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The Optimization Programme for Mammography in Italy

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THE OPTIMIZATION PROGRAMME FOR MAMMOGRAPHY IN ITALY

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I T A L Y

Abstract

The results of the second phase of the optimization programme (DQM) for mammography in Italy are analysed; 181 centers were checked from February 1987 to August 1988. Exposure, HVL and focal spot size were measured by means of the same devices used in the first phase of the DQM program (1985) while the evaluation of image quality was accomplished with a new performance phantom. We noted that very few units performed a complete quality control programme; moreover the choice of the film screen combination is not rigorous. An attempt was made to correlate dose and image quality in order to classify the units in groups with different efficiency level and to suggest the ways to improve their situation.

[illegible]

Mammography is one of the most effective methods for obtaining an early diagnosis of breast carcinoma. Reduction of breast dose while preserving image quality is the aim of an ongoing optimization programme in Italy, named "Dose and Quality in Mammography" (DQM) [1]. In the following we are presenting the results of the second phase of the programme, that started in February 1987. The programme is recommended by *Ministero della Sanità* and adopted by the Italian Society of Radiology and Nuclear Medicine.

The steps of the programme are:

1) collection of the working parameters of each center: data are first gathered through a questionnaire and then by means of in-field measurements (breast exposure, HVL, focal spot size and information content);
2) evaluation of dose and image quality;
3) result analysis and suggestions for possible improvements to the centers.

Two central laboratories (*Dipartimento di Fisica, Università di Ferrara,* for the North Italy and *Istituto Superiore di Sanità* for the South) collect and elaborate the experimental data.

Instruments and methods

The measurements in each mammography unit are performed with the same devices and methods in order to obtain a significant comparison. The devices are simple enough to be mailed and used by the unit operators themselves. The devices contained in a case are:

a) performance phantom for the visual evaluation of the image quality [2];

b) devices for HVL and exposure measurements, using TLD detectors [3];

c) dosimetric phantom for exposure evaluation at various depths;

d) star pattern for the focal spot size evaluation.

In each mammography unit the performance phantom (having about the same transmission as a 5cm 50% fat and 50% water breast) is first exposed using the same conditions as a routine cranio-caudal projection. If necessary, this step is repeated modifying the exposure parameters until a satisfactory image is obtained. Then, the instruments b),c) and d) are exposed using the same conditions as the best phantom radiograph. All the radiographs and the devices are returned to the central laboratories.

Results

The centers (181) that have been checked, from February 1987 to August 1988, are all Mo anode units; 33.7% (61 centers) used anti-scatter grids, 37.6% (68 centers) used phototimers and 21.0% (38 centers) uses both grids and phototimers.

Only three centers used direct exposure films, all the others film-screen combinations. We counted 9 screen brands combined with a large number of films; moreover we found at least 15 film processing schemes.

70.2% of the centers used a kV value in the range 26-32kV.

About 50% of the units have an HVL ranging from 0.26 to 0.34mm Al. In Fig.1 we compare the trend of the average HVL of the centers setting the same kV value with the actual HVL trend of a Mo anode, Be window, 30μm Mo added filter tube fed by a 3-phase 6-pulse generator. The mismatching of the average HVL of the centers setting less than 25kV may be due to a lack of calibration in the front panel indicator.

The focal spot size was measured by means of a star pattern: 53% of the centers has a focal spot size higher than 1mm and 11.6% lower than 0.5mm.

63% of the units presents an exposure value lower than 1R (2.58×10^{-4}C/kg); the centers having exposures higher than 5R (12.9×10^{-4}C/kg) use direct exposure films.

The average whole breast dose per view [4] for a 5cm thick organ, 50% fat + 50% water, is calculated for each center on the basis of the values of the entrance exposure, HVL and focus-skin distance. Our dose evaluation method agrees with Hammerstein's data [5] and with the Handbook of Glandular Tissues Doses in Mammography [6]; 60.8% of the centers presents doses lower than 0.15cGy and only 35.8% doses lower than 0.10cGy. Doses higher than 0.80cGy are related with the use of direct exposure X-ray films.

Before introducing an acceptable dose range we have to relate doses with image quality.

The evaluation of image quality in each center is performed analyzing all the best performance phantom radiographs. Three observers assigned to each radiograph a score based on the detection of the details contained in the phantom. The readings were performed at the Physics Department of Ferrara University.

Fig.2 presents the visibility trend of the 15 details contained in the phantom. All the centers detect at least 5 details and no-one detects 13 or more details. Only 5% of the centers (9 centers) detects more than 11 details and 51.9% (94 centers) detects more then 9 details.

The distribution of the centers detecting the same number of details is shown in Fig.3 where the use of the grid is also outlined. The distribution of the centers not using the grid presents the maximum at 8 details while the distribution of the centers using the grid presents the maximum at 10 details, but with a wider spread.

The trend of the average breast dose of the centers with the same visibility level is shown in Fig.4. The centers detecting 9 details present the lowest average dose and those detecting more than 9 details (better image quality) deliver higher doses. The centers detecting less than 9 details present an anomalous trend: they obtain poor image quality delivering doses higher than the minimum.

The average breast doses of the centers operating with and without the grid are shown in Fig.5. As can be seen the centers detecting more than 8 details present no differences in the mean dose delivered with or without the grid. The centers with poor image quality show that the use of the grid leads to higher mean doses.

Comments and conclusions

We noted that very few units performed a quality control programme.

The lack of film processing control and the not rigorous ways of combining films with screens make very difficult to correlate dose with quality data; nevertheless we will make an attempt.

This is based on two assumptions:

a) the units detecting 8 details or more have an acceptable image quality (about 50% of the centers);

b) the maximal acceptable doses of the centers with the same score (9,10,11,12) are the mean doses of each group.

Consequently all the centers having coordinates (score and average whole breast dose per view) inside the dashed area of Fig.4 are accepted as "good" centers (not optimized centers).

All the centers above the dashed area (area B) can reduce the dose by checking the film processing, the film screen combination and the filtration.

All the centers on the left side of the dashed area (area C) can improve image quality by checking the beam quality, the film screen contact, the focus film distance and the focal spot.

All the centers in the area A need to check all the radiological chain.

Applying this acceptance criterion to the centers checked in our programme we obtained 57 "good" centers, 37 centers having too high dose, 54 centers having poor image quality and 33 centers having both too high dose and poor image quality.

In conclusion the units out of range have to improve their situation performing quality control measurements following the previous suggestions, then they have to verify the improvements with a performance phantom and a dosimetric evaluation. If a center is not able to perform the quality control measurement it has to improve its situation using a performance phantom and measuring at least the entrance exposure. In fact the trends of average breast dose and average exposure for the centers detecting the same number of details are similar, so it is possible to define, in a first approximation, an acceptance area on the plain Detail-Exposure too.

Acknowledgements

We are grateful to Dr E.De Guglielmo (*Dipartimento di Fisica, Università degli Studi,* Ferrara), Mr G.Civolani (*ENEA,* Bologna) and Mr A.Barboni (*Servizio di Fisica Sanitaria, USL-31,* Ferrara) for their technical assistance.

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Figure captions

Fig.1 - Comparison between the trend of the average HVL of the centers setting the same kV value with the HVL actual trend of a Mo anode, Be window, 30μm Mo added filter tube fed by a 3-phase 6-pulse generator.

Fig.2 - Visibility trend of the 15 details contained in the phantom.

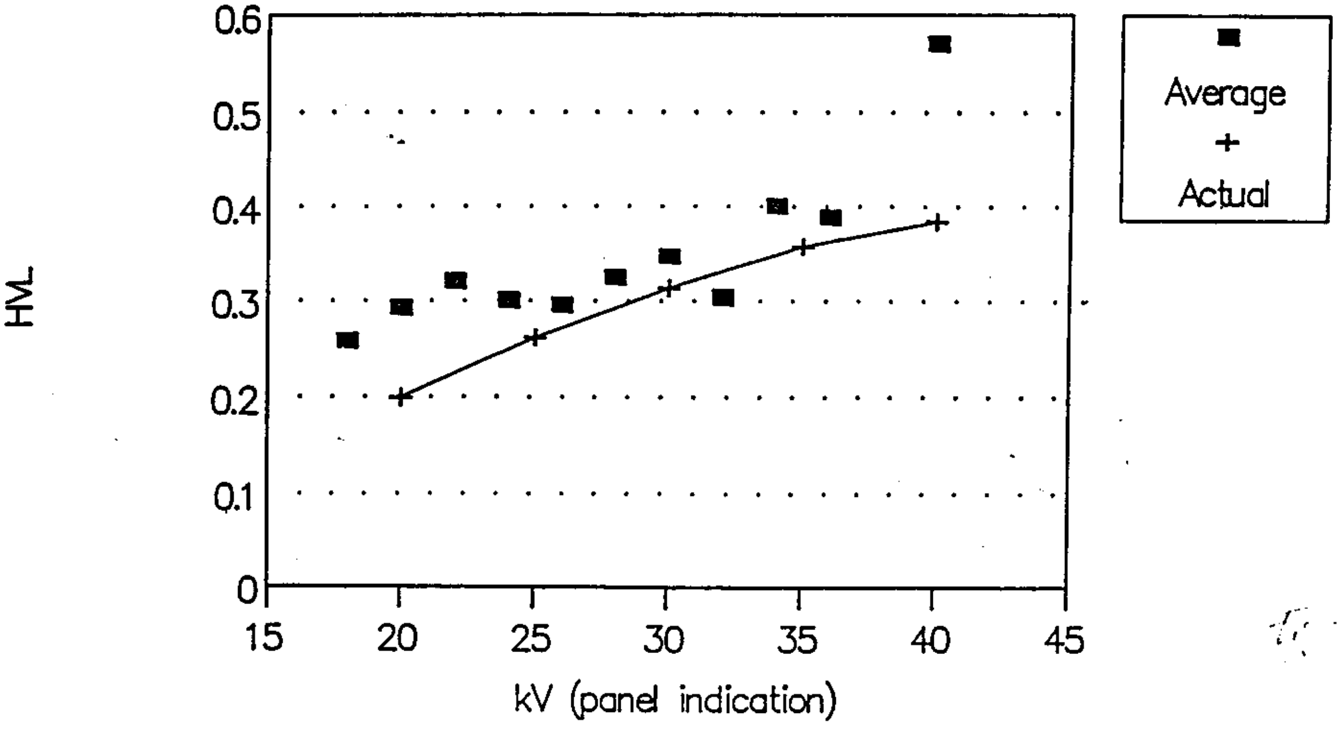
Fig.3 - Distribution of the centers detecting the same number of details.

Fig.4 - Trend of the average breast dose of the centers with the same visibility level.

Fig.5 - Average breast doses for the centers operating with and without the grid.

HVL vs kVp

181 centers



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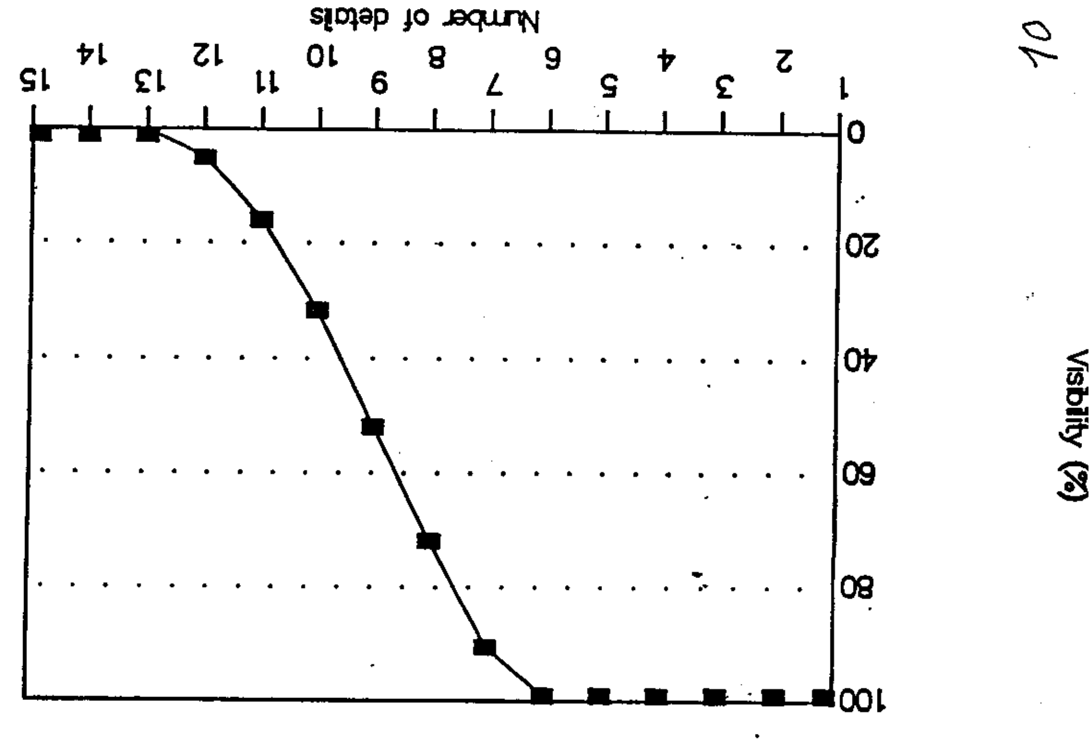
Visibility vs details

181 centers



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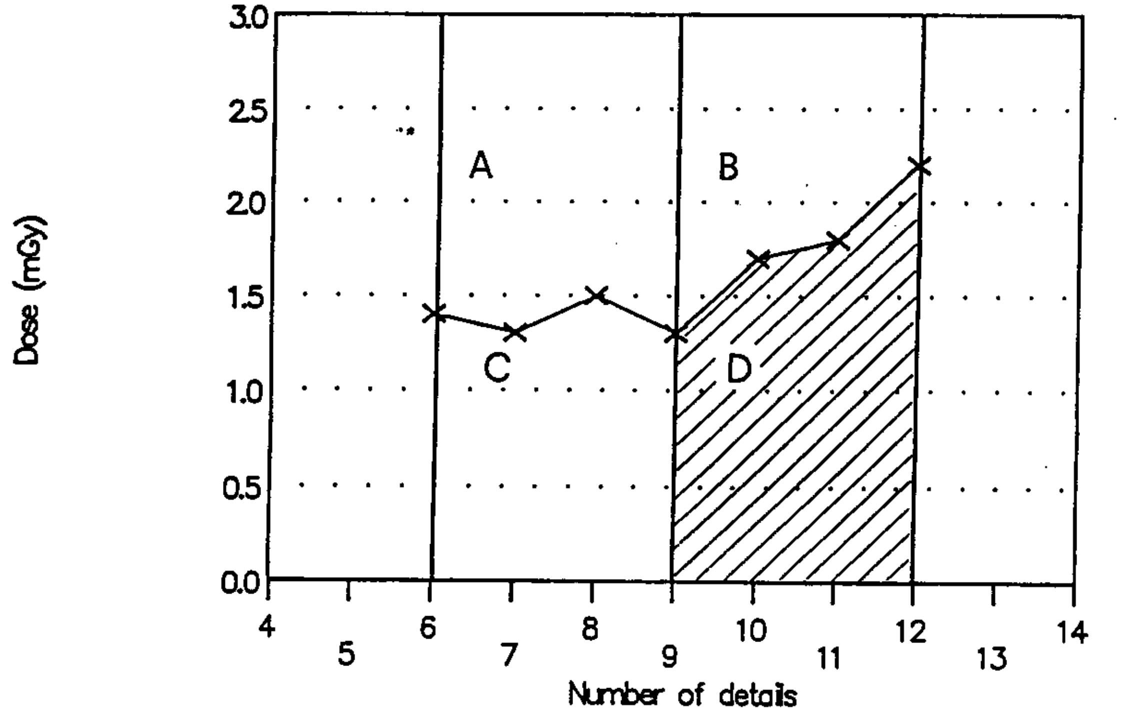
Dose vs details

181 centers



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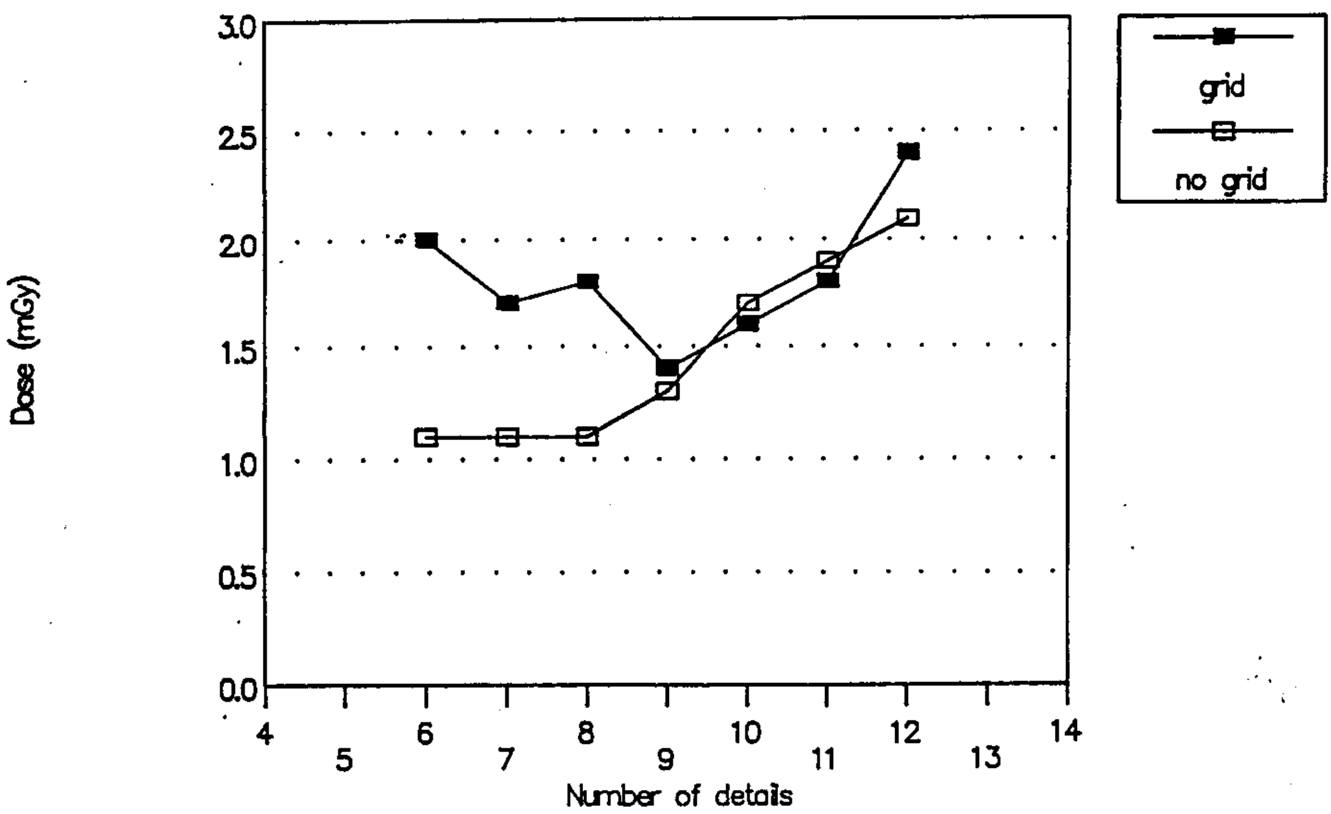
Dose vs details



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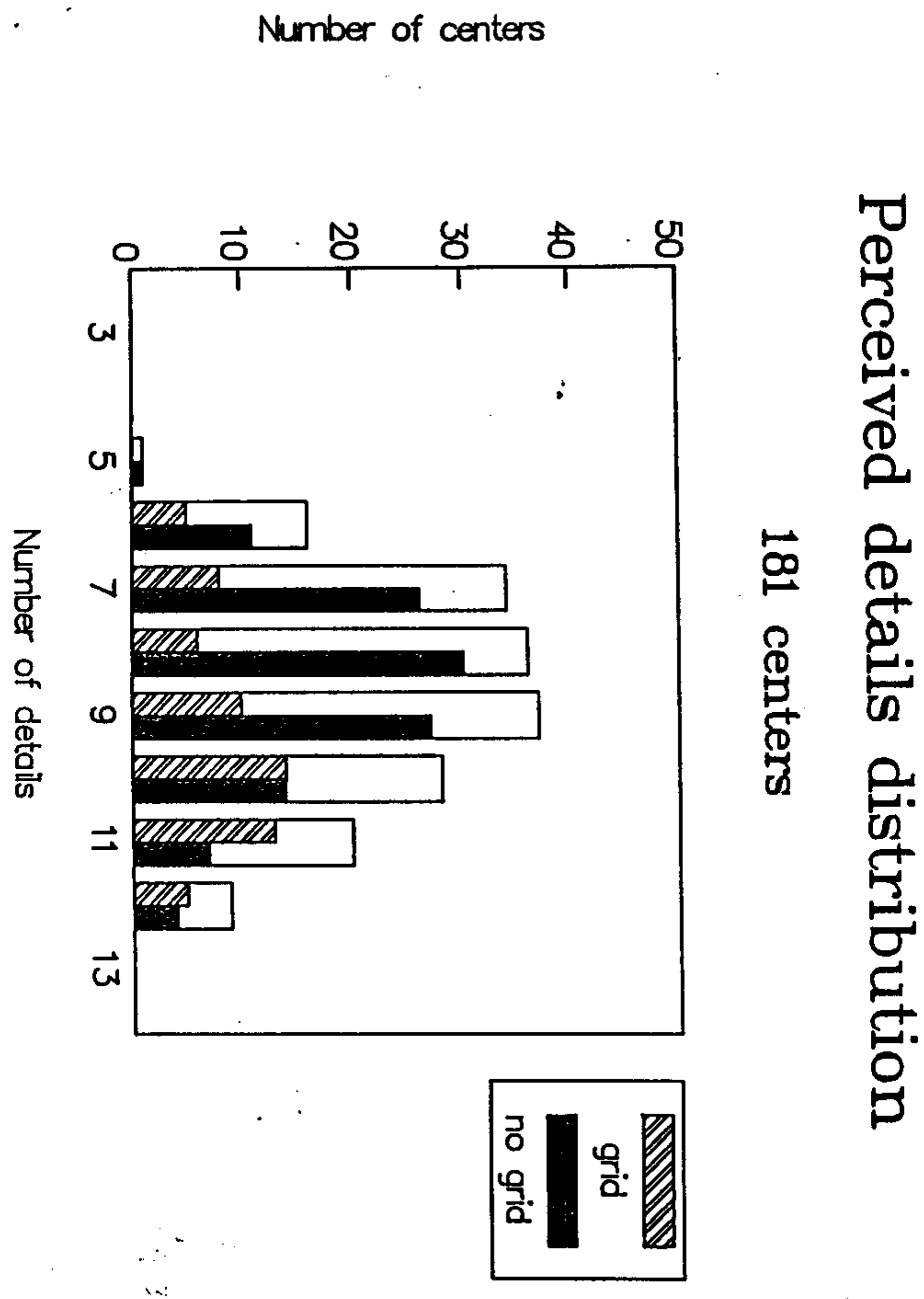

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PHANTOM FOR IMAGE QUALITY EVALUATION IN MAMMOGRAPHY

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INTRODUCTION

A phantom for evaluating image quality in mammography was designed. The device will be used in the national program "Dose and Quality in Mammography" (D.Q.M.). The project basic criteria of the phantom prototype are the following: a) the same x-ray transmission as a 5cm 50% fat and 50% water breast (F.W.B.) for energies between 15 and 50keV; b) the optimum energies for the imaging of the test objects (included in the phantom) have to agree very closely with the optimum energies for the imaging of calcifications and tumors in the F.W.B. [1]; c) the size range of the test objects has to be wide enough to evaluate the differences between mammographic systems quantitatively.

MATERIALS AND METHODS

1) Tissue substitute materials

The phantom prototype consists of three slabs with the same area ($10x10cm^2$) and different thicknesses: dentist wax (0.9cm), water (1.9cm) and lucite (1.9cm). The thicknesses of the slabs were calculated with the three components theory [2], in order to obtain the same transmission of F.W.B.

The primary radiation transmission (without scatter) relative to F.W.B. of the prototype and some other phantoms were calculated; the results are shown in Fig.1. Curve A (5cm lucite) is about 20% lower than F.W.B.. curve B (prototype) complies with F.W.B. within ±2-3% above 15keV. curve C (5cm BR12, [3]) agrees quite well. curves D (CGR phantom) and E (Random phantom) present higher transmissions in the interval 15-25 keV.

2) Phantom test objects

The optimum photon energy, relevant to a certain test object, corresponds to the abscissa of the minimum ordinate of the curve representing the entrance exposure vs photon energy, X_{rel}, for a constant signal to noise ratio [1]:

$$X_{rel} = K(E) / [\Delta\mu(E)]^2 \cdot T$$

where E is the photon energy, $\Delta\mu$ is the difference between the attenuation coefficients of the object and the material where it is included, T is the phantom transmission and K(E) is the conversion factor between photon

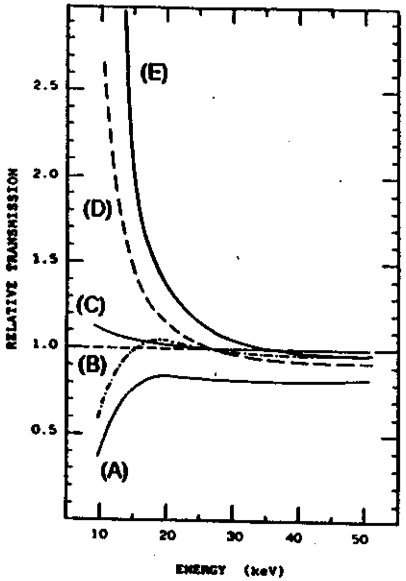

Fig.1 - Transmissions relative to a 5 cm 50% fat and 50% water breast (F.W.B.) of some phantoms: 5cm lucite (curve A), prototype (curve B), 5cm BR12 (curve C), CGR phantom (curve D), RANDOM phantom (curve E).

fluence and exposure:

$$K(E) = 4.75 \cdot 10^{-15} \cdot (\mu_{en}/\varrho)_{air} \cdot E \quad (C/Kg)/(photon/cm^2)$$

where E is the photon energy in keV, (μ_{en}/ϱ) is the mass energy absorption coefficient.

The calculated values of X_{rel} for quartz (curve C), Al (curve B) and nylon (curve D) in wax and for water (curve A) in F.W.B. are shown in Fig.2. As can be seen curve D does not present a minimum while curves B and C have the minimum in the same photon energy interval of curve A. We note that the curves for quartz and Al in F.W.B. have the same shape of curve A [1] too. These results suggest not using nylon as a material for the prototype test objects.

The test objects of the commercial phantoms are made of different compounds: bakelite, aluminium oxide, copper, air and nylon. The X_{rel} curves of these materials, taking into account the compound they are included in, were calculated by the Authors. Only the curve of aluminium oxide and Cu have the minima in the same energy interval of curve A in Fig.2; the other curves have a shape like that of nylon.

As to the dimensions of the prototype test objects, the size range was chosen empirically on the basis of the observation of the radiographs of another phantom (not the prototype) exposed in 73 centers participating in the D.Q.M. programme [4]. The test objects of the prototype are presented in Table I.

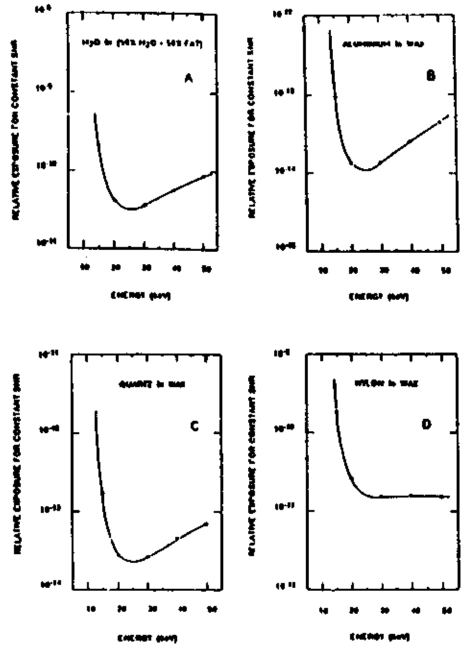

Fig.2 - Relative entrance exposure vs energy (for a constant Signal to Noise Ratio) of some test object materials included in some phantoms: F.W.B. (A), prototype (B and C), RANDOM (D).

TABLE I : PROTOTYPE TEST OBJECTS

Quartz microspheres ø(μm)	Al discs ø 3mm	ø 6mm	Al strips Length 12mm Width (mm)	Thickness (μm)
	Thickness (μm)			
170	6	6	0.3	10
190	9	9	0.4	12
206	12	12	0.5	15
231	15	15	0.6	18
282	18	18	0.7	20

EXPERIMENTAL TESTS

The phantom transmission calculations without scatter were tested experimentally. The transmission fluences vs photon energy of all the phantoms were measured in good geometry (without scatter) by means of an X-ray spectrometer (channel width: 0.1keV) connected to a personal computer. The ratio (ordinate by ordinate) between the phantom spectra and the spectrum transmitted by a 5cm BR12 slab was calculated.

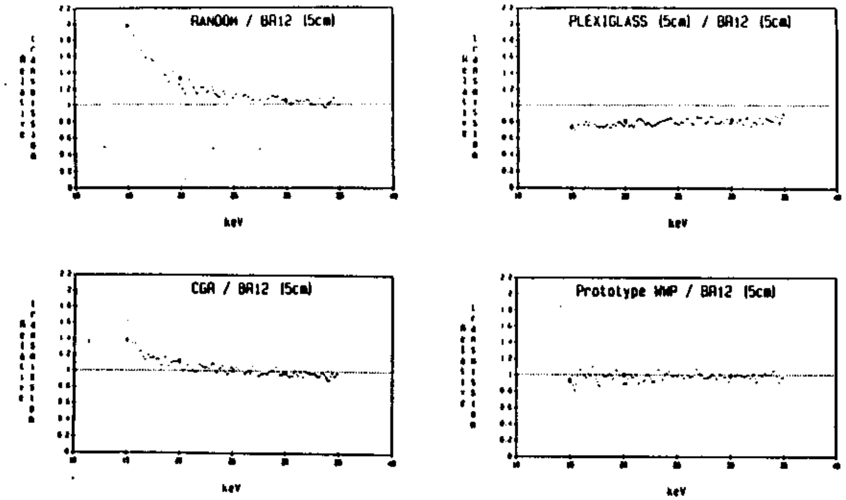

Fig.3 - The measured ratios between the spectra transmitted (without scatter) by the phantoms and the spectrum transmitted by a 5cm BR12 slab (dotted curve) are compared with the theoretical ratios calculated without scatter (dark spots).

The incident photon fluences were emitted by a Mo anode tube (Be window, 30μm Mo filter) fed by a 36.5kV constant voltage and a very low current. The fluence repetibility was assured within ±1%. The measurement results are in good accordance with the theoretical values, as can be seen in Fig.3.

The effect of scattered radiation was considered measuring the ratios, vs photon energy, between the photon fluences transmitted by the phantoms and by the BR12 slab in condition of bad geometry, *i.e.* with scatter. The ratios of all the phantom spectra are not significantly different from the theoretical values calculated without scatter. The scatter radiation does not affect significantly the transmission curves of the primary radiation. Measurements are in progress in order to test the prototype efficiency to evaluate the performances of mammographic systems quantitatively.

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● *Paper*

A SURVEY OF RADIATION DOSE AND IMAGE QUALITY IN MAMMOGRAPHY: AN ONGOING PROGRAM IN ITALY*

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Abstract—A program for mammography optimization in individual x-ray units, named Dose and Quality in Mammography (DQM), is now underway in Italy. The project has three stages: (a) measurement of the parameters that affect dose and image quality by means of devices that are practical to use (specifically designed for the purpose), (b) analysis of data to evaluate dose and image quality and (c) suggestion of possible improvements to each unit operator. Instruments and methods employed in our survey are described. Our results, like those of the American survey (Je78) Breast Exposure: Nationwide Trends (BENT), show widespread variations of exposure, half value layer (HVL), optical density, dose and resolution. Facilities using the same type of x-ray apparatus (Mo target-Mo filter) and film-screen combinations present very different exposure values, ranging from 1.6×10^{-4} to 27.6×10^{-4} C kg^{-1}. The causes of these variations—ascribable to the individual units, radiologist preferences, processing condition, kVp indicator and timer accuracy—are being explored.

INTRODUCTION

RADIOGRAPHY is one of the most effective means of obtaining an early diagnosis of breast carcinoma. Reduction of breast dose, while preserving image quality, is an important goal. With this objective in mind, we have been conducting a Dose and Quality in Mammography (DQM) program for mammography optimization in individual units (Ba81; Ri81a; Ri81b).

The steps of the program are:

(a) Collection of the working parameters of each unit. Data are first collected by means of a questionnaire and then by means of measurements.

(b) Dose and image quality evaluation. A computerized program has been prepared to evaluate dose and image quality in individual units.

(c) Analysis of results. Results are analyzed so that improvements may be suggested to unit operators to help them start quality assurance work.

INSTRUMENTS AND METHODS

The principal parameters, breast exposure, HVL, focal spot size and image density, have been measured with devices that are practical for mailed surveys and simple enough for use by unit operators.

Our devices and calculation procedures are outlined below.

(a) *Exposure meter*

The exposure meter and its expanded view are shown in Fig. 1. Three TLD-100[1] detectors (3 × 3 × 0.9 mm) are placed in the seatings in cardboard disc No. 5 and three TLD-100s in the seatings in disc No. 3. A 0.5-mm Al filter (disc No. 4) is placed between the two TLD groups. All discs are secured to the top of a Lucite®† tube 5 cm high and 5 cm wide with a 0.5-cm-thick wall.

The device is exposed in the same way as a 5-cm

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[1] Harshaw Chemical Co., 6801 Cochran Rd., Solon, OH 44139.
† E. I. du Pont de Nemours & Co., Wilmington, DE 19898.

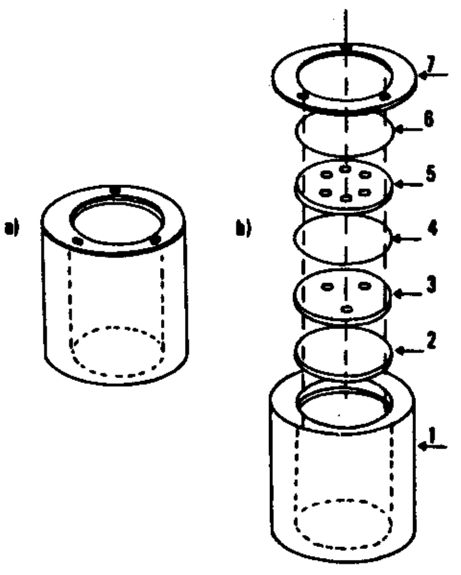

Fig. 1(a). Exposuremeter. (b) Exposuremeter expanded view: 1 = Lucite® tube; 2 = Bakelite® disc (Isotessile, via Piave 6, Somma Lombardo, Varese, Italy); 3, 5 = Cardboard disc; 4 = 0.5 mm Al filter; 6 = black paper; and 7 = stop ring.

thick breast in a craniocaudal projection. Individual irradiation conditions (kV, mA, time and focus-skin distance) are defined by the radiologist of each unit; the conditions are repeated for all subsequent consistency measurements. Exposure in air (X_a) is measured by the first group of detectors taking into account TLD-100 energy dependence and backscatter from the exposure-meter frame. The ratio between readings of the second (under Al filter) and first TLD groups give beam HVL on the basis of a calibration curve (Wo78).

TLD-100 detectors (each marked with a number) are annealed and the relative individual sensitivities are evaluated after exposure to ^{60}Co emission assuring the same exposure (about 12.9 C kg^{-1}) for each detector. Energy dependence (TLD reading per unit exposure) is measured in the mammography energy range (HVL between 0.22 mm Al and 0.45 mm Al) using a Senographe CGR Mo anode unit,§ a Be window, a 0.03-mm Mo filter, a single-phase fully rectified wave form, a soft x-ray chamber‡ (volume, 0.2 cm^3) and associated electronics.‡

Chamber calibration factors are measured in the secondary standard calibration laboratory,‡ comparing the chamber against a secondary standard reference dosimeter; calibration factor uncertainty ranges from ±3% to ±2% in the HVL interval of 0.06–0.93 mm Al. Finally the calibration curve to evaluate HVL in the field has been obtained exposing groups of six exposure meters to the same beams, of known HVL, employed for energy dependence calibration. TLD-100 readings are taken with a TLD reader* in a nitrogen purge, at the Laboratorio di Fisica Sanitaria of the Comitato Energia Nucleare ed Energie Alternative, Via Mazzini 2, Bologna 40100, Italy.

(b) *Device for focal spot measurement*

The device for focal spot measurements consists of a Cu-coated board for printed circuits (Cu thickness is 0.07 mm) etched to a star pattern with two-degree vertex angles, a star pattern support that defines the geometrical conditions of exposure and a spatial recording system consisting of a sandwich of three films and three filters (Fig. 2). The film sandwich is preferred to a single film because it enables operators to obtain at least one suitable image with normal mammography exposures. In other words, at least one film will have sufficient image contrast. Radiation scattered by the filters does not appear to affect image contrast significantly.

(c) *Lucite® phantom*

A phantom (10 × 10 × 5 cm) containing TLD-100 detectors set at various depths (0, 2.5 and 5 cm) is exposed in the same way as the exposure meter. The exposure value for a normal radiograph is applied at least five times so that even TLD detectors placed inside the phantom receive adequate irradiation for exposure measurements.

(d) *Kodak ITO*** *for mammography*

As is well known, one indicator for mammography technique operation is a phantom with various details. It may be used for both optical and physical evaluations of radiographs. It is exposed in the same way as an exposure meter and the film is developed by unit operators.

(e) *Resolution evaluation*

Total resolution is calculated for individual units and is expressed in terms of the total modulation transfer function (MTF), which refers to an object plane 5 cm from the recording system. The total MTF is the product of the MTF recording system multiplied by the MTF geometry by means of the bar pattern method, which is precise enough to compare the different recording systems (Ba81). (The MTFs of the various types of film screen used in the medical centers are measured in our laboratory.) The MFT geometry of each unit is calculated taking

§ Senographe, 13 Sq. M. Hymans, 75736 Paris, Cedex 15, France.

‡ Soft x-ray chamber, Model M23344 and associated electronics, DL4-D14, Physikalisch Technische Werkstaetten DL4-D14 electronics, 7800 Freiburg, Loerracher Str. 7, Federal Republic of Germany.

* Pitman 654, D. A. Pitman Ltd., Jessamy Road, Weybridge, Surrey KT13 8LE, England.

** Indicator for Technique Operation (ITO), Kodak-Pathé, 8-26 rue Villiot, 75580 Paris, Cedex 12, France.

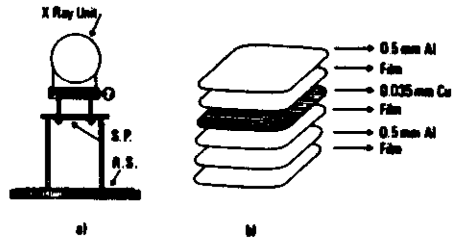

Fig. 2(a). Exposure arrangement for focal spot measurement. Star pattern (S.P.) support, x-ray unit and recording system (R.S.). (b) Expanded view of the recording system.

into account magnification and focal spot size, measured with the star pattern, assuming a rectangular shape with uniform emission.

(f) *Dose evaluation*

The average dose to the whole breast per craniocaudal projections, $\bar{D}$, ($\bar{D} = \bar{D}_N X_a$, where $\bar{D}_N$ is the mean dose per unit incident exposure and X_a is exposure in air) for a 5-cm-thick organ, 50% fat + 50% water, is estimated for each Mo anode mammography unit.

$\bar{D}_N$ is evaluated by the energy fluence method (Sh81). In exact terms, $\bar{D}_N$ is calculated when the following factors are known: energy fluence per unit exposure in air (ψ), its spectral distribution, its backscatter factor (BSF) and the amount of scattered and primary radiation reaching the cassette. The total energy of radiation laterally scattered from the breast does not affect significantly the dose calculation.

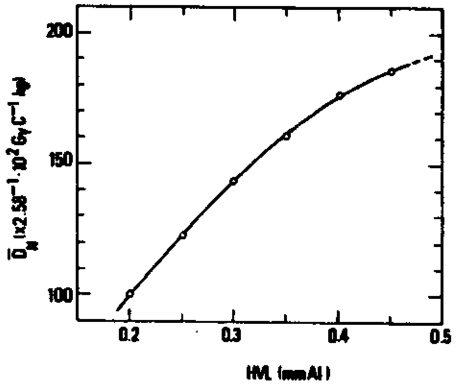

Fig. 3. $\bar{D}_N$ vs HVL calculated for a breast, which is 50% fat + 50% water, 5 cm thick, and where radiation is from an Mo anode and a 0.03-mm Mo filter.

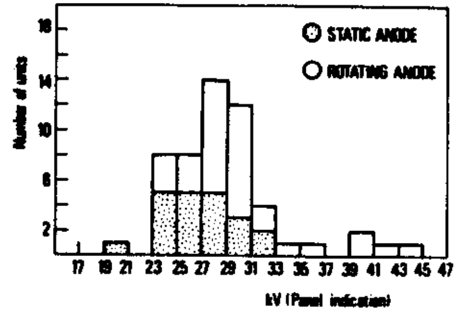

Fig. 4. Distribution of high-voltage values (kV), panel indication.

The energy fluence ψ corresponding to the data taken in the field unit (anode, filter, kVp, HVL) is estimated using published spectral data (Fe78). When the kVp and HVL of a field unit do not match exactly the published spectral conditions, we find the fluence, ψ^*, for the spectrum corresponding to the closest kVp, we search theoretically for a thickness which when multiplied times the thickness of Al (in millimeters) will match the HVLs and then we modify ψ^* by accounting for the attenuation in millimeters of Al to find ψ. To ensure that ψ values are precise enough, dose measurements taken at a 2.5-cm depth along the central axis of the Lucite® phantom exposed in each unit are compared with calculated doses. The average percent difference between calculated and measured doses is 0.5%, and the standard deviation is 11%. We believe that this evaluation method is precise enough to compare doses from different mammography units. Exposure at a depth of 2.5 cm is measured with TLD-100s (six detectors), allowing for TLD energy dependence on HVL at this depth. The Lucite® rad/R factor in the 10- to 40-keV interval is found to be nearly independent of energy and also of depth. For dose calculation

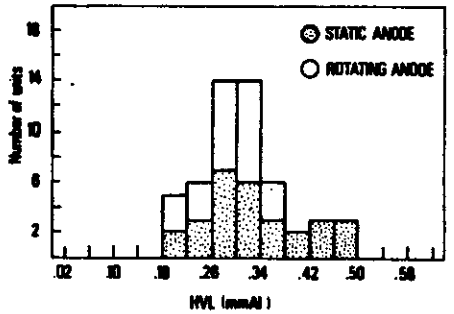

Fig. 5. Distribution of HVL values.

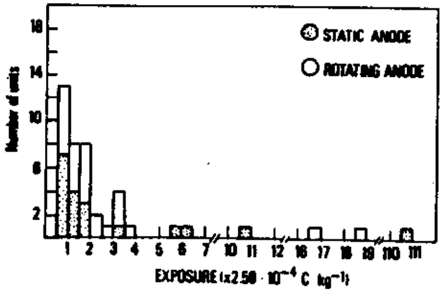

Fig. 6. Distribution of exposure values.

at centrally located parts, we assume that scatter radiation is in equilibrium (Sh81), i.e. energy scattered from the primary beam is regained from scatter in adjacent areas.

The BSF used to calculate $\bar{D}_N$ is taken from Fig. 10 of St82. The scattered radiation reaching the cassette is estimated, assuming the scatter to primary ratio, S/P, = 0.7 (Ba78; Fr83). Beam divergence inside the breast is also taken into account. Figure 3 presents $\bar{D}_N$ vs. HVL. Our results agree with published data (St84).

RESULTS

Measurements have been taken in 57 units, 53 of which used Mo anode tubes and four of which used W anode tubes. The Mo anode tubes included 21 GCR Senographe (static anode),§[‖] three GCR Senographe 500 T,§ four Siemens Vertix M,[‖] seven Siemens Mammomat,[‖] four Philips Mammodiagnost,[1] six Gilardoni[2] (various models) and eight other types.

Only four units use direct x-ray film, all the others use film-screen combinations (Min R Kodak 29, Lo Dose duPont 7[3], T2 3M 13[4]).

Figure 4 presents the distribution of kV as read on the unit's front panel; 49% of the units range from 27 to 31 kV, the optimal interval for Mo/Mo units and film-screen systems (NCRP80).

About 53% of the units have HVLs that range from 0.26 to 0.34 mm Al (Fig. 5), i.e., an acceptable interval for Mo/Mo units. Exposure in air, X_a, has a wide distribution, as may be seen from Fig. 6. Rotating anodes give

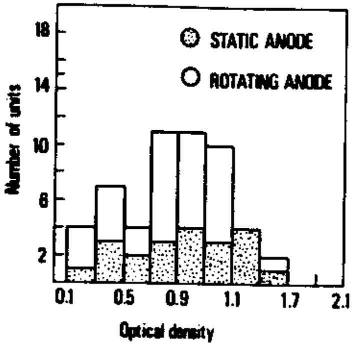

Fig. 7. Distribution of optical densities.

the lowest exposure due to the greater sensitivity offered by the film-screen combination for shorter exposure times.

The optical density of ITO radiographs, measured in a no-detail region (4.5 cm thick), varies considerably (Fig. 7). It is precisely these wide variations in optical density that prevent significant image quality comparisons (optical density has been found to be too low in 12 centers). Figure 8 shows the distribution of average dose $\bar{D}$.

The range of resolution (total MTF) evaluated in the various centers is presented in Fig. 9; maximum and minimum MTF for static and rotating anode units are given. Resolution for rotating anodes is better than for static anodes because the former have greater focus skin distance and, in some cases, small focal spots. However, when a rotating anode has too large a focal spot, the MTF is comparable to or worse than that for static anodes.

RESULT ANALYSIS

The maximum exposure measure in 28 screening centers of the Cancer Demonstration Project (Ha79) was 2.84 × 10^{-4} C kg^{-1} (1.1 R). In our survey, only 45% of

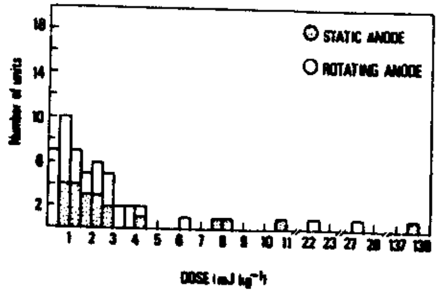

Fig. 8. Value distribution of the average dose to the whole breast D for a craniocaudal projection.

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‖ Siemens Aktiengesellschaft, Erlangen, Federal Republic of Germany.

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[2] Gilardoni, S. p. A., Via Fermi 2, 22054 Mandello Lario (Como), Italy.

[3] Du Pont de Nemours, GMBM, Photoproducts Department, 6 Frankfurt/Main 1, Federal Republic of Germany.

[4] 3M-Italy, 17016 Ferrania (Savona), Italy.

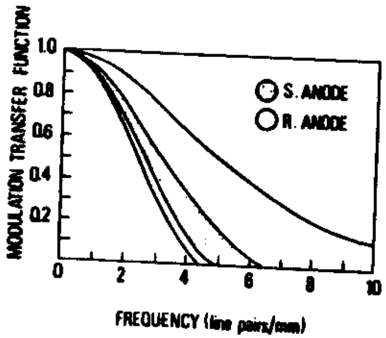

Fig. 9. Total modulation transfer function (MTF) range.

centers exhibited exposure levels lower than this value. About 43% of centers show exposure values between 2.58 × 10^{-4} C kg^{-1} and 12.9 × 10^{-4} C kg^{-1} (5 R). The highest exposures are associated with use of direct x-ray film (without screen) and accidental absence of the Mo filter.

Our range of dose distribution is comparable to that from the BENT survey, where all types of mammography units were taken into consideration (Je78), although screening centers in Italy use only Mo/Mo units and predominantly screen film systems. In our survey, facilities using the same types of x-ray apparatus and film-screen combinations have widely different exposure values ranging from 1.6 × 10^{-4} C kg^{-1} to 27.6 × 10^{-4} C kg^{-1}. This variation could be due to a number of causes such as film processing conditions, kVp indicator accuracy, time accuracy, radiologist preferences, etc. These causes are being explored on an individual basis.

In conclusion, the wide variations in results show that routine mammography in Italy has to be optimized. Physical factor measurements in mammography must be improved and extended to a more complete set of parameters. At the same time, images should be assessed with a "good" breast phantom. The Kodak phantom is not suitable for this purpose because its image quality index does not have a sufficient correlation with clinical image quality (Mc83; St79).

Recently, in view of the results obtained, the Italian Society of Radiology and Nuclear Medicine has decided to extend the DQM program to include all the mammography units operating in Italy in order to optimize radiological exams.

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Criteria and Methods for Quality Assurance
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III.B.5 Preliminary results of new NEXT programme

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ABSTRACT

NEXT (Nationwide Evaluation of X-ray Trends) is a programme originally designed at the Center for Devices and Radiological Health (CDRH) (USA) and then adapted to Italian conditions. Since November 1983 an improved computer code has been available. For each apparatus surveyed, all the parameters influencing patient exposure are collected and on this basis the doses to the most important organs of the patient's body, such as thyroid, bone marrow, uterus and gonads, are computed. Equipment and radiological techniques causing excessive doses are easily picked out and may then be adjusted or corrected; using the same data, the relevant authorities can choose the most adequate programme to improve radiation protection of the patient.

Results of a representative sample from the region of Emilia-Romagna are presented, showing how this programme could influence quality assurance.

In 1976, the National Committee for Nuclear and Alternative Energies (ENEA) and the High Institute for Health (Istituto Superiore di Sanità) (ISS) decided to examine how much patient radiation exposure for medical purposes contributes to overall population exposure and how it is possible to reduce this contribution.

After a study (Benassai et al, 1977) carried out on Genetically Significant Dose (GSD) due to medical exposure in Italy, attention was drawn to X-ray diagnostic exposure as one of the heaviest components of the overall exposure. ENEA and ISS considered that the NEXT programme, run by the Center for Devices and Radiological Health (CDRH) of the US FDA, was the most suitable programme to evaluate the influence on patient dose of different radiological techniques, equipment status and operator training. ENEA and ISS have been carrying out this programme in Italy since July 1977, when it was applied in Umbria. Since the end of 1983, a new development of the NEXT programme has been available, with more detailed output.

THE NEXT PROGRAMME

The NEXT programme, its features and aims, were described in a CEC seminar held in Munich in 1981, entitled *Patient Exposure to Radiation in Medical X-ray Diagnosis* (Marchetti et al, 1981). Doses to the body of the patient are computed by a Monte Carlo technique (Rosenstein, 1976) for 12 radiological projections; beam exposure, HVL and beam sizes are measured directly, whereas voltage, current and time are only recorded. The earlier code could only compute gonadal doses; the improved code, now available, is also able to compute doses to bone marrow, thyroid, lungs, uterus and total body; and it can also compute patient doses for other radiological projections which are not considered in the NEXT programme. So far, the programme has been applied in the regions of Umbria, Emilia and Abruzzi and in the provinces of Palermo and Trieste, using the earlier code. Regional operators have already been trained to carry out NEXT surveys in Tuscany and Liguria.

TABLE I

MEAN VALUES OF SOME TECHNICAL PARAMETERS FOR THE MOST FREQUENT PROJECTIONS.

Projection	Voltage kV	Current. time mAs	HVL mm Al	Beam area/ film area	Skin entrance exposure C. kg^{-1}*
Chest (PA)	71	20	2.0	2.2	$137.5 \cdot 10^{-7}$
Skull (L)	74	65	2.2	0.95	$864.5 \cdot 10^{-7}$
Abdomen (AP)	76	76	2.0	1.64	$2630.5 \cdot 10^{-7}$
Lumbo-sacral spine (AP)	75	105	2.1	1.2	$2464.9 \cdot 10^{-7}$

* 1 mR = $2.58 \cdot 10^{-7}$ C·kg^{-1}.

TABLE II

MEAN DOSES TO SOME PATIENT ORGANS FOR THE MOST FREQUENT PROJECTIONS (μGy*).

Projection	Whole body	Thyroid	Lung	Bone marrow	Ovarian	Testicular
Chest (PA)	46	7	137	33	< 5	< 5
Skull (L)	84	569	< 5	76	< 5	< 5
Abdomen (AP)	998	< 5	579	291	1506	1619
Lumbo-sacral spine (AP)	478	< 5	64	145	1291	105

* 1 mrad = 10 μGy.

TABLE III

RANGES OF VARIATION OF SOME TECHNICAL PARAMETERS FOR THE MOST FREQUENT PROJECTIONS.

Projection	Voltage kV	Current. time mAs	HVL mm Al	Beam area/ film area
Chest (PA)	50–100	1–80	0.9–3.6	0.5–9.3
Skull (L)	58–100	24–140	1.2–2.8	0.7–1.9
Abdomen (AP)	58–90	24–500	1.4–2.8	0.3–2.9
Lumbo-sacral spine (AP)	52–96	19–310	1.2–3.2	0.6–2.4

PRELIMINARY RESULTS

Preliminary results using the new computer code are presented here. They refer to 100 facilities and about 200 X-ray sets spread over Emilia-Romagna, chosen on a sample basis.

Mean values of voltage, mAs, HVL and ratio of beam area to film area are reported in Table I, together with skin entrance exposure, for the four most frequent projections. For the same projections, mean doses to patient organs are reported in Table II.

Equipment parameters range very widely, as is shown in Table III. Skin entrance exposure and organ doses, in consequence, can vary by several orders of magnitude, as shown in Table IV.

According to the recommendations of ICRP Publication 26 (1977), ionising radiation should be used only if its use is justified and with optimised techniques, therefore those techniques causing the minimum and maximum doses cannot be correct. Low doses might be due to underexposed films; high doses may be

TABLE IV

RANGES OF VARIATION OF SKIN ENTRANCE EXPOSURE (10^{-7} C·kg^{-1})* AND SOME ORGAN DOSES (μGy)† FOR THE MOST FREQUENT PROJECTIONS.

Projection	Skin entrance exposure	Whole body	Lung	Bone marrow	Ovarian	Testicular
Chest (PA)	15.5–3217	< 5–410	10–1390	< 5–240	< 5–150	< 5
Skull (L)	511–3914	40–290	< 5–10	40–220	< 5	< 5
Abdomen (AP)	586–7965	90–2420	< 5–2790	20–790	310–5310	< 5–10150
Lumbo-sacral spine (AP)	475–7309	90–1180	10–400	20–420	290–4380	10–660

* 1 mR = $2.58 \cdot 10^{-7}$ C·kg^{-1}.
† 1 mrad = 10 μGy.

associated with better image quality. Although it is not an aim of this programme to state which technique is correct, nevertheless it is quite difficult to believe that all the techniques recorded, with such a wide range of variations, can produce radiological images of the same good quality, with the same information content. In any case, it is evident that the choice of beam quality is not always justified and that beam sizes are frequently larger than films.

The NEXT programme is not directly concerned with image quality, but it can give an analytical basis for programmes to improve image quality and to reduce patient exposure. For instance, since the mean voltage for a chest PA projection is 71 kV, by employing only those techniques which use between 65 and 75 kV, the variation in lung dose can be reduced to between 10 and 210 μGy (cf. Table IV). Since the mean HVL is 2.0 mm Al, by employing X-ray beams with only those values between 1.8 and 2.2 mm Al, the variation in lung dose is reduced to between 10 and 130 μGy.

Conclusion

It is evident that this programme can supply radiologists and health physicists with useful information on which to base advice on optimised radiological techniques. Regional operators are now carrying out an accurate analysis of the results, on the basis of which regulations and directives will be issued. Their efficacy will be tested by repeating the NEXT programme on a sample of facilities.

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Criteria and Methods for Quality Assurance in Medical X-ray Diagnosis

IV.5. Instruments and methods for the DQM programme

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Abstract

The principal parameters affecting dose and image quality are evaluated by means of the devices and computer programs here described; the devices are calibrated using an X-ray facility assembled for the purpose. Measurement results are presented in Chapter II.9.

The programme for optimising mammography in individual X-ray units (DQM) has three stages: measurements of the main parameters affecting dose and image quality, analysis of the data to evaluate dose and image quality, and suggestions of possible improvements for each unit. To carry out the first two stages we have developed devices that are easy to use, computer programs and a calibration facility (Rimondi et al, 1981; Bagni et al, 1981).

Calibration Facility

The facility consists of two X-ray tubes having Mo and W anode respectively (both with Be windows), a three-phase HV generator, an HV divider for direct kVp measurement and an optical bench.

Exposure Meter and Dose Calculation

The exposure meter is made up of two groups of TLD-100 detectors; the first group above the 0.5 mm Al filter and the other below. The detectors and Al filter are secured to the top of a plexiglass cylinder 5 cm high and 5 cm wide (Fig. 1).

The device is exposed in the same way as a breast 5 cm thick; exposure is measured by the first group of detectors taking into account the LiF energy dependence; the ratio between the readings of the second and first group of detectors gives the HVL on the basis of the calibration curve.

The computer program for dose calculation in each unit gives the doses at various depths for three breast compositions: 100% water, 50% fat + 50% water, 50% fat + 50% gland; the input data are: exposure value, exposure geometry and HVL. The flow chart is shown in Fig. 2.

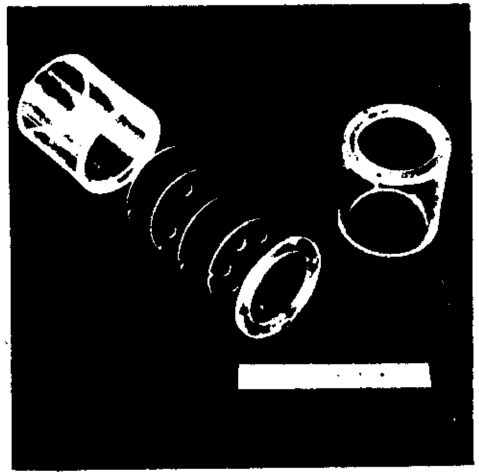

Fig. 1.
Exposure meter and its expanded view. The plexiglass cylinder is 5 cm high and 5 cm wide.

* Research supported by the Commission of the European Communities (contract no. BIO-F-446-I), by Consiglio Nazionale delle Ricerche (contract no. 83.00550.57) and by Ministero Pubblica Istruzione.

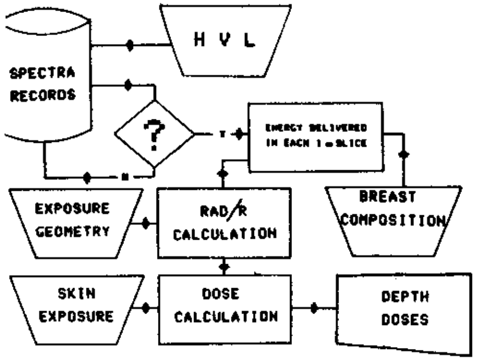

FIG. 2.
Dose calculation program flow chart.

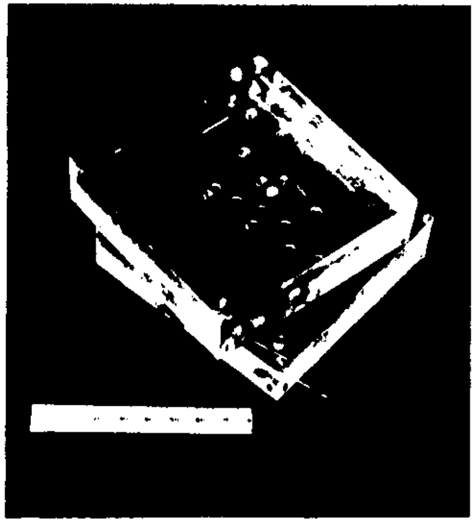

FIG. 3.
Plexiglass phantom (10 × 10 × 5 cm).

TABLE I
RESULTS OF MO ANODE UNITS

		Total	Stationary anode	Rotating anode
No. of units		28	11	17
Exposure (R)	mean	2.20	2.58	1.04*
	S.D.	3.60	3.19	1.10
	range	0.16–16.60	0.74–10.70	0.16–3.60
HVL (mm Al)	mean	0.32	0.29	0.33
	S.D.	0.09	0.06	0.11
	range	0.2–0.5	0.2–0.37	0.2–0.5
Focal spot (mm)	mean	1.34 × 1.01	1.48 × 1.07	1.12 × 0.97
	S.D.	0.45 × 0.29	0.52 × 0.14	0.14 × 0.35
Optical density (ITO)	mean	0.84	0.97	0.76
	S.D.	0.34	0.38	0.29
	range	0.19–1.37	0.27–1.37	0.19–1.20
Dose, first cm (mrad)	mean	960	1100	460*
	S.D.	1510	1240	420
	range	90–7240	295–4260	90–1360
Dose, mid-plane (mrad)	mean	135	149	66*
	S.D.	218	146	55
	range	18–1110	36–500	18–158
Resolution† (lp/mm) $MTF_{total} = 0.5$	mean	3.34	3.01	3.47
	S.D.	0.73	0.21	0.88
	range	2.4–5.2	2.6–3.3	2.4–5.2

* The exposure value of the centre using direct film is not included.
† Resolution is expressed by the spatial frequency corresponding to 0.5 value of total MTF.

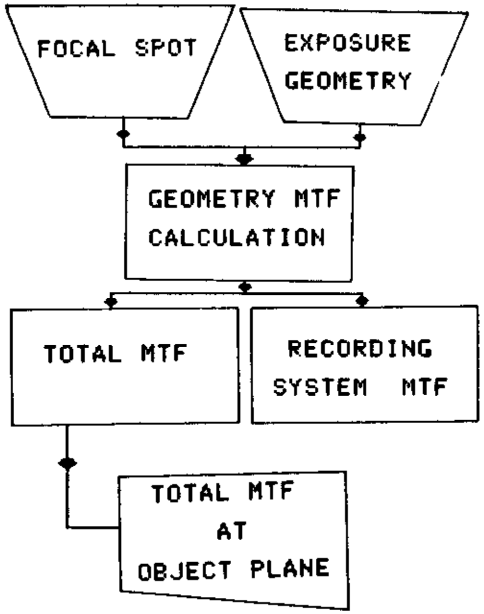

FIG. 4.
Resolution calculation program flow chart.

PLEXIGLASS PHANTOM

A plexiglass phantom (10 × 10 × 5 cm) containing TLD-100 detectors at various depths (0, 2.5, 5.0 cm) (Fig. 3), is exposed in the same way as a breast 5 cm thick. The resulting doses are compared with the ones obtained by computer program.

EQUIPMENT FOR FOCAL SPOT MEASUREMENTS AND RESOLUTION EVALUATION

The equipment for focal spot measurements consists of a 2° sector star pattern (Cu thickness 0.070 mm), a support defining the exposure arrangement, and a special recording system consisting of three films and three filters. The film sandwich is preferred to a single film because it enables the operator to obtain at least one suitable image using typical mammography exposure parameters. The resolution is calculated for individual units, by means of a computer program which gives the total MTF referred to the object plane at 5 cm from the recording system. The input data are: focal spot dimension, film-screen type and exposure geometry. The flow chart is shown in Fig. 4.

KODAK ITO FOR MAMMOGRAPHY

The Kodak indicator for technique operation (ITO) phantom contains various kinds of details. It may be used for visual and physical evaluation of the radiographs. It is exposed in the same way as a breast and the film is processed by the unit operators themselves.

CONCLUSIONS

Measurement and calculation results obtained, using the instruments and methods described, in 28 mammography units are presented in Table I. Dose, resolution and optical density values cover a wide range. In order to seek the causes of this variation we have to measure other parameters too (*i.e.*, kVp, exposure time) and to control the film processing conditions.

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Criteria and Methods for Quality Assurance in Medical X-ray Diagnosis

III.A.8 Italian programmes to optimise X-ray diagnostic exposure

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ABSTRACT

Scientific associations in Itlay such as the Associazione Italiana di Radioprotezione (AIRP), the Società Italiana di Biologia e Medicina Nucleare (SIBMN) and the Associazione Italiana di Radiologia Medica e Medicina Nucleare (SIRMN) have been working on the problem of patient radiation protection for many years; their latest activities are described. Principal features and aims of the NEXT programme and the programme "Dose and quality image in mammography" will follow. Local administrations and Health Physics Services are involved in programmes on Genetically Significant Dose (GSD) evaluation or quality assurance: examples of these programmes are shown. Lastly, problems related to the education of radiological operators and radiologists are dealt with.

Italian legislation on the peaceful use of ionising radiation lacks precise directives on patient radiation protection, both for X-ray apparatus and for radioisotopes, both for therapy and diagnosis. General recommendations are only issued in order to permit control of the activities of radionuclides actually delivered to patients and to the environment. This is due to a strict acceptance in Italy of the 1958 ICRP Recommendations and EEC Directives of the same year. As Italian regulations on this matter have not been changed since that date, it is generally hoped that the 1980 EEC Directives on radiation protection and the latest EEC Directive on patient radiation protection, when accepted in Italy, will compensate for this lack. The need for such a directive is widely felt and recognised. For instance, as results from the NEXT programme have shown, X-ray equipment is very often used improperly; performance is not often checked; peak voltage, current, time, collimators, source-to-skin distance are often chosen without any consideration of the examination to be performed and the film to be used.

Regional and Local Health Administrations (USL) have been entrusted with authorisation and survey tasks since 1978, when a National Health Service was established in Italy.

Due to differences of organisation in each region, it is quite difficult to get information about facilities and types of X-ray apparatus available in each region. Anyway, a recent study (Chiesa, 1983) showed that both radiological facilities and operators and radiologists are underemployed, though the Italian population is X-rayed at a rate of 609 examinations per 1000 people (SIRMN, 1982). It can be concluded that facilities and apparatus are too widely distributed over Italian territory, but frequently misused and underemployed. This is stressed in a proposal (Bartolozzi et al, 1981), to optimise the distribution of X-ray facilities and their use, issued by the SIRMN. 5000 examinations/facility/year, 8000 examinations/radiologist/year and 3500 examinations/operator/year are goals we would like to achieve, though they are not up to the standard of other European countries.

ACTIVITIES OF SCIENTIFIC ASSOCIATIONS

Three main Scientific Associations have been operating in Italy for many years: the Italian Association for Radiation Protection (AIRP), the Italian Society of Biology and Nuclear Medicine (SIBMN) and the Italian Society of Radiology and Nuclear Medicine (SIRMN). Their efforts were initially aimed at diffusing available knowledge about radiation protection, in general, and all useful means to limit patient exposure. Later, the need for a balance between patient dose reduction and image quality in X-ray diagnosis has been stressed, mainly since ICRP 26 was issued.

Seminars and round tables on this problem were held, during annual meetings of these associations or specially organised, during last year (Rimondi et al, 1983). Some of them were organised by the three associations in close cooperation: the latest ones were all devoted to the problem of image quality in X-ray diagnosis. We would like to stress here the importance of the work (SIRMN, 1982) carried out by SIRMN on the criteria for planning radiological facilities. On this basis the Health Physics Section of the SIRMN is devising a survey programme on image quality in X-ray diagnosis, as described by Belletti and his coworkers (Chapter IV.17).

PROGRAMMES OF NATIONAL BOARDS AND LOCAL ADMINISTRATIONS

Since 1976, the National Committee for Nuclear and Alternative Energies (ENEA) and the High Institute for Health (Istituto Superiore di Sanità (ISS)) have been carrying on a joint programme called NEXT on the evaluation of doses delivered to patients for radiological examinations. Though the need for its application in Italy was widely recognised, great difficulties were encountered in convincing local administrations to apply it in their areas. Some regions are now showing great interest and we hope to get results on a large scale in the near future. This programme and its relationship to the problems of image quality are described by other authors.

. The DQM programme is carried on by the ISS and the University of Ferrara in cooperation with the Local Health Administration: the programme is described by Professor Rimondi and his colleagues in Chapter II.9. Another programme, aimed at evaluating GSD for X-ray examinations, is being carried out by the Local Health Administration of Udine. All of these three programmes are involved in both aspects of patient exposure optimisation: dose reduction and information content of the radiological image. Important work has been done for many years by the Health Physics Services of some major hospitals: some of them are represented at this meeting and their activities are illustrated in another session.

PROBLEMS RELATED TO PERSONNEL EDUCATION

In the final round table discussion at a meeting held in Rome in November 1983, sponsored by the AIRP, SIBMN and SIRMN, attention was drawn to the problem of the education and training of Italian physicians and radiologists. It should be stressed that at Italian medical faculties, physics is studied during the first year only and that a course on radiology is not obligatory at every university: therefore, X-ray examinations are frequently demanded by physicians with very poor knowledge of the physical processes generating radiological images, and are thus liable to cause useless patient exposure. It is hoped that the institution of higher education courses in radiology and health physics will be useful for personnel education. On the other hand, courses are frequently organised for X-ray operators and a programme of education and training is continuously updated by Local Health Administrations.

CONCLUSIONS

We believe that patient radiation exposure could be optimised, if health programmes were carried out along the following lines.

(i) Physicians and radiologists should be better educated about the physics of the production and effects of X-rays.
(ii) X-ray apparatus should be installed only after QA tests; surveys of performance should be carried out by trained inspectors.
(iii) Programmes to improve image quality in X-ray diagnosis should be encouraged and supported by the relevant local authorities.
(iv) Programmes to evaluate patient doses should be applied over the whole of Italian territory.
(v) The distribution of facilities, apparatus and personnel should correspond to precise directives and planning.
(vi) The public should be informed that X-ray examinations are to be performed only when justified and according to optimised techniques.

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