APPLICATION NOTE

RTI Electronics

RTI Electronics AB, Sweden **Revision B, November 2005**

How to measure ESAK and average glandular dose correctly with a Barracuda MPD or ionization chamber.

In mammography, the most common quantity to measure is the average glandular dose, AGD, or mean glandular dose, MGD (in USA). AGD is calculated as:

AGD = g • ESAK,

Where the conversion factor g, is a function of HVL and ESAK is the entrance skin exposure. This note describes how the included parameters are measured in a correct way. It also contains some hints about AEC measurements.

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INTRODUCTION

The most common measurements on a mammographic system are conducted to determine the dose to the breast tissue. In Europe the quantity is called average glandular dose, AGD, and in USA mean glandular dose, MGD. To acquire the dose value, parameters as HVL and air kerma at the entrance surface must be measured (ESAK, Entrance Surface Air Kerma, Europe and ESE, Entrance Skin Exposure, USA).

To measure Average Glandular Dose, AGD

A standard method for the procedure of determining AGD (in mGy) is defined by the European Commission[1]. AGD is calculated according to the following equation:

$$AGD = g \cdot ESAK \,, \qquad (1)$$

where g is a conversion factor. AGD is determined by a number of measured or registered parameters such as HVL, tube voltage, tube charge, and breast thickness. See appendix A for an example of AGD determination.

Air Kerma at the entrance surface, ESAK or ESE

The air kerma at the entrance surface (ESAK, Entrance Surface Air Kerma, Europe and ESE, Entrance Skin Exposure, USA) is one of the parameters that is measured for the acquirement of AGD. It must according to the standards mentioned be measured directly after the compression paddle and is a function of the tube voltage and filtration. The compression paddle introduces extra scattered radiation which is important to include. See further in this note for more information on the scatter contribution.

Conversion factors, g_{PB}, g, c and s

The conversion factors are tabulated as a function of HVL value (mm Al) and compressed breast thickness (mm). The factors have throughout the years been revaluated and extended to account for glandularity and beam quality. In Europe, there are two sets of tables, the European protocol[2] and the Euref protocol[3]. In USA the relevant protocols are the MQSA protocol[4] and the ACR protocol[5].

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[1] The method is described in the European Protocol on Dosimetry in Mammography. European Commission, (1996) EUR 16263.

[2] Zoetelief, J., Fitzgerald, M., Leitz, W. and Säbel, M. *European protocol on dosimetry in mammography.* EUR 16263 (Luxemburg: EC) (1996).

[3] van Engen, R., Young, K., Bosmans, H. and Thijssen, M. *Addendum on digital mammography to chapter 3 of the European guidelines for quality assurance in mammography screening*, ver 1.0, EUREF, (2003).

[4] Mammography Quality Standards Acts, MQSA requirements, Mammography Quality Control Manual, p 281-283.

[5] www.acr-research.com

European protocol:

$$AGD = ESAK \cdot g_{PB} \cdot s \qquad (2)$$

Euref protocol:

$$AGD = ESAK \cdot g \cdot c \cdot s \qquad (3)$$

The factors g_{PB} and g converts ESAK to AGD and c corrects for the breast glandularity for the anode/filter combination Mo/Mo. The factor s corrects for the actual anode/filter combination.

The MQSA and ACR protocols:

$$MGD = ESE \cdot \text{Correction Factor}$$

The factors in the US protocols are functions of HVL and tube voltage instead of breast thickness. The factors are only valid for a 4.2 cm compressed breast thickness. Conversion factors for other thicknesses can be found in articles by Dance, Wu *et al*, and by Sobol *et al*.

The filter/anode combination Mo/Mo is most commonly used today. However, the market is growing for other combinations such as Mo/Rh and W/Al. The reason is that the population is becoming larger and the Mo/Mo combination is not optimal for larger breasts which need a higher energy radiation. The filter/anode combination W/Al is both practical and commercial when it has a greater width to suit the digital environment.

INFLUENCING PARAMETERS

Half Value Layer, HVL

The HVL measurement should be performed without any scatter contribution according to a well-collimated prescribed[6] geometry. The MPD has the prescribed geometry built-in and does not measure scattered radiation. This is due to its narrow collimation, the detectors are placed 8.1 mm in from the surface of the MPD top panel. It has a small detector area and registers a smaller angle of the x-ray field. By using the check filter before the measurement the alignment of the detectors can be assured. Read more about the MPD in Appendix D. The built-in geometry is especially useful when HVL measurements are made on some scanning mammography systems. The HVL filter can be placed on the compression paddle without any extra collimation even at close distance to the MPD.

Table 1 shows how important it is to have the correct geometry when doing HVL measurements. In the correct geometry, the Radcal 6M, the PTW 23344 and the Barracuda MPD all measures accurately. The HVL measurement in some scanning mammography units such as Sectra MDM, can not be performed with "good geometry" because of the short distance between the scanning pre-collimator and the breast support. The ionizing chambers that lack the built-in geometry do not measure correctly when the geometry is non-ideal, i.e. no collimation and scattered radiation present. However, the MPD gives stable HVL values

[6] Zoetelief, J., Fitzgerald, M., Leitz, W. and Säbel, M. *European protocol on dosimetry in mammography.* EUR 16263 (Luxemburg: EC) (1996).

[*] Hemdal, B., Herrnsdorf, L., Andersson, I., Bengtsson, G., Heddson, B., Olsson, M. *Average Glandular dose in routine mammography screening with Sectra MicroDose Mammography, MDM.* Radiation Prot. Dosimetry (2005)

thanks to its built-in geometry.

Table 1. The HVL values (in mm Al) showing the geometry dependence of the Radcal 6M, the PTW 23344 and the MPD. The measurements are made on a Sectra MDM unit.

	Good geometry*			Non-ideal geometry*					
Tube potential (kV)	Ionizing chamber Radcal 6M	Ionizing chamber PTW 23344	Solid state detector Barracuda MPD	Ionizing chamber Radcal 6M	Ionizing chamber Radcal 6M, ΔHVL	Ionizing chamber PTW 23344	Ionizing chamber PTW 23344, ΔHVL	Solid state detector Barracuda MPD	Solid state detector Barracuda MPD, ΔHVL
26,4	0,350	0,358	0,351	0,385	0,035	0,396	0,038	0,345	-0,006
29,5	0,408	0,409	0,385	0,436	0,028	0,454	0,045	0,382	-0,003
35,5	0,498	0,498	0,509	0,544	0,046	0,561	0,063	0,500	-0,009

Read more about measurements on the specific case of the Sectra MDM unit in the poster in Appendix F.

FLOW CHART DESCRIBING THE TRANSFORMATION OF THE MPD RAW SIGNAL TO DISPLAYED AIR KERMA VALUE, IN THIS CASE ESAK.

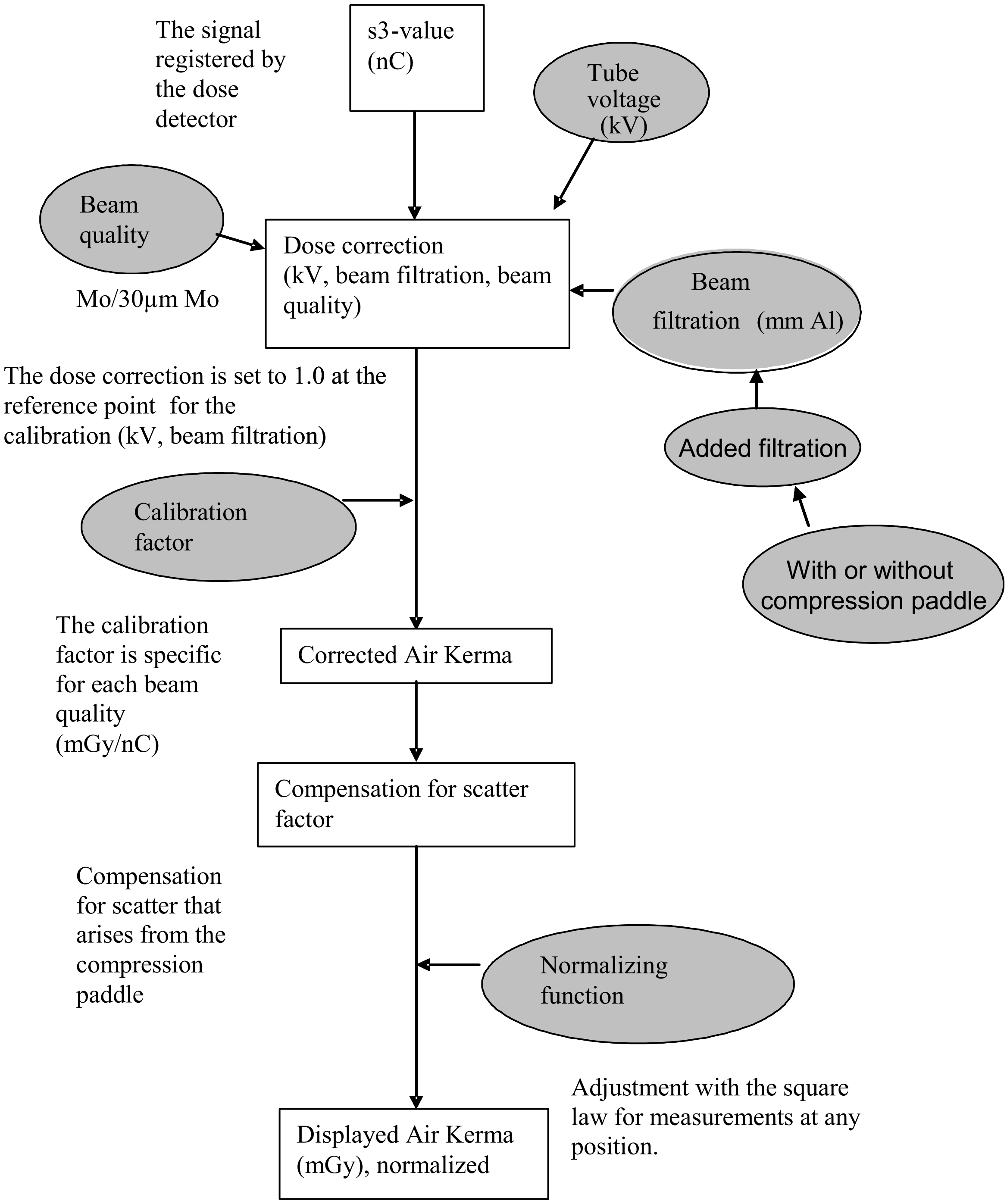

Figure 1. A flow chart of the handling of signal from the MPD to the Barracuda.

FLOW CHART DESCRIBING THE TRANSFORMATION OF THE RAW SIGNAL FROM THE IONIZING CHAMBER TO DISPLAYED AIR KERMA VALUE, IN THIS CASE ESAK.

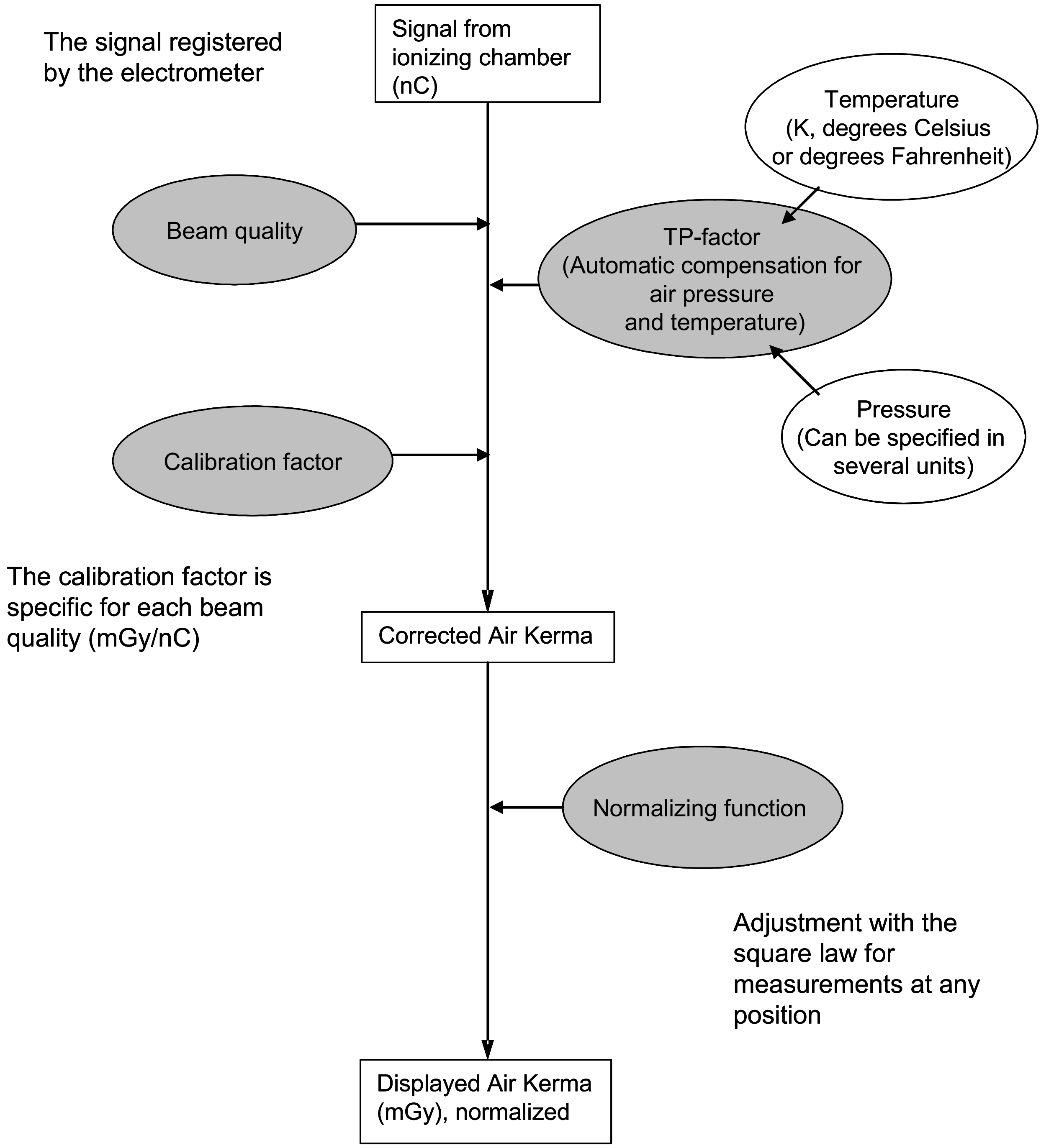

Figure 2. A flow chart of the handling of signal from the ionizing chamber to the Barracuda.

THE EFFECT OF THE SCATTER FACTOR FROM THE COMPRESSION PADDLE

A factor has been introduced which enables the MPD to take the scattered radiation from the compression paddle into consideration and produce measured results as if it was an ionizing chamber, which senses the scattered radiation directly.

When an ionizing chamber is placed directly below the compression paddle, a relatively constant scatter factor of 6 % is found. The factor is typical for ionizing chambers such as Radcal 6M, PTW 23344, and Standard Imaging Magna 1cc in the range of 20-55 kV.

Measurements

Both the MPD and the Standard Imaging Magna 1cc were connected to a Barracuda system for simultaneous measurement of kV, dose, exposure time, HVL, uncorrected output signals and waveforms. The tube voltage is measured with a traceable reference voltage divider. The MPD is placed in the centre of the X-ray field and the Magna is placed to the left, 50 mm from the MPD centre, fig. 4 and 5.

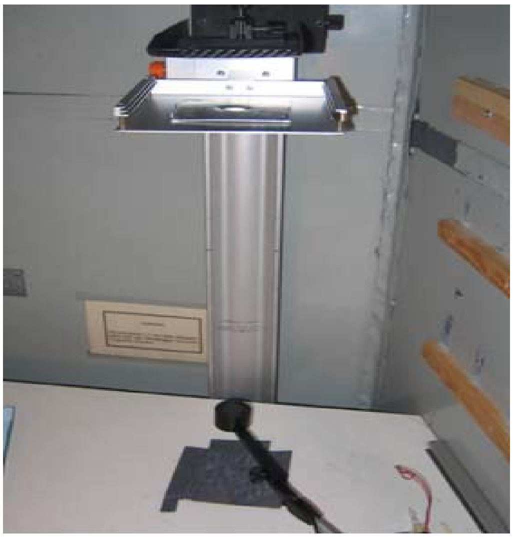

Figure 3. The Standard Imaging Magna 1cc without compression paddle. The Radcal 6M is used as the reference chamber.

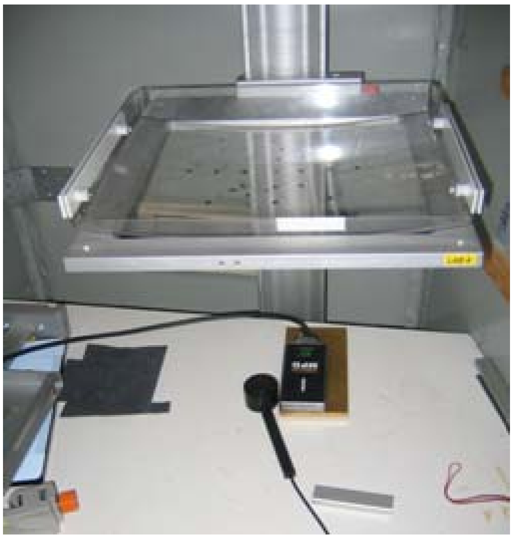

Figure 4. The Barracuda MPD and the Standard Imaging Magna 1cc positioned under the compression paddle (far from the detectors).

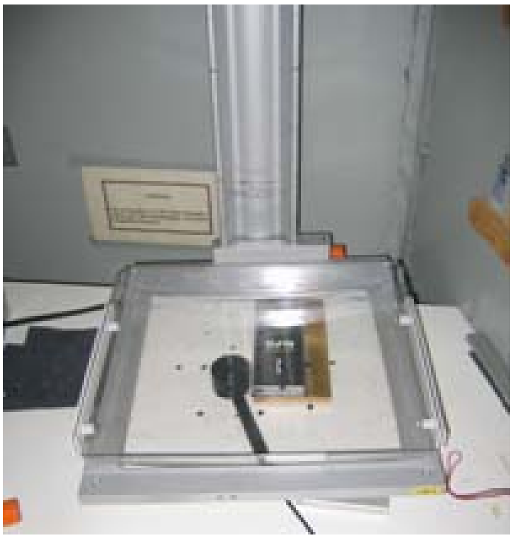

Figure 5. The Barracuda MPD and the Standard Imaging Magna 1cc positioned under the compression paddle (close to the detectors).

The magnitude of the scatter factor is described below. The simultaneous measurements reduce errors as output variation.

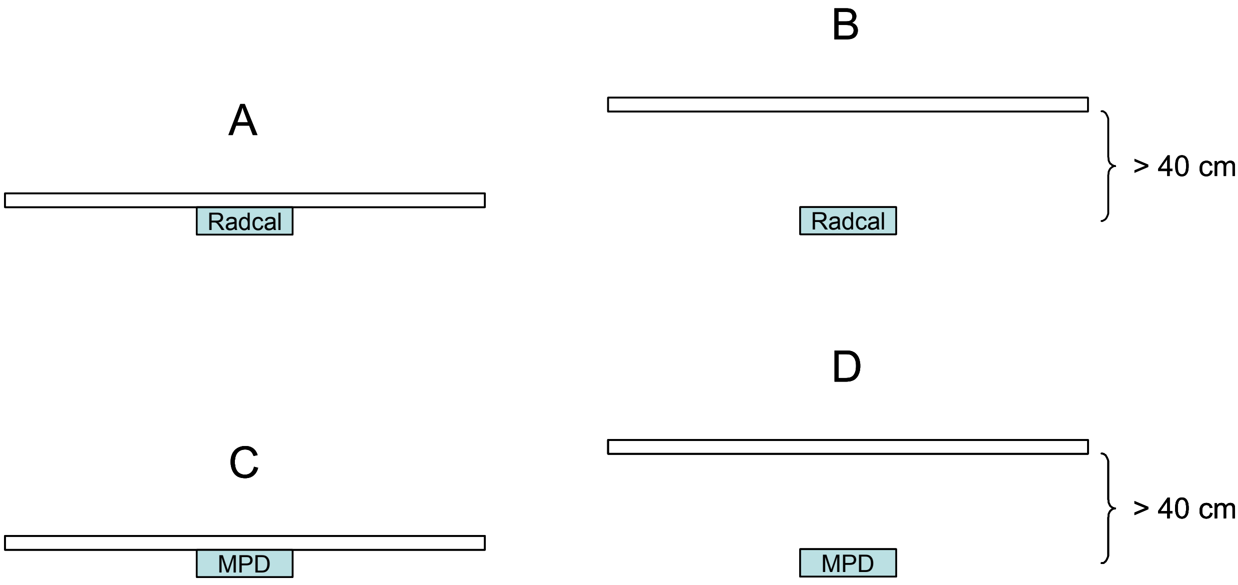

Figure 6. The thin white paddle is the compression paddle and the blue small rectangle symbolizes the detector. All measurements are made on a Sectra MDM.

The magnitude of the scatter from the compression paddle measuring with the ionizing chamber is investigated by taking the ratio between A and B in fig. 6:

$$\frac{A}{B} = 1.06$$

When the compression paddle is close to the ionizing chamber, the measured value is 6% larger than when it is far from the detector. This suggests that the amount of scattered radiation from the compression paddle is in the order of 6 %. The ionizing chamber is replaced with the Barracuda MPD and the ratio between C and D is calculated:

$$\frac{C}{D} = 1.01$$

When measuring with the MPD, the error introduced is of the magnitude 1 % and it is hence negligible.

The MPD is calibrated free in air without compression paddle and furthermore, its narrow geometry prevents it from detecting scattered radiation. If the tube output is measured on a device with a compression paddle, the scattered radiation from the paddle must be taken into account. The correction can easily be added in both the QABrowser (fig. 7) and in oRTIgo.

Figure 7. The scatter factor correction is added when you check the compression paddle box.

When the compression paddle is not used, the scatter factor is automatically set to 1.00.

The publicized tables and protocols for g factors for determination of AGD is most certain calculated without scatter from the compression paddle. If this is the case, the MPD should measure correctly because it does not "see" the scatter contribution. For the first time there is a practical detector with values that can be directly compared with Monte Carlo calculations.

When measuring HVL with the MPD, the criteria for good geometry is fulfilled. The MPD does not have to be moved and the HVL filters can be placed directly on the compression paddle. When measuring with an ionizing chamber, the geometry must be altered to fulfill the geometry requirements.

UNDERSTANDING THE NORMALIZATION FUNCTION

The Barracuda has a normalization function which enables all measurements to be performed at the same position. According to standards, ESAK should be measured 45 mm above the breast support. The QA Browser supports calculation of the dose at a distance. When the normalizing function is used it is indicated with a ”N” at the upper right corner in fig. 8.

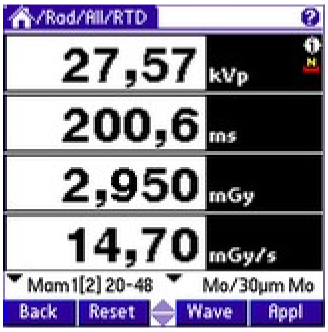

Figure 8. The window displayed in the QABrowser when using both the compression paddle and the normalization function.

A practical consequence of the usage of the normalizing function and scatter factor is that the MPD can be kept at the same position on the breast support all the time when data is collected for determination of the AGD. For an ionizing chamber it is not quite as easy because of the scatter contribution that is not allowed during HVL measurement. The ionizing chamber and/or the compression paddle must be moved to support good geometry and it is not possible to measure at breast support and then use the square law to correct for the distance. See appendix B for an example.

APPENDIX A – An example of AGD determination

To practically determine AGD, the tube voltage and tube current is measured and from these values ESAK is calculated. To be able o find the correct conversion factor (see equations 1, 2 and 3), the HVL is measured. It is important include the scattered radiation and this is done by marking the use of compression paddle (fig. 9). Typically for Mo/Mo beam quality, a 0.10 mm Al equivalent compression paddle (equal to approximately 3 mm plexiglas) is used.

Figure 9. QABrowser display showing the scatter factor correction.

In the QABrowser and oRTIgo software choose the application called “HVL measurement”. You are told which filter to place in the beam path (usually placed on the compression paddle). When the measurement is finished, you can choose graph (at the lower right part of fig. 10a) and the graph in fig. 10b is shown.

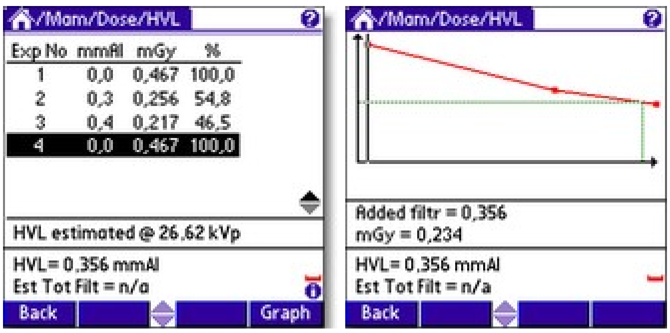

Figure 10a and b. The QABrowser display when performing a HVL measurement. By clicking on “waveform” the right figure appears.

Once you have measured all influencing parameters, AGD is calculated according to equation 1.

APPENDIX B – An example of normalization

The readings from an exposure (fig. 11). Let us assume that the distance from the X-ray tube to the breast support, where the MPD is placed, is 650 mm. Note that the symbol for the compression paddle is visible.

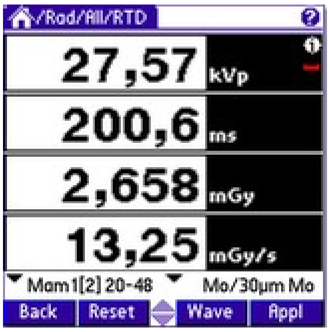

Figure 11. Exposure without the normalization function activated.

The sensitive detector area is situated 6.3 mm from the breast support, which makes the distance from the tube to the detector 643.7 mm (SDD in fig. 12). ESAK is measured 45 mm above the breast support and taking the detector placement into consideration, the distance from tube to the wanted measuring position is then 605 mm (SDD Norm in fig. 12).

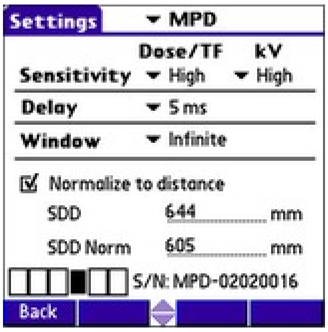

Figure 12. The setting of the normalizing function.

A new measurement with corrected values (fig. 13). Note that when the normalizing function is used it is indicated with a "N". The dose and dose rate values are then normalized to the virtual position, compare with fig. 11.

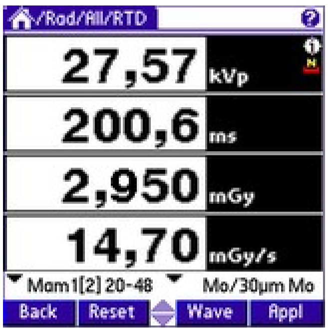

Figure 13. Normalized values at a virtual distance.

APPENDIX C – AEC Measurements

AEC systems are designed and calibrated to terminate the X-ray exposure once a pre-determined amount of radiation has been received at the receptor. A well-designed AEC system is able to modify the required receptor exposure based on exposure conditions (beam energy based on selected kVp, patient thickness based on exposure duration, grid usage, etc.) in order to maintain a consistent output level. Evaluation of the AEC performance thus requires clinical relevant conditions. Most commonly used are procedures that include the usage of acrylic sheets with a clinically relevant thickness range[7]. The MPD will disturb the measurement if it is placed in the X-ray field during the AEC exposure. A way to avoid this is to first perform the measurement with a phantom without the detector. In the manual mode the same output level is set and the detector is placed at the same position as the phantom in order to get the correct readings.

APPENDIX D – The MPD

The MPD design makes it possible to measure small field sizes, less than 3 mm wide, and low output levels, down to approximately 1 µGy/s. Basically the detector package consists of four separate electrometer channels connected to detectors D1, D2, D3 and D4 and a moveable filter package that can change to one of six positions, each a combination of different filters for the detectors. The filter pairs have different thicknesses which are optimized for different ranges of the tube voltage; two (1 and 2) are used for the low mammography energy range 20 to 45 kV, and three filters (3 - 5) are used for the radiography range 35 to 155 kV (35 - 75, 55 - 105, and 80 - 155 kV).

Using the signals S1-S4 (from detectors D1 to D4) the MPD can accurately calculate the corresponding tube voltage. The signal S3 is not affected by the moveable filters and is designed to measure the dose. The detector D4 is placed directly under D3 with additional filter in between. The ratio between S3 and S4 is used to estimate the total filtration for the radiography range. This does not apply to the mammography range, where the total filtration is not estimated and to find the HVL, a normal HVL-measurement has to be made.

It is also easy to check that the detector area is fully and uniformly irradiated. One of the filter positions mentioned above is used as a "check-filter". It has the same filter thicknesses for both detector D1 and D2. When the MPD is perfectly positioned and both detectors have the same radiation, the ratio between the two signals should thus be exactly "1.000". The check-filter makes it possible to place the MPD arbitrarily in the beam as long as it pass the check. If the displayed number is between 0.950 and 1.050 the position is acceptable and a correction factor is applied to correct the position to 1.000. The correction factor is valid until you perform a new check or quit the QABrowser or oRTIgo. The check should be made after repositioning of the detector or after change of target/filter combination when measuring on a mammography unit.

[7] Goldman, L. W. and Yester, M. V. Yester *Specifications, Performance, Evaluations, and quality Assurance of Radiographic and Fluoroscopic Systems in the Digital Era.* American Association of Physicists in Medicine. Medical Physics Monograph No. 30. p 284 (2004)

APPENDIX E – Energy Dependence and Angle Dependence

Energy Dependence

The output is varying with tube voltage. In fig. 14 the ratio is taken between the MPD and the ionizing chamber Standard Imaging Magna 1cc. The ratio remains constant through the different kV, hence the ionizing chambers as well as the MPD shows no energy dependence.

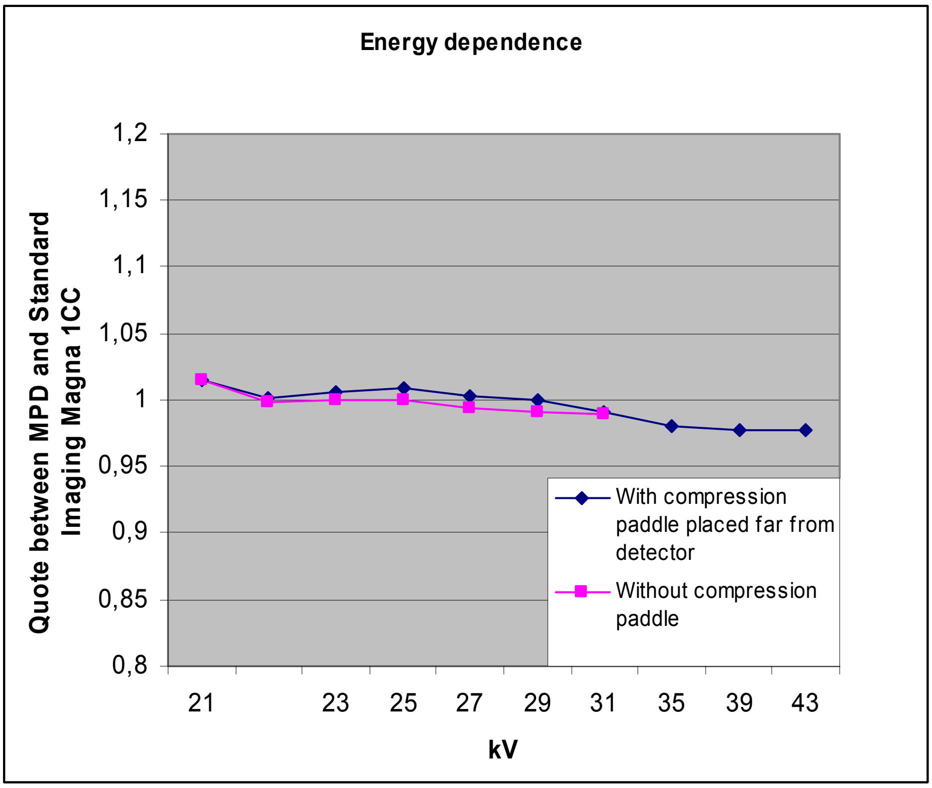

Figure 14. The energy dependence of the MPD compared to Standard Imaging Magna 1cc[8].

Angle Dependence

If a MPD and a ionizing chamber are placed next to each other in the radiation field there is a risk that the output the measured output will differ between them because of inhomogeneous thickness of the compression paddle. The heal effect may also cause errors. This type of measurements are not recommended by RTI. However, if for some reason the MPD has to be tilted during a measurement, the scatter factor can be used to correct for the radiation that does not reach the detector (because the corrections have the same magnitude).

APPENDIX F - Poster

[8] DeWerd, L.A., Micka, J.A., Laird, R.W. and Pearson, D.W. *The effect of spectra on calibration and measurementwith mammography ionization chambers.* Med. Phys. 29, 2649-2654 (2002).

Average glandular dose in routine mammography screening with Sectra MicroDose Mammography, MDM

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Introduction

The Sectra MDM, a scanning multi-slit digital mammography system, uses a direct photon counting technique with a solid-state detector, Si(B). A substantial dose reduction can be expected due to high photon absorption in the detector (90 %) and scatter rejection (97 %) as well as improved energy weighting compared to conventional screen-film and other digital techniques.

The aim of this work was to implement the European protocol[1] and the Euref protocol[2] to estimate average glandular dose levels and their variation by breast thickness[3] for the first Sectra MDM used in routine mammography screening (Helsingborg, Sweden, since September 2003). Earlier studies[4,5] have been performed on prototypes of the Sectra MDM unit.

Material and Methods

The multi-slit pre-collimator (Fig. 1) scans 115 mm above the breast support, making it impossible to follow the procedure prescribed[1] for the HVL measurement (Fig 2a). By using the same type of X-ray tube in a test stand (Fig. 2b), such procedures as well as the Sectra MDM geometry (Fig. 2c) could be simulated.

Figure 1. Tube output measurement at the Sectra MDM. There is a scatter contribution from both the mult-slit pre-collimator and the compression paddle (in contact with the ionisation chamber).

Average Glandular Dose, AGD

The AGD is calculated as:

European protocol[1]:

$AGD = ESAK \cdot g_{PB} \cdot s$

Euref protocol[2]:

$AGD = ESAK \cdot g \cdot c \cdot s$

Entrance Surface Air Kerma, ESAK

ESAK = tube output (mGy/mAs) • tube loading (mAs)

Tube output is measured with the compression paddle in contact with the dosemeter, usually an ionisation chamber (Fig. 1). A sensitive electrometer has to be used due to low signal compared to conventional mammography units. If a well-collimated solid-state detector is used, correction (about 6 %) for scattered radiation is needed (Fig. 3).

Conversion factors g_{PB}, g, c and s

Factors g_{PB} and g that converts ESAK to AGD and c that corrects for breast glandularity are tabulated in the dose protocols as a function of HVL for the anode/filter combination Mo/Mo.

A factor s corrects for the actual anode/filter combination used. However, no factor is provided for the W/Al combination used in this case. An assumption is made that s = 1.05 (range of published values 1.000-1.061). The s-factor is used for both protocols although not specified for the European one.

Half Value Layer, HVL

Non-invasive measurements of the HVL can be performed with a sensitive and well-collimated solid-state detector with simultaneous correction for the energy dependence (MPD-Barracuda, RTI Electronics AB). See Table 1 and Fig. 4.

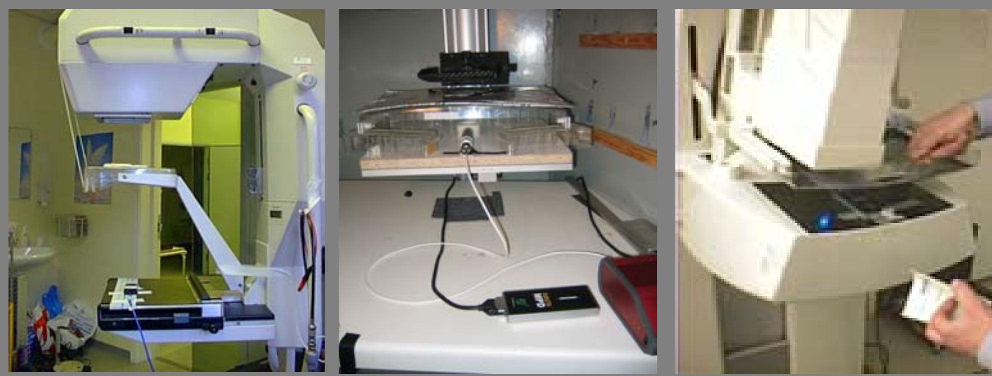

Figure 2. HVL measurements a) with a conventional unit, b) in a test stand with geometry similar to the Sectra MDM and c) at the Sectra MDM.

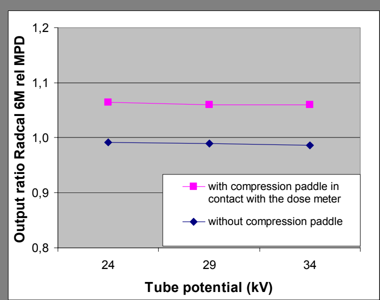

Figure 3. The energy dependence of the Radcal 6M compared to the MPD. When the ionising chamber is placed close to the compression paddle, a contribution of scattered radiation is added (with a magnitude of appr. 6 %).

Results and Conclusions

A method for Sectra MDM absorbed dose measurements according to the European protocol[1] and the Euref protocol[2] has been developed. The average glandular dose was found to be 0.29 mGy for a 50 mm standard breast with 50 % glandularity simulated with 45 mm PMMA (Table 2), which is much lower than for any other mammography unit on the market today. However, for increased accuracy, the existing dose protocols should be revised to account for the anode/filter combination W/Al, the scattered radiation from the multi-slit pre-collimator device and the occurrence of a dose profile in the scanning direction.

Table 1. HVL measurements in a test stand with ionising chamber and MPD in both prescribed[1] and simulated Sectra geometry (without diaphragm). Unlike the ionising chambers, the HVL values measured with the MPD is stable in both geometries.

	Geometry as prescribed[1]			Geometry similar to Sectra MDM		
Tube potential (kV)	Ionising chamber Radcal 6M	Ionising chamber PTW 23344	Solid state detector Barracuda MPD	Ionising chamber Radcal 6M	Ionising chamber PTW 23344	Solid state detector Barracuda MPD
26.4	0.350	0.358	0.351	0.385	0.396	0.345
29.5	0.408	0.409	0.385	0.436	0.454	0.382
35.5	0.498	0.498	0.509	0.544	0.561	0.500

Figure 4. A practical HVL measurement using the Barracuda-MPD.

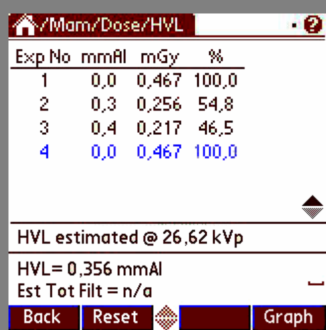

Table 2. ESAK and AGD values determined for the Sectra MDM unit according to the European[1] and Euref[2] dose protocols with a factor s = 1.05 applied in both cases for the AGD calculation.

Dose protocol	Equivalent breast thickness (mm)	Breast glandularity (%)	ESAK (mGy)	AGD (mGy)
Euref	21	97	0.55	0.21
Euref	32	67	0.92	0.26
Euref	45	41	1.22	0.31
European	**50**	**50**	**1.25**	**0.29**
Euref	53	29	1.39	0.32
Euref	60	20	1.89	0.43
Euref	75	9	3.06	0.63
Euref	90	4	3.16	0.54
Euref	103	3	3.26	0.49

Acknowledgements

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1) Zoetelief, J., Fitzgerald, M., Leitz, W. and Säbel, M. *European protocol on dosimetry in mammography.* EUR 16263 (Luxemburg: EC) (1996).
2) van Engen, R., Young, K., Bosmans, H. and Thijssen, M. *Addendum on digital mammography to chapter 3 of the European guidelines for quality assurance in mammography screening*, ver 1.0, EUREF, (2003).
3) Hemdal, B., Herrnsdorf, L., Andersson, I., Bengtsson, G., Heddson, B. and Olsson, M. *Average glandular dose in routine mammography screening using a Sectra MicroDose Mammography unit.* Radiat. Prot. Dosim. Vol. 114, Nos 1-3, pp. 436-443 (2005).
4) Hansson, B., Cederström, B., Danielsson, M. and Åslund, M. *Dose measurements on a scanning multi-slit digital mammography system.* Proc. 6th Int. Workshop on Digital Mammography, Springer Verlag Publishers, Heidelberg, Germany, pp. 17-19 (2003).
5) Herrnsdorf, L. and Åslund, M. *Radiation measurements on the Sectra MicroDose Mammography system using the RTI Barracuda.* Poster presentation (2002).

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