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COMPARISON BETWEEN DIFFERENT KINDS OF ADDITIONAL FILTRATION IN STANDARDS X-RAY BEAMS, MAMMOGRAPHY LEVEL

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ABSTRACT

In this work has been made a comparison between different materials used as filtration in standards X-ray beams, mammography level. For this, was analyzed the parameters that give the radiation spectrum, such as tube voltage and current, additional filtration and half-value layer. For the additional filtration have been used Molybdenum (Mo) and Aluminum (Al), in an X-ray system with a tube of Tungsten (W) target. Because of the difficulty to establish mammography qualities in a standard X-ray system, given the limitations created by the IEC 61267, it is necessary to create a procedure based on different reports, presented by different organizations, such as the International Atomic Energy Agency and the Physikalisch-Technischen Bundesanstalt (PTB). The last one presents some results obtained with an X-ray tube with an anode of W. The IEC 61267 presents a fixed filtration of 0.03 mm of Mo, for a tube with an anode of this same material. In this work was determined an additional filtration of Mo that could simulate the specter emitted by an anode of this material, using the HVL as parameter. For the filtration of Al, it was followed the data presented by the PTB. The additional filtration has been determined using the same parameter.

1. INTRODUCTION

One of the greatest difficulties in the implementation of standards X-ray beams, mammography level, in a radiation system with Tungsten (W) target, is to know which additional filtration must be used. The International Electrotechnical Commission, in its publication IEC 61267[1], is very restrictive about this. It fixed three parameters for the establishment of mammography qualities: emitting target of Molybdenum, X-ray tube voltage with a percentage ripple of not more than 4% and a total filtration of (0.032 $\pm$ 0.002)mm Molybdenum (Mo) in the X-ray source assembly. The Half-Value Layer (HVL) values are also fixed. The HVL gives the energy of the radiation, and that is why it cannot be changed. However, the International Atomic Energy Agency (IAEA), in the Technical Reports Series Nº 457[2] (TRS-457), shows the possibility of use a system with W target, with an additional filtration of Mo, but it does not specify a method to obtain it, in the case of mammography beams. The Physikalisch-Technischen Bundesanstalt (PTB), in its website[3], presents some radiation qualities with different materials for the anode (W, Mo and Rhodium (Rh)), and different filtrations (Mo, Rh and Aluminum (Al)), with different thickness, in systems used for calibration of instruments in standards beams, mammography level.
The qualities in mammography are RQR-M 1, RQR-M 2, RQR-M 3 and RQR-M 4 (X-ray tube voltage of 25 kV, 28 kV, 30 kV and 35 kV, respectively).
There is not an agreement of what method must be used, or what the best is. Because of the fact that the IEC is so restrictive about this, it is necessary to follow other references, in order to find the better solution, or at least, the one that could solve this problem in the best way.

For the filtration of Mo, it was followed the recommendations given by the IEC, that provides a fixed additional filtration (0.03mm of Mo) and HVL, and a tube with anode of Mo. In this work was determined which filtration, beyond that given by the IEC, must be used in the beam to simulate an anode of Mo. The objective was to reach the HVL given by the IEC.
In the case of the filtration of Al, the reference was the PTB. The HVL has been fixed, and the additional filtration has been determined, using a method similar to that presented by the TRS-457.
With these results, was possible to compare the materials used, and determine how they should be used in a calibration system, mammography level.

2. MATERIALS AND METHOD

2.1 – Materials

The qualities were established in one X-ray system Pantak Seifert (from 25 to 35 kV). The reference ionization chamber is a Radcal, model 10x5-6M, with volume of 6 cm^3 coupled to a Radcal electrometer, model 9015. All aluminum and molybdenum filters used are f 99.9% of purity.

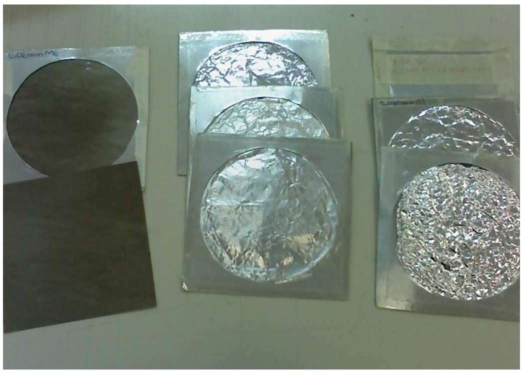

Figure 1: Filters used in this study. Molybdenum (left) and Aluminum.

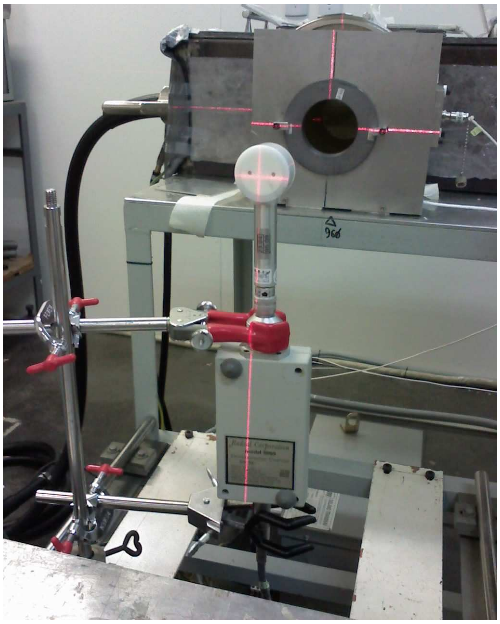

Figure 2: Experimental apparatus

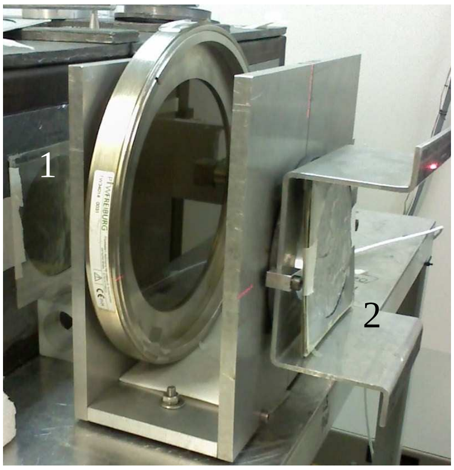

Figure 3: Additional filtration of Mo (1) and the HVL (2)

2.2 – Methods

The first step in this work was to determine the amount of additional filtration in each case (filters of Mo and Al). To do that, the TRS-457 recommends a procedure, to be used to establish the RQR qualities (non attenuated qualities) in the range of conventional diagnostic radiology, from 50 to 150 kV. In this work it was used this procedure in the range of mammography level. This procedure, initially recommended by the IEC 61267 [1] consists in make some measurements and plots the attenuation curve for this quality, using a linear scale on the abscissa for the attenuation layer thickness and a logarithmic scale on the ordinate for the attenuation factor. Then, prepare a rectangular template, the height and width of which, both in the respective units of the diagram, are given by a factor of four and by the first HVL of the standard radiation quality to be realized multiplied by $(1 + 1/h)$, respectively, where h is the homogeneity coefficient of the standard radiation quality (see an example at the figure 4). To obtain the additional filtration, the edges of the template must be parallel to the axes of the diagram, and the points 1, 2 and 3 must be aligned with the attenuation curve. The difference between the position of the left edge of the template and the ordinate gives the amount of additional filtration required to establish the radiation quality RQR. However, this procedure is only for qualities of diagnostic radiology, and not for mammography qualities. The IEC 61267 doesn't even give the second HVL, nor the homogeneity coefficient, so it is not possible to draw the second part of the rectangle. It was necessary to make an adaptation. In most cases, it is only possible to align the points 1 and 2 that are formed using only the first HVL. With the values of HVL given by the IEC and the PTB[3] was possible to draw the first part of the rectangle, as shown in the figure 5, and obtain the needed additional filtration.

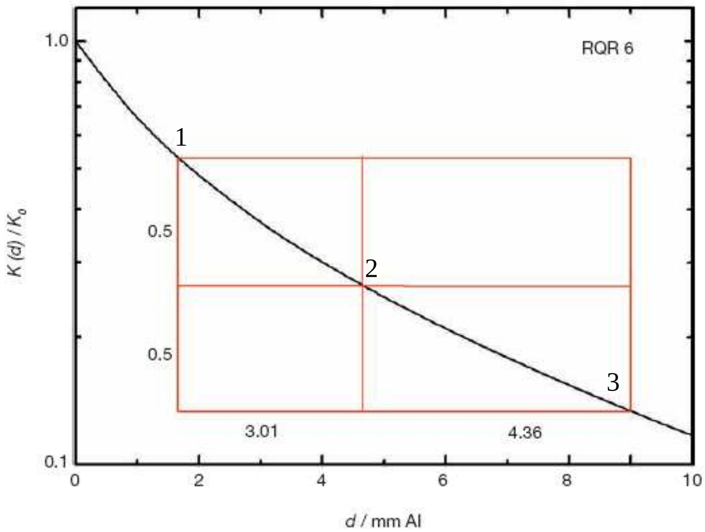

Figure 4: Example of the attenuation curve expressed as the ratio of the air kerma, K(d), behind a filtration of thickness, d, to the air kerma, K_0, of the unattenuated beam. (Withdrawal from the TRS-457, page 72)

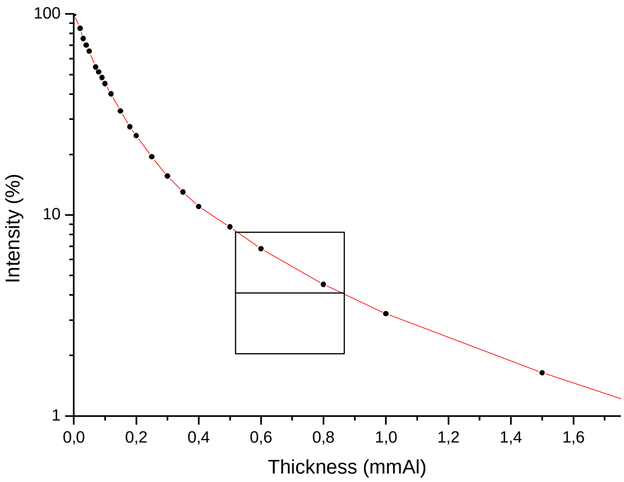

Figure 5: Attenuation curve for RQR-M 1, based on the TRS-457

From the attenuation curve in the figure 5, it was possible to determine the additional filtration about 0.5 mmAl. To obtain the exact value it was required to make a "fine-adjusting": the HVL was fixed and the additional filtration was varied, until the relation attenuated beam/unattenuated beam be between 0.485 and 0.515. This method is applicable only with the filtration of Al. The ionization chamber was positioned at 100 cm from the X-ray focus. The RQRM qualities are characterized as RQR-M 1, RQR-M 2, RQR-M 3 and RQR-M 4. The tube voltages for each one were, respectively, 25 kV, 28 kV, 30 kV and 35 kV. To RQA-M qualities it is added a filtration of 2 mm of aluminum.

For the determination of the Mo filtration was necessary to use a different method, due to the fact that the attenuation curve in figure 5 is based in the thickness in mmAl. To compare these two filtrations were adopted two procedures. The first one was to find the thickness of Mo was enough to produce the same HVL as recommended by the IEC 61267, which uses (0.032 ± 0.002) mmMo in one X rays system with Mo target. According to Guerra[4] it is necessary to add 0.06 mm of Mo to simulate the spectrum of a Mo target. Different thicknesses of Mo have been tested, changing the amount of filters, in order to reach the HVL given by the IEC (see table 1), with the maximum variation of ± 0.02 mmAl.

Table 1: Characterization of standard radiation qualities RQR-M 1 to RQR-M 4 (according to IEC 61267)[1]

Standard Radiation Quality Characterization	X-ray tube voltage (nominal value) kV	Nominal first Half-Value Layer in mm of aluminum
RQR-M 1	25	0.28
RQR-M 2	28	0.31
RQR-M 3	30	0.33
RQR-M 4	35	0.36

The second procedure used was the determination of the additional filtration of Aluminum to reproduce these same values of HVL, without the filtration of Mo. For this, it was used the attenuation curves shown above, for each one of the mammography qualities. For the data given by the PTB (see table 2), the same procedure has been used, obtaining the filtration of Al from the attenuation curve and making the “fine-adjusting”, with the fixed HVL values, for each radiation quality.

Table 2: Mammography qualities based on W-anode and Al-filtration (W Al), established at the PTB[3]

PTB code	Tube Voltage	Total filtration	1^{st} HVL	mean energy (fluence)	mean energy (air kerma)	air kerma rate 1m, 10 mA
	kV	mmAl	mmAl	keV	keV	mGy/s
WAV 20	20	0.5	0.26	15.2	14.3	0.16
WAV 25	25	0.5	0.35	17.7	16.1	0.34
WAV 28	28	0.5	0.40	19.1	17	0.46
WAV 30	30	0.5	0.43	19.9	17.5	0.54
WAV 35	35	0.5	0.51	22	18.7	0.75
WAV 40	40	0.5	0.58	23.9	19.8	0.96
WAV 50	50	0.5	0.70	27.6	21.7	1.37

For the Mo filtration, the data given by the PTB are shown in the table 3.

Table 3: Mammography qualities based on W-anode and Mo-filtration established at the PTB[3]

PTB code	Tube Voltage	Total filtration		1st HVL	mean energy (fluence)	mean energy (air kerma)	air kerma rate 1m, 10 mA
	kV	mmMo	mmAl	mmAl	keV	keV	mGy/s
WMV 20	20	0.06		0.31	15.8	15.1	0.07
WMV 25	25	0.06		0.36	16.8	15.9	0.14
WMV 28	28	0.06		0.37	17.2	16.2	0.18
WMV 30	30	0.06		0.38	17.7	16.4	0.20
WMV 35	35	0.06		0.41	19.6	17.1	0.26
WMV 40	40	0.06		0.45	22.3	18.1	0.33
WMV 50	50	0.06		0.56	28.4	20.7	0.46

Following the code used by the PTB, it were only analyzed the qualities WAV25, 28, 30, 35, and WMV 25, 28, 30 and 35. The results are shown below.

3. RESULTS

3.1 – IEC based data

The table 4 shows the results obtained varying the filtration of Al and making the measurements with the reference mammography ionization chamber coupled to its electrometer.

Table 4: Values of intensity obtained from measures made in RQR-M 1, using a filtration of Al.

Filtration (± 0.005 mmAl)	Intensity (%)	Measure (uGy/s)
--	100	5011.8 (±0.06%)
0.020	84.99	4259.6 (±0.07%)
0.030	75.40	3779 (±0.05%)
0.040	69.92	3504 (±0.10%)
0.050	65.27	3271.4 (±0.09%)
0.070	54.47	2729.8 (±0.07%)
0.080	51.52	2582 (±0.09%)
0.090	48.30	2420.8 (±0.08%)
0.100	45.07	2259 (±0.10%)
0.120	40.05	2007.4 (±0.11%)
0.150	32.85	1646.2 (±0.17%)
0.180	27.43	1374.6 (±0.15%)

Filtration (± 0.005 mmAl)	Intensity (%)	Measure (uGy/s)
0.200	24.77	1241.4 (±0.17%)
0.250	19.45	974.56 (±0.16%)
0.300	15.62	782.8 (±0.17%)
0.350	13.01	652.18 (±0.14%)
0.400	11.01	551.92 (±0.16%)
0.500	8.71	436.7 (±0.22%)
0.600	6.79	340.46 (±0.19%)
0.800	4.52	226.32 (±0.11%)
1.000	3.23	161.96 (±0.12%)
1.500	1.64	82.38 (±0.69%)

With the values of this table, the attenuation curve shown in figure 6 has been made.
The rectangle present in this figure has been made using the HVL given by the IEC 61267.

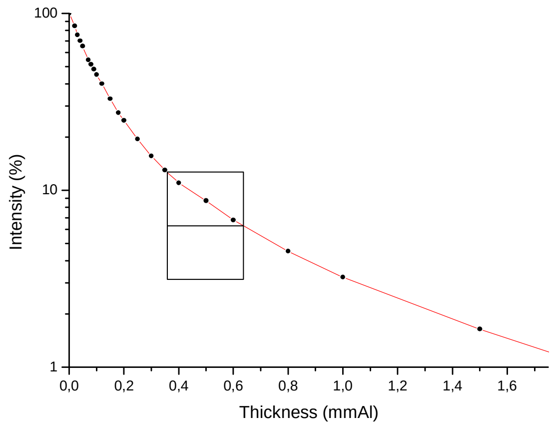

Figure 6: Attenuation curve for RQR-M 1, using the HVL value given by the IEC 61267[1]

Using this procedure for all qualities, and making the “fine-adjusting”, it was obtained the results shown in table 5.

Table 5: Additional filtration, in mmAl, using the HVL given by the IEC

Quality	Additional filtration (mmAl)	HVL given by IEC	Reduction (%)[a]
RQR-M 1	0.400 ± 0.005	0.28 mmAl	49.76 ± 0.13
RQR-M 2	0.430 ± 0.005	0.31 mmAl	50.31 ± 0.09
RQR-M 3	0.420 ± 0.005	0.33 mmAl	49.65 ± 0.07
RQR-M 4	0.400 ± 0.005	0.36 mmAl	49.74 ± 0.07

[a]ratio between measurements with and without the HVL

The additional filtration of Al shown in the table above is sufficient to reach the HVL given by the IEC, which means that the energy of this X-ray system is the same as that of the IEC. For the Mo filtration the procedure was a little different. Since it was not possible to use the method given in the TRS-457, because the filtration was not Al, it was necessary an adaptation. In this case, it was tested different thickness of Mo, trying to reach the HVL given by the IEC. The thickness of Mo was varied in 0.01mmMo until to obtain the closest value of HVL given by the IEC. The results are shown in table 6.

Table 6: Filtration of Mo obtained fixing the HVL from the IEC

Quality	Filtration (mmMo)	HVL obtained (mmAl)	HVL IEC 61267
RQR-M 1	0.050 $\pm$ 0.005	0.295 $\pm$ 0.005	0.28 mmAl
RQR-M 2	0.060 $\pm$ 0.005	0.330 $\pm$ 0.005	0.31 mmAl
RQR-M 3	0.060 $\pm$ 0.005	0.350 $\pm$ 0.005	0.33 mmAl
RQR-M 4	0.060 $\pm$ 0.005	0.379 $\pm$ 0.005	0.36 mmAl

It is important to realize that the HVL values obtained are within the maximum variation given by the IEC, of $\pm$ 0.02 mmAl. This indicates that these filtrations are enough to reach the energy recommended by the IEC.

3.2 – PTB based data

The method given in the TRS-457 has been also used here. The same attenuation curve presented in the figure 5 was obtained, with the values of the table 4. The difference here is the width of the rectangle, which was made using the HVL given by the PTB. The curve for this situation is shown in the figure 7.

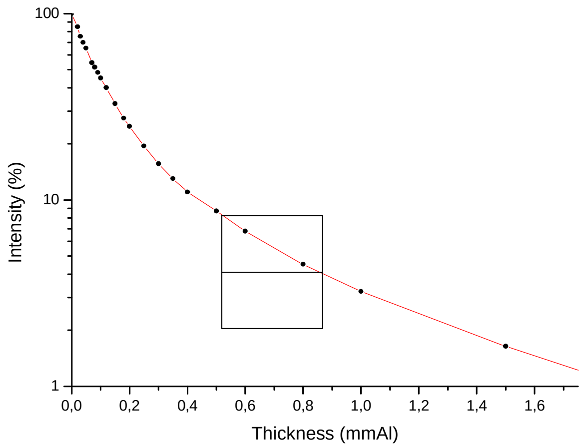

Figure 7: Attenuation curve for RQR-M 1, using the HVL value given by PTB

Using this procedure for all qualities, and making the “fine-adjusting”, it was obtained the results shown in table 7.

Table 7: Additional filtration, in mmAl, using the HVL given by PTB

Quality	Additional filtration (mmAl)	HVL given by PTB (mmAl)	Reduction (%)[a]
RQR-M 1	0.472 ± 0.005	0.35	49.95 ± 0.18
RQR-M 2	0.460 ± 0.005	0.40	50,06 ± 0.12
RQR-M 3	0.450 ± 0.005	0.43	49.94 ± 0.07
RQR-M 4	0.400 ± 0.005	0.51	50.10 ± 0.11

[a]ratio between measurements with and without the HVL

The additional filtration obtained in this case has been enough to reach the HVL given by the PTB. Finding an HVL that is close to that given by a standard laboratory indicates that the secondary laboratory is able to perform dosimeters calibration, since the effective energy is almost the same.

For the Mo, it was made the same analysis. The HVL has been fixed and the additional filtration varied. The results are shown in the table 8.

Table 8: Filtration of Mo obtained fixing the HVL from the PTB

Quality	Filtration (mmMo)	HVL obtained (mmAl)	HVL PTB
RQR-M 1	0.060 ± 0.005	0.345 ± 0.005	0.36 mmAl
RQR-M 2	0.060 ± 0.005	0.357 ± 0.005	0.37 mmAl
RQR-M 3	0.060 ± 0.005	0.366 ± 0.005	0.38 mmAl
RQR-M 4	0.060 ± 0.005	0.396 ± 0.005	0.41 mmAl

As well as in the case of IEC, the HVL found here is within the maximum variation of ± 0.02 mmAl. As previously, the filtrations found here are enough to reach the energy recommended by the IEC.

4. CONCLUSIONS

The results showed that both filtrations can be used to establish mammography radiation qualities in a standard X-ray system. Considering that the HVL gives the energy of the X-ray, and that the TRS-457 states that this value must be fixed, the system used is able to receive these qualities. It is also possible to use the IEC as reference, even if an X-ray tube with Mo target is not available. Considering that the IEC fixes a 0.032 mmMo as additional filtration, the results presented in table 6 show that, for RQR-M 1, 0.02 mmMo is enough to simulate a Mo target and for the other qualities, 0.03 mmMo. In the absence of this material, Al can be used to implement these qualities, since the beam attenuation, when used the HVL given by the references together with the additional filtration found, is within the interval of 0.485-0.515, given by the TRS-457. The sequence in this study is to compare the spectra from both qualities using a spectrometer.

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