MEAN GLANDULAR DOSE AND CDMAM PHANTOM IMAGE QUALITY FOR SIEMENS MAMMOMAT INSPIRATION

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Abstract: In performing breast screening, a mammography must be capable of imaging microcalcifications with the smallest possible size. However, the mean glandular dose (MGD) should not exceed the recommended limits. To achieve the goal, the utilization of target/filter combination should be adjusted to the thickness of the breast. The evaluation of image quality against variations in target/filter combinations can be done by using CDMAM phantom. There are two methods of CDMAM phantom image quality assessment, and the digital method is considered superior to the manual one. In addition to the evaluation of image quality, MGD received by the phantom was also calculated by multiplying the air kerma value at each thickness with the air kerma conversion factor into MGD. The calculation of MGD follow the equation and conversion factor published by IAEA Human Health Series No. 17 – Quality Assurance Programme for Digital Mammography, then being compared with three other publications. The best image quality for the phantom thickness below 32 mm achieved by using Mo/Mo target/filter combination, and Mo/Rh for the phantom thickness above 45 mm.

***Keywords**: mammography, mean glandular dose, CDMAM phantom, Siemens Mammomat Inspiration*

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I. INTRODUCTION

Mammography is one of the diagnostic modality of producing low-energy X-ray which can detect changes in breast tissue composition. As with other diagnostic modality using X-rays, the small potential risk of cancer growth cannot be avoided. Therefore it is important to evaluate the risk of X-ray dose given during the examination of mammography. American College of Radiology (ACR) recommended the MGD (mean glandular dose) values to 4.5 cm of a compressed breast should not exceed 3 mGy. The dose is the combined dose of imagery Craniocaudal (CC) and Mediolateral Oblique (MLO) for the breast [4].

MGD is obtained by multiplying the measurements of air kerma with some correction factors. There are few studies which focus on determining the method of calculating MGD and the use of the correction factor. In this study, MGD value will be calculated based on four different publications, which are the publication of Wu et al. (1991), Klein et al. (1997), Dance et al. (2000), and the IAEA Human Health Series No. 17-Quality Assurance Programme for Digital Mammography. Performance evaluation of mammography will also be done by using Contrast-Detail Mammography (CDMAM) phantom. CDMAM phantom is considered superior to others because the objects inside it is represented in the shape of dot, which likely the shape of microcalcifications. CDMAM phantom consists of matrix with gold plate in various size and contrast is planted inside. There are two gold plates of the same size in every 205 matrix cells, one of which is located in the central part and the other will randomly be in one of the corner of the cell [13].

CDMAM phantom special configuration could create images which the object contrast and the spatial resolution allowed being analyzed based on exposure method used. The phantom image of digital mammography will be analyzed manually or digitally. Phantom exposures performed by varying the combination of target/filter (W/Rh, Mo/Mo, and Mo/Rh) and the thickness of the phantom (2 cm, 3 cm, 4 cm, 4.5 cm, 5 cm, and 6 cm). This is done in order to determine the combination of target/filter that can produce the best image quality for any thickness variations.

II. MATERIALS AND METHODS

The study was conducted in Dharmais Cancer Hospital, used Siemens Mammomat Inspiration with model / serial number control 3122509, tube type P 40 Mo W, and tube serial number 501635 which produced in July 2011, the maximum condition is 32 kV and 200 mAs. Image view system using digital radiography (DR) and stored as DICOM. Air kerma was measured using Unfors Xi R / F Mammo detectors which is able to measure kVp, dose, dose rate, irradiation time, and HVL. The CDMAM phantom that is used for images evaluation is the output product of Artinis, CDMAM 3.4 with serial number 2031.

Since the mammography shall be ensured in good condition, it performed several test suitability before data collection. The tests performed include;

- Collimation and compression equipment
- Generators and X-ray tube (kVp accuracy, kV reproducibility and output, output linearity, determination of HVL, and AEC)

Data collection was divided into two parts. The first part, aims to acquire phantom images, the exposure is done by using the CDMAM phantom. The second part is done without the use of phantom with the aim to measure the value of the air kerma (Ki) of each thickness using Unfors Xi detector. The exposure parameters which varied in the first and second parts are created equal. The air kerma values measured in the second part will be used to calculate the MGD value for each measurement.

Data collection was performed by varying the thickness of the PMMA phantom used in the first part, which are 2 cm, 3 cm, 4 cm, 4.5 cm, 5 cm, and 6 cm. Based on the publication of the IAEA Human Health Series No. 17 - Quality Assurance Programme for Digital Mammography, the thickness of the PMMA phantom used is equivalent to a compressed breast thickness of 2.1 cm, 3.2 cm, 4.5 cm, 5.3 cm, 6 cm, and 7.5 cm. The compressed breast thickness will be used in the measurement of air kerma (*Ki*) in the second part data collection.

Each thickness exposed three times. First exposure performed using AEC mode while for the rest two performed using manual mode. Target/filter used when using manual mode are differentiated by the AEC mode, while the exposure parameters created equal. Air kerma measured using the Unfors Xi detector, performed using 2 cm thick PMMA phantom. PMMA was applied with the aim to protect the mammography detector so it is not exposed by the direct X-ray from the tube. Unfors Xi detector laying on the top of the PMMA surface, it made such that it is in the middle of the field of radiation with the distance between the chest wall and the center of the detector is 6 cm.

Exposing performed 18 times with varying target/filter combinations and kVp/mAs correspond to the option in AEC mode (Table 1). Unfors Xi detector will measure kVp, dose (air kerma), the dose rate, irradiation time, and HVL. Location of the detector and the phantom does not change for each measurement, and the value of the air kerma at the desired thickness will be calculated using inverse square law, while the HVL value will be relatively the same at each thickness.

Table 1 kVp and mAs settings used for the exposure using manual mode

Phantom thickness (mm)	kVp setting	mAs setting
21	26	36
32	27	50
45	28	80
53	29	80
60	30	125
75	31	180

The image phantom then analyzed with the manual and digital methods. The results will be compared to determine differences in the performance of both. The quality of the image can be seen from the ratio of the number of cells indicated correctly of the overall total of the cell:

$$Observation\ ratio = \frac{Correctly\ indicated\ cells}{Overall\ total\ cells} \times 100\% \qquad (1)$$

Another method of determining image quality is to calculate the value of IQF (Image Quality Figure). IQF of an image represents the quality of the image, the higher the value the better the quality.

Manual method done by identifying the location of gold plates in each column of the cell to the minimum diameter of the contrast that can still be seen. Observer errors in identifying the location of the plate indicates the inability of the observer to see the object contrast of the particular size, or the exposure techniques with exposure parameters that is used produce poor image quality. To anticipate the errors of observation, the observer was asked to keep identified two additional cells (per column) after the cell with the object contrast can still be observed easily.

The equation used to calculate IQF manually is as follows:

$$IQF = \frac{n}{\sum_{i=1}^{n} C_i \times D_{i,min}} \qquad (2)$$

$D_{i,min}$ is the smallest diameter of the gold plates identified correctly in the column C_i. C_i is the thickness of the gold plate, while n is the number of columns that can still be observed correctly. The bigger the IQF indicates the better image quality produced.

There is a difference equation in calculating IQF when evaluated using digital image [12]. Evaluation of the digital method is done by using the following equation:

$$IQF_{inv} = \frac{100}{\sum_{i=1}^{16} C_{i,th} \times D_i} \qquad (3)$$

$C_{i,th}$ is the smallest thickness of gold that still can be evaluated on the column diameter Di. Contrast computed in µm while the diameter in mm. In contrast to the manual evaluation which can only evaluate the available cells in the phantom, digital methods using special software also evaluates the cells that are missing on the top and bottom of the phantom.

The calculation of MGD is done with reference to four journal publications, the publication of Wu *et al.* (1991), Klein *et al.* (1997), Dance *et al.* (2000), and the IAEA Human Health Series No. 17 - Quality Assurance Programme for Digital Mammography. The results of the calculations will be compared to be able to see the difference, the equation used is as follows

Wu *et al.* (1991) ➔ $MGD = X_{ESE} \times D_{gN}$ (4)

Kleint *et al.* (1997) ➔ $MGD = K \cdot g$ (5)

Dance *et al.* (2000) ➔ $MGD = K \cdot g \cdot c \cdot s$ (6)

X_{ESE} is the value of ESAK (entrance surface air kerma) were measured in Roentgens (R), while K is the air kerma in units of mGy. Both are measured on the surface of the phantom without backscatter. D_{gN} is air kerma conversion factor into MGD with units of mGy/R or mrad/R [1]. D_{gN} factor and g conversion factor on Kleint et al. (1997) are both dependent on the quality of the beam, target / filter combination, thickness and composition of the breast [11].

In Dance *et al.* (2000), g factor is specific only for the breast with a composition of 50% glandular and 50% fat and only depends on the thickness and HVL. Furthermore, factor c will convert breast with a different composition, the value depends on the thickness, while s is a correction factor for the combination of target/filter used [2]. Equation by Dance *et* *al.* (2000) also used by the IAEA. Slightly different from Dance *et al.* (2000), the value of *g* and *c* on Human Health Series No. 17 - Quality Assurance Programme for Digital Mammography displayed in the one value of multiplication

III. RESULTS AND DISCUSSION

A. Compliance test result

Some compliance tests that conducted before the data collection was the evaluation of the light beam collimation, compression equipment, generators and X-ray tube, and the AEC system. The compliance tests performed by following the criteria of Perka BAPETEN No. 9 of 2011.

Room light illumination (background) were measured at 62.21 lux, while the average collimation light illuminations of four field area is 299.55 lux. The collimation illumination is obtained by reducing the collimation light illuminations with room light illumination, the amount is 237.34 lux. The maximum difference allowed between the collimation field with the X-ray beam, collimation field with the image receptor, and the X-ray beam with image recertor is equal to 2% of the distance SID. The test results showed that the difference between the three is still below the limit of tolerance.

Voltage accuracy test was performed to see the accuracy of the X-ray voltage generated by the voltage of the panel selected. Average discrepancy of measured detector voltage is equal to 3.23%. The deviation is relatively large but still below the tolerance limit of 6%. The coefficient of variation (COV) obtained for the reproducibility of the voltage is equal to 0.002, while the COV of output reproducibility test obtained is 0.003 with a COV maximum allowed is 0.05. Radiation output generated at the output radiation test is considered quite good because the linearity coefficient obtained is 0.026, while the maximum value that is allowed is 0.1. Therefore, it can be said that the output radiation generated X-ray tube is quite linear. The value of CNR (Contrast to Noise Ratio) on the evaluation system for the AEC phantom thickness of 2 cm, 4 cm and 6 cm respectively are 1.32, 0.98, and 0.74. The thicker the phantom used obtained a smaller CNR value.

B. CDMAM image quality comparison by using manual and digital method

The results of image evaluation is shown in Table 1, Table 2 and Table 3. Although IQF and detection percentage values obtained fluctuated, but it appears that the two methods produce the same trend value. The greater the thickness of the phantom produced the smaller IQF and detection percentage, represents the declining quality of the image.

Because of the difference of equation used to calculate IQF in both methods, then the comparison between two methods can be seen from the percentage of gold plate detected, its value is obtained by using Equation (1). Comparison of detection percentage of manual and digital method for the use of the three target/filter combination can be seen in Figure 1.

Percentage value of the digital method is much higher than the percentage value of the manual method. The difference of the detection percentage of both methods for the three target/filter combinations used is increase with the increase of phantom thickness. With an average value of 42.82 ± 7.19% (W/Rh), 39.45 ± 7.92% (Mo/Mo), and 42.18 ± 5.77% (Mo/Rh), it can be said that the performance evaluation of manual method decrease with the increase of the phantom thickness.

Table 1 Image evaluation for manual and digital methods using W/Rh target/filter

Compressed breast thickness (mm)	IQF		Percentage (%)	
	Manual	Digital	Manual	Digital
21	7.44	155.4	39.5	81.0
32	8.90	156.9	44.4	77.6
45	8.19	134.6	41.0	77.3
53	5.36	185.9	31.2	79.5
60	4.87	132.3	28.3	73.9
75	3.95	131.4	22.9	74.9

Table 2 Image evaluation for manual and digital methods using Mo/Mo target/filter

Compressed breast thickness (mm)	IQF		Percentage (%)	
	Manual	Digital	Manual	Digital
21	12.6	164.8	53.7	82.4
32	8.67	197.5	45.4	82.0
45	8.02	127.3	42.0	75.9
53	5.81	154.6	33.2	74.6
60	5.24	144.5	29.3	75.4
75	3.92	124.1	22.4	72.4

Table 3 Image evaluation for manual and digital methods using Mo/Rh target/filter

Compressed breast thickness (mm)	IQF		Percentage (%)	
	Manual	Digital	Manual	Digital
21	9.38	188.4	45.9	82.0
32	9.10	176.5	45.9	80.7
45	5.84	176.7	34.1	78.5
53	6.29	155.8	35.1	76.8
60	4.69	144.1	27.3	74.6
75	4.63	141.0	26.3	75.1

Evaluation using manual method has some weakness so that the results are no better than digital method. Since there were a lot of images that should be evaluated, then the observer may experience eye fatigue that affects the accuracy of the readings at the end of the observation. In addition, learning effects can arise due to the repeated observation, allowing observer familiar with the pattern of laying gold.

Figure 2 shows CDMAM phantom image with breast equivalent thickness of 21 mm using a Mo/Mo target/filter, while Figure 3 displays the results of the evaluation of the same image using the software. Contrast score detail diagram in Figure 3 shows the number of gold were detected. Red dots on each cells indicates that 2 of 2 gold plates in the cell can be detected. While the pink circle indicates that only one of the gold plates that can be detected. Contrast detail curve obtained by plotting the smallest thickness of the gold plate detected for each column diameter gold plate.

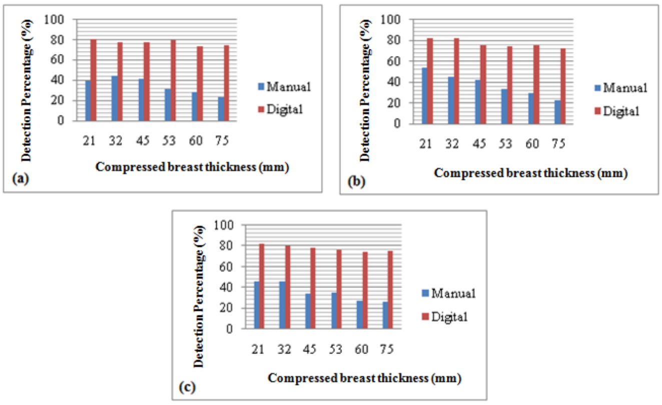

Figure 1 Detection percentage comparison chart of manual and digital method on the use of (a) W/Rh, (b) Mo/Mo, (c) Mo/Rh

Figure 2 The image of 21 mm breast equivalent phantom using Mo/Mo target/filter

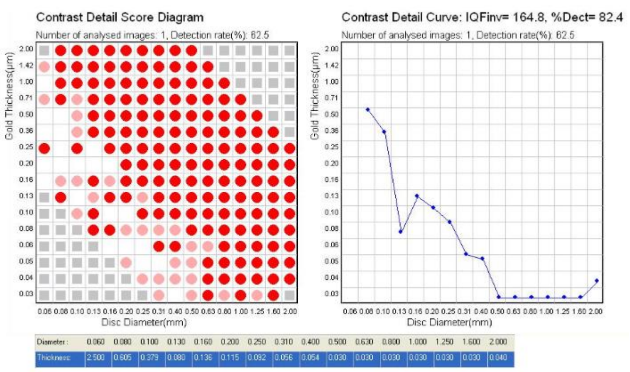

Figure 3 Image evaluation of phantom images in Figure 2 by using software

Evaluation using digital method generate greater detection percentage because computer program detecting image per pixel, so the result is much better and accurate. Manual calculations is inefficient because it spends a lot of time. Variations readings can occur by different observers (inter-reader variability) as well as the reading of the image that is repeated by the same observer (intra-reader variability) [13].

C. MGD comparison based on different MGD determination recommendations

Conversion factor that converts air kerma to MGD determined by interpolation because the exposure parameters given during data collection is not entirely available in the reference publication. HVL values are relatively not constant over the same exposure parameters so that interpolation between the two data should be done.

MGD calculation is done with reference to the publication of IAEA Human Health Series No. 17 - Quality Assurance Programme for Digital Mammography, then the result is used as a benchmark for later comparison with the calculated MGD based on Dance *et al.* (2000), Klein *et al.* (1997), and Wu *et al.* (1991) publications. MGD values were calculated using Equations (4), (5), and (6). Conversion factors contained in the publication of Klein *et al.* (1997) and Wu *et al*. (1991) isn't as complete as the publication of IAEA and Dance *et al.* (2000). As a consequences, there are some exposure parameters that can not be calculated. Just like publication of Wu *et al.* (1991) which does not measure the conversion factor for the use of the target/filter W/Rh, moreover the HVL value is restricted between 0.24 to 0.43 mmAl.

From the graph shown in Figure 4, it appears that the MGD of calculations based on the publication of the IAEA and Dance *et al.* (2000) are not too different. It caused by the publication of the IAEA Human Health Series No. 17 - Quality Assurance Programme for Digital Mammography refers to Dance *et al.* (2000), only the display table are changed so that reading becomes easier. IAEA publications show the conversion factor *g* and *c* in the one table and based on thickness variations of PMMA. For a given thickness of PMMA, the value of equivalent thickness and breast glandularity are always the same, so the breast glandularity has no effect to the conversion factor. Except for glandularity, the value of *g* and *c* are influenced by the same factors, breast thickness and beam HVL, so both of these factors can be displayed in one table.

On Klein *et al.* (1997) and Wu *et al.* (1991), the value of conversion factor is also affected by kVp. However, tube voltage won't cause bigger affect than HVL beam, because the same tube voltage can be generated different HVL values. MGD calculation refers to the publication of the IAEA. Table 4, Table 5 and Table 6 show MGD discrepancy (%) on mammography display, and MGD that obtained by Dance *et al.* (2000), Klein *et al.* (1997), and Wu *et al.* (1991) publication against to MGD that were obtained based on IAEA publication for three variations target / filter combination. The maximum display MGD discrepancy that still allowed is 6%.

Mammography performance in determining MGD when using the W/Rh target/filter is quite good at low thickness (under 45 mm), along with the increased of compressed breast thickness then the discrepancy becomes higher. Even though, the discrepancy at 21 mm is also fairly high, reaching 9.40%.

In contrast to the use of the W/Rh target/filter, when the Mo/Mo and Mo/Rh target/filter is used, the MGD discrepancy of mammography display obtained fairly good on compressed breast thickness above 53 mm. Discrepancy tends to decrease against increase in thickness although the average is still above 6%. Meanwhile, in the use of Mo /Rh target/filter, the discrepancy obtained for 6 and 7.5 cm thickness is below the maximum value, respectively 4% and 5%.

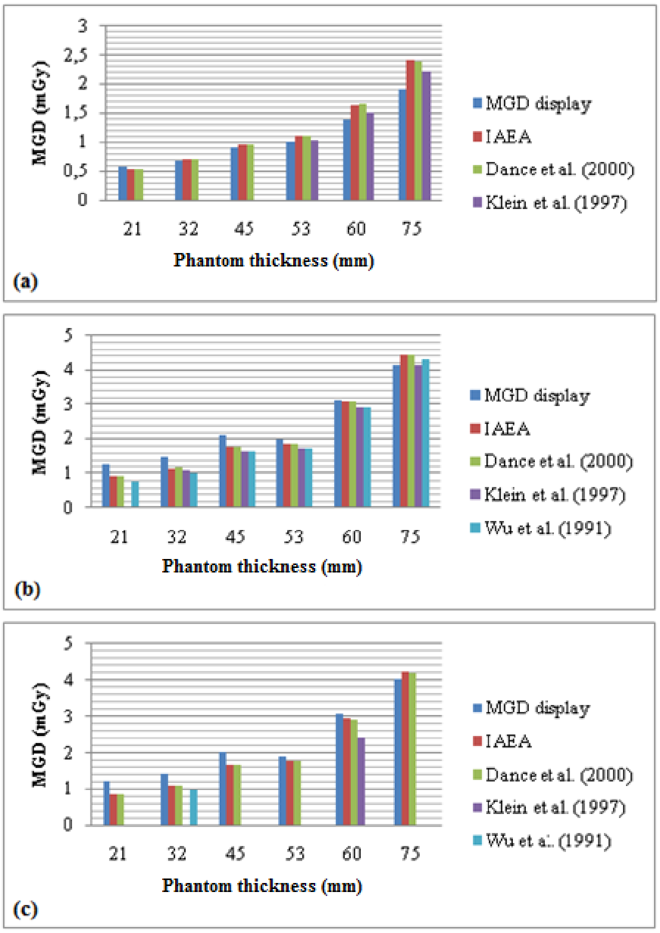

Figure 4 MGD against to the breast thickness using (a) W/Rh, (b) Mo/Mo, (c) Mo/Rh target/filter

Table 4 MGD discrepancies against to MGD calculation (refers to IAEA) using W/Rh target/filter

Breast thickness (mm)	Display	Dance *et al.* (2000)	Klein *et al.* (1997)	Wu *et al.* (1991)
21	9.40%	0.20%	-	-
32	1.13%	0.06%	-	-
45	4.87%	0.16%	-	-
53	8.69%	0.47%	6.89%	-
60	16.03%	1.46%	8.14%	-
75	20.38%	0.32%	8.25%	-

Table 5 MGD discrepancies against to MGD calculation (refers to IAEA) using Mo/Mo target/filter

Breast thickness (mm)	**Display**	**Dance *et al.* (2000)**	**Klein *et al.* (1997)**	**Wu *et al.* (1991)**
21	36.67%	0.30%	-	17.68%
32	28.14%	0.46%	6.54%	11.34%
45	19.59%	0.49%	6.84%	7.77%
53	6.80%	0.64%	6.93%	7.39%
60	1.84%	0.66%	5.44%	4.95%
75	6.88%	0.68%	7.06%	3.43%

Table 6 MGD discrepancies against to MGD calculation (refers to IAEA) using Mo/Rh target/filter

Breast Thickness (mm)	**Display**	**Dance *et al.* (2000)**	**Klein *et al.* (1997)**	**Wu *et al.* (1991)**
21	42.02%	1.11%	-	-
32	31.32%	0.23%	-	10.78%
45	20.24%	0.47%	-	-
53	6.93%	1.28%	-	-
60	4.00%	0.49%	17.32%	-
75	5.00%	1.24%	-	-

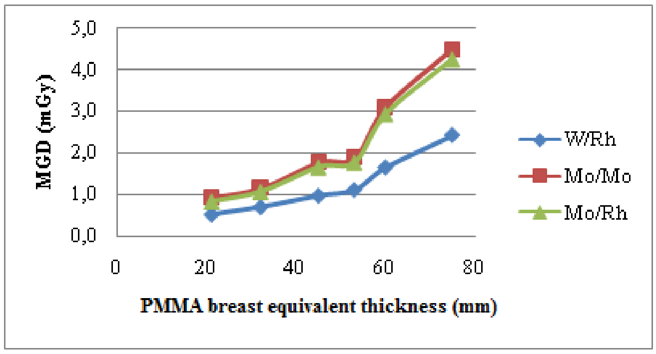

Figure 5 MGD charts against the increase of PMMA breast equivalent thickness for W/Rh, Mo/Mo, and Mo/Rh target/filter

D. MGD and image quality comparison based on target/filter combination variations

Basically, breast thickness will affect the dose received by the tissue. The thicker the compressed breast, the more scattered radiation that occurs, as a consequence the dose becomes larger. Figure 5 is a graph showing the increase in the value of MGD against compressed breast thickness for the three target/filter combinations varied in the study. The results is in accordance with the theory that MGD increases with increase of the compressed breast thickness.

It can can be seen from the graph in Figure 5 the relation between dose and target/filter combination used. The highest dose was obtained when using Mo/Mo target/filter combination, followed by Mo/Rh and W/Rh. Dose differences in using Mo/Mo and Mo/Rh target/filter was not significant with an average of 0.105 ± 0.017 mGy. While when using W/Rh target/filter the MGD is low.

MGD when using the Mo/Mo target/filter is the largest compared to the others because of the K shell X-ray characteristic spectrum of the it produces a high intensity, that is equal to 45 x 106 photons/mm^2. Slightly higher when compared with the use of Mo/Rh target/filter which is 30 x 106 photons/mm^2 [1]. This is affected by the filter used. When using the filter of Rh, the intensity of the Mo K shell X-ray characteristic being more attenuated since at that energy (17.5 keV) the linear attenuation coefficient of Rh is higher than Mo.

The combination of W/Rh target/filter produce low intensity bremsstrahlung spectrum with energy range 10-23 keV. This causes the MGD obtained is lower than the two others targets/filters combinations. Although only bremsstrahlung spectrum formed, but the use of this target/filter combination can produce images good enough because the X-ray energy produced was below 25 keV, there are still attenuation differences between breast glandular and cancerous tissue in this energy. Low energy bremsstrahlung spectrum below 10 keV, which can provide a significant dose to the breast trimmed by the using of the 50 µm Rh filters.

Mo/Mo target/is good for low breast thickness imaging. For phantom thicker than 32 mm, the MGD obtained is under 1.5 mGy with the best image quality is obtained when using Mo/Mo target/filter, detection percentage of digital method is 82.4% for thickness of 21 mm and 82.0% for thickness of 32 mm (Figure 6). The use of Mo/Mo target/filter can produce images with better contrast because the X-ray energy spectrum is low,20 keV

In the low energy X-ray, the attenuation differences between glandular and cancerous tissue becomes larger so that the image will provide high contrast. However, for the larger phantom thickness (≥45 mm) X-ray energy spectrum of the Mo/Mo target/filter does not provide sufficient penetrability, thus requiring the target/filter that produces more energy.

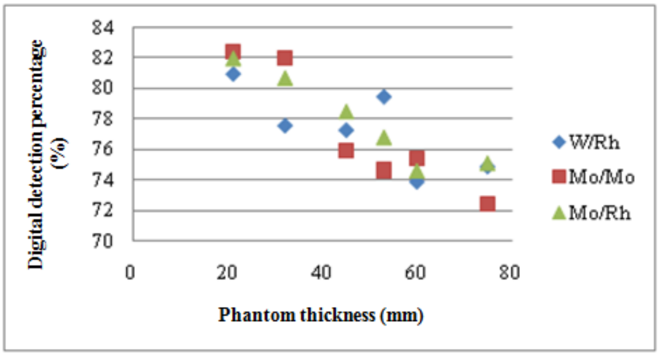

Figure 6 Graph of image quality against the increase of phantom breast equivalent thickness using W/Rh, Mo/Mo, and Mo/Rh target/filter

W/Rh and Mo/Rh target/filter spectrum has greater energy than Mo/Mo, up to 23 keV. The difference in attenuation between the glandular and cancerous tissue in that energy is still large enough so that the contrast between the two can still be distinguished. Among W/Rh and Mo/Rh target/filter, the best image quality produced when using the Mo/Rh target/filter. However, MGD values obtained when using the Mo/Rh target/filter is much larger, MGD when using W/Rh target/filter is 40.0 ± 3.6% of Mo/Rh. The MGD of W/Rh target/filter is lower because the X-ray spectrum that is formed has a lower intensity.

Image quality for phantom ≥45 mm when using W/Rh target/filter is not too good because the shape of X-ray spectrum is generated bremsstrahlung. Bremsstrahlung spectrum is less well when used for diagnostic because the spectrum form polienergetik that will reduce the contrast.

IV. CONCLUSION

From these study obtained some conclusions:

1. X-ray mammography is in standard conditions according to the rules of Perka BAPETEN No. 9 of 2011.
2. The results of digital evaluation of CDMAM image is better than the manual one.
3. MGD values were calculated in this study (based on IAEA) is in accordance with the publication of Dance *et al.* (2000) with a maximum discrepancy of 1.46%, its value is less than 2%, then it said being at good compliance.
4. For thickness below 32 mm, the best image quality is obtained when using Mo/Mo target/filter combination, meanwhile the best target/filter combination for the thickness above 45 mm is Mo/Rh.

REFERENCES

[1] Bushberg Jerrold T, Seibert J. Anthony, Leidholdt Jr Edwin M, Boone John M. *The Essential Physics of Medical Imaging – Second Edition.* 2002. University of California, Davis, Saeramento, California. Lippincott Williams & Wilkins.

[2] D. R. Dance, C. L. Skinner, K. C. Young, J.R. Beckett, C. J. Kotre. *Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protokol.* Phys. Med. Biol. 45 (2000) 3225-3240.

[3] IAEA (2011) Human Health Series No. 17. *Quality Assurance Programme for Digital Mammography.*

[4] L. D. Hartley, B. J. Cobb, D. E. Hutchinson. *Estimating mean glandular dose using proprietary mammography phantoms.* Applied Radiation and Isotopes (1999) 205-213.

[5] R. Klein, H. Aichingert, J. Dierkert. *Determination of Average Glandular Dose with Modern Mammography Units for Two Large Group Patient.* Phys. Med. Biol. 42 (1997) 651 – 671.

[6] R. van der Burght, M. Thijssen, R. Bijerk. *Manual Contrast-detail Phantom CDMAM 3.4.* 2013. Department of Radiology, Radboud University Nijmegen, Netherlands.

[7] R. van Engen. *Supplement to the European Guidlines fourth edition.* 2011. Nijmegen, The Netherlands.