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Abstract
A comparison of the standards of air kerma of the Slovenský Metrologický Ústav (SMU) and of the Bureau International des Poids et Mesures (BIPM) has been carried out in ^{60}Co radiation. It shows that the SMU and BIPM standards agree to 0.33 %, which is compatible with the comparison uncertainty.

1. Introduction

A comparison of the standards of air kerma of the Slovenský Metrologický Ústav (SMU), Bratislava, Slovakia, and of the Bureau International des Poids et Mesures (BIPM), has been carried out in ^{60}Co radiation. The SMU standard of air kerma is a graphite cavity ionization chamber constructed at the Országos Mérésügyi Hivatal (OMH), Budapest, Hungary (type ND1005/A, serial number 8111), details of which are given in section 3 of this report. The BIPM air kerma standard is described in [1]. The comparison took place at the BIPM in September 2000. The results obtained with the two standards agree to 0.33 %, which is compatible with the uncertainty (0.27 %) of the comparison.

2. Conditions of measurement

The air kerma is determined at the BIPM under the following conditions [2]:
- the distance from source to reference plane is 1 m;
- the field size in air at the reference plane is 10 cm × 10 cm, the photon fluence rate at the centre of each side of the square being 50 % of the photon fluence rate at the centre of the square.

3. Determination of the air kerma

The air kerma rate is determined by

$$\dot{K} = \frac{I}{m}\frac{W}{e}\frac{1}{1-\bar{g}}\left(\frac{\mu_{\mathrm{en}}}{\rho}\right)_{\mathrm{a,c}} \bar{s}_{\mathrm{c,a}} \prod k_i \quad , \tag{1}$$

where

I/m is the ionization current per unit mass of air measured by the standard,
W is the average energy spent by an electron of charge e to produce an ion pair in dry air,
$\bar{g}$ is the fraction of electron energy lost by bremsstrahlung,
$(\mu_{\mathrm{en}}/\rho)_{\mathrm{a,c}}$ is the ratio of the mean mass-energy absorption coefficients of air and graphite,
$\bar{s}_{\mathrm{c,a}}$ is the ratio of the mean stopping powers of graphite and air,
$\prod k_i$ is the product of the correction factors to be applied to the standard.

The main characteristics of the SMU primary standard are given in Table 1.

Table 1. Characteristics of the SMU standard of air kerma

Type	ND1005/A - 8111	Nominal values
Chamber	Outer height / mm	19
	Outer diameter / mm	19
	Inner height / mm	11
	Inner diameter / mm	11
	Wall thickness / mm	4
Electrode	Diameter / mm	2
	Height / mm	10
Volume	Air cavity / cm^3	1.0185
	relative standard uncertainty / cm^3	0.0019
Wall	Material	ultrapure graphite
	Density / $(\mathrm{g \cdot cm^{-3}})$	1.71
	Impurity fraction	$< 1.5 \times 10^{-4}$
Applied tension	Voltage / V	300

4. Experimental results

Data concerning the various factors entering in the determination of air kerma in the ^{60}Co beam using the two standards are shown in Table 2. They include the physical constants [3], the correction factors entering in (1), the volume of each chamber cavity and the associated uncertainties [2]. Also shown are the components of the relative standard uncertainty in the ratio $R_K = \dot{K}_{\mathrm{SMU}} / \dot{K}_{\mathrm{BIPM}}$.

Table 2. Physical constants and correction factors entering in the determination of air kerma and their estimated relative standard uncertainties in the BIPM ^{60}Co beam

	BIPM values	relative (1) standard uncertainty/ %		SMU values	relative (1) standard uncertainty / %		R_K relative (1) standard uncertainty / %	
		s_i	u_i		s_i	u_i	s_i	u_i
Physical constants								
ρ_{air} dry air density / kg·m^{-3} (2)	1.293 0	-	0.01	1.293 0	-	0.01	-	-
$(\mu_{\mathrm{en}}/\rho)_{\mathrm{a,c}}$	0.998 5	-	0.05	0.998 5	-	0.05	-	-
$\bar{s}_{\mathrm{c,a}}$ stopping power ratio	1.001 0	-	0.11	1.001 0	-	0.11	-	-
W/e /(J C^{-1})	33.97			33.97				
$\bar{g}$ fraction of energy lost by bremsstrahlung	0.003 2	-	0.02	0.003 2	-	0.02	-	-
Correction factors								
k_{s} recombination losses	1.001 5	0.01	0.01	1.001 7	0.01	0.03	0.01	0.03
k_{h} humidity	0.997 0	-	0.03	0.997 0	-	0.03	-	-
k_{st} stem scattering	1.000 0	0.01	-	0.999 7	0.01	-	0.01	-
k_{at} wall attenuation	1.039 8	0.01	0.04					
k_{sc} wall scattering	0.972 0	0.01	0.07	1.010 9	0.02	0.10	0.02	0.13
k_{CEP} mean origin of electrons	0.992 2	-	0.01					
k_{an} axial non-uniformity	0.996 4	-	0.07	0.999 8	-	0.01	-	0.07
k_{rn} radial non-uniformity	1.001 6	0.01	0.02	1.000 3	-	0.01	0.01	0.02
Measurement of $I/v\rho$								
v volume / cm^3	6.802 8	0.01	0.03	1.018 5	0.19	0.10	0.19	0.10
I ionization current		0.01	0.02		0.02	0.04	0.02	0.04
Uncertainty								
quadratic summation		0.03	0.17		0.19	0.20	0.19	0.19
combined uncertainty		0.17			0.27		0.27	

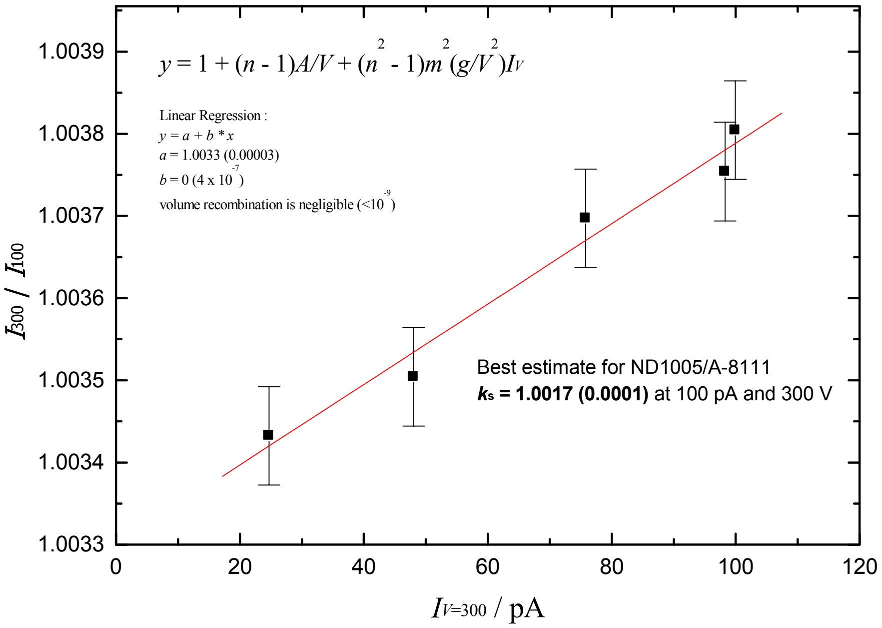
(1) Expressed as one standard deviation.
s_i represents the relative standard Type A uncertainty, estimated by statistical methods;
u_i represents the relative standard Type B uncertainty, estimated by other means.

(2) At 101 325 Pa and 273.15 K.

The correction factors for the SMU standard were determined at the SMU [4]. Some measurements concerning the effect of ion recombination and the effect of attenuation and scatter in the chamber walls were also made in the BIPM beam.

The ratio of the ionization currents obtained with applied voltages of 300 V and 100 V (both polarities in each case) was measured for a series of four different air kerma rates in the BIPM ^{60}Co beam. The resultant linear fit identified an ion recombination effect at 300V identical to that previously determined at the BIPM for this chamber type. Consequently, the correction k_s of 1.0017 (0.0001) for ion recombination was applied to the SMU standard in the BIPM beam. Figure 1 shows the experimental determination. As this correction is primarily for initial recombination, a similar correction would be expected to apply at the SMU although a larger correction would be appropriate for an air kerma rate in excess of 5 mGy s^{-1}.

Figure 1 Recombination effect for SMU primary standard



The procedure of adding graphite to the walls of the cavity chamber is used to determine the attenuation in the walls and the scatter correction at the SMU. The value obtained, 1.0109 (0.0010), agrees with that measured by the SMU method at the BIPM for a transfer standard of the same shape and size. However, this method is discussed further in the next section.

An additional correction factor k_{rn} for the radial non-uniformity of the BIPM beam over the section of the SMU standard has been estimated from [5]; its numerical value is 1.0003.

The volume of the standard was re-measured at the SMU subsequent to some repairs. A comparison made with another laboratory agreed with the new value for the volume of 1.0185 cm^3 within the estimated uncertainty of 0.19 %.

The result of the comparison $R_K = \dot{K}_{SMU} / \dot{K}_{BIPM}$ is given in Table 3. The $\dot{K}_{BIPM}$ value is the mean of measurements that were performed over a period of one month before and after the present comparison. The ratio of the values of the air kerma rate determined by the SMU and the BIPM standards is 1.0033 with a combined standard uncertainty, u_c, 0.0027. Some of the uncertainties in $\dot{K}$ which appear in both the BIPM and the SMU determinations (such as air density, W/e, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{c,a}$ and k_h) cancel when evaluating the uncertainty of R_K.

Table 3. Results of the SMU-BIPM comparison of standards of air kerma

$\dot{K}_{\text{SMU}}$ (1) / (mGy·s^{-1})	$\dot{K}_{\text{BIPM}}$ (1) / (mGy·s^{-1})	R_K	u_c
3.123 94	3.113 54	1.0033	0.0027

(1) The $\dot{K}$ values refer to an evacuated path length between source and standard and are given at the reference date of 2000-01-01, 0h UT where the half life of ^{60}Co is taken as 1 925.5 days (u = 0.5 days) [6].

6. Discussion

For more than 10 years there have been intensive discussions on wall correction factors for cavity ionization chambers determined with an experimental extrapolation method versus those calculated using Monte Carlo methods [7-9]. There has also been considerable debate over the corrections for non-uniformity and the point of measurement [10, 11].

The majority of the NMIs currently use wall correction factors that have been determined by the linear extrapolation method. Both experimental and theoretical results have been provided in recent years which strongly support the validity of calculated wall correction factors and these calculated values differ significantly from those obtained by linear extrapolation of experimental data to zero wall thickness. This is particularly the case for the cylindrical cavity chambers, such as the ND 1005, that are used as primary air kerma standards by some national metrology institutes (NMIs). In some cases, the differences amount to 50 % of the correction itself [12].

During the 14th CCRI(1) meeting in 1999, the various approaches for determining wall and axial non-uniformity correction factors for graphite cavity standards were discussed in detail [13]. It became apparent that several NMIs were actively re-evaluating their correction factors for ^{60}Co air kerma standards including their uncertainties at the time of the meeting. It was agreed to set up a working group (WG) to study the implications of using correction factors for ^{60}Co air kerma standards based on Monte Carlo methods. The members of the WG included the BNM-LNHB, NIST, NMi, NPL and the BIPM. The NRC agreed to act as a consultant and submit to the working group a paper that it intended to publish on this topic. Furthermore it was decided that before publishing results in the key comparison database (KCDB), which shows the degrees of equivalence between the NMIs (Appendix B of the MRA), the BIPM would ask the NMIs to review their uncertainty budgets for air kerma standards in ^{60}Co gamma radiation. It was further suggested that the method of determining the correction factors (e.g. Monte Carlo or experimental) should be identified in the KCDB together with a statement on the implications of differences between the two methods with respect to the uncertainty [13].

The debate continued during the 15th CCRI(I) meeting in 2001 and several NMIs produced working documents [12, 14-16] describing the work undertaken since the 1999 meeting. Significant contributions were made to the debate on wall correction factors for cavity chambers. As a consequence, it was agreed that the WG evaluate the information available and make recommendations on the procedure to ensure that the results to be entered in the

KCDB are valid. A draft report is in progress and will be distributed to all NMIs who have made comparisons of their primary standards with the BIPM.

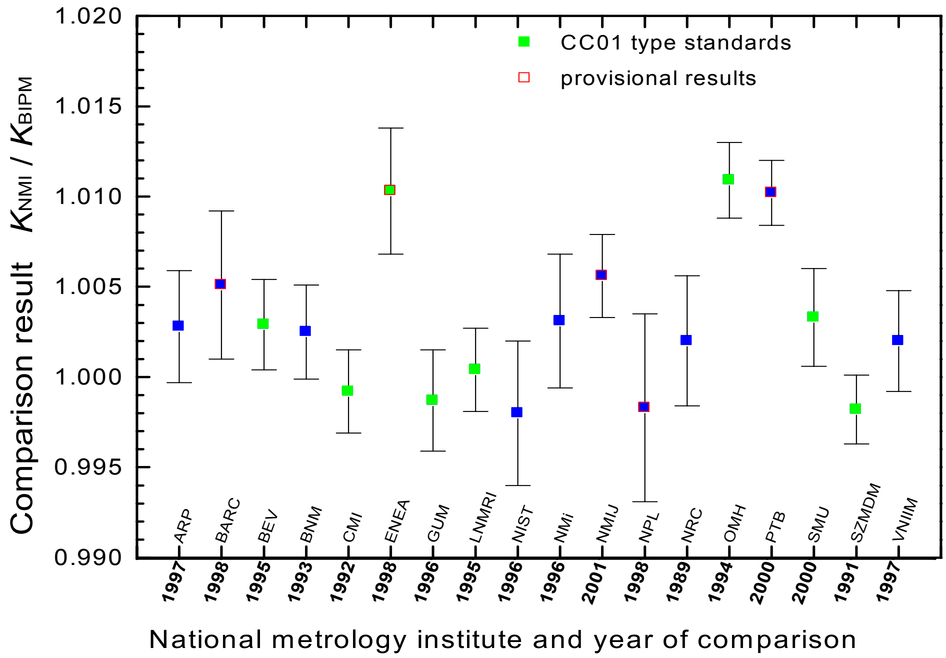
The results of comparisons at the BIPM with standards of the same type as that of the SMU are given in Table 4 and shown in Figure 2 (in green). The OMH has recently declared a new value for its air kerma standard. There appear to be two groups of results, each of which is self-consistent within the estimated uncertainties, but different from each other by about 1 %. The group with the higher values has re-evaluated its wall correction factor using Monte Carlo calculations. However, some of the other NMIs with different shaped standards have also used Monte Carlo calculations but their results are consistent with the lower group.

It is anticipated that the debate will continue for a further year before all the NMIs are ready for their results to be entered into the KCDB.

Table 4. Comparison of the BIPM standard with CC01-type standards belonging to national laboratories

Laboratory and year		$\dot{K}_{\mathrm{Lab}} / \dot{K}_{\mathrm{BIPM}}$ ^{60}Co	Relative standard uncertainty u_c / %
SZMDM	1991 [18]	0.998 2	0.2
UDZ	1992 [19]	0.999 2	0.2
OMH	1972 [20]	1.003 9	0.5
	1986 [21]	1.000 9	0.3
	1994 [22, 14]	1.010 9	0.2
BEV	1980 [23] 1989 [24]	1.001 4	0.3
	1994 [25]	1.004 0	0.2
	1995 [26]	1.002 9	0.3
LNMRI	1986 [27]	1.001 0	0.3
	1995 [28]	1.000 4	0.2
GUM	1996 [29]	0.998 7	0.3
SMU	[this work]	1.003 3	0.3

Figure 2 International air kerma comparison results



7. Conclusion

The SMU standard for air kerma in ^{60}Co gamma radiation is in agreement (0.33 %) with the BIPM air kerma standard and with other national standards. This is shown in Figure 2. However, all the NMIs and the BIPM are currently re-evaluating their cavity chamber wall correction factors and the overall picture for the comparison results may well change as a consequence.

References

[1] BOUTILLON M. and NIATEL M.-T., A study of a graphite cavity chamber for absolute measurements of ^{60}Co gamma rays, *Metrologia*, 1973, **9**, 139-146.

[2] BOUTILLON M. ALLISY-ROBERTS P.J. and BURNS D.T., Measuring conditions used for the calibration of ionization chambers at the BIPM, *Rapport BIPM-01/04*, 2001, 19 pp.

[3] BIPM, Constantes physiques pour les étalons de mesure de rayonnement, *BIPM Com. Cons. Etalons Mes. Ray. Ionisants*, *Section (I)*, 1985, **11**, p. R45 (Paris: Offilib).

[4] GABRIS F., PRIBYLSKY P., DOBROVODSKY J., Photon radiation standard complex report representing quantities photon air kerma, photon absorbed dose to water, photon dose equivalents and their rates, Final SMU Report, December 2000, 42 pp.

[5] BOUTILLON M. and PERROCHE A.-M., Radial non-uniformity of the BIPM ^{60}Co beam, *Rapport BIPM-89/2*, 1989, 9 pp.

[6] IAEA, X- and gamma-ray standards for detector calibration, *IAEA TECDOC-619,* 1991.

[7] ROGERS D.W.O., BIELAJEW A.F. and NAHUM A.E. Ion chamber response and A_{wall} correction factors in a ^{60}Co beam by Monte Carlo simulation, *Phys. Med. Biol.* **30**, 1985, 429–443.

[8] BIELAJEW A.F. and ROGERS D.W.O. Implications of new correction factors on primary air kerma standards in ^{60}Co beams, *Phys. Med. Biol.* **37**, 1992, 1283–1291.

[9] ROGERS D.W.O. and TREURNIET J. Monte Carlo calculated wall and axial non-uniformity corrections for primary standards of air kerma, *NRCC Report PIRS–663* and *CCRI Working document* CCRI(I)/99-26, 1999, 25 pp.

[10] KONDO S. and RANDOLPH M.L. Effect of finite size of ionization chambers on measurements of small photon sources, *Radiat. Res.* **13**, 1960, 37–60.

[11] BIELAJEW A.F. Correction factors for thick-walled ionisation chambers in point-source photon beams, *Phys. Med. Biol*. **35**,1990, 501–516.

[12] BÜERMANN L., KRAMER H.-M. and CSETE I. Results supporting calculated wall correction factors for cavity chambers, *CCRI Working document* CCRI(I)/01-18, 2001, 10 pp.

[13] BIPM, (1999) The estimation of k_{att}, k_{sc} k_{CEP} and their uncertainties in, *Com.Cons.Ray.Ionisants* **16** 145-146 (Paris:Offilib).

[14] CSETE I., New correction factors for the OMH air kerma standard for ^{137}Cs and ^{60}Co radiation, *CCRI Working document* CCRI(I)/01-03, 2001, 2 pp.

[15] KRAMER H.-M., BÜERMANN L. and CSETE I. Comparison of the PTB and OMH air kerma standards for ^{60}Co and ^{137}Cs gamma radiation, *CCRI Working document* CCRI(I)/01-17, 2001, 9 pp.

[16] ROGERS D.W.O., CAFFREY J.P., KAWRAKOW I. and SHORTT K.R. (2001) Wall correction factors for graphite walled ion chambers, *CCRI Working document* CCRI(I)/01-25, 10 pp.

[17] ROGERS D.W.O., CAFFREY J.P., KAWRAKOW I. and SHORTT K.R. Update to wall correction factors for graphite walled ion chambers, *CCRI Working document* CCRI(I)/01-39, 2001, 8 pp.

[18] PERROCHE A.-M. and SPASIC JOKIC V., Comparison of the air kerma standards of SZMDM and BIPM for ^{60}Co radiation, *Rapport BIPM-92/3*, 1992, 6 pp.

[19] PERROCHE A.-M., BOUTILLON M., KOVAR I and WAGNER R., Comparison of the air kerma standards of the UDZ and the BIPM for ^{60}Co radiation, *Rapport BIPM-93/1*, 1993, 6 pp.

[20] NIATEL M.-T., Comparaison des étalons d'exposition (^{60}Co) du BIPM et de l'OMH, *Procès-verbaux du CIPM*, **41** (1973) 62 (Paris: Offilib).

[21] ALLISY A., BIPM comparison of exposure rate and air kerma rate in ^{60}Co gamma rays, *BIPM Rapport*, October 1986.

[22] PERROCHE A.-M., BOUTILLON M. and CSETE I., Comparison of the standards of air kerma of the OMH and the BIPM for ^{137}Cs and ^{60}Co γ rays, *Rapport BIPM-94/13*, 1994, 10 pp.

[23] NIATEL M.-T. and BOUTILLON M., Comparaison d'étalon d'exposition, *Procès-verbaux du CIPM*, **49** (1981) 61 (Paris: Offilib).

[24] LEITNER A., Adoption of new values of physical constants for radiation measurement standards, *Letter to BIPM*, (Personal communication) August 1989.

[25] PERROCHE A.-M., BOUTILLON M. and LEITNER A., Comparison of the standards of air kerma and absorbed dose to water of the BEV and the BIPM for ^{60}Co γ rays, *Rapport BIPM-94/7*, 1994, 7 pp.

[26] ALLISY-ROBERTS P.J., BOUTILLON M. and WITZANI J., Comparisons of the standards of air kerma of the BEV and the BIPM for ^{137}Cs and ^{60}Co γ rays, *Rapport BIPM-95/5*, 1995, 9 pp.

[27] DE ALMEIDA C.E. and NIATEL M-T., Comparisons between IRD and BIPM exposure and air kerma standards for cobalt-60 gamma rays, *Rapport BIPM-86/12*, 1986, 20 pp.

[28] ALLISY-ROBERTS P.J., BOUTILLON M. and RODRIGUES L.N., Comparison of the standards of air kerma of the LNMRI and the BIPM for ^{60}Co γ rays, *Rapport BIPM-96/3*, 1996, 8 pp.

[29] ALLISY-ROBERTS P.J., BOUTILLON M., REFEROWSKI Z. and PAZ N. Comparison of the standards of air kerma of the GUM and the BIPM for ^{60}Co γ rays, *Rapport BIPM-97/2*, 1997, 6 pp.

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