Comparison of the standards of air kerma and of absorbed dose to water of the BEV and the BIPM for ^{60}Co γ rays

by A.-M. Perroche* and M. Boutillon
Bureau International des Poids et Mesures, F-92312 Sèvres Cedex

A. Leitner
Bundesamt für Eich-und Vermessungswesen, A-1163 Wien

Abstract
Comparisons between the standards of air kerma and absorbed dose to water of the Bundesamt für Eich-und Vermessungswesen and of the Bureau International des Poids et Mesures have been carried out in the ^{60}Co radiation. They show an agreement of 0,4 % and 0,1 % between the standards of air kerma and absorbed dose, respectively.

1. Introduction

Comparison of the standards of air kerma and absorbed dose to water of the Bundesamt für Eich-und Vermessungswesen (BEV), Wien, Austria, and of the Bureau International des Poids et Mesures (BIPM), have been carried out in ^{60}Co radiation.
The standard of air kerma of the BEV is a cavity ionization chamber constructed at the Oesterreichisches Forschungszentrum (OFS), Seibersdorf, Austria (type CC1, serial number 125). The BEV uses the scaling theorem to determine the absorbed dose to water from its calorimetric determination of absorbed dose to graphite by two methods [1]. In the first the absorbed dose to water is obtained by calculation and in the second a graphite cavity ionization chamber (type CC1), calibrated in terms of absorbed dose to graphite, is used. At the BIPM, the standards are graphite cavity chambers (see [2,3]).

The comparison took place at the BIPM in April 1994. The standards of air kerma had already been compared in 1980. At that time, the BEV standard was a different cavity ionization chamber of the same type, with design modifications to the collecting electrode, the insulator,the guard electrode and the stem.

2. Conditions of measurement

The air kerma and the absorbed dose are determined under conditions defined by the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants (CCEMRI) [4]:
- 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,
- the reference depth for absorbed dose measurements is 5 $g \cdot cm^{-2}$.

* Service Central de Protection contre les Rayonnements Ionisants, F-78110 Le Vésinet.

3. Comparison of the air kerma standards

The air kerma rate is determined by

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

where

I/m	is the mass ionization current 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 energy lost by bremsstrahlung,
$(\mu_{en}/\rho)_{a,c}$	is the ratio of the mean mass-energy absorption coefficients of air and graphite,
$\bar{s}_{c,a}$	is the ratio of the mean stopping powers of graphite and air,
Πk_i	is the product of the correction factors to be applied to the standard.

For the BEV standard, the physical constants and the correction factors entering in (1) and the uncertainties associated with the measurements of $\dot{K}$ are given in Table 1 of the present report. Table 7 of [5] gives this data for the BIPM standard.

The correction factors for the BEV standard were determined at the BEV. An additional correction factor, k_{rn}, for the radial non-uniformity of the BIPM beam over the section of the BEV standard, has been estimated from [6].

The main characteristics of the BEV standard are given in Table 2. The volume was determined mechanically at the BEV. Another determination was made by filling the chamber with water. The two results are in good agreement (0,01 %). The collecting voltage applied to the BEV standard is ± 250 V. The polarity effect I_+ / I_- is equal to 1,001 2.

The result of the comparison $R_K = \dot{K}_{BEV} / \dot{K}_{BIPM}$ is given in Table 3. The $\dot{K}$ values refer to an evacuated path length between source and standard. They are given at the reference date of 1994-01-01, 0h UT (the half life of ^{60}Co is taken as (1 925,5 ± 0,5) days [7]). The $\dot{K}_{BIPM}$ value is the mean of measurements which were performed over a period of three months before and after the comparison at the BIPM. The ratio of the air kerma rates determined by the BEV and the BIPM standards is 1,004 0.

Some of the uncertainties in $\dot{K}$ which appear in BIPM and BEV determinations (such as air density, W/e, μ_{en}/ρ, $\bar{g}$, $\bar{s}_{c,a}$, k_h, ...) cancel when evaluating the uncertainty of R_K, which is estimated to be 0,22 %. A detailed analysis is given in Table 1. The two standards differ by nearly 2σ. The present result is 0,25 % higher than the value obtained during the 1980 comparison. This difference is explained by the change of the BEV standard: the air kerma measured at the BEV is 0,20 % higher with the new standard than with the old one.

Table 1. Physical constants and correction factors entering in the determination of the air kerma rate, $\dot{K}_{BEV}$, in the BIPM ^{60}Co beam.

The estimated relative uncertainties* are given as standard deviations (in %).

			$\dot{K}_{BEV}$ uncertainty		$\dot{K}_{BEV}$ / $\dot{K}_{BIPM}$ uncertainty**	
		value	s_i	u_j	s_i	u_j
Physical constants						
dry air density (293,15 K, 101 325 Pa)	(kg·m^{-3})	1,204 6		0,01		
$(\mu_{en}/\rho)_{a,c}$ [8]		0,998 5		0,05		
$\bar{s}_{c,a}$ [8]		1,001 0				0,03
W/e [8]	(J·C^{-1})	33,97		0,11***		
$\bar{g}$ fraction of energy lost by bremsstrahlung [10]		0,003 2		0,02		
Correction factors						
k_s recombination losses		1,002 4	0,02	0,01	0,02	0,02
k_h humidity		0,997 0		0,03		
k_{st} stem scattering		1,000 0		0,01		0,02
k_{at} wall attenuation k_{sc} wall scattering k_{CEP} mean origin of electrons		1,012 8	0,01	0,10	0,01	0,13
k_{an} axial non-uniformity		1,000 0		0,10		0,12
k_{rn} radial non-uniformity		1,000 3		0,01		
Measurement of $I/v\rho$						
v volume	(cm^3)	1,018 7		0,10	0,01	0,11
I ionization current			0,03	0,05	0,03	0,05
Uncertainty in $\dot{K}_{BEV}$						
by quadratic summation			0,04	0,22		
combined uncertainty			0,22			
Uncertainty in $\dot{K}_{BEV}$ / $\dot{K}_{BIPM}$						
by quadratic summation					0,04	0,22
combined uncertainty					0,22	

* s_i = uncertainty estimated by statistical methods, type A,
u_j = uncertainty estimated by other means, type B.

** See Table 7 of ref. [5] for a detailed analysis of the uncertainty in $\dot{K}_{BIPM}$.

*** Uncertainty in the product $W\,\bar{s}_{c,a}$.

Table 2. Characteristics of the BEV standard of air kerma

Dimensions (nominal values) (mm)			
	Chamber	Outer height and outer diameter	19
		Inner height and inner diameter	11
		Wall thickness	4
	Electrode	Diameter	2,00
		Height	8,97
Volume of the air cavity (cm^3)			1,018 7
Materials			
	Wall	ultrapure graphite EK51 Ringsdorf, of density 1,72 g·cm^{-3} and with impurities less than 1,5 x 10^{-4}	
	Insulator	PTFE (Teflon)	

Table 3. Result of the BEV-BIPM comparison of standards of air kerma

$\dot{K}_{BEV}$ * (mGy·s^{-1})	$\dot{K}_{BIPM}$ (mGy·s^{-1})	$\dot{K}_{BEV} / \dot{K}_{BIPM}$
6,882	6,854	1,004 0 ± 0,002 2

* Mean value of 80 measurements.

4. Indirect comparison of the absorbed dose to water standards

The indirect comparison of the standards of absorbed dose to water was performed by means of two transfer chambers, type NE-2561 and NE-2571. The comparison was made at the reference depth of 5,000 g·cm^{-2}.

The calibration factors in terms of absorbed dose to water, N_W, are determined using the relations

$$(N_W)_{BIPM} = \frac{(\dot{D}_W)_{BIPM}}{(I_W k_{pf})_{BIPM}}^{*}, \qquad (N_W)_{BEV} = \frac{(\dot{D}_W)_{BEV}}{(I_W)_{BEV}}, \qquad (2)$$

where

$(\dot{D}_W)_{BIPM}$ is the absorbed dose rate to water measured by the BIPM standard at the reference depth of 5,000 g·cm^{-2} in water,

$(I_W)_{BIPM}$ is the ionization current measured by the transfer chamber, embedded in a waterproof envelope made at the BIPM and located in the BIPM water phantom, in the reference conditions [5],

k_{pf} is a correction factor which accounts for the non-equivalence of the perspex front face of the BIPM phantom with water [5],

$(\dot{D}_W)_{BEV}$ is the absorbed dose rate to water determined at the BEV from its calorimetric determination of absorbed dose to graphite using the scaling-theorem method. $(\dot{D}_W)_{BEV}$, is the mean value of the two determinations, by calculation and by means of the graphite cavity chamber (type CC1) calibrated in terms of absorbed dose to graphite (the difference between the two determinations is 0,30 %),

$(I_W)_{BEV}$ is the ionization current measured by the transfer chamber, embedded in a waterproof envelope made at the BEV and located in the BEV water phantom.

The physical constants and correction factors entering in the determination of the absorbed dose rate to water, together with their uncertainties, are given in [3] for the BIPM standard and in Table 4 for the BEV standard.

* The $(\dot{D}_W)_{BIPM}$ and $(I_W)_{BIPM}$ values refer to an evacuated path length between source and phantom. They are given at the reference date of 1994-01-01, 0 h UT (the half life of ^{60}Co is taken as (1 925,5 ± 0,5) days [7]).

Table 4. Physical constants and correction factors entering in the BEV determination of the absorbed dose rate to water at 5 g·cm^{-2}, and estimated relative uncertainties (1σ, in %)

	numerical value	uncertainty s_i	uncertainty u_j
Determination of $(\dot{D}_C)_{BEV}$			
calorimetric measurement of absorbed dose rate in graphite at 5,56 g·cm^{-2} (see[1])			0,25
interpolation on BEV depth dose curve			0,03
Conversion to absorbed dose to water:			
method 1: by calculation			
distance from the source to the phantom			0,20
depths in graphite and in water			0,10
front wall of water phantom			0,05
method 2: with ionization chamber CC1			
measurement of ionization current ratio		0,05	0,05
position of chamber in graphite			0,05
position of chamber in water			0,05
envelope of the chamber			0,05
front wall of the water phantom			0,05
replacement factor	1,015 0		0,20
Physical constants			
$(\mu_{en}/\rho)_W$ / $(\mu_{en}/\rho)_C$	1,112 3		0,10
β_W/β_C	1,000 3		0,10
Uncertainty in $(\dot{D}_W)_{BEV}$			
method 1: by quadratic summation		0,05	0,37
combined uncertainty		0,37	
method 2: by quadratic summation		0,05	0,37
combined uncertainty		0,37	

The $(\dot{D}_W)_{BIPM}$ value is the mean value of measurements performed over a period of three months, before and after the calibration at the BIPM, with $(\dot{D}_W)_{BIPM}$ = 6,858 mGy·s^{-1} at 5,000 g·cm^{-2}.

The result of the comparison is given by

$$R_W = \frac{(N_W)_{BEV}}{(N_W)_{BIPM}} \quad . \tag{3}$$

Table 5 gives the result of the comparison. The standards are in good agreement, within their uncertainties. The various contributions to the total uncertainty in R_W are listed in Table 6.

Table 5. Result of the BEV-BIPM comparison of standards of absorbed dose to water at 5,000 g·cm^{-2}

Chamber	$(N_W)_{BEV}$ (Gy·µC^{-1})	$(N_W)_{BIPM}$ (Gy·µC^{-1})	R_W	Relative uncertainty (1 σ, in %)
NE 2571-1050	45,406	45,417	0,999 8	0,53
NE 2561-276	103,52	103,73	0,998 0	0,53
		mean value	0,999 0	0,53

Table 6. Estimated relative uncertainties in the comparison result, R_W (1σ, in %)

	uncertainty	
	s_i	u_j
Determination of $(\dot{D}_W)_{BIPM}$		
ionometric measurement of absorbed dose rate to water, $(\dot{D}_W)_{BIPM}$, at 5 g·cm^{-2} (see [5])*	0,20	0,35
Determination of $(\dot{D}_W)_{BEV}$		
(see Table 4)*	0,05	0,34
Comparison result R_W		
by quadratic summation	0,21	0,49
combined uncertainty	0,53	

* Without the uncertainties in μ_{en}/ρ and in $\beta_{W,C}$ which are common to the BEV and the BIPM.

5. Conclusion

The agreement between the standards of air kerma of the BEV and the BIPM is of order 0,4 %. This result is 0,25 % higher than the value found in a previous comparison in 1980. The change of the BEV standard of air kerma explains this difference. The comparison of the standards of absorbed dose to water shows a very good agreement (0,1 %).
The difference between the ratios $(\dot{D}_W / K)_{BEV}$ and $(\dot{D}_W / K)_{BIPM}$ is found to be 0,5 %. This result is consistent with the difference of about 0,5 % observed between the experimental determination of C_λ as measured in the two laboratories for various types of transfer chambers [14].

References

[1] LEITNER A., The realization of the unit of absorbed dose to water at BEV, (to be presented at the NPL Calorimetry workshop (13-15 October 1994).

[2] 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.

[3] BOUTILLON M. and PERROCHE A.-M., Ionometric determination of absorbed dose to water for cobalt-60 gamma rays, *Phys. Med. Biol.*, 1993, **38**, 439-454.

[4] BIPM, Comparaisons d'étalons de dose absorbée, *BIPM Com. Cons. Etalons Mes. Ray. Ionisants*, Section (I), 1979, **5**, p. R(I) 5 (Paris: Offilib).

[5] PERROCHE A.-M. and BOUTILLON M., Measuring conditions used for the calibration of ionization chambers at the BIPM, *Rapport BIPM-91/5*, 1991, 11 pages.

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

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

[8] 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).

[9] OWEN B., Revision of the NPL-BIPM Cobalt-60 comparison of absorbed dose to water 1987/88, *Document CCEMRI(I)/93-2*, 1993, 3 pages.

[10] PERROCHE A.-M., BOUTILLON M., GUERRA A.S., LAITANO R.F. and PIMPINELLA M., Comparison of the standards of absorbed dose of the ENEA and the BIPM for ^{60}Co γ rays, *Rapport BIPM-94/4*, 1994, 6 pages.

[11] BOUTILLON M. and PERROCHE A.-M., Determination of absorbed dose to water for ^{60}Co by the scaling theorem, *Rapport BIPM-92/1*, 1992, 8 pages.

[12] PERROCHE A.-M., BOUTILLON M., DAURES J., DELAUNAY F., LEROY E., OSTROWSKY A. and CHAUVENET B., Comparison of the standards of air kerma and absorbed dose of the LPRI and the BIPM for ^{60}Co γ rays, *Rapport BIPM-94/6*, 1994, 10 pages.

[13] BOUTILLON M., Determination of absorbed dose in a water phantom from the measurement of absorbed dose in a graphite phantom, *Rapport BIPM-81/2*, 1981, 6 pages.

[14] LEITNER A., TIEFENBÖCK W., WITZANI J. and STRACHOTINSKY C., Investigation of some aspects of the IAEA code of practice for absorbed dose determination in photon and electron beams, *International Symposium on measurement assurance in dosimetry*, 1993, IAEA-SM-330/61.

(May 1994)