

## **Behavior of Radiation meters applied to Radiation Survey in Mammographic Rooms: A Brazilian Reality**

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**Abstract:** The reality of Radiation Surveys (RS) carried out in mammography facilities in Brazil is mostly stuffed of tests performed by equipment not suitable for this purpose. To verify the performance of these radiation meters in calibration condition in terms of ambient dose equivalent, tests were carried out on the radiation qualities applied to RS tests in mammography (ISO N 20 - 30) and conventional radiology (ISO N 60 - 100). The results showed that most of them had bad responses, underestimating by up to 17x in relation to the reference measures for mammography ranges. Such results suggest the imminent need to calibrate them in the appropriate qualities, as well as in integrated dose measurement modes, as suggested by one of the manufacturers, and, whenever possible, with instruments designed for these applications.

**Keywords:** Radiation Survey. Mammography. ISO 4037.

### **1. INTRODUCTION**

Breast cancer is the most common in Brazilian women. About 66,280 new cases is predicted for 2020, that corresponds to 27.9% of all women cancer cases. (INCA, 2020) According WHO, and also the Healthy Ministry of Brazil, mammographic exams are recommended to that cancer diagnosis and its screening programs. (INCA, 2016; WHO, 2014) This scenario requires, according DATASUS, 5.660 mammographs in use in Brazil. (DATASUS, 2020)

An overview of recommendations and regulations was made by Macedo et al (2019), where no specific information or requirements to perform radiation surveys in mammographic installations (RSM). Besides, some field equipment that are fitted to be used in that kind of tests are scarce e not commonly found in RSM reports evaluated by Navarro et al. (MACEDO et al., 2019; NAVARRO et al., 2015)

A Brazilian new regulation, called RDC 330, with its normative instructions (IN), was published in 2019 December by national healthy surveillance agency, ANVISA, replacing the previous one. Both in RDC 330:2019 and in IN n° 54:2019 do not have specific instructions about features of the radiation meter or method should be used. (ANVISA, 2019a, 2019b)

Those “GAP” of information about RSM can lead people to perform tests non accurately and this work aims to bring information about the behavior of some of the most used radiation meters in Brazil for this purpose and to help medical physicists, surveillance professionals and other individuals in the public to understand more about the importance of the proper use of these equipment.

This work is an expansion from the master’s dissertation of the author, incorporating data from other radiation meters tested at Labprosaud/IFBA (*Laboratório de Produtos para a Saúde do IFBA*, Salvador, Bahia, Brazil). (MACEDO, 2020)

## 2. MATERIALS AND METHODS

The used setup GE® ISOVOLT TITAN E is an X-ray generator of constant potential, with ripple lower than 1%. The 160 M2 X-ray tube has a voltage range from 1 to 160 kV, tungsten anode and an inherent filtration of 1 mm of Beryllium. The measurements of ambient dose equivalent rate,  $\dot{H}^*(10)$ , in a point of test of 2.5 m far from X-ray source, based on ISO N calibration setup. The reference ionization chamber is a PTW® spherical 1-liter chamber [TM 32002], traceable to PTB. The same setup was used by Macedo, 2020. (MACEDO, 2020)

### 2.1. Narrow Spectrum Series radiation qualities

The features of the calibration setup are on table 1. As discussed by Macedo, some requirements could not be fulfilled, as the 1<sup>st</sup> and 2<sup>nd</sup> HVL calculated, that is out of the required deviation, but within  $\pm 5\%$ . The uncertainties ( $k = 2$ ) evaluated are indicated between parenthesis. (ISO, 2019a)

Table 1. Radiation qualities established on Labprosaud/IFBA, ISO N 20, 25 and 30.

ISO N	Voltage* [kV]	Additional Filtration [mm]	1 <sup>st</sup> HVL @1m [mm]	2 <sup>nd</sup> HVL @1m [mm]	h**
20	20.0 (4)	1.007 (12) Al	0.362 (16) Al	0.414 (16) Al	0.87
25	25.0 (5)	2.033 (22) Al	0.694 (18) Al	0.772 (18) Al	0.90
30	30.0 (6)	4.04 (4) Al	1.22 (6) Al	1.26 (6) Al	0.97

\*Peak Practical Voltage

\*\*Homogeneity coefficient

Table 2. Radiation qualities already set on Labprosaud/IFBA, ISO N 60, 80 and 100.

ISO N	Voltage* [kV]	Additional Filtration [mm]	1 <sup>st</sup> HVL @1m [mm]	2 <sup>nd</sup> HVL @1m [mm]	h**
60	60	4,0 Al + 0,61 Cu	0,240 Cu	0,264 Cu	0,91
80	80	4,0 Al + 2,02 Cu	0,574 Cu	0,613 Cu	0,94
100	100	4,0 Al + 5,13 Cu	1,08 Cu	1,17 Cu	0,93

\*Peak Practical Voltage

\*\*Homogeneity coefficient

For a more complete analysis, the field chambers were submitted to calibration on ISO N 60, 80 and 100 radiation qualities, as described on table 2. That was made because most of meters energy dependence are within the energy range of those radiation qualities.

It's important to point that the reference ionization chamber has also PTB traceability for radiation qualities stated above.

The data of the Reference Ambient Dose Equivalent Rate and Air kerma to ambient dose equivalent coefficient conversion [ $h_N^*(10; N)$ ] applied to mGy/h and R/h meters on that setup are described on table 3. (ISO, 2019b)

Table 3. Data of reference measurements and conversions.

ISO N	$H^*(10)$ [mSv/h]	$h_N^*(10; N)$ [Sv/Gy]	$h_N^*(10; N)$ [Sv/R]*
20	1,19 (12)	0,323	$2,83 \times 10^{-3}$
25	1,26 (10)	0,576	$5,05 \times 10^{-3}$
30	1,17 (10)	0,814	$7,13 \times 10^{-3}$
60	1,22 (5)	1,59	$1,39 \times 10^{-2}$
80	1,21 (5)	1,73	$1,52 \times 10^{-2}$
100	1,20 (5)	1,71	$1,50 \times 10^{-2}$

\* Conversion 1 Gy = 114,16 R (ICRU, 1971)

## 2.2. Field equipment tested

The radiation meters tested in this work are described on table 4. They were selected by availability on Labprosaud/IFBA, between 2018-2020.

Table 4. List of radiation meters tested.

<b>Ticker</b>	<b>Type</b>	<b>Energy Dependence [keV]</b>	<b>Range [Gy.h<sup>-1</sup>]</b>	<b>N° samples</b>
Reference	Electrometer PTW® UNIDOSWeblin + Ion chamber PTW® TM 32002 1000 cm <sup>3</sup>	±5%, 3×10 <sup>1</sup> to 1.33×10 <sup>3</sup>	10 <sup>-6</sup> to 15	-
Radcal® 9010 + 10X5-180	Elec Radcal® 9010 + IC 10X5-180, 180 cm <sup>3</sup>	±5%, 3×10 <sup>1</sup> to 1.33×10 <sup>3</sup>	10 <sup>-6</sup> to 15	6
Radcal® 9010 + 10X5-1800	Elec Radcal® 9010 + IC 10X5-1800, 1800 cm <sup>3</sup>	±5%, 3.3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	10 <sup>-7</sup> to 5.75×10 <sup>-1</sup>	2
Radcal® 2086 + 10X9-1800	Elec Radcal® 2086 + IC 10X9-1800, 1800 cm <sup>3</sup>	±5%, 3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	10 <sup>-6</sup> to 15	2
Radcal® 2026C + 20X6-180	Elec Radcal® 2026C + IC 10X5-180, 180 cm <sup>3</sup>	±5%, 3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	10 <sup>-5</sup> to 8.8×10 <sup>-1</sup>	2
Radcal® 2026C + 20X6-1800	Elec Radcal® 2026C + IC 10X5-1800, 1800 cm <sup>3</sup>	±5%, 3.3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	1.8×10 <sup>-7</sup> to 7.2×10 <sup>-1</sup>	1
Radcal® 9015 + 10X5-180	Elec Radcal® 9010 + IC 10X5-180, 180 cm <sup>3</sup>	±5%, 3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	1×10 <sup>-5</sup> to 8.8	3
Radcal® 9015 + 10X5-1800	Elec Radcal® 9010 + IC 10X5-1800, 1800 cm <sup>3</sup>	±5%, 3.3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	10 <sup>-6</sup> to 5.7×10 <sup>-1</sup>	1
Radcal® AccuGold + 10X6-180	Elec Radcal® 9010 + IC 10X5-180, 180 cm <sup>3</sup>	±5%, 3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	3.6×10 <sup>-6</sup> to 17.6	7
Radcal® AccuGold + 10X6-1800	Elec Radcal® 9010 + IC 10X5-1800, 1800 cm <sup>3</sup>	±5%, 3.3×10 <sup>1</sup> keV to 1.33×10 <sup>3</sup> keV	1.8×10 <sup>-7</sup> to 7.2×10 <sup>-1</sup>	4
Atomtex® AT1121	Atomtex® AT1121 Plastic scintillator detector	35%, 5×10 <sup>0</sup> keV to 6×10 <sup>1</sup> keV	5×10 <sup>-8</sup> to 10	1
Fluke® 451P	Fluke/Victoreen® 451P Pressurized IC, 600 cm <sup>3</sup>	> 2.5×10 <sup>4</sup> keV	10 <sup>-6</sup> to 5×10 <sup>-1</sup>	1
Fluke® 451B	Fluke/Victoreen® 451B Pressurized IC, 600 cm <sup>3</sup>	> 7×10 <sup>3</sup> keV	10 <sup>-6</sup> to 5×10 <sup>-1</sup>	2
Fluke® TNT 12000D + 96020C	Fluke® Elec TNT 12000D + IC 96020C, 150 cm <sup>3</sup>	X-ray beam from 3×10 <sup>1</sup> to 1.5×10 <sup>2</sup> kV*	2×10 <sup>-5</sup> to 7.2×10 <sup>1</sup>	1
Unfors® Xi + Survey Detector	Unfors/Raysafe® Xi Platinum + Xi Survey Detector, SSD	1.3×10 <sup>1</sup> keV – 1.25×10 <sup>3</sup> MeV	10 <sup>-6</sup> to 10 <sup>-1</sup>	1

Legend: “Elec”: Electrometer; “IC”: Ion Chamber; “SSD”: Solid State Detector.

\*The instruction manual indicates only voltage range.

The calibration procedure was based on ISO 4037-2 (2019), and the setup is showed on figure 1. Specifically, for these tests, both reference and test devices were submitted to irradiation until stabilization ( $\sim 30$  s) and 5 measures were taken periodically ( $\sim 10$  s intervals). In open ionization chambers, was included an air density correction ( $k_{TP}$ ). (ISO, 2019c)

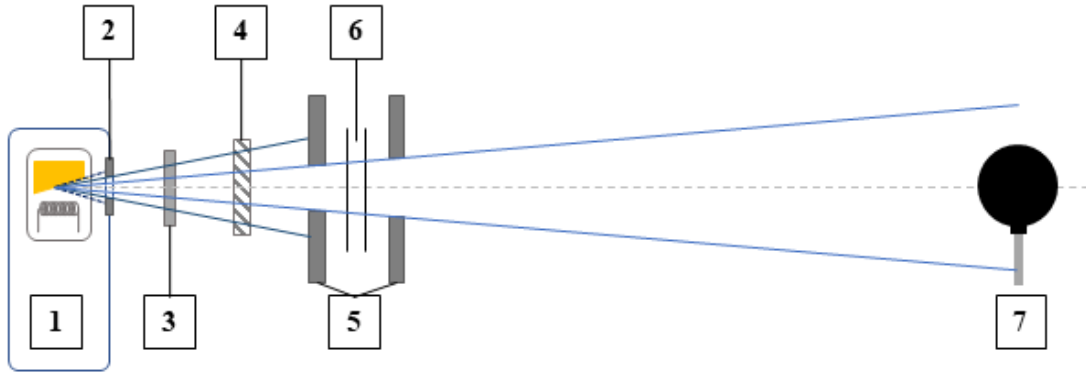


Figure 1. Setup from ISO Narrow Spectrum Series.  
(ISO, 2019c)

### 2.3. Calibration factor

The results will be evaluated through the calibration factor ( $N_{H,N}^{CP}$ ), that is calculated by equation 1: (IAEA, 2000; ISO, 2019c; LABPROSAUD/IFBA, 2019)

$$N_{H,N}^{CP} = N_{H,N}^{ref} \left( \frac{M_N^{ref}}{m_N^{ref}} \right) \left( \frac{m_N^{CP}}{M_N^{CP}} \right) \quad (1)$$

Where,

$N_{H,N}^{ref}$  is the calibration factor of the reference to ISO N radiation quality;

$M$  is the mean of the measures corrected from reference or the field meter;

$m$  is the mean of the measures corrected from the monitor chamber at the same moment of reference or field meter irradiation;

The reference values, as they are already traceable by a primary laboratory, were used by the ISO reference coefficient conversion,  $h_N^*(10; N)$ , from air kerma to ambient dose equivalent, once the calibration factor of field meters are also presented in terms of  $Sv/Gy$  (or  $Sv/R$ , depending of the meter).

On results section, it will be shown a table with a ratio between reference coefficient conversion,  $h_N^*(10; N)$  and the field meters calibration factor, equation 2. This will give the idea of how much underestimate or overestimate are the behavior of them.

$$R = \frac{h_N^*(10; N)}{N_{H,N}^{CP}} \quad (2)$$

### 3. RESULTS E DISCUSSIONS

The table 5 shows the results of the tests with the field meters in ISO N 20, 25, 30 (assumed to mammographic range), 60, 80 and 100 (assumed to general range) in terms of the Ratio ( $R$ ) calculated, as indicated in equation 2.

Table 5. Ratio calculated by meter vs quality.

Radiation Quality vs Radiation Meter	ISO N 20	ISO N 25	ISO N 30	ISO N 60	ISO N 80	ISO N 100
Atomtex® AT1121	1.66	0.65	0.57	0.78	0.88	0.95
Radcal® 2086 + 10X9-1800	1.44	1.18	1.07	0.93	0.92	0.93
Fluke® TNT 12000D + 96020C	1.08	1.06	1.06	1.02	1.01	1.00
Fluke® 451P	17.37	6.29	3.58	1.50	1.29	1.19
Fluke® 451B	4.07	2.14	1.59	1.10	1.06	1.07
Radcal® 2026C + 20X6-180	1.10	1.03	1.02	0.98	0.99	0.99
Radcal® 2026C + 20X6-1800	1.38	1.13	1.03	0.91	0.92	0.93
Radcal® 9010 + 10X5-180	1.13	1.09	1.07	1.04	1.05	1.04
Radcal® 9010 + 10X5-1800	1.56	1.26	1.14	0.99	0.99	1.03
Radcal® 9015 + 10X5-180	1.09	1.04	1.03	0.99	0.99	1.00
Radcal® 9015 + 10X5-1800	1.48	1.20	1.09	0.94	0.94	0.95
Radcal® AccuGold + 10X6-180	1.09	1.04	1.04	0.97	0.97	0.97
Radcal® AccuGold + 10X6-1800	1.43	1.18	1.09	0.94	0.94	0.93
Unfors® Xi + Survey Detector	1.33	1.15	1.02	0.95	0.97	1.01

As observed on table 5 and discussed by Macedo 2020, in general lines the Ratio trends to reference value as the radiation quality becomes more energetic. The SSD included in the tests also showed a similar behavior to other meters. Except for Atomtex® AT1121, that responded presenting a different tendency when compared to others. Mainly ISO N 20 and 25. (MACEDO, 2020)

Fluke® TNT 12000D + 96020C, Radcal® 2026C + 20X6-180, Radcal® 9015 + 10X5-180, Radcal® 9010 + 10X5-180 and Radcal® AccuGold + 10X6-180 performed always in the  $\pm 20\%$  interval, that indicates a good fit to RSM energy levels. Instead their energy range specified to state that works “well” ( $\pm 5\%$ ) only above 30 keV.

Radcal® 1800 cm<sup>3</sup> ion chambers (Radcal® 2086 + 10X9-1800, Radcal® 2026C + 20X6-1800, Radcal® 9015 + 10X5-1800, Radcal® 9010 + 10X5-1800 and Radcal® AccuGold + 10X6-1800) had ratios greater than 1,10 for ISO N 20 and 25.

An interesting point to consider is that, one of likely answer for the difference between Radcal® chambers of 180 and 1,800 cm<sup>3</sup> is that the first one has a thinner polycarbonate walls and exterior coat of graphite. Instead of both energy range specified to state the same value. According ICRU Report 20, there is a strong relation between the wall thickness and the electronic equilibrium in open ionization chambers. For lower energies a thinner wall is required, once that larger one can absorb the electrons generates on the wall and does not compensating the loss of signal from the electrons that scape from the cavity, causing, then, a lower ion current generation. (ICRU, 1971)

In the other side, as can be seen on table 5, 180 cm<sup>3</sup> ion chambers, instead of having a good energy dependence behavior, they have one order of magnitude less sensitive, that can be critical in RSM tests.

A Radcal’s engineer, through an e-mail on 5/27/2015, wrote that “*Old and new 180 chamber may exhibit significant difference when compared in the mammographic region, even though they meet our specifications (diagnostic)*”, same as 1800. This only endorses what can be seen on manual. When the matter is temporal dependence, he said that “Live dose rate readings should not be used except for long exposures. Always use dose and time whenever possible”. According Navarro et al (2015), most equipment used to RSM was calibrated on ISO N 60 – 100 qualities, tests performed using short exposure times (less than 1 s) and using “Dose Rate” as the operation mode of the radiation meter. This can lead to tests results with poor reliability. (MACINTOSH, 2015)

The Unfors® Xi Survey Detector had the same profile of response that Radcal® 1800 cm<sup>3</sup> ion chambers.

Fluke® 451P had results that underestimate measurements of until 17x and Fluke® 451B 4x for low energies (ISO N 20). As explored above, they also trend to improve their behavior as energy becomes higher. “Freeze Mode” of operation in Fluke® 451P and Fluke® 451B helps to improve measurements with short times exposures in Radiation Surveys Tests, promoting a little reducing on effects of temporal dependence highlighted by Leyton et al (2015) and Navarro et al (2015). But, how it can be seen in tests, the energy dependence is not improved, even in continuous exposures and wait for stabilization of measurements. (FLUKE® BIOMEDICAL, 2005, 2013; LEYTON et al., 2015; NAVARRO et al., 2015)

Fluke® and Raysafe have launched a new survey sensor, Raysafe 452 Radiation Survey Meter (2019), based on a detector semiconductor, that has technical specifications fitted with RSM applications. Unfors®/Raysafe has launched X2 Survey detector (2017), that is also fitted to RSM.

The uncertainties evaluated in those calibrations are described on table 6.

Table 6. Uncertainty budget.

Uncertainty source	$u_i$ (%)	$u_i$ (%)	$u_i$ (%)	$u_i$ (%)	$u_i$ (%)	$u_i$ (%)
	N-20	N-25	N-30	N-60	N-80	N-100
Reference Calibration	5.0	4.0	4.0	2.0	2.0	2.0
Reference repeatability	0.01	0.01	0.01	0.02	0.02	0.02
Reference resolution	0.042	0.045	0.041	0.040	0.041	0.041
Reference long-term stability	0.72	0.72	0.72	0.72	0.72	0.72
Reference Field homogeneity	0.29	0.29	0.29	0.29	0.29	0.29
Air density correction factor ( $k_{TP}$ )	0.13	0.13	0.13	0.13	0.13	0.13
Reference Energy dependence	0.14	0.14	0.14	0.14	0.14	0.14
Reference positioning	0.14	0.14	0.14	0.14	0.14	0.14
Reference Scattering	0.23	0.23	0.23	0.23	0.23	0.23
Reference Leakage and zero shift	0.081	0.081	0.081	0.081	0.081	0.081
Field meter repeatability*	0.5	0.5	0.5	0.5	0.5	0.5
Field meter resolution*	0.5	0.5	0.5	0.5	0.5	0.5
Field meter homogeneity	0.29	0.29	0.29	0.29	0.29	0.29
Field meter Positioning	0.14	0.14	0.14	0.14	0.14	0.14
Field meter Air density correction factor ( $k_{TP}$ )	0.13	0.13	0.13	0.13	0.13	0.13
Combined (%) [k = 1]	<b>5.13</b>	<b>4.16</b>	<b>4.16</b>	<b>2.31</b>	<b>2.31</b>	<b>2.31</b>
Expanded (%) [k = 2]	<b>10.3</b>	<b>8.3</b>	<b>8.3</b>	<b>4.6</b>	<b>4.6</b>	<b>4.6</b>

\* Considering maximum values calculated in all field meters evaluated.

#### 4. CONCLUSION

Disclaimer: 1. Any “bad” or “good” results of field meters tested in this work does not mean that this or that meter is “bad” or “good”. The behavior of meters may be evaluated according their intended use and technical specifications, besides weighted by number of samples of each one. A group of 7 meters of same model tested has, due a lower sampling error, statistically more relevance than those that has only 1. (VUOLO, 1996)

2. An obvious question has already made to the author, that is “Why are you evaluating meters in ranges that them are not intended for?”. And the answer is because, at least in Brazilian reality, most of radiation meters used in field to perform RSM tests are those. (NAVARRO et al., 2015)

Evaluating behavior of most used radiation meters applied to radiation survey in mammographic rooms, in a Brazilian approach, indicates that in low energies (N20-30) they tend to get measurements more divergent than when submitted to higher energies (N60-100). Meters can underestimate until 17x the measurements. Otherwise, other ion chambers had ratios within  $\pm 10\%$  interval, when compared to reference values in all radiation qualities, instead of them technical specifications do not fulfill requirements to be applied to RSM tests.

The results strongly suggest that the calibration of field tests in RSM energetic range, ISO 20 – 30, is mandatory. Not only because it is a Brazilian legal requirement, but because the correct calibration, and further correct correction, can avoid critical underestimation of the measurements in quantification of ambient dose equivalent levels around the mammographic installation.

In Brazilian reality, it seems hard to ignore or discard those models of radiation meter in RSM tests, even because, most of equipment applied to general Radiation Survey are those models tested in this work. And Brazil has almost 70.000 mammographs in use.

We recommend the calibration of those meters in terms of Air Kerma or Ambient Dose Equivalent under ISO N 20-30 radiation qualities. Additionally, perform RSM tests in “Accumulated Dose” operation mode to attenuate temporal dependence and, whenever possible, to use a calibrated radiation meter with an appropriate energy range to RSM tests in “Accum Dose” mode.

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