50% GLANDULAR TISSUE

<table>
<thead>
<tr>
<th></th>
<th>H (per cent)</th>
<th>C (per cent)</th>
<th>O (per cent)</th>
<th>N (per cent)</th>
<th>Cl (per cent)</th>
<th>Ca (per cent)</th>
<th>Nominal Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>BREAST TISSUE</td>
<td>10.70</td>
<td>40.20</td>
<td>46.40</td>
<td>2.50</td>
<td>&lt;0.30</td>
<td>0.98 *</td>
<td></td>
</tr>
<tr>
<td>BR12</td>
<td>8.68</td>
<td>69.95</td>
<td>17.91</td>
<td>2.37</td>
<td>0.14</td>
<td>0.95</td>
<td>0.97 #</td>
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<tr>
<td>PAPER (Cellulose)</td>
<td>5.90</td>
<td>45.20</td>
<td>48.0</td>
<td>0.05</td>
<td>0.12</td>
<td>0.62 +</td>
<td></td>
</tr>
</tbody>
</table>

* Calculated from Hammerstein et al. (Ha79)

# White et al. (Wh77)

+ Melbourne Yellow Pages Telephone Directory 1988 (AM88)
### TABLE 2

**SUMMARY OF STATISTICS ON MAMMOGRAPHIC TECHNIQUES.**

- 262 active units, 5 awaiting commissioning
- 258 units measured
  - 3 centres use Xerox imaging (one no longer used)
  - 1 centre using general purpose X-ray equipment with film screen techniques (no longer used).
- 249 units with Molybdenum anode X-ray tubes
  - 6 units with Tungsten anode X-ray tubes with film-screen techniques
- 86% use automatic exposure device all or most of the time
- 80% use grid on 90% or more of patients
- 12% do not use grid
- <3% use grid only for large and/or dense breasts
- 24% use dedicated processing
- 19% use modified processing cycle
- 100% use compression
### TABLE 3

**GEOGRAPHIC DISTRIBUTION AND UTILIZATION OF MAMMOGRAPHIC UNITS**

<table>
<thead>
<tr>
<th>State</th>
<th>Population '1,000s</th>
<th>Number of Mammography Units</th>
<th>No. of Units per 100,000 People</th>
<th>Number of Mammographic Examinations per Year †</th>
<th>per 1,000 People †</th>
<th>per 1,000 Year *</th>
<th>per 1,000 People *</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>5,612</td>
<td>85</td>
<td>1.52</td>
<td>103,100</td>
<td>18</td>
<td>118,000</td>
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<tr>
<td>VIC</td>
<td>4,208</td>
<td>77</td>
<td>1.83</td>
<td>74,700</td>
<td>18</td>
<td>92,000</td>
<td>22</td>
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<tr>
<td>QLD</td>
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<td>49</td>
<td>1.84</td>
<td>52,300</td>
<td>20</td>
<td>59,000</td>
<td>22</td>
</tr>
<tr>
<td>WA</td>
<td>1,500</td>
<td>13</td>
<td>0.86</td>
<td>21,000</td>
<td>14</td>
<td>32,000</td>
<td>21</td>
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<tr>
<td>SA</td>
<td>1,394</td>
<td>18</td>
<td>1.29</td>
<td>27,050</td>
<td>19</td>
<td>34,500</td>
<td>25</td>
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<tr>
<td>TAS</td>
<td>447</td>
<td>7</td>
<td>1.46</td>
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<td>6,900</td>
<td>26</td>
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<td>NT</td>
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<td>2.56</td>
<td>650</td>
<td>4</td>
<td>1,100</td>
<td>7</td>
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<tr>
<td>AUST</td>
<td>16,259</td>
<td>258</td>
<td>1.59</td>
<td>292,000</td>
<td>18.3</td>
<td>353,400</td>
<td>22.4</td>
</tr>
</tbody>
</table>

† Based on numbers for a 12 month period.

* Based on ‘number done in last 3 months’ multiplied by 4.
### TABLE 4a.
**X-RAY MACHINE BRAND IN USE.**

<table>
<thead>
<tr>
<th>X-ray Machine Brand</th>
<th>Number of Units</th>
<th>%</th>
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<tbody>
<tr>
<td>CGR</td>
<td>104</td>
<td>40.0</td>
</tr>
<tr>
<td>SOREDEX</td>
<td>38</td>
<td>15.0</td>
</tr>
<tr>
<td>PHILIPS</td>
<td>21</td>
<td>8.1</td>
</tr>
<tr>
<td>TOSHIBA</td>
<td>20</td>
<td>7.7</td>
</tr>
<tr>
<td>SIEMENS</td>
<td>16</td>
<td>6.2</td>
</tr>
<tr>
<td>ACOMA</td>
<td>13</td>
<td>5.0</td>
</tr>
<tr>
<td>BENNETT</td>
<td>10</td>
<td>3.8</td>
</tr>
<tr>
<td>LORAD</td>
<td>10</td>
<td>3.8</td>
</tr>
<tr>
<td>FISCHER</td>
<td>7</td>
<td>2.7</td>
</tr>
<tr>
<td>GE</td>
<td>6</td>
<td>2.3</td>
</tr>
<tr>
<td>ELSCINT</td>
<td>4</td>
<td>1.6</td>
</tr>
<tr>
<td>METALTRONICA</td>
<td>3</td>
<td>1.2</td>
</tr>
<tr>
<td>INSTRUMENTARIUM</td>
<td>3</td>
<td>1.2</td>
</tr>
<tr>
<td>GM-MERATE</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>GEC</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>XEROX</td>
<td>1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### TABLE 4b.
**FILM BRANDS IN USE.**

<table>
<thead>
<tr>
<th>Film Brand</th>
<th>Number of Users</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>KODAK ORTHO-M</td>
<td>126</td>
<td>50.0</td>
</tr>
<tr>
<td>KODAK T-MAT</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>DUPONT MICROVISION</td>
<td>46</td>
<td>18.2</td>
</tr>
<tr>
<td>FUJI MI-MA</td>
<td>23</td>
<td>9.1</td>
</tr>
<tr>
<td>FUJI MI-NH</td>
<td>17</td>
<td>6.7</td>
</tr>
<tr>
<td>FUJI MI-NC</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>AGFA MR</td>
<td>23</td>
<td>9.1</td>
</tr>
<tr>
<td>AGFA CURIX</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>KONICA C</td>
<td>8</td>
<td>3.2</td>
</tr>
<tr>
<td>KONICA CM</td>
<td>5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### TABLE 4c.
**SCREEN BRANDS IN USE.**

<table>
<thead>
<tr>
<th>Screen Brand</th>
<th>Number of Users</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>KODAK MIN-R</td>
<td>222</td>
<td>89.2</td>
</tr>
<tr>
<td>AGFA</td>
<td>22</td>
<td>8.9</td>
</tr>
<tr>
<td>KONICA</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>FUJI</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>DUPONT</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Age Groups</td>
<td>Number of Women Mammographed</td>
<td>% of Mammographic Examinations</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Less than 41</td>
<td>46,900 (48,500)</td>
<td>16.6</td>
</tr>
<tr>
<td>41 to 50</td>
<td>106,100 (109,200)</td>
<td>37.4</td>
</tr>
<tr>
<td>51 to 60</td>
<td>85,600 (88,200)</td>
<td>30.2</td>
</tr>
<tr>
<td>Over 60</td>
<td>44,800 (46,100)</td>
<td>15.8</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>283,400 (292,000)</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

† Numbers derived from the 237 centres which answered the relevant question (ie 21 centres did not provide age group breakdown). Numbers in brackets are derived assuming the centres that did not provide information had the same age group breakdown as the others.
### TABLE 6.

**MEAN GLANDULAR DOSE IN UNITS OF MILLIGRAY.**

**All Centres**

<table>
<thead>
<tr>
<th></th>
<th>Depth Dose NCRP Method</th>
<th>Average of Both Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of X-ray Units</td>
<td>258</td>
<td>258</td>
</tr>
<tr>
<td>Average</td>
<td>1.73</td>
<td>1.70</td>
</tr>
<tr>
<td>Median</td>
<td>1.64</td>
<td>1.60</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.82</td>
<td>0.82</td>
</tr>
<tr>
<td>Std. Error in Mean</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Maximum</td>
<td>6.71</td>
<td>6.75</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Range</td>
<td>6.62</td>
<td>6.66</td>
</tr>
</tbody>
</table>

**Centres Using Grids.**

<table>
<thead>
<tr>
<th></th>
<th>Depth Dose NCRP Method</th>
<th>Average of Both Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of X-ray Units</td>
<td>217</td>
<td>217</td>
</tr>
<tr>
<td>Average</td>
<td>1.87</td>
<td>1.83</td>
</tr>
<tr>
<td>Median</td>
<td>1.74</td>
<td>1.72</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.77</td>
<td>0.77</td>
</tr>
<tr>
<td>Std. Error in Mean</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Maximum</td>
<td>6.71</td>
<td>6.75</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.20</td>
<td>0.19</td>
</tr>
<tr>
<td>Range</td>
<td>6.51</td>
<td>6.56</td>
</tr>
</tbody>
</table>

**Centres NOT Using Grids. (Film-Screen Only)**

<table>
<thead>
<tr>
<th></th>
<th>Depth Dose NCRP Method</th>
<th>Average of Both Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of X-ray Units</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Average</td>
<td>0.85</td>
<td>0.84</td>
</tr>
<tr>
<td>Median</td>
<td>0.79</td>
<td>0.78</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.47</td>
<td>0.47</td>
</tr>
<tr>
<td>Std. Error in Mean</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.81</td>
<td>1.87</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Range</td>
<td>1.72</td>
<td>1.78</td>
</tr>
</tbody>
</table>
### TABLE 7.

**COLLECTIVE AND POPULATION WEIGHTED MEAN GLANDULAR DOSE (MGD)**

<table>
<thead>
<tr>
<th></th>
<th>Number of Mammographic Examinations</th>
<th>Collective MGD per exam. Based on 2 films per exam. (gray)</th>
<th>Population Weighted Average MGD per film (milligray)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Centres.</td>
<td>292,000</td>
<td>992</td>
<td>1.70</td>
</tr>
<tr>
<td>Centres Using Grids</td>
<td>252,900</td>
<td>909</td>
<td>1.79</td>
</tr>
<tr>
<td>Centres NOT Using Grids *</td>
<td>39,200</td>
<td>83</td>
<td>1.06</td>
</tr>
</tbody>
</table>

* Determined by summing the product of the number of women examined at each centre by the MGD delivered by that centre and dividing by the total number of women examined at all centres.

* Includes centres using Xerox.
**TABLE 8**

**COMPARISON WITH OVERSEAS STUDIES**

**MEAN GLANDULAR DOSE**

<table>
<thead>
<tr>
<th>Source</th>
<th>Breast Thickness (cm)</th>
<th>Mean Glandular Dose With Grid (mGy SD)</th>
<th>Mean Glandular Dose Without Grid (mGy SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present study</td>
<td>4.8</td>
<td>1.83 0.8</td>
<td>0.84 0.47</td>
</tr>
<tr>
<td>NSW 1983◊</td>
<td>6</td>
<td>1.50</td>
<td>0.70</td>
</tr>
<tr>
<td>USA (NEXT - 1985)*</td>
<td>6</td>
<td>1.51 0.6</td>
<td>0.70 0.34</td>
</tr>
<tr>
<td>USA 1989 #</td>
<td>5</td>
<td>1.4</td>
<td>1.12</td>
</tr>
<tr>
<td>USA 1989 +</td>
<td>4.5</td>
<td>1.51 0.6</td>
<td>0.70 0.34</td>
</tr>
<tr>
<td>New Zealand 1989 ©</td>
<td>4.5</td>
<td>2.34 1.03</td>
<td>1.08 0.26</td>
</tr>
<tr>
<td>Canada 1987-88 †</td>
<td>4.7</td>
<td>1.4 0.5</td>
<td></td>
</tr>
<tr>
<td>(Manitoba)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy 1987 †</td>
<td>5.0</td>
<td>1.4 - 2.5</td>
<td>1.1 - 2.0</td>
</tr>
<tr>
<td>(approx range)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

◊ Based on Colgan & O’Reilly (Co84) using a HVL of 0.31 and NCRP calculation method.

* Rueter (Ru87) Survey data.

# Haus (Ha90b) Laboratory data based on Stanton (St84)

+ From Hendrick (He90) Survey data

© Williamson (Wi90) Survey data

† Rimondi et al. (Ri89) Survey data

‡ Huda et al. (Hu90) Survey data
**TABLE 9**

AVERAGE MGD FOR MOST COMMON BRANDS OF X-RAY MACHINE

*(For Grid Technique Only)*

<table>
<thead>
<tr>
<th>Brand</th>
<th>Sample Size</th>
<th>MGD (mGy)</th>
<th>Std Error of Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoma</td>
<td>12</td>
<td>1.56</td>
<td>0.11</td>
</tr>
<tr>
<td>Bennett</td>
<td>7</td>
<td>1.44</td>
<td>0.18</td>
</tr>
<tr>
<td>CGR 500T</td>
<td>45</td>
<td>1.91</td>
<td>0.11</td>
</tr>
<tr>
<td>CGR 600T</td>
<td>42</td>
<td>1.86</td>
<td>0.11</td>
</tr>
<tr>
<td>Lorad</td>
<td>9</td>
<td>2.30</td>
<td>0.28</td>
</tr>
<tr>
<td>Philips</td>
<td>21</td>
<td>1.77</td>
<td>0.24</td>
</tr>
<tr>
<td>Siemens</td>
<td>19</td>
<td>1.43</td>
<td>0.18</td>
</tr>
<tr>
<td>Soredex</td>
<td>27</td>
<td>2.21</td>
<td>0.22</td>
</tr>
<tr>
<td>Toshiba</td>
<td>14</td>
<td>1.76</td>
<td>0.15</td>
</tr>
</tbody>
</table>

(Caution should be exercised in the interpretation of the above results. See Section 7.2.)

**TABLE 10**

MEAN GLANDULAR DOSE AND USE OF AUTOMATIC EXPOSURE CONTROL

<table>
<thead>
<tr>
<th>Number of X-ray Units</th>
<th>Mean Glandular Dose (mGy)</th>
<th>Standard Error of Mean</th>
<th>Automatic Exposure Control Used</th>
<th>Grid Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1.15</td>
<td>0.18</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>182</td>
<td>1.92</td>
<td>0.06</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>10</td>
<td>0.72</td>
<td>0.13</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>19</td>
<td>0.97</td>
<td>0.11</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>
### TABLE 11

**EFFECT OF PROCESSING ON THE MEAN GLANDULAR DOSE**

<table>
<thead>
<tr>
<th>Number of Machines (n)</th>
<th>MGD (mGy)</th>
<th>Standard Error of the Mean</th>
<th>Grid</th>
<th>Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>122</td>
<td>2.02</td>
<td>0.08</td>
<td>Yes</td>
<td>Conventional</td>
</tr>
<tr>
<td>94</td>
<td>1.65</td>
<td>0.06</td>
<td>Yes</td>
<td>Dedicated or Modified</td>
</tr>
<tr>
<td>24</td>
<td>0.78</td>
<td>0.09</td>
<td>No</td>
<td>Conventional</td>
</tr>
<tr>
<td>14</td>
<td>0.97</td>
<td>0.11</td>
<td>No</td>
<td>Dedicated or Modified</td>
</tr>
</tbody>
</table>
Figure 1. Histogram of compressed Breast Thickness for a sample of 900 measurements. The mean value is 4.8 cm with a standard deviation of 1.3 cm.
Attenuation Coefficients for Glandular, Adipose, 50/50 tissue and Phone Book.

Figure 2. Mass attenuation coefficients as a function of photon energy. Top curve is for adipose tissue, bottom curve for glandular tissue, middle curves for a 50%/50% mix of adipose/glandular tissues and for the paper used as a monitor.
Figure 3. Comparison between the measured attenuation ratio (the number of incident photons to exit photons) for equivalent thicknesses of paper and CIRS phantom material, for monochromatic photons between 10 and 45 keV. (Paper thickness was adjusted to give equivalent density of phantom material.)
A.R.L. Mammography Monitor

= LiF TLD Sachets

Figure 4. Schematic representation of the ARL monitor used for the survey.
Figure 5. Response of LiF sachets per unit exposure relative to Cs-137. Three dedicated mammography units, and an X-ray diffraction unit having both tungsten and molybdenum anode X-ray tubes, were used to obtain this data.
Half Value Layer Determined from TLDs vs True Exposure Half Value Layer.

Figure 6. Half value layer measured using an MDH X-ray monitor as a function of half value layer determined from the TLD sachets.
Mean Glandular Dose (DD Method) vs Mean Glandular Dose (NCRP Method).

Figure 7. Comparison of MGD calculated by the NCRP method and the Depth Dose method.
Location of Mammographic X-ray Units in Australia.

Figure 8. Geographic distribution of mammographic X-ray equipment. Each dot represents one X-ray machine.
Figure 9. Utilization of mammographic equipment for a 12 months period. Only 15 units are being used for a patient load of 3000 per year or more. Some of these centres were taking part in the Commonwealth Government pilot screening program.
Histogram of Half Value Layers for Film Screen Techniques.

Half Value Layer, mm Aluminium.

Figure 10. Distribution of half value layer for all centres using film-screen techniques. The average half value layer is 0.32 mm aluminium and most values are clustered tightly around this mean.
Figure 11. Mean glandular dose for all centres using a grid with film-screen imaging. This histogram is based on an average of the NCRP and DD methods of calculation. The average MGD was 1.86mGy and the median 1.73mGy.
Histogram of Mean Glandular Dose for Film-Screen Techniques Without Grid

Figure 12. Mean glandular dose for all centres not using a grid with film-screen imaging. This histogram is based on an average of the NCRP and DD methods of calculation. The average MGD was 0.82mGy and the median 0.78mGy.
Histogram of Entrance Exposure for Film-Screen Techniques with Grid.

Figure 13. Distribution of entrance exposure for all centres using a grid with film-screen imaging.
Figure 14. Distribution of exit exposure for all centres using a grid with film-screen imaging.
Histogram of the Ratio of Entrance to Exit Exposure

Figure 15. Distribution of the ratio of entrance to exit exposure.
Do you use mammography at your centre? Yes [ ] No [ ]

Please initial this form and return.

Use complete the following table.

<table>
<thead>
<tr>
<th>EXAMPLE</th>
<th>UNIT 1</th>
<th>UNIT 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Smith</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brickwell Clinic</td>
<td>12 High St.</td>
<td>Brickwell</td>
</tr>
<tr>
<td></td>
<td>NSW 2999</td>
<td></td>
</tr>
<tr>
<td>Fischer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Athena</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nely</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you have more than two X-ray units please use space provided on back of this sheet.
SURVEY OF MAMMOGRAPHY EQUIPMENT

QUESTIONNAIRE - CONFIDENTIAL

Please do not break the seals of the paper packaging on the enclosed monitor (see Page 6 - Instructions for use).

ROOM NO: .................................................................

MAKE OF X-RAY UNIT: ................................................

MODEL: ........................................................................

MONITOR NO: ............................................................

The information in this questionnaire is required for calculation of patient dose from the monitor and for the estimation of population dose.

A separate questionnaire is provided for each unit to be monitored.

NB Please confine answers in this questionnaire to the unit specified above ONLY.

There may be more than one answer to some questions - please indicate as necessary - e.g film-screen combination may be used for some patients, film-screen-grid combination may be used for others.

EQUIPMENT

1. What is the anode material of this unit?
   - Tungsten [ ]
   - Molybdenum [ ]
   - Tungsten/Molybdenum alloy [ ]

2. What is/are the size(s) of the focal spot(s)?
   (1) [ ] (2) [ ] (3) [ ]

3. Is automatic exposure control available? Yes[ ] No[ ]

   If yes, when used in auto-exposure mode, does it indicate:
   mA [ ] time [ ] mAs [ ]

The answers to the following questions 4 to 6, may be obtained from the manufacturer’s handbook for the unit.

4. What is the thickness (in mm) of the inherent filtration of the tube? (See NOTE at bottom of page.)
   - Al equiv. [ ] mm
   - Be [ ] mm

5. What is thickness (in mm) of the added filters available?
   - Al [ ] mm
   - Mo [ ] mm
   - other [ ] mm - state

6. What is the Half Value Layer?
   - not known [ ]
   - mm Al equivalent at [ ] kV peak
   - mm Al equivalent at [ ] kV peak
   - mm Al equivalent at [ ] kV peak

NOTE: INHERENT FILTRATION includes all parts which are intrinsically part of the X-ray tube and cannot be removed or altered e.g. glass of the X-ray tube, insulating oil, seal of the X-ray port.

Molybdenum or Aluminium or other materials, which are used to produce a beam of a particular quality, are considered to be ADDED FILTER.
Please confine answers on this page to the unit specified on face page

**Radiographic Technique**

13. What is the focus-film distance used for a normal examination?
   - Fixed distance for all patients [ ] cm
   - Variable from [ ] cm min. to [ ] cm max

14. What type of compression is used?
   - Balloon [ ]
   - Flared cone [ ]
   - Perspex plate with moulded curve at breast wall edge [ ]
   - Perspex plate with sharp right angle at breast wall edge [ ]
   - Other - describe [ ]

15. Does your unit have a compression gauge which can be set at the required pressure?
   - Yes [ ]
   - No [ ]

   If yes, what pressure setting do you use? ...................................................

   If no, what other criteria do you use to establish desired compression?

16. What combination of kVp and added filter is used?

<table>
<thead>
<tr>
<th>kVp</th>
<th>Filter Material</th>
<th>Filter Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>the same for all breast thicknesses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>varies with breast thickness</td>
<td>small</td>
<td></td>
</tr>
<tr>
<td></td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>large</td>
<td></td>
</tr>
</tbody>
</table>

17. Do you use magnification techniques? Yes [ ] No [ ]

   On what percentage of patients is the magnification technique used? (Give estimate if precise numbers not known.) [ ]

   What is the magnification factor? (e.g. 1.5, 1.8) [ ]

   Is grid used? Yes [ ] No [ ]

   Other comment:...........................................................................................................

//5
STATISTICAL INFORMATION

1. How many patients were mammographed:
   in the last 12 months? [ ]
   in the last 3 months? [ ]
   in the same 3 months last year? [ ]

2. During the last 12 months, what number of examinations were for one breast only?
   Actual number [ ] or Estimate percent [ ]

3. During the last 12 months, how many patients were in the following age groups? If actual numbers are not readily available, give an estimate percent of patients in each category.

<table>
<thead>
<tr>
<th>ACTUAL OR ESTIMATE NUMBER PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 40 years old......</td>
</tr>
<tr>
<td>41 - 50 years old..................</td>
</tr>
<tr>
<td>51 - 60 years old..................</td>
</tr>
<tr>
<td>61 and over......................</td>
</tr>
</tbody>
</table>

4. What percentage of patients require two films to include the whole breast for a given view? [ ] percent

5. What are the ROUTINE views used for a TYPICAL mammographic examination?

   Cranio-caudal [ ]
   Medio-lateral [ ]
   Latero-medial [ ]
   Lateral oblique to include axilla [ ]
   Other

   [ ]

6. /6
monitor - part b - exposure details

name of exposure: ........................................

using a felt tipped pen, write on the monitor
(a) the room number
(b) the date of exposure and
(c) distance from the focus to top of monitor.

complete the details below and return the questionnaire, and the
dosed and control monitors in the reply-paid postbag provided.

the monitor was exposed using the following details for each exposure:

kvp [ ] ma [ ] mAs [ ]

exposure time (if known) [ ]

was auto exposure used? yes [ ] no [ ]

was grid used? yes [ ] no [ ]

focus-film distance was [ ] cm

distance from focus to top of monitor was [ ] cm

the added filtration used was ........mm of ........................................

........mm of ........................................

what focal spot size was used? [ ]

for your convenience, tick each time you make an exposure, or if auto exposure varies, indicate kv/mas e.g. [28/250].

1. [ ]
2. [ ]
3. [ ]
4. [ ]
5. [ ]
6. [ ]
7. [ ]
8. [ ]
9. [ ]
10. [ ]

time interval between exposures [ ] seconds.

thank you for completing the questionnaire
and for taking part in this survey.
MEASUREMENTS MADE AT YOUR CENTRE

GENERAL INFORMATION

Machine Number: 9999999
Location/Rm No:
Make: SOREDEX
Anode Material: MOLY
Image Receptor: Film-Screen

Measurement Date: 05/02/90
Model: MAMEX DC
Filters Used: 0.500 mm of AL
Focus-Skin Distance: 48 cm.

kVp Used: 31
Grid Used: Y
MAS used:
Auto-Exposure used: Y

MEASUREMENT RESULTS

The following data is applicable to a cranio-caudal view of a 50% adipose-50% glandular, uniform breast, compressed to a thickness of 4.8 cm.

Entrance Exposure: 1.06 Roentgen. (Air Kerma = 9.28 mGy)
Exit Skin Exposure: 0.023 Roentgen. (Air Kerma = 0.20 mGy)
Entrance/Exit Exp. Ratio: 46
Half Value Layer: 0.32 + or - 0.03 mm of Aluminum.
Mean Glandular Dose: 1.46 + or - 0.10 mGy.*
Mid-Line Glandular Dose: 1.07 + or - 0.09 mGy.*

* Errors quoted represent one standard deviation. No allowance has been made for inaccuracy of the data used from NCRP 85.

COMMENTS

The measured mean glandular dose and half value layer quoted are within the expected range for the above equipment and techniques. Moly tube units are usually used with a thin moly filter. The use of just an aluminium filter for average breasts is unusual. The kVp used is also higher than usual. Check that you are obtaining optimum image.
errors quoted for the dose and half value layer represent an estimate of one standard deviation. Statistically, about one of the results will be in error by one standard deviation less than 5% will be in error by two standard deviations. It possible, therefore, that some of results will be appear rer or lower than expected purely as a result of the errors associated with our measurement. Nonetheless, where we have tented on a particular result, we believe the value is sufficiently different from expected to warrant further estigation.

several occasions during the course of the survey 'errors' or takes' that occurred when the monitor was exposed were eted back to us. Some of these, which will lead to correct results are:

(i) omission of the grid during exposure when it was stated a grid was used,
(ii) use of a grid during exposure when it was stated a grid was NOT used,
(iii) omission of the cassette during exposure,
(iv) omission of the film inside the cassette,
(vi) incorrect number of exposures given to the monitor,
(v) density settings for the automatic exposure device not set for a 5 cm 50/50 breast.

we have made a comment about measured mean glandular dose or value layer at your centre and you are satisfied that the nitor was exposed correctly the following points should be sidered and/or checked.

High mean glandular dose.

(i) Inappropriate filtration or KVP.
(ii) Sub-optimal film processing, consider dedicated ocessing if it is not being used.
(iii) Faulty grid or inappropriate type of grid.
(iv) Film density too high.

Low mean glandular dose.

(i) Inappropriate filtration or KVP.
(ii) Image quality, lack of resolution and contrast.
(iii) Film density too low.

HIGH half value layer.

(i) Inappropriate added filter. For molybdenum anode X-ray tubes it is usual for ONLY a .03mm Molybdenum filter to be used for medium sized breasts. In these cases it is not recommended to use aluminium filters with or without the molybdenum filter.

(ii) KVP higher than appropriate. For film-screen mammography of a medium sized breast it is usual for a KVP in the range from 24 to 28 KVP to be used.

(iii) The paddle, used for compression, attenuates the X-ray beam excessively.

Low half value layer.

(i) Missing or inappropriate filtration. Check to ensure the filtration fitted to your machine is present. This is usually .03 mm molybdenum for molybdenum anode units. You may need advice from supplier/service personnel for your X-ray unit.

Remember your State Health Department is there to help you. If you have difficulty with the operation of your equipment, that you cannot easily resolve, you should contact them.
APPENDIX 4

RISK OF CANCER INDUCTION FROM MAMMOGRAPHY

An estimate of the number of cancers induced for 2 films per examination based on a mean glandular dose of 1.7 mGy per film and using a risk coefficient of 6 per 10^4 women.Gy.year, may be made as follows:

For one examination the number of cancers induced is:

\[ \frac{6 \times 3.4 \times 10^{-3}}{10^4} = 2 \times 10^{-4} \text{ cancers per year (see Section 8)} \]

Based on a life expectancy of 80 years, this gives the induction rates of cancers for various ages as,

<table>
<thead>
<tr>
<th>Age 40 when examined</th>
<th>Age 50 when examined</th>
<th>Age 60 when examined</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 years lead time</td>
<td>10 years lead time</td>
<td>10 years lead time</td>
</tr>
<tr>
<td>then 30 years risk</td>
<td>then 20 years risk</td>
<td>then 10 years risk</td>
</tr>
<tr>
<td>2.0 \times 10^{-4} \times 30</td>
<td>2.0 \times 10^{-4} \times 20</td>
<td>2.0 \times 10^{-4} \times 10</td>
</tr>
<tr>
<td>= 6 \times 10^{-3} \text{ Ca/exam.}</td>
<td>= 4 \times 10^{-5} \text{ Ca/exam.}</td>
<td>= 2 \times 10^{-5} \text{ Ca/exam.}</td>
</tr>
<tr>
<td>1 per 16,500 exams.</td>
<td>1 per 25,000 exams.</td>
<td>1 per 50,000 exams.</td>
</tr>
<tr>
<td>60 per 10^4 exams.</td>
<td>40 per 10^4 exams.</td>
<td>20 per 10^4 exams.</td>
</tr>
</tbody>
</table>