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Comparison of the air kerma standards for ^{137}Cs and ^{60}Co gamma-ray beams between the IAEA and the NIST

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Abstract

A comparison of the air kerma standards for ^{137}Cs and ^{60}Co gamma ray beams was performed between the NIST and the IAEA. Two reference class ionization chambers owned by the IAEA were used as part of this comparison and were calibrated at each facility. The calibration coefficients, N_K, were determined for both chambers and in both gamma-ray beams. The measurements were performed at the IAEA and NIST facilities starting in the fall of 2009 and were completed in 2010. The comparison ratio of the calibration coefficients for each chamber, $N_{K,\mathrm{IAEA}}$ / $N_{K,\mathrm{NIST}}$, between the IAEA and NIST were 0.999 and 0.997 for the ^{137}Cs and ^{60}Co gamma ray beams respectively. The relative standard uncertainty for each of these ratios is 0.5 %.

1. Introduction

The air kerma standards for ^{137}Cs and ^{60}Co gamma ray beams of the National Institute of Standards and Technology (NIST) and the International Atomic Energy Agency (IAEA) were compared for the first time under the auspices of the regional metrology organization known as the Inter-America Metrology System (SIM). This supplementary comparison is identified as SIM.RI(I)-S1. For this comparison, two reference class chambers owned by the IAEA were used. The calibration coefficient, N_K, was obtained for each chamber in each radiation protection level beam at both facilities. The comparison results are expressed as the ratio of the calibration coefficients obtained at each laboratory.

2. Transfer chambers

Two reference class ionization chambers owned by the IAEA were used during this comparison. The physical properties of these two chambers are listed in Table 1. Both chambers are spherical and made of C552 air equivalent plastic. The nominal volumes of the chambers were 100 cm^3 and 1000 cm^3 for the models A5 and PTW TN32002, respectively. They were aligned with the stems perpendicular to the gamma-ray beam and with the white mark on the chamber facing the source of radiation. A negative voltage was applied to the outer wall while the center electrode was kept at ground potential. In this way negative charge was collected.

Table 1. Description of the chambers.

Chamber Name and Model[a]	Serial Number	Sensitive volume (nominal) / cm^3	Outside Diameter (nominal) / cm	Wall Thickness (nominal) / mm	Applied Potential / V
Exradin A5	XY032721	100	6	3	300
PTW TN32002	277	1000	14	3	400

3. Reference beams at the NIST and at the IAEA.

3.1. Reference rates at the NIST

The gamma-ray measurements were made in the NIST ^{137}Cs and ^{60}Co gamma ray beam calibration facilities. The air kerma rates in these facilities were obtained by applying a decay correction to the reference air kerma rate. The reference air kerma rates were determined using a suite of six graphite-wall cavity ionization chambers which constitute the NIST primary standard instruments. Details on the determination of the construction and evaluation of the reference air kerma rates are in [1].

In brief, the reference air kerma rates, $\dot{K}$, at the NIST were determined from the equation

$$\dot{K} = \frac{I}{V\rho_{\mathrm{air}}} \frac{(W_{\mathrm{air}}/\mathrm{e})}{1-\bar{g}} (S/\rho)^{graphite}_{air} (\mu_{\mathrm{en}}/\rho)^{air}_{graphite} \prod_i k_i \, , \qquad (1)$$

where
I is the measured ionization current,
V is the volume of air cavity,
ρ_{air} is the density of dry air at the measurement temperature and pressure,
W_{air}/e is the mean energy expended in dry air by electrons per ion pair formed (33.97 J/C),
$\bar{g}$ is the mean fraction of the initial kinetic energy of secondary electrons liberated by photons that is lost through radiative processes in air. The value of $\bar{g}$ for ^{60}Co has been re-evaluated [2] and found to be consistent with the previous value [3] of 0.0032 adopted by the NIST,
k_i, are correction factors,
$(S/\rho)^{graphite}_{air}$ is the ratio of the mean collision mass stopping powers,
$(\mu_{\mathrm{en}}/\rho)^{air}_{graphite}$ is the ratio of photon mass energy-absorption coefficients.

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[a] Certain commercial equipment, instruments, and materials are identified in this work in order to specify adequately the experimental procedure. Such identification does not imply recommendation nor endorsement by NIST nor does it imply that the material or equipment identified is the best available for the purposes described in this work.

The value of the quantities and factors used in (1) can be found in earlier publications [1, 4 and 5]. The correction factors k_i include: a humidity correction for the effects of moist air; a correction for the loss of ionization due to ion recombination, k_{sat}; and corrections for stem scattering, and wall absorption and scattering (k_{wall}). The value of the wall correction, k_{wall}, was revised by Seltzer and Bergstrom [2] resulting in a change of 0.90 % for the ^{137}Cs air kerma rates and 1.05 % for the ^{60}Co air kerma rates. This change was implemented on July 1, 2003.

The decay-corrected daily values of the air kerma rate are checked routinely using a large variety of reference class chambers. A history is maintained for the calibration coefficient for these reference class chambers which can be traced back to the original reference date. The gamma beams used were collimated and are uniform over the area across the chamber. The source to detector distances, the beam size and air kerma rates used for each chamber are listed in Table 2a.

Table 2a. Beam parameters at the NIST

Chamber Model	Serial Number	Source	Distance / cm	Beam Radius / cm	Air Kerma Rate / (Gy/s)
A5	XY032721	^{137}Cs	195	41	2.53×10^{-5}
		^{60}Co	150	29	7.90×10^{-7}
TN32002	277	^{137}Cs	307	58	1.06×10^{-6}
		^{60}Co	307	59	1.86×10^{-7}

3.2. Reference air kerma rates at the IAEA

The gamma-ray measurements were made in the IAEA ^{137}Cs and ^{60}Co gamma ray beams. The air kerma rates were determined using the secondary standard ionization chamber LS-01. This chamber was calibrated in terms of air kerma for ^{137}Cs and ^{60}Co gamma ray beams at BIPM in June 2008. As of 1 November 2009, a correction reflecting the change of the BIPM standards has been introduced [6, 7].

The reference air kerma rates, *K*, at the IAEA were determined from the equation

$$\dot{K} = I \cdot k_{T,P,H} \cdot k_{sat} \cdot N_K \cdot k_{BIPM} \qquad (2)$$

where

I	is the measured current
$k_{T,P,H}$	correction of the ionization chamber response for the environmental conditions
k_{sat}	correction for the loss of ionization due to ion recombination
N_K	air kerma calibration coefficient
k_{BIPM}	correction to reflect a change of the primary standard [6].

The air kerma rates at the reference point of the IAEA calibration facility are checked routinely with various ionization chambers as a part of the Quality Assurance system. A history of air kerma rates determined is maintained. The gamma beams used were collimated and are uniform over the cross-sectional area of the chamber volume. The source to detector distances, the beam size and kerma rates used for each chamber are listed in Table 2b

Table 2b. Beam parameters at IAEA.

Chamber Model	Serial Number	Source	Distance / cm	Beam Radius / cm	Air Kerma Rate / (Gy/s)
A5	XY032721	^{137}Cs	200	50	1.07 x 10^{-6}
		^{60}Co	200	50	9.48 x 10^{-8}
TN32002	277	^{137}Cs	300	75	2.38 x 10^{-6}
		^{60}Co	300	75	2.10 x 10^{-7}

4. Calibration coefficients

For each chamber, the air kerma calibration coefficient, N_K was determined by evaluating the ratio

$$N_K = \dot{K} / I \qquad (3)$$

where $\dot{K}$ is the air-kerma rate at each calibration facility (determined by applying a decay correction to the original reference air-kerma rate value) and I is the ionization current measured with one of the chambers and corrected for influence quantities. The air kerma rate, $\dot{K}$, is expressed in units of Gy/s while the ionization current is expressed in units of C/s. The value of the ionization current I includes corrections to account for deviations of the ambient temperature and pressure from the NIST reference conditions of 295.15 K and 101.325 kPa, respectively. No correction for electronic recombination was applied to the measurements since the magnitude of the correction was the same at both facilities (of the order of 0.05 %) and therefore the effect on the comparison result was negligible.

5. Procedure, measurement conditions at the NIST and the IAEA.

At both facilities each calibration was made by using the substitution method in which the transfer chambers listed in Table 1 are calibrated following the prior calibration of a check chamber. A check chamber is any of the reference class chambers owned by the IAEA and the NIST for which a significant amount of data has been collected over the years. In this way the response and stability of the chamber is well known in the radiation beams in which they are used. A successful calibration of a check chamber ensures that the measurement system and the air kerma rates delivered meet the expected results. For all the measurements performed, the chambers are positioned with the stem perpendicular to the beam axis. The chambers are aligned relative to the source using the center of the detection volume using an alignment telescope. The uncertainty in the position is better than 0.1 mm. Since the measurement distances are of the order of 200 cm, the uncertainty in the position results in a negligible contribution to the overall uncertainty of the measurements (less than 0.01 %). The distances at which the detectors were positioned at both the NIST and the IAEA are listed in Tables 2a and 2b. The exact beam geometry was not prescribed in the protocol so that both participants could use the appropriate geometry depending on the field size and field uniformities available and the conditions that best represents routine calibrations at their facility. The influence of field size was not investigated for this comparison.

At both facilities the chamber background current was measured before and after the chamber was exposed to the source of radiation. The average of the background currents was determined and subtracted from the measured ionization current produced in the chamber when exposed to the source of radiation. Typical background currents were of the order of 0.1 % of the ionization current. The integration time used both at the NIST and the IAEA was 60 s. At both facilities the measured ionization currents were normalized to standard values of temperature and pressure. The normalizing value for pressure at the NIST and the IAEA is 101 325 kPa. The normalization values for temperature are usually 295.15 K and 293.15 K at the NIST and the IAEA, respectively, but for the comparison, the normalization of 295.15 K was used. The humidity was monitored and recorded and was typically in a range of 30 %, however the currents were not corrected for humidity. Only the negative polarity measurements were used for the comparison results, resulting in a negative charge collected on the electrometers. No correction was applied to the calibration coefficient to account for polarity effect since at both facilities the same polarity was used.

6. Uncertainties

The uncertainties associated with the measurements made at the NIST and the IAEA are listed in Tables 3a and 3b. The various sources of uncertainty are grouped according to Type A and Type B methods of evaluation, following the guidelines described elsewhere [8]. Type A evaluations are based on statistical analysis while Type B evaluations are based on scientific judgment. The uncertainty of the calibration coefficient, N_K, is obtained essentially by combining the uncertainties of the standard air kerma rate, $\dot{K}_{std}$, and the ionization current corrected for all influence quantities. As shown in the table, the relative fractional combined uncertainty of the calibration coefficients, N_K, at the NIST is 0.0034 while the value at the IAEA is 0.0037. This results in relative combined uncertainties of 0.34 % and 0.35 %, respectively and relative expanded uncertainties of 0.68 % and 0.74 %, respectively. The relative expanded uncertainty is obtained by multiplying the relative combined uncertainties by a coverage factor of $k = 2$. The relative expanded uncertainty is considered to have approximately the significance of a 95 % confidence interval. Table 4 lists the relative combined uncertainty of the comparison ratios obtained in both gamma-ray beams.

Table 3a. Relative uncertainties associated with the measurements made at the NIST

	NIST	
Relative standard uncertainty	u_{iA}	u_{iB}
Charge	0.0010	0.0010
Time		0.0005
Air density correction (temperature and pressure)		0.0003
Distance		0.0002
k_{sat}, loss of ionization due to recombination	0.0001	0.0005
Probe orientation		0.0001
Humidity		0.0006
Chamber current, u_i corrected for all influence quantities	0.0010	0.0014
	0.0017	
$\dot{K}_{\text{Standard}}$	0.0029	
$N_{\boldsymbol{K},\text{NIST}}$ – combined standard uncertainty	0.0034	

Table 3b. Relative uncertainties associated with the measurements made at IAEA

	IAEA	
Relative standard uncertainty	u_{iA}	u_{iB}
Air density correction (temperature)	0.0002	0.0003
Air density correction (pressure)	0.0005	0.0006
Chamber positioning		0.0001
Current measurement		0.0006
Chamber current, u_i corrected for all influence quantities	0.0005	0.0004
	0.0006	
$\dot{K}_{\text{Standard}}$	0.0035	
$N_{\boldsymbol{K},\text{IAEA}}$ – combined standard uncertainty	0.0036	

Table 4. Relative uncertainties associated with the comparison results

Relative standard uncertainty	u_i
$N_{K,\text{NIST}}$	0.0034
$N_{K,\text{IAEA}}$	0.0036
$N_{K,\text{IAEA}}$ / $N_{K,\text{NIST}}$	0.0049
$\dot{K}_{\text{IAEA}}/\dot{K}_{\text{NIST}}$	0.0049

7. Results and discussion

Table 5 shows a summary of the comparison results. It includes the actual value of the calibration coefficients $N_{K,\mathrm{NIST}}$ and $N_{K,\mathrm{IAEA}}$ obtained at the NIST and the IAEA facilities, respectively for each chamber in a given reference beam. The ratio of the calibration coefficients obtained with each chamber in a given reference beam is also shown in Table 5. The result of the comparison for each reference beam can be determined from the average of the ratios $N_{K,\mathrm{IAEA}}/N_{K,\mathrm{NIST}}$ obtained with each chamber. The final comparison ratios are 0.999 and 0.997 for ^{137}Cs and ^{60}Co, respectively. This represents an agreement of 0.1 % for ^{137}Cs and 0.3 % for ^{60}Co between NIST and IAEA.

Table 5: Comparison results

Beam	Chamber Model	$N_{K,\mathrm{IAEA}}$[b] / (Gy/C)	$N_{K,\mathrm{NIST}}$[b] / (Gy/C)	$N_{K,\mathrm{IAEA}}$ / $N_{K,\mathrm{NIST}}$ per chamber[c]	$N_{K,\mathrm{IAEA}}$ / $N_{K,\mathrm{NIST}}$
^{137}Cs	A5	$3.038_0 \times 10^5$	$3.040_4 \times 10^5$	0.999 (5)	0.999 (5)
	TN32002	$2.520_3 \times 10^4$	$2.522_9 \times 10^4$	0.999 (5)	
^{60}Co	A5	$2.988_0 \times 10^5$	$3.001_8 \times 10^5$	0.995 (5)	0.997 (5)
	TN32002	$2.479_8 \times 10^4$	$2.484_7 \times 10^4$	0.998 (5)	

8. Conclusions

The work presented here constitutes the first bilateral comparison between the IAEA and the NIST for air kerma from ^{137}Cs and ^{60}Co gamma ray beams. The realization of the air kerma standard at both metrological institutes is made differently. At the NIST the air kerma is realized from primary standards directly by evaluating (1). In the case of the IAEA the realization of the air kerma is obtained evaluating (2) using reference standards with traceability to the SI via the BIPM. Despite these different approaches the results obtained from the measurements performed in this work, show a good level of agreement of the air kerma standards maintained at both metrological institutes. An agreement of well within one standard uncertainty is obtained for the air kerma from ^{137}Cs and ^{60}Co protection-level gamma ray beams in this SIM.RI(I)-S1 supplementary comparison.

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[b] Numbers in subscript are included to minimize rounding errors when the air-kerma rates are used in calculations but do not represent the level of accuracy of the measurements.

[c] The number in parenthesis represents the standard uncertainty on the final digit i.e. a value of 0.005.

8. References

[1] Loftus, T.P., Weaver, J.T., 1974. Standardization of ^{60}Co and ^{137}Cs gamma-ray beams in terms of exposure. J. Res. Nat. Bur. Stand. 78A, 465-476.

[2] Seltzer, S.M., Bergstrom, P.M., 2003. Changes in the U.S. primary standards for the air kerma from gamma-ray beams. J. Res. Natl. Inst. Stand. Technol. 108, 359-381.

[3] M. Boutillon, *Report CCEMRI (I)/ 85-18 to Section I of CCEMRI (Consultative Committee for Standards for the Measurement of Ionizing Radiation),* Bureau International des Poids et Mesures, Sèvres, France (1985).

[4] Minniti, R., NIST Quality Manual, Ionizing Radiation Division QM-II, Procedure 4. Calibration of gamma-ray radiation detectors. Gaithersburg, MD: NIST, 2004;

[5] Minniti, R., Chen-Mayer H., Seltzer S. M. , Huq S. M. , Bryson L., Slowey T. , Micka J. A., DeWerd L. A., Wells N., Hanson W. F., and Ibbott G. S. (2006). “The US radiation dosimetry standards for ^{60}Co therapy level beams, and the transfer to the AAPM accredited dosimetry calibration laboratories.” *Med Phys* 33:1074.

[6] BIPM, private communication, 2009-Oct-14.

[7] Allisy-Roberts P.J., Burns D.T., Kessler C., Measuring conditions used for the calibration of national ionometric standards at the BIPM, *Rapport BIPM*-2009/04, 20 pp

[8] ANSI/NCSL Z540-2-1997, 1997. U.S. Guide to the Expression of Uncertainty in Measurement, American National Standard for Expressing Uncertainty. (NCSL, Boulder, CO).