



# Evaluation of a Digital Mammography System with the MAM-162 phantom

Castillo<sup>a</sup>, A.; Roas Zúniga<sup>a</sup>, R.A.

*<sup>a</sup>Universidad Nacional Autónoma de Nicaragua, Managua*

*acastillos@unan.edu.ni*

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## ABSTRACT

Quality controls are performed to verify the performance status of X-ray equipment in relation to image quality and patient dose. Originally, the Laboratory of Radiation Physics and Metrology (LAF-RAM) in Nicaragua had only one phantom to evaluate mammography image quality subjectively; however, under a cooperation project with the International Atomic Energy Agency (IAEA), the MAM-162 phantom was acquired for the evaluation of physical image quality. In this work a CR type digital mammography system was evaluated using the MAM-162 phantom with adaptation to a single quality control protocol based on international standards such as the German Institute for Standardization (DIN) DIN 6868-162:2013-06, the IAEA technical document TECDOC protocol No. 1958 and the European Federation of Organizations for Medical Physics (EFOMP) mammo protocol. Among the main tests performed are the evaluation of the lateral image limit of the chest wall with satisfactory results, the automatic exposure control, the Signal-to-Noise difference ratio that complies with the tolerances, in the case Ghosting and dynamic range the results of both are satisfactory, the presence of artifacts was observed when applying variance mapping, a base value of the dynamic range was also obtained. For the dosimetry, the half value layer and the determination of the Mean Glandular Dose were evaluated, which does not comply with the tolerances. The final protocol document could be validated and implemented as part of the management and service documents of the Quality Control and Monitoring Laboratory (LCM) of LAF-RAM.

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**Keywords:** DIN 6868-162:2013-06, Quality Control, MAM-162

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## 1. INTRODUCTION

Quality controls are performed to verify the performance status of X-ray equipment in relation to image quality and patient dose. In mammography, quality control is aimed at maintaining image quality, low radiation dose and detecting faults in the equipment or acquisition systems that could affect them. With routine quality controls, system failures can be detected and corrected in time, reducing resource costs if the failure becomes more serious. On the other hand, with this type of controls poor image quality could be avoided. The formation of the image is a chained process that involves all the elements of the system, this means that if only one of these elements fails, the image quality will be affected and will be reflected as a decrease in contrast or resolution, and an increase in noise or radiation dose. This is the importance of routinely evaluating each of the elements that influence image quality.

In the above context is that, in this work the measurement protocol and validation of a phantom MAM-162 was made, which is specific to perform quality control of digital mammography equipment. Moreover, this phantom did not have a manual for its implementation, although according to the manufacturer it was developed under a German technical standard. For this reason, it was necessary to collect information from several protocols to provide a protocol describing the tests to be performed in a quality control using the phantom MAM-162 to evaluate image quality in CR and DR digital mammography. The main international standards considered were the German Institute for Standardization (DIN) DIN 6868-162:2013-06, the IAEA technical document protocol TECDOC No. 1958 and the European Federation of Organizations for Medical Physics (EFOMP) mammo protocol. It was possible to validate the protocol and its implementation in a CR type digital equipment installed in the city of Granada, Nicaragua.

## 2. MATERIALS AND METHODS

A Philips CR type digital mammography system was evaluated using the MAM-162 phantom with adaptation to a single quality control protocol based on international standards: the German Institute for Standardization (DIN) DIN 6868-162: 2013-06 (Acceptance test according to the standards for X-ray equipment for digital mammography) [1,2], the protocol technical document ("Quality Control Protocols for Radiodiagnosis in Latin America and the Caribbean"), prepared by the International Atomic Energy Agency (IAEA) and the Pan-American Health

Organization (PAHO), IAEA TECDOC 1958 [3] and the European Federation of Organizations for Medical Physics (EFOMP) mammo protocol [4]. Among the main tests performed were the evaluation of the lateral image limit of the chest wall, determination of the automatic exposure control parameters, the Signal-to-Noise difference ratio, Ghosting, artifacts, and dynamic range.

This study used the MAM-162 phantom as seen in Figure 1; which consists of a 40 mm Polymethylmethacrylate (PMMA) Phantom Base itself with an Aluminum Step Wedge (14 steps of 0-5, 2 mm) as well as 2 rows of metal spheres to test the missing tissue on the side of the chest wall, it has additional materials such as: PMMA test insert with quadratic marking, test insert for SDNR (signal to noise difference ratio) evaluation, HC test insert (high contrast), Frame plate (6 mm) to place the different test objects attenuation plates (1 x 4 mm, 1 x 10 mm, 3 x 20 mm) in the shape of the breast and contains attenuation plate 320 x 260 x 20 mm.

Figure 1. Suitcase with a set of tools that compose the phantom MAM-162. Various structures or test objects can be observed, as well as different thicknesses of PMMA.

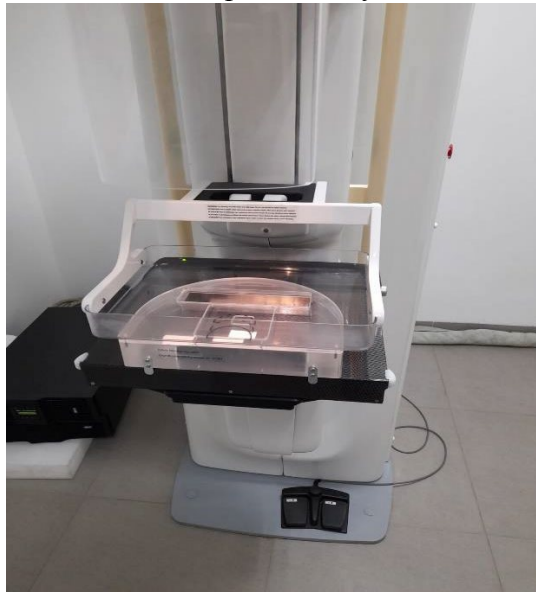


Source: (Artinis) [5].

The methodology for the assembly, measurement and analysis of the quality control tests performed with the MAM-162 is described below.

Lateral image limit of the chest wall (LILCW): Following DIN 6868-162:2013, this test was performed by placing the base structure or test object exactly flush with the edge of the chest wall as shown in Figure 2.

Figure 2. *Set-up of material structure placement for LILCW determination.*



Source: *Authors*

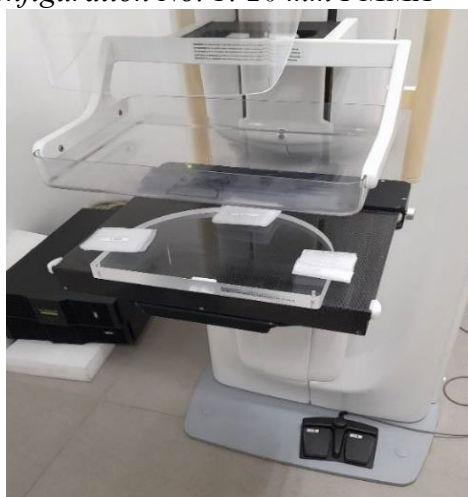
The Automatic Exposure Control CAE was determined based on the methodology of DIN 6868-162:2013-06 using seven configurations for different PMMA thicknesses simulating equivalent breast thicknesses as shown in Table 1. According to DIN 6868-162:2013-06, it is shown from 21 mm up to 90 mm and using polystyrene spacers. The tolerance for this test for the load, variation coefficient (mAs) should be less than 5%.

Table 1: Exposure configurations in AEC mode

<b>Configurations</b>	<b>Equivalent breast thickness</b>	<b>Total PMMA of MAM-162</b>	<b>Additional spacers (spacers)</b>
1	21	20	1
2	32	30	2
3	45	40	5
4	53	46	7
5	60	50	10
6	75	60	15
7	90	70	20

For the measurement setup an example is shown in Figure 3 used for the first configuration. All exposures were performed in automatic mode and different voltages and loads delivered by the equipment were recorded.

Figure 3. *Configuration No. 1: 20 mm PMMA + 1 mm spacer*



Source: Author

The Signal Difference to Noise Ratio (SDNR) test was performed according to the methodology and tolerances indicated in DIN 6868-162:2013-06. One image was obtained for each configuration described in Table 1 using the OP-SDNR test object of the phantom whose insert contains aluminum on one of its sides. The exposure was performed in manual mode acquiring the images with the radiographic technique found in AEC for each corresponding configuration (See example of setting in figure 4).

Figure 4. *Configuration No.7: 70 mm PMMA incl. OP-SDNR*



Source: Author

For the evaluation of the (SDNR), the raw images were analyzed in ImageJ and the region of interest (ROI) was determined for the different thickness and test object configurations where the mean and standard deviation of the background (B) and the aluminum contrast were extracted. Using equation 1 it was possible to determine the values of the signal difference to noise ratio and the variation of the signal difference to noise ratio  $\Delta$ SDNR through equation 2. This evaluation methodology is based on the indications of the IAEA TECDOC No. 1958 protocol.

$$SDNR=(VMP_A-VMP_B)/SD_C \quad (1)$$

Where:

SDNR is obtained for each image, with  $VMP_A$  being the mean value of the  $ROI_A$  pixels, i.e. the signal in the aluminum area,  $VMP_B$  is the mean value of the  $ROI_B$  pixels, i.e. the signal in the area outside the aluminum contrast (background).  $SD_C$  is the standard deviation of the mean value of the  $ROI_B$  pixels, i.e. standard deviation in the background region. For the variation of the signal difference to noise ratio, equation 2 shows:

$$\Delta SDNR=100 (SDNR_i-SDNR_{45mm})/SDNR_{45mm} \quad (2)$$

$\Delta$ SDNR is the difference signal-to-noise ratio difference between an image of thickness  $i$  and the reference of thickness 45 mm or configuration 4;  $SDNR_i$  is the SDNR for each image of obtained for thickness  $i$ .  $SDNR_{45mm}$  is the SDNR obtained for the reference image of thickness 45 mm or configuration 4.

The estimation of the Mean Glandular Dose was performed following the measurement methodology of DIN [1,2] using the PMMA configurations of the AEC test, performing the exposures with the radiographic techniques of the AEC. The NOMEX detector was placed on each breast configuration 6 cm from the side of the chest wall and centered as shown in Figure 5. For this test the values of Kerma, Half Value Layer (HVL), kilovoltage and time indicated by the detector were recorded.

Figure 5. Assembly of instruments and materials for MGD configuration 1



Source: Author

The MGD estimation was performed considering equation 3, which is a product of the research of Dance [6] and Dance et al. [7,8].

$$MGD = gt.ct.s.Ki \quad (3)$$

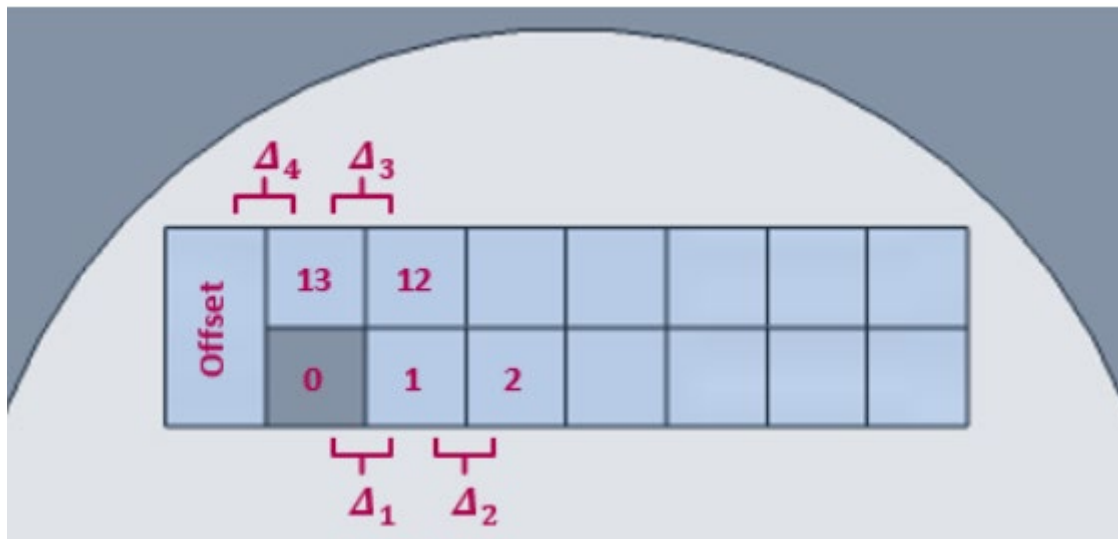
Where:

$K_i$  is the value of incident Kerma without backscatter for the corresponding equivalent breast thickness values,  $s$  is the factor that takes into account the anode/filter combination for this work it was W/Rh;  $gt$  is the factor that converts the input incident Kerma value to mean glandular dose for equivalent breast thickness  $t$ ,  $ct$  is the conversion factor that takes into account the glandularity of the equivalent breast thickness. This factor was considered with a value of 1 for any of the configurations.

As for the dynamic range it was calculated based on the methodology of [1,2] in this case the equipment was used in manual mode to obtain the exposure parameters for breast thickness of 53 mm i.e. 46 mm of PMMA. For this purpose, PMMA base with test object in the form of Al ladder along with structural plate is used. The image is extracted, and the average pixel signal measurement is performed on the steps as shown in Figure 6, and then the signal difference between consecutive steps is performed.

According to [1,2] it is a test of constancy, therefore, of the state, its frequency is suggested on a monthly basis. The results are then compared with respect to a base value.

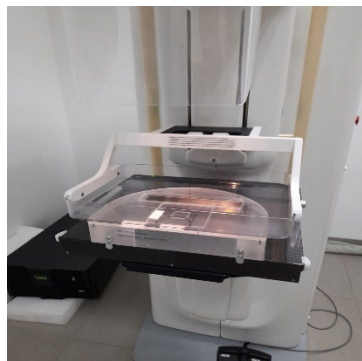
Figure 6. Illustration of steps involved in dynamic range analysis.



Source: [2]

The image was acquired in CAE mode resulting in a radiographic technique of 29.5 kV and 160 mAs with the same W/Rh combination. Figure 7 shows the setup used to perform this test.

Figure 7. Instrument and material placement set-up for Dynamic Range test.



Source: Author

To establish the dynamic range baseline was performed by calculating the differences in the mean values of the next pixel mean values of the adjacent steps of the dynamic staircase in the image as shown in Figure 7 and with the indications in Figure 6, i.e.:

Measurement at step "0" on the step with unattenuated radiation ("hole");

Measurement at step "1" on the thinnest step of the dynamic staircase;



Measurement in step "2" on the next step adjacent to the thinnest step of the dynamic staircase.

Measurement in step "12" on the adjacent step nearest the thickest step of the dynamic staircase

Measurement in step "13" on the thickest step of the dynamic staircase.

Measured in Offset is the most radiopaque area of the dynamic staircase;

$\Delta_n$  the difference of the average pixel values of two adjacent steps.

The dynamic range in digital image receivers is calculated, by the number of available signal values, according to the gradation of the dynamic range of the image is determined by the bit depth. The differences are calculated according to equation 4:

$$\Delta_n = |m_{step(n-1)} - m_{step(n)}| \quad (4)$$

$\Delta_n$  is the difference of the average pixel values of two stages;

$m_{step(n)}$  the mean value of the pixels of the nth stage.

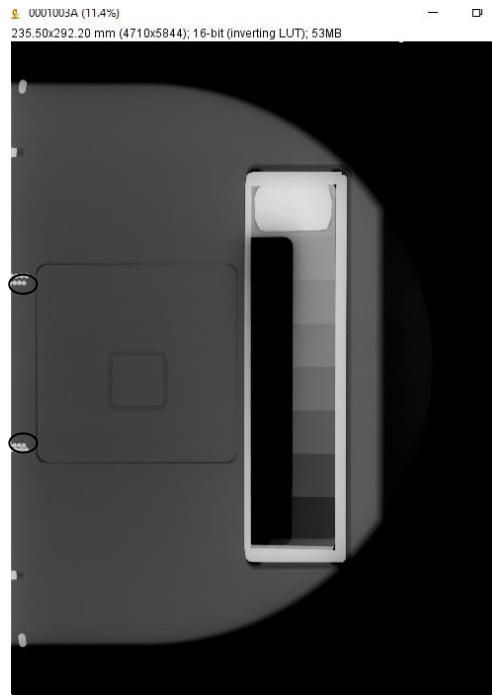
In the case of ghosting test, it was used methodology of DIN 6868-162:2013-06 and instrumentation as for the dynamic range test as long as the high contrast test object TO-HC, three images were acquired with the technical parameters of the dynamic range Image A and C for image B by placing the TO-HC using radiographic technic of configuration 7.

For the evaluation of artifacts, the image acquisition was based on the methodology of [1,2], for which a 20 mm thick PMMA base, large size in the shape of a square, was required. With the image obtained in the verification test for the presence of artifacts, the image was processed using variance mapping for the visualization of artifacts. In this sense, the EFOM mammo protocol analysis methodology was followed.

### 3. RESULTS AND DISCUSSION

The result of the evaluation of the lateral image limit of the chest wall indicates satisfactory results since the image shows three and a half spheres as shown in Figure 8. The tolerance according to DIN 6868-162:2013 corresponds to the visibility of at least 2½ of the 5 steel spheres per row [1].

Figure 8. Image processed with ImageJ software using the methodology for lateral chest wall image boundary assessment.



Source: Author

Table 2 shows the results of the exposure parameters using the different PMMA configurations and thicknesses in Automatic Exposure Control (AEC) mode.

Table 1: Exposure technique for each configuration in AEC mode.

	<b>PMMA thicknesses</b>						
	20PMMA + 1mm de spacer	30PMMA + 2mm de spacer	40PMMA + 5mm de spacer	46PMMA + 7mm de spacer	50PMMA + 10mm de spacer	60PMMA + 15mm de spacer	70PMMA + 20mm de spacer
Tube voltage (kV)	27,5	28,5	29,0	29,5	30,0	30,5	31,0
Tube load (mAs)	35,1	66,0	110,5	152,1	183,6	289,7	446,7

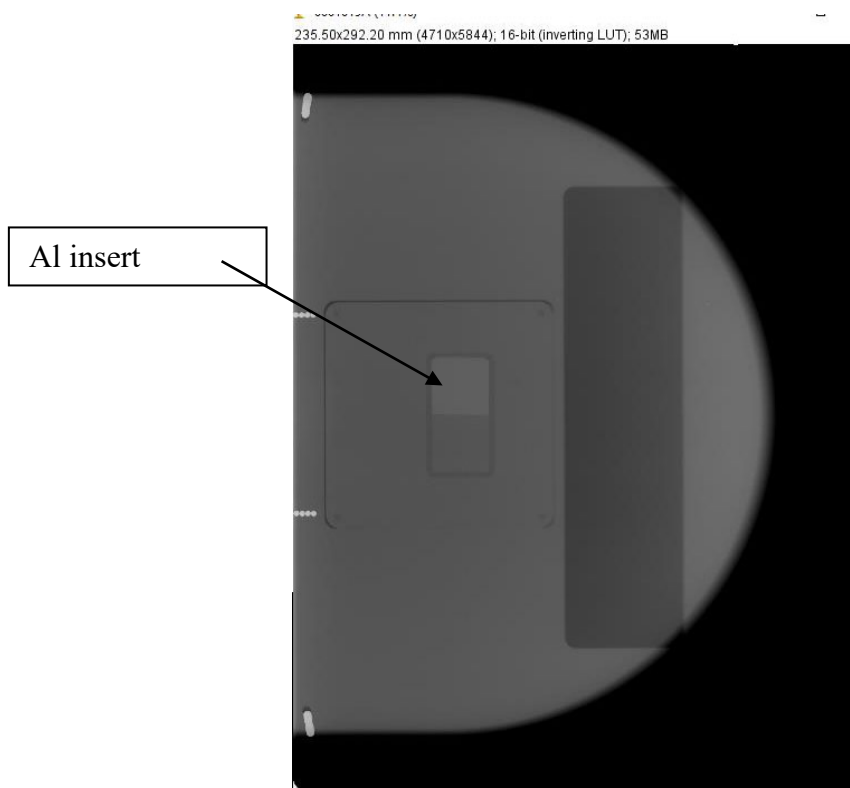
With the data obtained from the AEC, the values of the techniques used for the signal-to-noise ratio and the variation of the signal-to-noise difference were estimated. In order not to increase the risk of damage to the tube, the 5% rule was not applied to obtain the appropriate exposure techniques for each simulated breast, but the closest values of tube load in mAs were used as shown on table 3.

Table 3. mAs values used for SDNR and MGD tests.

	<b>PMMA thicknesses</b>						
	20PMMA + 1mm de spacer	30PMMA + 2mm de spacer	40PMMA + 5mm de spacer	46PMMA + 7mm de spacer	50PMMA + 10mm de spacer	60PMMA + 15mm de spacer	70PMMA + 20mm de spacer
Tube voltage (kV)	27,5	28,5	29,0	29,5	30,0	30,5	31,0
Tube load (mAs)	32	63	100	160	180	250	400

The figure 9 shows the images for configuration 1 (20PMMA + 1mm spacer). The test object with aluminum material is observed with which the analysis is performed by acquiring the mean pixel value signal inside the aluminum insert and the standard deviation of the background; according to equation 1 the SDNR and the  $\Delta$ SDNR were determined with equation 2. The results of the determination of the signal difference to noise ratio and the variation of the signal difference to noise ratio for each configuration are shown in Table 4.

Figure 9. Displays images processed with ImageJ.



Source: Author

The SDNR and the  $\Delta$ SDNR for this equipment according to the results complies except for the 40 and 70 PMMA configuration. In this case the information of tolerances established in the EFOMP protocol and the IAEA TECDOC 1958 for the 70 PMMA configuration specifically was considered. The results are shown in Table 4 as well together with the results of the mean glandular dose estimation. According to the determinations of HVL and PMMA configuration it was necessary to perform interpolations for this beam quality. MGD was not determined for 90 mm equivalent thickness as the mammography equipment indicated a message that it was not generating adequate anode current.

The tolerances described in the EFOMP mammo protocol compared to the results indicate that only for equivalent breast thicknesses (20 mm PMMA) the acceptable limit tolerance is met with unsatisfactory results for the rest of the equivalent breast thickness configurations.

Table 4. Results of SDNR and MGD estimation

PMMA thicknesses						
PMMA Thickness [mm]	SDNR	$\Delta$ SDNR	Limit values $\Delta$ SDNR respect to de 45 mm thickness	MGD Desired [mGy]	MGD Achievable [mGy]	MGD [mGy]
20	14.54	14.15	$\geq 0\%$	0.6	1.0	0.9
30	13.66	7.25	$\geq 0\%$	1.0	1.5	1.8
40	12.26	-3.73	$\geq 0\%$	1.6	2.0	2.4
45	12.73	0	0%	2.0	2.5	3.5
50	10.25	19.53	$\geq -15\%$	2.4	3.0	3.8
60	11.46	-9.98	$\geq -30\%$	3.6	4.5	5.2
70	8.21	-35.49	$\geq -30\%$			

With this work is the first time that the dynamic range of a digital equipment is evaluated, since the appropriate equipment was not available. This is why the results of this evaluation are considered the base value. Considering Figure 10, at each step of the test object we obtained  $\Delta n$  which is the difference of the mean values of the pixels of two adjacent steps. Table 5 shows the results of the calculation of the differences between mean pixel values of each corresponding step.

Figure 10. Image analyzed in ImageJ where ROIs of equal area were drawn on the corresponding steps for dynamic range estimation.

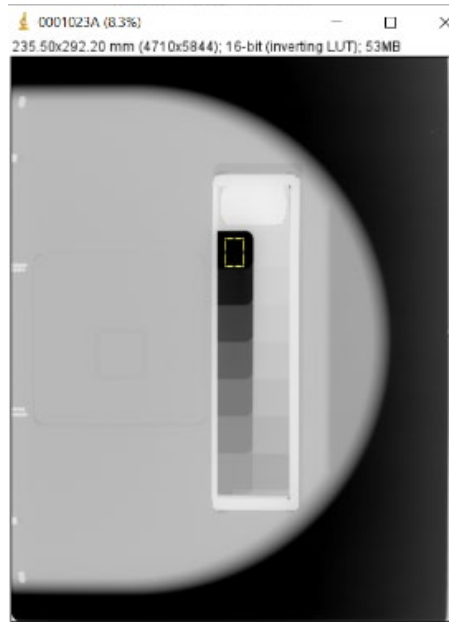


Table 5. Reference results for dynamic range

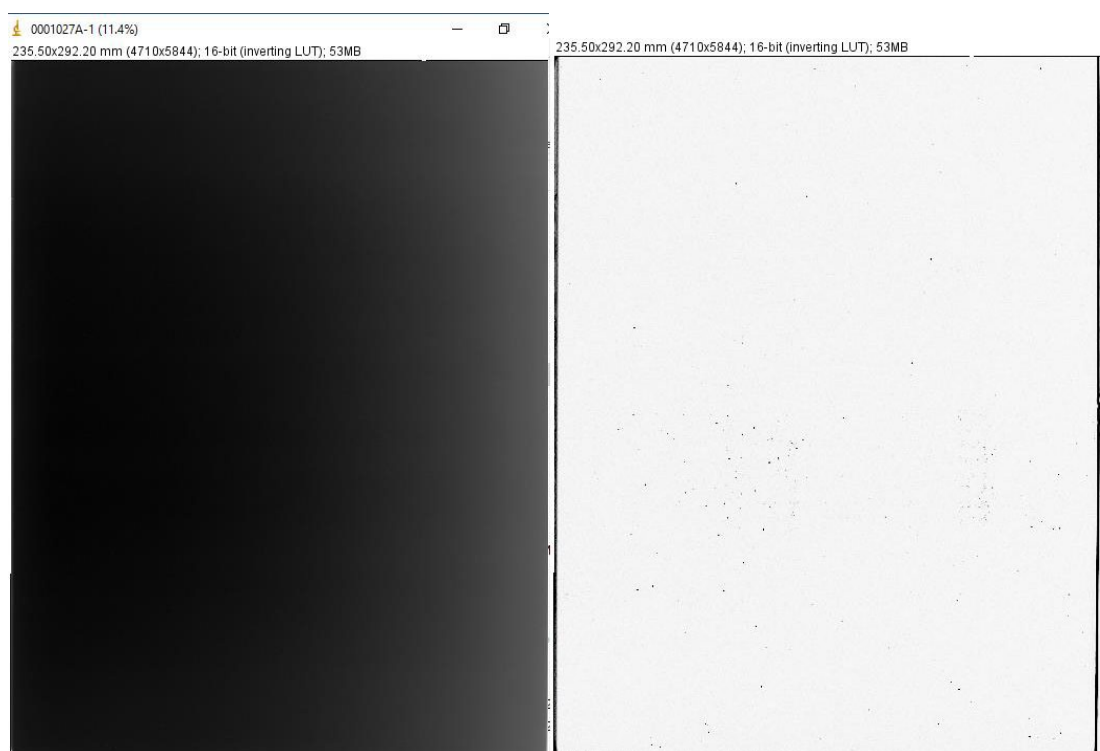
<b>Differences in average values</b>	
$\Delta 1$	7384
$\Delta 2$	7181
$\Delta 3$	813.8
$\Delta 4$	4013.9

In the case of ghosting the images following the methodology and sequence A, B and C described previously were analyzed, obtaining the mean pixel signal for a given ROI in both images. The SDNR was determined following equation 1 and the result was -7.4. According to DIN 6868-162; 2013-06 and what is indicated in the IAEA TECDOC No. 1958 Quality Control Protocol for Diagnostic Radiology in Latin America and the Caribbean; the equipment complies with the established limit of  $\leq 2.0$  for the ghosting test.

With the image obtained from the test to verify the presence of artifacts, it was processed using variance mapping for the visualization of artifacts. Figure 11 shows the comparison of the original image acquired without any adjustment and the same image to which a variance mapping was applied with a radius of 5.

The image on the right shows dot-like artifacts which can be mistaken for microcalcifications; this may be an indication that the cassette or the intensifying screen has dust residues. The risk of this type of result is that these artifacts can lead to misdiagnosis prompting treating physicians to perform unnecessary biopsies.

Figure 11. *The image on the left is the image to be processed and the image on the right is processed by variance mapping for artifact visualization.*



Source: Author

#### 4. CONCLUSION

The translation into Spanish of the practical guide for the implementation of the acceptance test of DIN 6868-162:2013-06 with the MAM-162 phantom was carried out, originally in German language. Moreover, the validation was performed on a CR type mammography equipment already known to the LCM staff, which meets the requirements for image processing as raw data assessment.

Two international protocols IAEA TECDOC No. 1958 and EFOMP Mammo Protocol were analyzed, in addition to the aforementioned standard, to generate a single protocol that can be implemented as part of the management and service documents of the LAF-RAM Quality Control and Monitoring Laboratory. For digital equipment it is possible to apply this protocol proposal which was validated under selected tests and mainly intrinsically related to the MAM-162 phantom. Therefore, some tests as dynamic range and lateral chest wall image were first time incorporated into the protocol of QC of the LCM and these tests can be performed in acceptance tests, not only as routine controls of image quality management. The limitations of this work are more related to the nature of the service provided by the LCM as routine quality controls. In this sense to perform the AEC and Mean Glandular Dose tests for all breast thickness configurations, becomes time consuming.

## ACKNOWLEDGMENT

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