Comparison of the standards of air kerma of the GUM and the BIPM for ^{60}Co γ rays

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Abstract
A comparison of the standards of air kerma of the Glówny Urzad Miar (GUM) and of the Bureau International des Poids et Mesures (BIPM) has been carried out in ^{60}Co radiation. It shows that the GUM and BIPM standards agree to 0,13 %.

1. Introduction

A comparison of the standards of air kerma of the Glówny Urzad Miar (GUM), Miar, Warsaw, Poland, and of the Bureau International des Poids et Mesures (BIPM), has been carried out in ^{60}Co radiation. The GUM standard of air kerma is a graphite cavity ionization chamber constructed at the Orszagos Mérésügyi Hivatal (OMH), Budapest, Hungary (type ND1005, serial number 8303) 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 November 1996. The results obtained with the two standards agree to 0,13 % which is within the standard uncertainties.

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 x 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 GUM primary standard are given in Table 1.

Table 1. Characteristics of the GUM standard of air kerma

Type	ND1005 - 8303	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	1,013
	relative uncertainty / cm^3	0,002
Wall	Material	ultrapure graphite
	Density / $g \cdot cm^{-3}$	1,71
	Impurity fraction	$< 1,5 \times 10^{-4}$
Applied tension	Voltage / V	±250

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 relative uncertainties in the ratio $R_K = \dot{K}_{\mathrm{GUM}} / \dot{K}_{\mathrm{BIPM}}$.

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

	BIPM values	relative [(1)] uncertainty / %		GUM values	relative [(1)] uncertainty / %		R_K relative [(1)] uncertainty / %	
		s_i	u_i		s_i	u_i	s_i	u_i
Physical constants								
dry air density / kg·m^{-3} [(2)]	1,293 0	-	0,01	1,293 0	-	0,01	-	-
$(\mu_{en}/\rho)_{a,c}$	0,998 5	-	0,05	0,998 5	-	0,05	-	-
$\bar{s}_{c,a}$	1,001 0	-	0,30	1,001 1	-	0,30	-	-
W/e	33,97	-	0,15	33,97	-	0,15	-	-
$\bar{g}$ fraction of energy lost by bremsstrahlung	0,003 2	-	0,02	0,003 2	-	0,02	-	-
Correction factors								
k_s recombination losses	1,001 6	0,01	0,01	1,002 3	0,02	0,03	0,02	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 4	0,01	-	0,01	-
k_{at} wall attenuation	1,040 2	0,01	0,04				0,01	0,04
k_{sc} wall scattering	0,971 6	0,01	0,07	1,015 5	0,01	0,10	0,01	0,12
k_{CEP} mean origin of electrons	0,992 2	-	0,01	0,995 5	0,01	0,10	0,01	0,10
k_{an} axial non-uniformity	0,996 4	-	0,07	1,000 0	-	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	6,811 6	0,01	0,03	1,013	-	0,20	0,01	0,20
I ionization current		0,01	0,02		0,03	0,06	0,03	0,06
Uncertainty								
quadratic summation		0,02	0,36		0,04	0,43	0,04	0,28
combined uncertainty		0,36			0,43		0,28	

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

(2) At 101 325 Pa and 273,15 K.

The correction factors for the GUM standard were determined at the GUM. Some measurements concerning the effect of ion recombination and the effect of attenuation and scatter in the chamber walls were made again in the BIPM beam.

The ratio of the ionization currents obtained with applied voltages of ± 250 V and ± 125 V was the same (to less than 0,01%) for the GUM standard as for the BIPM transfer chamber of the same type (CC01 serial 122). Consequently, the correction k_s (1,002 3) for ion recombination, determined for similar chambers at the BIPM, was applied to the GUM standard in the BIPM beam. The corresponding value obtained at the GUM was 1,002 0 which is in fair agreement with the BIPM value.

The effect of adding graphite (16 mm) to the chamber wall (4 mm) of the GUM chamber is the same in both the BIPM and the GUM beams (Table 3). Consequently, the correction factor $k_{\mathrm{at.sc}}$ (1,015 5) deduced from measurements made at the GUM, was used in the determination of air kerma at the BIPM.

Table 3. Check measurement with ND1005-8303 for $k_{\mathrm{at.sc}}$

Number of caps added	4	
Total wall thickness	20 g·cm^{-2}	
	Ratio I_4 / I_0	s_r / %
GUM beam	0,937 9	0,04
BIPM beam	0,937 6	0,03

An additional correction factor k_{rn} for the radial non-uniformity of the BIPM beam over the section of the GUM standard, has been estimated from [4]; its numerical value is 1,000 3.

The result of the comparison $R_K = \dot{K}_{\mathrm{GUM}} / \dot{K}_{\mathrm{BIPM}}$ is given in Table 4. The $\dot{K}_{\mathrm{BIPM}}$ value is the mean of measurements which 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 GUM and the BIPM standards is 0,998 7 with a standard combined uncertainty, u_c of 0,002 8. Some of the uncertainties in $\dot{K}$ which appear in both the BIPM and the GUM determinations (such as air density, W/e, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{\mathrm{c,a}}$ and k_h) cancel when evaluating the uncertainty of R_K.

Table 4. Results of the GUM-BIPM comparison of standards of air kerma

$\dot{K}_{\mathrm{GUM}}$ (1) / mGy·s^{-1}	$\dot{K}_{\mathrm{BIPM}}$ (1) / mGy·s^{-1}	R_K	u_c
5,261 7	5,268 4	0,998 7	0,002 8

(1) The $\dot{K}$ values refer to an evacuated path length between source and standard and are given at the reference date of 1996-01-01, 0h UT where the half life of ^{60}Co is taken as 1 925,5 days (u = 0,5 days) [5].

6. Conclusion

The GUM standard for air kerma in ^{60}Co gamma radiation is in good agreement (0,13 %) with the BIPM air kerma standard and with other national standards. This is shown in Figure 1 where s_{comp} is equal to 0,16 % and denotes the standard deviation of the international comparison results. The results of comparisons at the BIPM with standards of the same type as that of the GUM are given in Table 5. They are consistent within the estimated uncertainties.

The standard deviation of these comparison results is of the same order as for the whole set of comparison results.

Table 5. 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 [6]	0,998 2	0,2
UDZ 1992 [7]	0,999 2	0,2
OMH 1972 [8]	1,003 9	0,5
1986 [9]	1,000 9	0,3
1994 [10]	1,002 5	0,2
BEV 1980, 1989 [11,12]	1,001 4	0,3
1994 [13]	1,004 0	0,2
1995 [14]	1,002 9	0,3
LNMRI 1986 [15]	1,001 0	0,3
1996 [16]	1,000 4	0,2
GUM [this work]	0,998 7	0,3

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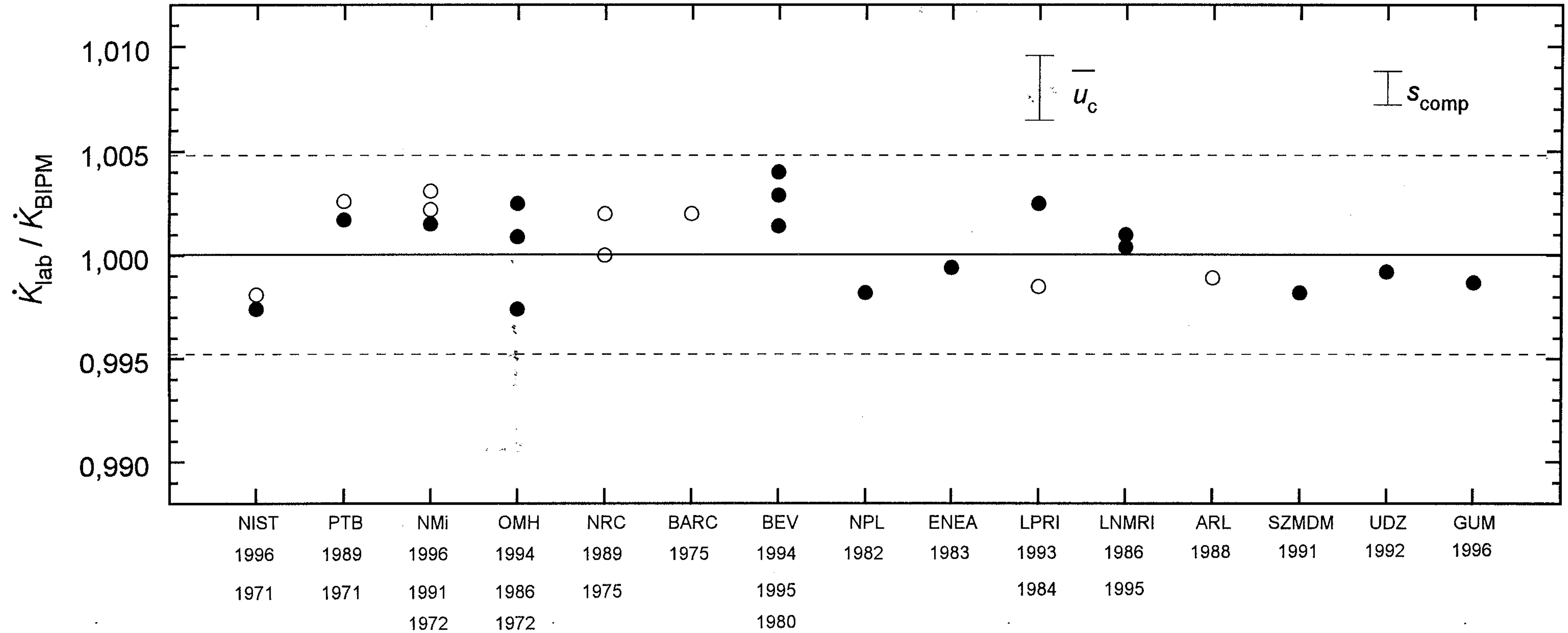
Figure 1

International comparison of AIR KERMA standards in ^{60}Co γ radiation



● direct comparison ○ indirect comparison

All values for each laboratory with comparison dates

- - - - bandwidth corresponds to $\pm$ 3 s_{comp}