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# Joint ICTP/IAEA Advanced School on Dosimetry in Diagnostic Radiology and its Clinical Implementation

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## Dosimetry for Mammography

Paola Bregant
*Ospedale Maggiore*
*Trieste*
*Italy*

# Dosimetry for mammography

***Paola Bregant*** *– S.C.Fisica Sanitaria*

*Azienda Ospedaliero-Universitaria "Ospedali Riuniti di Trieste"*

# Quality assurance in mammography screening

Radiographical guidelines

Radiological guidelines

Quality control of the physical and technical aspect

- X-ray generation (x-ray source, Tube voltage, AEC)
- detector performance
- image display evaluation
- image quality
- **dosimetry**

| Tissue or organ | Tissue weighting factors, $w_T$ | |
|---|---|---|
| | ICRP 60 | ICRP 103 |
| Gonads | 0.20 | **0.08** |
| **Breast** | **0.05** | **0.12** |
| Red bone-marrow | 0.12 | 0.12 |
| Liver | 0.05 | **0.04** |
| Colon | 0.12 | 0.12 |
| Bladder | 0.05 | **0.04** |
| Lung | 0.12 | 0.12 |
| Oesophagus | 0.05 | **0.04** |
| Stomach | 0.12 | 0.12 |
| Thyroid | 0.05 | **0.04** |
| Skin | 0.01 | 0.01 |
| Bone surface | 0.01 | 0.01 |
| Salivary glands | / | 0.01 |
| Brain | / | 0.01 |
| Remainder organ or tissue | 0.05 | **0.12** |

# Dosimetric quantities

$K_i$ Incident air kerma

$K_e$ Entrance surface air kerma

$D_G$ Mean glandular dose

**Mean glandular dose is the risk related quantity therefore is the primary quantity of interest**

# Dosimetric quantities

Two different approches:

- Measuremets using phantoms
- Measurements on patients

# References

- **IAEA: Technical reports series n. 457: “Dosimetry in Diagnostic Radiology: an international code of Practice” (2007)**
- European Commission: “European Protocol on dosimetry in Mammography” (1996)
- UK: Survey by Fitzgerald et al (1981)
- Germany: “DGMP Protocol” (1986)
- UK: “IPSM (now IPEM) Protocol” (1994)
- Sweden: “SSI Protocol” (1989)
- USA: “ACR Protocol” (1999)
- IAEA: Qualty Assurance in Screen-Film mammography (2009)

# Phantom used for breast dosimetry

| *Application or protocol* | *Phantom construction* |
|---|---|
| IAEA: Code of Practice | **45 mm PMMA** |
| Europe: “European Protocol” (1996) | 45 mm PMMA |
| UK: Survey by Fitzgerald et al (1981) | 40 mm BR12 |
| Germany: “DGMP Protocol” (1986) | 50 mm PMMA |
| UK: “IPSM (now IPEM) Protocol” (1994) | 40 mm PMMA (up to 2003)<br>45 mm PMMA (from 2005) |
| Sweden: “SSI Protocol” (1989) | 45 mm PMMA |
| USA: “ACR Protocol” (1999) | 44 mm PMMA with 7 mm dental wax layer<br>(containing embedded test objects) |


TOR MAS
TOR MAX
Leeds Test Objects

# Measurements using phantoms

1. Knowledge of the parameters for correct exposure of the phantom ;

2. Determination of incident air kerma;

3. Measurements of HVL;

4. Estimation of the mean glandular dose from the incident air kerma using the appropriate conversion coefficient.

# Determination of tube loading

Phantom on the breast table

Compression device onto the phantom

Cranio-caudal view

Select clinical exposure for standard breast (thickness: 50 mm; glandularity 50% - adipose tissue 50%)

**Target; Filter; kV, mAs**

Depending on the equipment the selection in made automatically, semi-automatically or manually

# Measurements of incident air kerma using a diagnostic dosimeter

Diagnostic dosimeter

suitable ionization chamber and electrometer

semiconductor dosimeter

The reference point of the dosimeter should be positioned at the **mammographic reference point,** i.e. 45 cm above the table, 40 mm from the chest wall edge and centred with respect to the lateral direction.

The compression plate should be in contact with the detector

The incident air kerma should be measured at the relevant tube loading

# Measurements of entrance surface kerma using TLDs

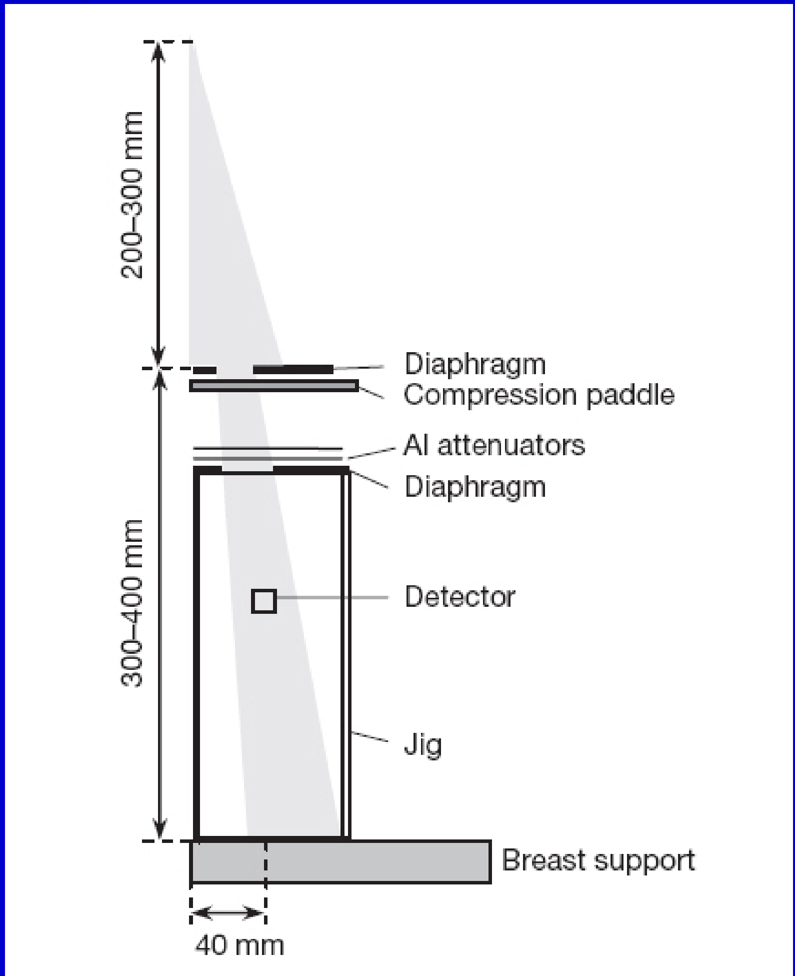
Phantom on the breast table

Sachet containing three TLDs on the surface of the phantom with the centre of the sachet 40 mm from the chest wall edge and centred with respect to the lateral direction

Compression plate down onto the phantom (taking care not to damage TLDs)

Use a further sachet of unexposed TLDs for background reading

# Measurements of HVL




Perform HVL measurements in the presence of the compression plate.

Select the <u>target</u>, the <u>filter</u> and the value for tube <u>voltage</u> and typical <u>tube loading</u> that would be used for the routine clinical examination of the breast being simulated.

# Tabulated values of HVL for selected target/filter combinations at tube voltages in the range 24 – 34 kV

| Tube voltage (kV) | Target/filter combination (mm Al) Mo/Mo | Mo/Rh | Rh/Rh | W/Rh |
|---|---|---|---|---|
| 24 | 0.317 | 0.381 | 0.369 | 0.507 |
| 25 | 0.326 | 0.389 | 0.382 | 0.516 |
| 26 | 0.336 | 0.397 | 0.394 | 0.525 |
| 27 | 0.345 | 0.405 | 0.407 | 0.534 |
| 28 | 0.355 | 0.413 | 0.419 | 0.543 |
| 29 | 0.365 | 0.422 | 0.432 | 0.552 |
| 30 | 0.374 | 0.430 | 0.444 | 0.561 |
| 31 | 0.384 | 0.438 | 0.457 | 0.571 |
| 32 | 0.394 | 0.446 | 0.469 | 0.580 |
| 33 | 0.403 | 0.454 | 0.482 | 0.589 |
| 34 | 0.413 | 0.463 | 0.494 | 0.598 |

* Data provided by Young [8.21].

# Measurements of incident air kerma using a diagnostic dosimeter

The mean diagnostic dosimeter reading M (**at least three readings shall be obtained**) of the incident air kerma at the reference point in used to calculate the incident air kerma $K_i$ for the PMMA phantom using the equation

$$\mathbf{K_i = M \cdot N_{KQo} \cdot k_Q \cdot k_{TP}}$$

| | |
|---|---|
| $N_{KQo}$ | dosimeter calibration coefficient |
| $k_Q$ | factor which corrects for differences in the response of the dosimeter at the calibration quality $Q_o$ and at the quality Q of the clinical X Ray beam |
| $K_{TP}$ | correction factor for Temperature and Pressure |

$$k_{TP} = \left(\frac{273.2 + T}{273.2 + T_0}\right)\left(\frac{P_0}{P}\right)$$

# Measurements of incident air kerma using TLDs

The average background corrected dosimeter reading $M$ of the entrance air kerma at the reference point in used to calculate the incident air kerma $K_i$ for the PMMA phantom using the equation

$$K_i = (M \cdot N_{KQo} \cdot k_Q \cdot k_f) / B$$

| | |
|---|---|
| $N_{KQo}$ | TLD calibration coefficient for the reference radiation quality |
| $k_Q$ | factor which corrects for differences in the response of the dosimeter at the calibration quality $Q_o$ and at the quality $Q$ of the clinical X Ray beam |
| $K_f$ | correction factor for fading of the thermoluminescence signal between irradiation of the dosimeter and its readout |
| B | backscatter factor |

# Values of the backscatter factor, B, for mammographiv beam qualities as a function of HVL

| HVL (mm Al) | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 |
|---|---|---|---|---|---|---|---|---|---|
| *B* | 1.07 | 1.07 | 1.08 | 1.09 | 1.10 | 1.11 | 1.12 | 1.12 | 1.13 |

* Data taken from Ref. [8.2].

*European Commission: "European Protocol on dosimetry in Mammography" (1996)*

# Calculation of mean glandular dose

$$D_g = c_{DG50,\,Ki,PMMA} \cdot s \cdot K_i$$

| HVL (mm Al) | $c_{DG50,Ki,PMMA}$ (mGy/mGy) |
|---|---|
| 0.25 | 0.149 |
| 0.30 | 0.177 |
| 0.35 | 0.202 |
| 0.40 | 0.223 |
| 0.45 | 0.248 |
| 0.50 | 0.276 |
| 0.55 | 0.304 |
| 0.60 | 0.326 |
| 0.65 | 0.349 |

* Data taken from Ref. [8.2].

| Target/filter combination | $s$ factor |
|---|---|
| Mo/Mo | 1.000 |
| Mo/Rh | 1.017 |
| Rh/Rh | 1.061 |
| Rh/Al | 1.044 |
| W/Rh | 1.042 |

* Data taken from Dance et al. [8.20].

Value of s Factor for different mammographic target/filter combinations

Conversion coefficient $_{cDG50,\ Ki,PMMA}$ used to calculate the mean glandular dose to a 50 mm standard breast of 50% glandularity from the incident air kerma for 45 mm PMMA phantom

# Monte Carlo model

Conversion coefficients are dependent on:

**Beam energy**
**Breast thickness**
**Breast composition**

Conversion coefficients can be obtained from measurements using phantoms or Monte Carlo calculations that simulate the X ray source and patient. The latter is the better established approach and all the conversion coefficients presented were obtained from Monte Carlo calculations. However, whichever approach is used, the conversion coefficients will be model dependent and will not correspond exactly to any individual patient.

## Factors which contribute to measurement uncertainty in the determination of mean glandular dose using the 45 mm PMMA mammographic phantom

| Source of uncertainty | Uncertainty ($k = 1$) (%) | | |
|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 |
| Measurement scenario (see Table 8.2) | 6.3 | 3.5 | 2.7 |
| Precision of reading | 1.0[b] | 0.6[c] | 0.6[c] |
| Uncertainty in measurement position[d] | 0.4 | 0.4 | 0.4 |
| Precision of tube loading indication | 1.0 | 1.0 | 1.0 |
| Uncertainty in conversion coefficient due to uncertainty of 3% in HVL measurement | 1.7 | 1.7 | 1.7 |
| Uncertainty in thickness of phantom of 0.5 mm[e] | 1.7 | 1.7 | 1.7 |
| Relative combined standard uncertainty ($k = 1$) | 6.9 | 4.5 | 3.9 |
| **Relative expanded uncertainty ($k = 2$)** | **13.8** | **9.0** | **7.8** |

[a] The data are for the use of a diagnostic dosimeter.
[b] One single reading taken.
[c] Standard deviation of the mean of three readings.
[d] Corresponding to ±2 mm at 600 mm focus to surface distance.
[e] Uncertainty due to effect on phantom attenuation [8.23].

# Measurements on patients

1. For each patient should be recorded:

   **Target / Filter combination, kV, mAs, indicated breast thickness**

2. Incident air kerma is estimated using knowledge of the selected exposure parameter

3. HVL of the X ray set should be measured

4. Mean glandular dose is calculated from the incident air kerma using conversion coefficient

# Selection of patients

The size of a sample of patients should be sufficiently large to avoid large statistical fluctuations (10 ÷ 50 patients).

Selection of the patients should take into account of the anatomical parameter (weight, breast thickness). Depending on the reference:

- mean weight of the sample: 70 kg ± 5 kg
- mean weight of the sample: 60 kg ± 5 kg
- compressed breast is between 40 end 60 thick (mean value (50 ± 5 mm)

*Deviations from the suggested limitations can be made, but it would be prudent exclude those patients whose weights lie outside the 20 kg limit on the required mean weight (the dose for a typical patient can be obtained by interpolation)*

# Measurements of the X ray tube output at the reference point

Measurement of incident air kerma in reference position should be repeated for

**each target / filter combinations in clinical use**

**a representative set of kV and mAs values**

Values for other tube voltage and tube loading may be found by appropriate interpolation.

Calibrated diagnostic dosimeter should be employed (TLDs are not appropriate)

# Measurement of the FPD
# Measurement of the HVL

The tube **f**ocus to breast support **p**late **d**istance (FPD) should be measured

The methodology has just been described.
The HVL value should be estimated for each target/filter combination and for a set of X ray tube voltage which adequately samples kV values selected for clinical examinations.

# Calculations

The incident air kerma for each patient exposure $K_i$ is obtained from the mean diagnostic dosimeter reading M of the incident air kerma at the reference point (at the tube loading selected for the patient) applying the appropriate conversion factors (as described for the measurements with phantom) and using the inverse square law to obtain the proper value at the top of the breast.

$$\left(\frac{d_P - d_{ref}}{d_P - d_B}\right)^2$$

$d_p$= distance from the focus to the top of the breast support platform

$d_{ref}$ = distanza di riferimento (45 mm)

$d_{B}$ = breast thickness

# Mean glandular dose

Conversion coefficient to estimate mean glandular dose from incident air kerma are dependent on the glandularity of each breast. Two approches are possible:

- Assume glandularity of 50%
- Estimate the effective glandularity

$$D_G = c_{D_{G50},K_i} c_{D_{Gg},D_{G50}} s K_i$$

Conversion factor, in mGy/mGy, used to calculate the mean glandular dose to breast of 50% gladularity from incident air kerma

Conversion coefficient for glandularities (g) of 0.1 – 100% in the central region of the breast

## Conversion factor, in mGy/mGy, used to calculate the mean glandular dose to breast of 50% gladularity from incident air kerma

| Breast thickness (mm) | HVL (mm Al) 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 |
|---|---|---|---|---|---|---|---|
| 20 | 0.390 | 0.433 | 0.473 | 0.509 | 0.543 | 0.573 | 0.587 |
| 30 | 0.274 | 0.309 | 0.342 | 0.374 | 0.406 | 0.437 | 0.466 |
| 40 | 0.207 | 0.235 | 0.261 | 0.289 | 0.318 | 0.346 | 0.374 |
| 50 | 0.164 | 0.187 | 0.209 | 0.232 | 0.258 | 0.287 | 0.310 |
| 60 | 0.135 | 0.154 | 0.172 | 0.192 | 0.214 | 0.236 | 0.261 |
| 70 | 0.114 | 0.130 | 0.145 | 0.163 | 0.177 | 0.202 | 0.224 |
| 80 | 0.098 | 0.112 | 0.126 | 0.140 | 0.154 | 0.175 | 0.195 |
| 90 | 0.086 | 0.098 | 0.111 | 0.123 | 0.136 | 0.154 | 0.172 |
| 100 | 0.076 | 0.087 | 0.099 | 0.110 | 0.121 | 0.138 | 0.154 |
| 110 | 0.069 | 0.079 | 0.089 | 0.099 | 0.109 | 0.124 | 0.139 |

* Data taken from Dance et al. [8.20, 8.24].

| HVL | Breast thickness | Breast glandularity (g) (%) | | | | |
|---|---|---|---|---|---|---|
| (mm Al) | (mm) | 0.1 | 25 | 50 | 75 | 100 |
| 0.30 | 20 | 1.130 | 1.059 | 1.000 | 0.938 | 0.885 |
| | 30 | 1.206 | 1.098 | 1.000 | 0.915 | 0.836 |
| | 40 | 1.253 | 1.120 | 1.000 | 0.898 | 0.808 |
| | 50 | 1.282 | 1.127 | 1.000 | 0.886 | 0.794 |
| | 60 | 1.303 | 1.135 | 1.000 | 0.882 | 0.785 |
| | 70 | 1.317 | 1.142 | 1.000 | 0.881 | 0.784 |
| | 80 | 1.325 | 1.143 | 1.000 | 0.879 | 0.780 |
| | 90 | 1.328 | 1.145 | 1.000 | 0.879 | 0.780 |
| | 100 | 1.329 | 1.147 | 1.000 | 0.880 | 0.780 |
| | 110 | 1.328 | 1.143 | 1.000 | 0.879 | 0.779 |
| 0.35 | 20 | 1.123 | 1.058 | 1.000 | 0.943 | 0.891 |
| | 30 | 1.196 | 1.090 | 1.000 | 0.919 | 0.842 |
| | 40 | 1.244 | 1.112 | 1.000 | 0.903 | 0.816 |
| | 50 | 1.272 | 1.121 | 1.000 | 0.890 | 0.801 |
| | 60 | 1.294 | 1.132 | 1.000 | 0.886 | 0.793 |
| | 70 | 1.308 | 1.138 | 1.000 | 0.886 | 0.788 |
| | 80 | 1.312 | 1.140 | 1.000 | 0.884 | 0.786 |
| | 90 | 1.319 | 1.145 | 1.000 | 0.884 | 0.786 |
| | 100 | 1.319 | 1.144 | 1.000 | 0.881 | 0.785 |
| | 110 | 1.322 | 1.142 | 1.000 | 0.882 | 0.784 |
| 0.40 | 20 | 1.111 | 1.054 | 1.000 | 0.949 | 0.900 |
| | 30 | 1.181 | 1.087 | 1.000 | 0.922 | 0.851 |
| | 40 | 1.227 | 1.105 | 1.000 | 0.907 | 0.825 |
| | 50 | 1.258 | 1.120 | 1.000 | 0.899 | 0.810 |
| | 60 | 1.276 | 1.125 | 1.000 | 0.890 | 0.798 |
| | 70 | 1.292 | 1.132 | 1.000 | 0.887 | 0.793 |
| | 80 | 1.302 | 1.136 | 1.000 | 0.885 | 0.790 |
| | 90 | 1.308 | 1.138 | 1.000 | 0.884 | 0.789 |
| | 100 | 1.311 | 1.138 | 1.000 | 0.883 | 0.788 |

Conversion coefficient for glandularities (g) of 0.1 – 100% in the central region of the breast

(values are tabulated for HVL ranging from 0.30 to 0.60 mm Al)

# Determinig glandular content

**Visual evaluation of the mammogram (Wolfe model)**

require the judgement of the radiologist

**Computer aided evaluation (Byng at al.)**

texture models are created to capture the mammographic appearance within the breast area

**Attenuation estimation**

phantoms which simulate different glandular-adipose tissue composition can be used to create a correlation between glandularity and mAs value, for a selected anode/filter and kV value

# Conversion factor, in mGy/mGy, used to calculate the mean glandular dose for individula patient

| Source of uncertainty | Uncertainty ($k = 1$) (%) | | |
|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 |
| Measurement scenario (see Table 8.2) | 6.3 | 3.5 | 2.7 |
| Precision of reading | 1.0[a] | 0.6[b] | 0.6[b] |
| Uncertainty in measurement position[c] | 0.4 | 0.4 | 0.4 |
| Precision of tube loading indication | 1.0 | 1.0 | 1.0 |
| Uncertainty in conversion coefficient due to uncertainty of 3% in HVL measurement | 1.7 | 1.7 | 1.7 |
| Uncertainty in conversion coefficient due to uncertainty in breast thickness of 5 mm[d] | 6.4 | 6.4 | 6.4 |
| Relative combined standard uncertainty ($k = 1$), single patient | 9.3 | 7.6 | 6.4 |
| **Relative expanded uncertainty ($k = 2$), single patient** | **18.5** | **15.3** | **14.6** |

[a] One single reading taken.
[b] Standard deviation of the mean of three readings.
[c] Corresponding to ±2 mm at 600 mm focus to surface distance.
[d] The error includes an inverse square law correction.