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Calibration Methodology for Instruments utilized in X Radiation Beams, Diagnostic Level

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Abstract

Methodologies for the calibration of diagnostic radiology instruments were established at the Calibration Laboratory of IPEN. The methods may be used in the calibration procedures of survey meters used in radiation protection measurements (scattered radiation), instruments used in direct beams (attenuated and non attenuated beams) and quality control instruments. The established qualities are recommended by the international standards IEC 1267 and ISO 4037-3. Two ionization chambers were used as reference systems, one with a volume of 30 cm^3 for radiation protection measurements, and the other with a volume of 1 cm^3 for direct beam measurements. Both are traceable to the German Primary Laboratory of Physikalisch-Technische Bundesanstalt (PTB). In the case of calibration of quality control instruments, a non-invasive method using the measurement of the spectrum endpoint was established with a portable gamma and X-ray Intertechnique spectrometer system. The methods were applied to survey meters (radiation protection measurements), ionization chambers (direct beam measurements) and kVp meters (invasive and non-invasive instruments).

1. INTRODUCTION

Considering that the underlying aim in radiology is to obtain the best possible diagnostic image with the least radiation exposure to patient and staff, and that about 25% of the instruments used for routine measurements in diagnostic radiology may require some adjustments[1], the calibration of the instruments used in diagnostic radiology measurements is essential.

Special methodologies for the calibration of this kind of instruments were established at the Calibration Laboratory of IPEN[2,3,4]. The established qualities were recommended by the international standards IEC 1267[5] and ISO 4037-3[6]. The methods may be applied in the calibration procedures of survey meters used for radiation protection measurements, instruments used in direct beams, and quality control instruments.

The objective of this work is to demonstrate the established methodologies at the Calibration Laboratory of IPEN and analyse the behaviour of different instruments used in diagnostic radiology measurements.

2. MATERIALS AND METHODS

The diagnostic radiology X-ray generating system consists of a Medicor Mövek Röntgengyara X-ray generator, model Neo-Diagnomax (125 kV). Measurements were taken from 30 to 90 kV, in the fluoroscopy mode. Two ionization chambers were used as reference systems, one with a volume of 30 cm^3 for radiation protection measurements, and the other with a volume of 1.0 cm^3 for direct beam measurements.

2.1. Radiation Protection Purpose Instruments

The qualities were established following the standard ISO 4037-3[6], C-series, which are the most suitable ones for the calibration of survey meters in diagnostic radiology because they are very similar to the radiation scattered by a patient[7]. They are listed in Table I. The utilized ionization chamber was a Physikalisch-Technische Werkstätten, PTW, type M23361 and an electrometer PTW UNIDOS type 10001, traceable to the German Primary Laboratory, PTB. All measurements were taken at 100 cm. The uncertainties associated were classified into type A (statistical methods, as the measurement means, temperature and pressure correction factors, etc) and type B (other than statistical, as the uncertainties associated to the measure instruments)[8]. The expanded uncertainties were evaluated considering the confidence level of 95% and were less than 3.5%. All instruments were initially calibrated and adjusted to gamma radiation (^{60}Co) as the manufacturer recommends. The survey meters tested are listed in Table II.

Table I. Main characteristics of the standard radiation beams to calibrate survey meters used in diagnostic radiology measurements established at the Calibration Laboratory of IPEN.
Q = Radiation quality

Q	Tube voltage	Additional filtration		Half-value layer	Effective Energy	Air kerma rates
	(kV)	(mmAl)	(mmCu)	(mmAl)	(keV)	(mGy/min)
C 40	43	1.0	--	0.83	20	3.47
C 60	63	3.9	--	2.34	30	3.01
C 70	70	5.4	0.15	3.7	35	2.96
C 80	80	7.2	0.50	5.2	40	3.29

Table II. Main characteristics of the survey meters tested at the Calibration Laboratory of IPEN in the established qualities , ISO 4037-3.

Instrument	Identification	Window Material (mg/cm^2)	Volume (cm^3)
Victoreen 450P	**A,B,C**	Conductive plastic ($200 mg/cm^2$)	300
Nardeaux Babyline 81	**D**	Tissue equivalent plastic ($7 mg/cm^2$)	515
Keithley 36150	**E**	Tissue equivalent plastic ($300 mg/cm^2$)	250

2.2. Direct Beam Measurements (attenuated and non attenuated beams)

The standard radiation qualities were established following the standard IEC 1267[5], and they are listed in Table III. The air kerma rates were determined with a standard ionization chamber traceable to the German Primary Laboratory, PTB. This chamber is a parallel plate chamber, PTW, model 77334 and it was connected to a PTW electrometer type UNIDOS 10001, traceable to the German Primary Laboratory, PTB. All measurements were taken at 50 cm. The calibration method was applied to some ionization chambers listed in Table IV.

Table III. Diagnostic radiology qualities established at the Calibration Laboratory of IPEN.

RQR : Radiation qualities in radiation beams emerging from the tube assembly

RQA : Radiation qualities based on a phantom made up of an aluminium added filter

Radiation Quality	Tube Voltage (kV)	Total Filtration (mmAl)	Half-Value Layer (mmAl)	Effective Energy (keV)	Air Kerma Rate (mGy/min)
RQR 3	52	2.5	1.82	32.0	5.06
RQR 5	70	2.5	2.45	39.2	6.59
RQR 7	90	2.5	3.10	46.0	6.92
RQA 3	52	12.5	4.0	38.8	0.363
RQA 4	63	18.5	5.7	45.6	0.309
RQA 5	70	23.5	7.1	51.8	0.256
RQA 6	80	29.5	8.4	57.9	0.200
RQA 7	90	32.5	9.1	62.9	0.481

Table IV. Main characteristics of the ionization chambers tested at the Calibration Laboratory of IPEN in the established qualities , IEC 1267.

Instrument	Wall Material	Volume (cm^3)
F. Radcal 10x5-6	Policarbonate	6
G. Radcal 10x5-6	Policarbonate	6
H. Radcal 10x5-180	Policarbonate	180
I. Radcal 10x5-180	Policarbonate	180
J. Radcal 10x5-6M	Aluminized Mylar Window	6
K. Radcal 10x5-60E	Policarbonato	60

2.3. Quality Control Instruments (kVp measurements)

A non-invasive method to calibrate kVp meters using the measurement of the spectrum endpoint with a portable gamma and X-ray spectrometer system was established. The portable Intertechnique spectrometer system used consists of a planar hyper pure Germanium (HPGe) Σurisys Mesures detector (16 mm diameter, 13 mm thickness), with the interpc spectrometry software. The HPGe detector efficiency was determined by Souza[9] using the Monte Carlo Method. The Figure 1 shows the obtained efficiency curve from 20 to 150 keV.

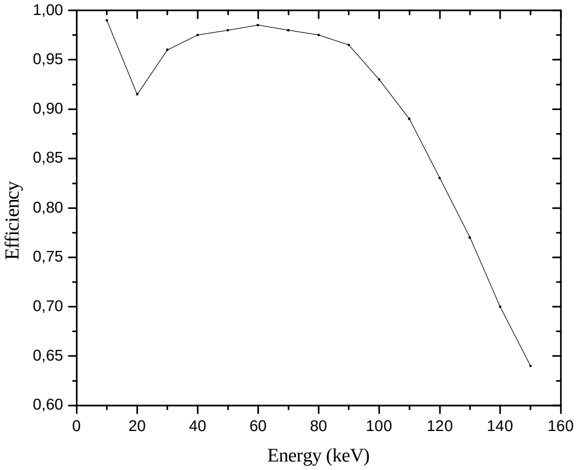

Figure 1. HPGe detector efficiency[9].

The spectrometer was calibrated using an ^{241}Am source with emission peaks at 59.537 keV (γ rays) and 17.611 keV (X-rays) and the calibration curve is shown in Figure 2.

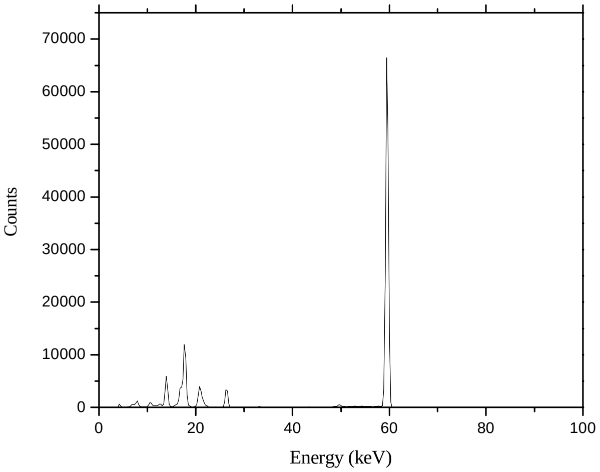

Figure 2. Calibration curve of the HPGe detector using the ^{241}Am source.

To reduce the pile-up effect, aluminium filters with thicknesses from 4 to 30 mmAl were used. The irradiation conditions of the HPGe detector for each tube voltage (kVp) value marked on the machine panel are shown in Table V. The measurements were taken with the lowest and the highest possible current values.

Table V. Irradiation conditions of the spectrometric system HPGe detector for the tube voltage peak determination of the Neo-Diagnomax X radiation system.

Tube Voltage (kV)	Additional Filtration (mmAl)	Current (mA)
50	4	0.5 4.0
60	10	0.5 4.8
70	16	0.5 4.5
80	21	0.5 5.0
90	26	0.5 5.0
100	30	0.5 5.0

As an application of the established method, three commercial kVp meters which are usually used for quality control measurements were tested. Their main characteristics are listed in Table VI.

Table VI. Main characteristics of the kVp meters tested in this work.

Instrument	Model	Type
L. Victoreen	NERO 6000M	Non-invasive
M. Radcal	Dynalizer III	Invasive
N. Gammex	RMI 242	Non-invasive

3. RESULTS

3.1. Radiation Protection Purpose Instruments

The behaviour of the survey meters tested in the established radiation protection qualities is shown in Table VII. All instruments showed a high energy dependence (except the **D** instrument which presents only 3% of energy dependence), specially in relation to ^{60}Co energy. It is possible to see variations up to 47%, case of the **C** instrument. The **A** instrument showed 45% of energy dependence and for **B** instrument it was 37%. The values obtained in the case of the **E** instrument showed the real necessity of calibration in the suitable range of energy, the calibration coefficients are almost 5 times more than those obtained for gamma radiation .

Table VII. Calibration coefficients of the survey meters (ionization chambers) used in diagnostic radiology measurements tested in established qualities at the Calibration Laboratory of IPEN. The calibration coefficients were normalized to ^{60}Co.

Radiation quality	Calibration coefficient				
	A	B	C	D	E
C 40	1.45	1.37	1.47	0.810	3.54
C 60	1.41	1.34	1.43	0.816	3.65
C 70	1.24	1.19	1.25	0.822	4.01
C 80	1.17	1.13	1.18	0.830	4.50
^{60}Co	1.00	1.00	1.00	1.00	1.00

3.2. Direct Beam Measurements (attenuated and non attenuated beams)

Figure 3 shows the behaviour of the ionization chambers tested in this work for the RQR and RQA qualities respectively. The Radcal ionization chambers showed a good behaviour, except the mammography chamber, **J**, which shows 17% of energy dependence for RQA qualities and 14% for RQR qualities. This behaviour can be explained by the fact that this ionization chamber is suitable for mammography energies (lower than the energies studied in this work). The other ionization chambers (**F**, **G**, **H**, **I**, and **K**) showed lower energy dependence. The maximum obtained values were 5% for **F** and **G** ionization chambers .

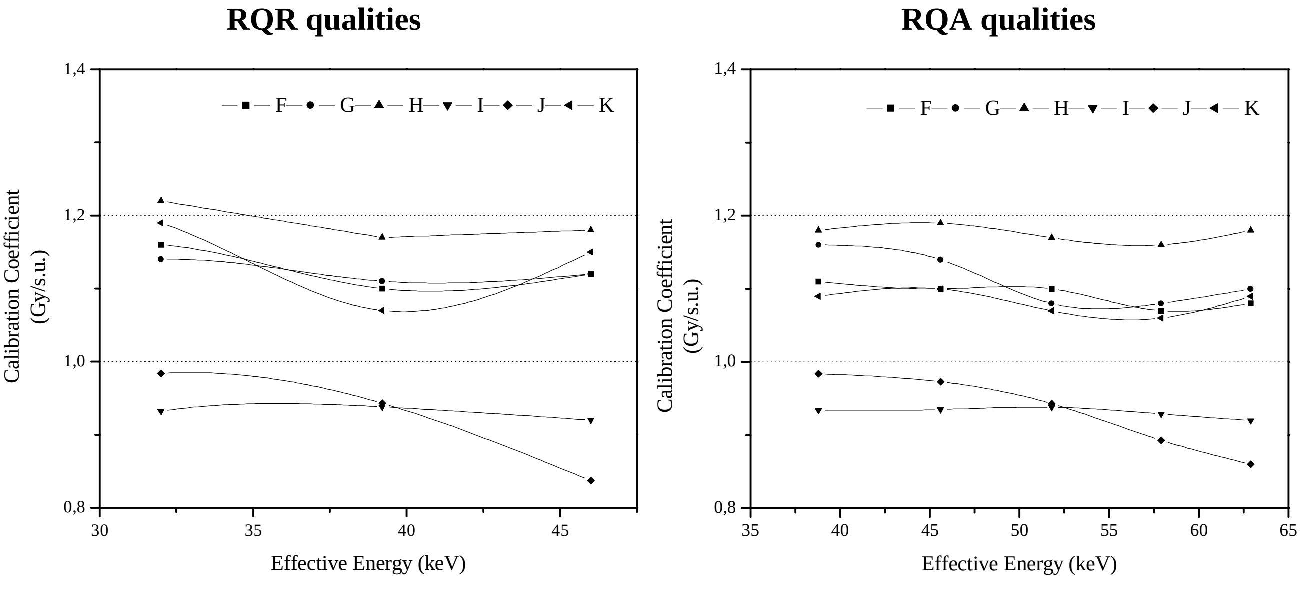

Figure 3. Energy dependence of the tested ionization chambers for RQR (non-attenuated beams) and RQA (attenuated beams) qualities established in the diagnostic radiology system of the Calibration Laboratory of IPEN.
s.u. : scale unit

3.3. Quality Control Instruments (kVp measurements)

The spectra obtained for each tube voltage value are presented in Figures 4 and 5. The values obtained using the spectrometer are in all cases about 10 kV less than that the machine panel shows. It can be observed that the tube voltage decreases as the current value increases. In the case of 60 kV, the variation is 2%, while to higher voltage values, this variation is 1.3 %. Table VIII shows the peak kilovoltage values (kVp) obtained by spectrometry.

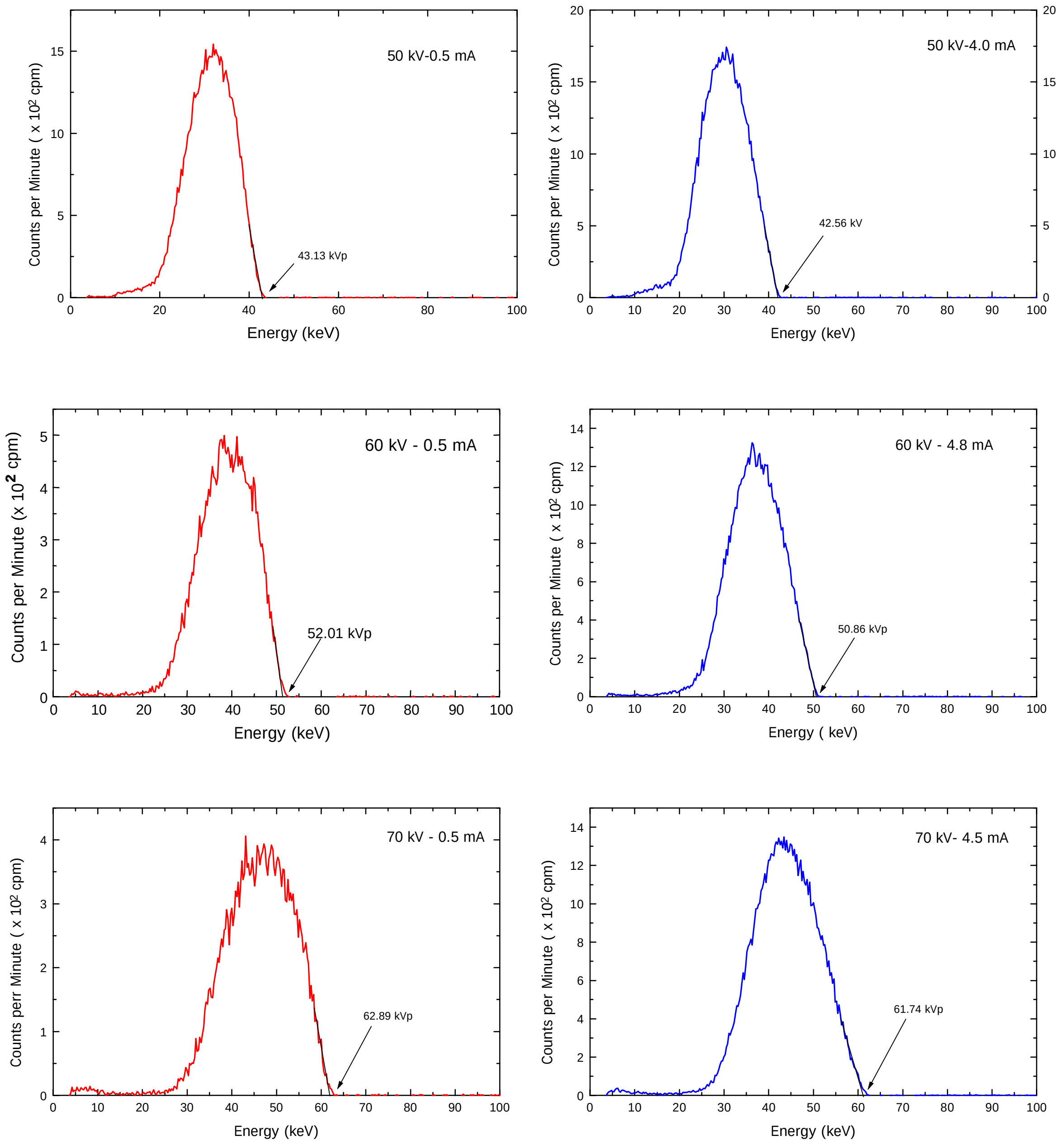

Figure 4. Spectra for 50, 60 and 70 kV X-rays obtained in the Neo-Diagnomax diagnostic radiology system.

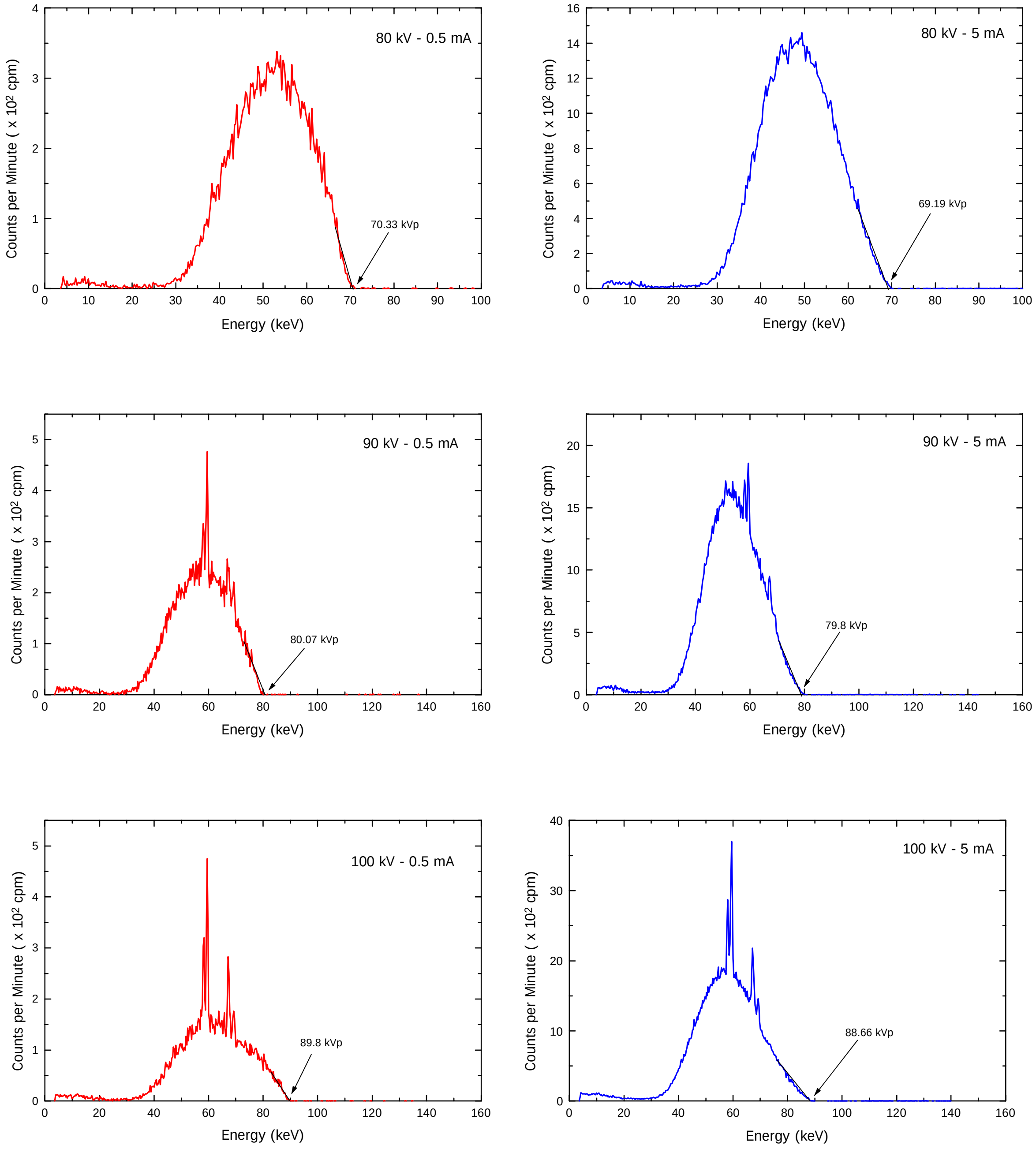

Figure 5. Spectra for 80, 90 and 100 kV X-rays obtained in the Neo-Diagnomax diagnostic radiology system.

Table VIII. Peak kilovoltage values obtained with the Intertechnique spectrometer using the Neo-Diagnomax radiation system.

Tube Voltage (kVp)		Current	Variation
Machine panel	Spectrometer	(mA)	(%)
50	43.13	0.5	13.7
	42.56	4.0	14.9
60	52.01	0.5	13.3
	50.86	4.8	15.2
70	62.89	0.5	11.4
	61.74	4.5	13.0
80	70.33	0.5	12.1
	69.19	5.0	13.5
90	80.07	0.5	11.0
	79.78	5.0	11.4
100	89.80	0.5	10.2
	88.66	5.0	11.3

To test the established methodology, the kVp meters described in Table VI were calibrated. They were positioned at the same distance used to calibrate diagnostic radiology dosemeters, 50 cm. The lowest current was chosen as reference (0.5 mA), due to the difficulty to keep the highest value on the panel machine. The values obtained are presented in Table IX. The instrument **N** shows sensibility only above 60 kV. The instrument **M** presents the best behaviour, with only 2.7% of maximum variation. The other instruments present a variation about 10% when compared to the spectrometer results. The maximum standard deviation was 1.3% in all cases.

Table IX : Tube voltage values obtained using the tested kVp meters in the diagnostic radiology system, using as reference the spectrometer system.

Spectrometer System (kV)	L (kV)	M (kV)	N (kV)
43.1	39.2	43.0	--
52.0	47.4	53.4	--
62.9	59.0	62.2	63.5
70.3	67.1	69.9	66.1
80.1	78.6	80.2	72.9
89.8	89.4	91.0	80.6

4. CONCLUSIONS

The results showed the importance of the calibration of all instruments used in diagnostic radiology measurements in the adequate energy range for their use. The energy dependence demonstrates the need of calibration of this kind of instruments. The spectrometric measurements always turn the field characteristics reliable. Their use as reference to calibrate kVp meters is valid.

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