Intercomparison of Ionization Chambers in Standard X-Ray Beams, Radioprotection Level

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Abstract

An ionization chamber intercomparison in X-ray beams, radioprotection level, was realized, using the calibration coefficients of the instruments as a comparison factor. Response energy dependence curves were obtained for the ionization chambers. The ionization chambers tested in these X-ray beams were: 22 Radcal chambers, models 10x5-1800, 10x5-180, 10x5-6, 10x5-6M, 10x5-60, 20x5-3, 20x5-180, 20x5-6M and 10x5-6-3; a Smart Ion chamber, model 2100; an Inovision chamber, model 451B; two Victoreen chambers, model 450P, and a Babyline 81 chamber. Among these ionization chambers, the Radcal chamber, model 10x5-60, presented the lowest energy dependence relative to the radiation quality N-80: 2.3% in the studied energy range. Victoreen ionization chambers, specially designed for use in X-ray beam intercomparisons, models 415, 415A and 415B, all coupled to a PTW electrometer, model Unidos, were also tested. The Victoreen ionization chambers presented, respectively, maximum energy dependence of 6.2%, 4.9% e 2.0% in the energy range from 49 to 117 keV.

1. INTRODUCTION

The confidence of the readings of radiation monitoring instruments relies on the calibration of each unit. The International Atomic Energy Agency (IAEA) recommends [1] that each individual instrument used in radiation monitoring should be calibrated before its first use, and then it should be calibrated periodically, usually every 12 to 14 months. In Brazil, this kind of calibration may be performed at the Calibration Laboratory of the Instituto de Pesquisas Energéticas e Nucleares (IPEN).

Intercomparisons can be defined as comparisons of measurements among instruments of the same metrological classification in order to compare their performance. A comparison of instruments of the same model and of the same metrological level in different radiation beam qualities is important to determine the best application of each instrument model and the correction factors that should be applied when the instrument is utilized in a different beam quality than that in which it was calibrated.

Since a great number of radiation monitoring instruments are calibrated in the Calibration Laboratory every year, an intercomparison was performed in X-ray beams, radioprotection level, using the calibration coefficients of the instruments as a comparison factor. The energy dependence of the response of the ionization chambers was studied in this work.

2. MATERIALS AND METHODS

The X-ray beams used in this work were the narrow series ISO beams, qualities N-60, N-80, N-100 e N-150, according to the standard ISO 4037-1 [2]. These beam qualities are recommended by the International Atomic Energy Agency [1] for calibration of radiation protection monitoring instruments. The beams were established at a Seifert/Pantak X-ray system, model ISOVOLT 160. The characteristics of these narrow beams are shown in Table I.

Table I – Characteristics of the established standard radiation protection beams at the Calibration Laboratory of IPEN.

Radiation Quality	Voltage [kV]	Additional Filtration [mm]	1st HVL [mm Cu]	2nd HVL [mm Cu]	Mean Energy [keV]	Air Kerma Rate* [$mGy.h^{-1}$]
N-60	60	4 Al + 0.6 Cu	0.25	0.27	49	20.1
N-80	80	4 Al + 2 Cu	0.60	0.62	65	10.7
N-100	100	4 Al + 5 Cu	1.10	1.11	83	5.05
N-150	150	4 Al + 2.5 Sn	2.32	2.40	117	42.0

* Air kerma rates were measured at a focal-detector distance of 2.5 m and with a filament current of 20 mA.

The reference instrument used for the measurements of air kerma rates was a spherical 1 liter PTW ionization chamber, type 32002, coupled to a PTW electrometer, model Unidos. For the monitoring of the intensity variations of the X-ray beams during the calibrations, a PTW transmission ionization chamber, model TW34014, and a PTW electrometer, model Unidos E, were utilized.

Victoreen ionization chambers, specially designed for use in X-ray beam intercomparisons, models 415, 415A and 415B, all coupled to a PTW electrometer, model Unidos, were tested. The ionization chambers, models 415 e 415B, are cylindrical chambers, recommended for measurements in high and medium energy X-ray beam qualities. The ionization chamber model 415A has a cylindrical electrode and a Mylar window, and it is for use in low energy X-ray beams.

The 22 Radcal ionization chambers tested in these X-ray beams were of models 10x5-1800, 10x5-180, 10x5-6, 10x5-6M, 10x5-60, 20x5-3, 20x5-180, 20x5-6M and 10x5-6-3. Two Victoreen ionization chambers, model 450P, an Inovision chamber, model 451B, a Smart Ion chamber, model 2100, and a Babyline 81 chamber were also tested.

The energy dependence is expressed according to IEC 61674 [3], which recommends that energy dependence shall be expressed as a variation of the measurement in a reference condition, as a radiation quality around the half of the energy range. In this work, the radiation quality N-80 was used as a reference quality for the study of the energy dependence of response of the ionization chambers.

For the determination of the calibration coefficients [4] of an instrument under calibration in terms of air kerma rate, Equation 1 was utilized. If the quantity measured by the instrument under calibration differs from the quantity measured by the reference instrument, additional corrections factors should be applied.

$$N_I = \frac{M_R \times N_R \times k_{tp1}}{M_I \times k_{tp2}} \qquad (1)$$

where

N_I is the calibration coefficient of the instrument under calibration in terms of air kerma (at reference conditions);
M_R is the measured value of the reference instrument;
N_R is the calibration coefficient of the reference instrument in terms of air kerma (at reference conditions);
k_{tp1} is the correction factor for differences in air density, from measurements of pressure and temperature, for the measured value of the reference instrument;
M_I is the measured value of the instrument under calibration;
k_{tp2} is the correction factor for differences in air density, from measurements of pressure and temperature, for the measured value of the instrument under calibration.

3. RESULTS

The calibration coefficients of the Victoreen ionization chambers models 415, 415A and 415B, obtained in standard radioprotection beams (Table I), are presented in Table II. The energy dependence of these chambers is showed in Figures 1 to 3. The ionization chambers models 415, 415A and 415B presented maximum energy dependence, relative to the beam quality N-80, of 6.2, 4.9% and 2.0%, respectively. This is a low energy dependence, considering that the standard radiation protection beams used in this work include a wide energy range, from 49 keV to 117keV.

Table II – Calibration coefficients of the Victoreen ionization chambers models 415, 415A and 415B, obtained in standard radioprotection beams of Table I.

Radiation Quality	1st HVL [mm Cu]	Calibration Coefficient [Gy.µC^{-1}]					
		415	U [%]	415 A	U [%]	415B	U [%]
N-60	0.25	3.075	3.05	10.63	3.06	14.61	3.06
N-80	0.60	2.896	3.05	10.14	3.08	14.60	3.10
N-100	1.11	2.871	3.06	09.91	3.09	14.61	3.11
N-150	2.32	2.818	3.05	10.06	3.06	14.89	3.09

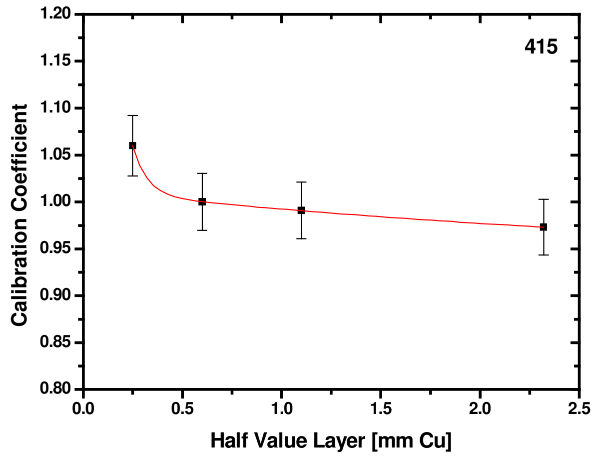

Figure 1 – Energy dependence of the Victoreen ionization chamber model 415.

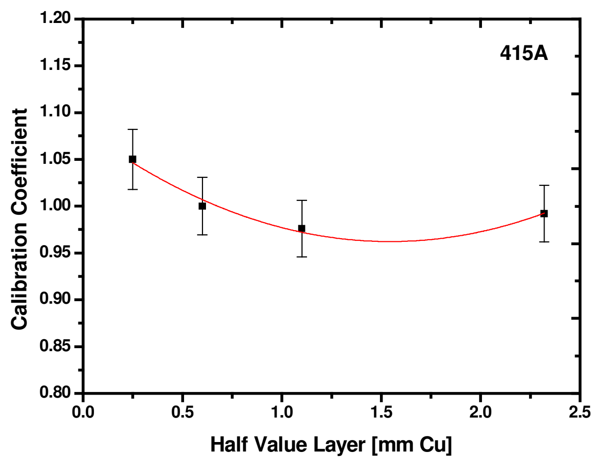

Figure 2 – Energy dependence of the Victoreen ionization chamber model 415A.

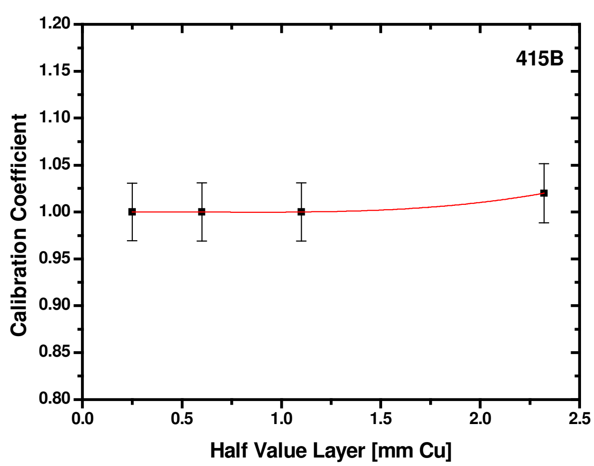

Figure 3 – Energy dependence of the Victoreen ionization chamber model 415B.

The dispersion of the calibration coefficients obtained from the calibration data of the ionization chambers shown in Table III in standard radiation protection beams recommended by ISO 4037-1 [2] is presented in Figure 4. Table III also shows the maximum energy dependence relative to the radiation quality N-80 for each chamber model.

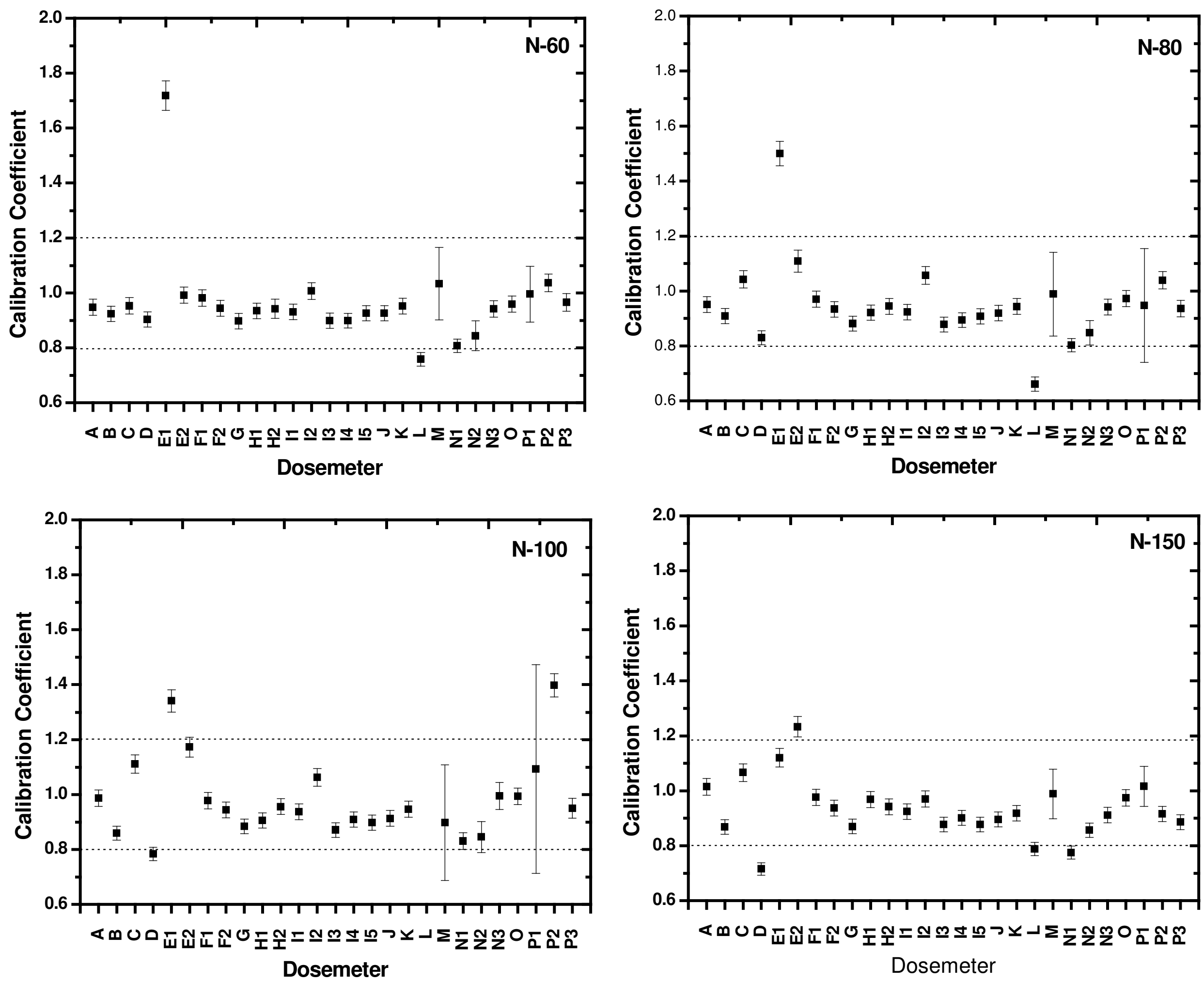

Figure 4 – Dispersion of the calibration coefficients of the ionization chambers shown in Table III obtained in the standard radioprotection beams of Table I. The dashed lines show the variation of $\pm 20\%$ relative to the conventional true value.

Table III – Calibration coefficients [N_I] and maximum energy dependence relative to the radiation quality N-80 for each chamber model, in ISO [2] standard radioprotection beams.

Dosemeter	Chamber	Volume [cm^3]	Monitor	N-60 [N_I]	U [%]	N-80 [N_I]	U [%]	N-100 [N_I]	U [%]	N-150 [N_I]	U [%]	Energy Dependence [%]	Major Application
A	Radcal 10x5-1800	1800	Radcal 9015	0.95	3.08	0.95	3.03	0.99	3.03	1.01	3.03	6.70	Radiation Protection
B	Baby Line 81	515	-	0.92	3.02	0.91	3.02	0.86	3.02	0.87	3.03	5.42	
C	Smart Ion 2100	460	-	0.95	3.09	1.04	3.04	1.11	3.02	1.07	3.03	8.55	
D	Inovision 451B	349	-	0.90	3.08	0.83	3.04	0.78	3.04	0.72	3.07	13.9	
E1	Victoreen 450P	300	-	1.72	3.10	1.50	3.02	1.34	3.02	1.12	3.02	25.3	
E2	Victoreen 450P	300	-	0.99	3.02	1.11	3.59	1.17	3.09	1.23	3.03	15.4	
F1	Radcal 10x5-180	180	Radcal 9015	0.98	3.09	0.97	3.03	0.98	3.03	0.98	3.03	3.23	Scattered Radiation
F2	Radcal 10x5-180	180	Radcal 9015	0.94	3.03	0.93	3.03	0.94	3.03	0.94	3.03	1.17	
G	Radcal 10x5-180	180	Radcal 1515	0.90	3.09	0.88	3.03	0.88	3.03	0.87	3.03	1.81	
H1	Radcal 10x5-180	180	Radcal 9010	0.94	3.04	0.92	3.04	0.91	3.04	0.97	3.03	5.16	
H2	Radcal 10x5-180	180	Radcal 9010	0.94	3.76	0.94	3.06	0.96	3.05	0.94	3.07	1.28	
I1	Radcal 20x5-180	180	Radcal 2025	0.93	3.02	0.92	3.02	0.94	3.02	0.92	3.03	1.52	
I2	Radcal 20x5-180	180	Radcal 2025	1.01	3.02	1.06	3.02	1.06	3.02	0.97	3.03	8.22	
I3	Radcal 20x5-180	180	Radcal 2025	0.90	3.03	0.88	3.03	0.87	3.03	0.88	3.03	2.34	
I4	Radcal 20x5-180	180	Radcal 2025	0.90	3.02	0.89	3.03	0.91	3.02	0.90	3.03	1.72	
I5	Radcal 20x5-180	180	Radcal 2025	0.93	3.02	0.91	3.03	0.90	3.02	0.88	3.03	3.32	
J	Radcal 10x5-6	6	Radcal 9010	0.93	3.04	0.92	3.09	0.91	3.15	0.90	3.03	2.50	Conventional Diagnostic Radiology
K	Radcal 10x5-6	6	Radcal 9015	0.95	3.03	0.94	3.07	0.95	3.09	0.92	3.04	2.65	
L	Radcal 10x5-6	6	Radcal 1515	1.03	12.7	0.99	15.5	0.90	23.5	0.99	9.14	19.2	
M	Radcal 10x5-6-3	6	Radcal 9010	0.76	3.25	0.66	3.88	0.55	3.49	0.79	3.04	9.16	
N1	Radcal 10x5-6-3	6	Radcal 9010	0.81	3.02	0.80	3.02	0.83	3.61	0.77	3.05	3.55	
N2	Radcal 10x5-6-3	6	Radcal 9010	0.84	6.42	0.85	5.29	0.85	6.68	0.86	3.05	1.10	
N3	Radcal 20x5-3	3	Radcal 2025	0.94	3.16	0.94	3.02	1.00	4.95	0.91	3.04	5.71	
O	Radcal 10x5-60	60	Radcal 9015	0.96	3.03	0.97	3.03	0.99	3.03	0.97	3.03	2.29	Fluoroscopy
P1	Radcal 20x5-6M	6	Radcal 2025	1.00	10.2	0.95	21.9	1.09	34.77	1.02	7.19	15.4	Mammography
P2	Radcal 20x5-6M	6	Radcal 2025	1.04	3.09	1.04	3.02	1.40	3.02	0.92	3.06	34.6	
P3	Radcal 20x5-6M	6	Radcal 2025	0.97	3.29	0.94	3.20	0.95	3.77	0.89	3.08	5.31	

4. CONCLUSIONS

The Victoreen ionization chambers models 415, 415A and 415B showed low energy dependence in the ISO standard narrow radioprotection beams used in this study. The ionization chamber model 415B presented the best performance: only 2.0% of energy dependence.

The two Victoreen ionization chambers model 450P presented energy dependence greater that the other chambers designed for the same use, in radioprotection beams: 25.3% and 15.4%. In relation to the spread of the calibration coefficients presented in Figure 4, one Victoreen chamber model 450P (E1) showed the worst performance, since the measurements obtained for this ionization chamber in three of four radioprotection beams of this work presented a variation greater than 20% in relation to the conventional true value. The Radcal chamber model 20x5-6M (P2) showed a great energy dependence: 34.6% (in the N-100 beam), but this occurs because this chamber is designed for use in mammography, which use beams of lower energy than the narrow beams for radioprotection of this work.

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