Rapport BIPM-90/9

Comparison of the standards of absorbed dose to graphite of the IRA and the BIPM for ^{60}Co γ rays

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Abstract
A comparison between the standards of absorbed dose to graphite of the Institut de Radiophysique Appliquée and the Bureau International des Poids et Mesures has been performed at depths from 3 to 16 g cm^{-2}. The ratio of the absorbed dose rates determined by each standard is 0,997 6 at the reference depth of 5 g cm^{-2}.

1. Introduction

The standard of absorbed dose to graphite of the Institut de Radiophysique Appliquée (IRA) is a graphite calorimeter operating in the quasi-adiabatic mode. It has been developed at IRA from calorimeters in use at this laboratory [1, 2]. It was compared to the ionometric standard of absorbed dose to graphite of the Bureau International des Poids et Mesures (BIPM) in November 1989.

2. Conditions of measurement

The absorbed dose to graphite, at the reference depth and in the reference plane, is determined in the following conditions defined by the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants (CCEMRI) [3]:

- the graphite phantom is homogeneous,
- the diameter of the phantom is 30 cm and the thickness is sufficient to provide full backscatter,
- 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 center of each side of the square being 50 % of the photon fluence rate at the center of the square,
- the reference depth in graphite is 5 g cm^{-2}.

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The centers of the detectors (calorimeter core and ionization chamber) were placed in the reference plane.

The comparison was made mainly at the reference depth, and at other depths ranging from 3,03 to 16,03 g cm^{-2}.

3. Determination of absorbed dose rate to graphite

a) *BIPM determination of absorbed dose rate to graphite at the reference depth (5 g cm^{-2})*

The BIPM reference absorbed dose rate, $(\dot{D}_5)_{BIPM}$, at the reference depth (5 g cm^{-2}), is given by

$$(\dot{D}_5)_{BIPM} = \frac{I}{m}\frac{W}{e}\,\bar{s}_{c,a}\,k_p\,k_{rn}\,k_{dist}\,, \tag{1}$$

where

I is the ionization current measured in the mass m of the gas of the chamber cavity. The middle plane of the cavity is located in the reference plane, at 5,018 6 g cm^{-2} in the graphite. I is corrected for humidity (k_h) and for ion recombination (k_s). The I values refer to an evacuated path length between source and phantom, and are given at the reference date of 1989-01-01 (the half life is (1 926 ± 2) days).

W is the average energy spent by an electron of charge e to produce an ion pair in dry air [4];

$\bar{s}_{c,a}$ is the weighted mean ratio of the stopping powers for carbon and air [4];

k_p is the perturbation correction factor of the BIPM cavity chamber [5];

k_{rn} is the correction factor for the radial non-uniformity of the ^{60}Co beam over the section of the BIPM standard [6];

k_{dist} is the ratio of the absorbed dose rates in graphite at 5,00 g cm^{-2} and 5,018 6 g cm^{-2}, determined previously from the BIPM experimental curve of absorbed dose, versus depth.

The measurement of $(\dot{D}_5)_{BIPM}$ took place over a period of one month before and after the IRA calorimetric measurements at BIPM.

Numerical values

$$\frac{I}{m} = 369{,}36\ \mu\mathrm{A\ kg}^{-1}, \quad \text{on 1989-01-01, 0 h UT},$$

$$(\dot{D}_5)_{\mathrm{BIPM}} = 12{,}500\ \mathrm{mGy\ s}^{-1}, \quad \text{on 1989-01-01, 0 h UT}.$$

The physical constants and the correction factors entering in the ionometric determination of the absorbed dose rate to graphite at 5,00 g cm^{-2}, together with their uncertainties, are given in Table 1.

b) *BIPM determination of absorbed dose rate to graphite at other depths*

The absorbed dose rate to graphite, at a depth d, determined ionometrically at BIPM is given by the relation

$$(\dot{D}_d)_{\mathrm{BIPM}} = (\dot{D}_5)_{\mathrm{BIPM}} \left(\frac{\dot{D}_d}{\dot{D}_5}\right)_{\mathrm{BIPM}}, \qquad (2)$$

where

$(\dot{D}_5)_{\mathrm{BIPM}}$ is defined in Eq. (1),

$(\dot{D}_d/\dot{D}_5)_{\mathrm{BIPM}}$ is the ratio of the absorbed dose rate in graphite at depth d and at 5,00 g cm^{-2}, determined from the BIPM experimental curve of the absorbed dose, versus depth.

The numerical values of $(\dot{D}_d/\dot{D}_5)_{\mathrm{BIPM}}$ and $(\dot{D}_d)_{\mathrm{BIPM}}$ for the depths of the comparison are given in Table 5, and their uncertainties in Table 6.

c) *IRA calorimetric determination of absorbed dose rate to graphite*

The main characteristics of the IRA calorimeter are given in Table 2 and details about the calorimetric measurements in [7].

The absorbed dose rate $(\dot{D}_d)_{\mathrm{IRA}}$, at depth d, is given by the relation

$$(\dot{D}_d)_{\mathrm{IRA}} = \dot{D}_{\mathrm{cal}}\, k_{\mathrm{dec}}\, k_a, \qquad (3)$$

where

$\dot{D}_{\mathrm{cal}}$ is the absorbed dose rate, at depth d, measured at BIPM with the IRA calorimeter, and not corrected for decay and air attenuation between source and phantom. The $\dot{D}_{\mathrm{cal}}$ values are referred to the day of measurement at 12 h UT. The correction factors entering in the determination of $\dot{D}_{cal}$ and their uncertainties are given in Table 3. $\dot{D}_{cal}$ is corrected for the lack of backscatter radiation (k_{bs}) because the length of the IRA phantom behind the reference plane is not sufficient to provide full backscatter. The effect of the difference in phantom diameter (28 cm instead of 30 cm) is estimated as negligible. $\dot{D}_{cal}$ is corrected for the slight differences (0,1 to 0,4 mm) between the positions of the calorimeter measuring plane and the reference plane.

k_{dec} is the correction factor for the ^{60}Co decay to refer the $\dot{D}_{cal}$ measurements to the reference date 1989-01-01, 0 h UT,

k_a is the correction factor for the air attenuation between the source and the front face of the phantom.

The values of $(\dot{D}_d)_{IRA}$ are given in Table 4 for depths ranging from 3,03 to 16,03 g cm^{-2}. The calorimetric measurements have been performed at BIPM with the IRA graphite discs in front of the calorimeter. The density and the thickness of the IRA discs have been measured by the manufacturer (Le Carbone-Lorraine, France) and checked at the IRA. Their density ($\approx$ 1,82 g cm^{-3}) is different from that of the BIPM discs (1,74 and 1,77 g cm^{-3}). Thus the difference between absorbed doses at the same depth in the BIPM and IRA phantoms, due to change in graphite density, is not negligible [9].

Measurements were performed at BIPM to estimate the value of this effect. For this purpose the BIPM graphite discs, placed in front of the ionometric standard in the phantom, were substituted by IRA discs. The value of the absorbed dose $\dot{D}_{IRA}$ thus obtained differs from the value $\dot{D}_{BIPM}$, determined at the same depth, with the BIPM discs. The ratio $r = \dot{D}_{IRA}/\dot{D}_{BIPM}$ varies from 1,000 5 to 1,007 2 when the depth in graphite increases from 3 to 16 g cm^{-2}. As seen in Fig. 1, these results are in agreement with those previously obtained with graphite discs of other laboratories [9].

In the present comparison the difference between the graphite densities of the two laboratories is taken into account in the results.

4. Results

The result of the comparison of absorbed dose to graphite at a depth d is given by

$$R_d = \frac{(\dot{D}_d)_{IRA}}{(\dot{D}_d)_{BIPM}} f_\rho , \qquad (4)$$

where $f_\rho = 1/r$.

The R_d values are listed in Table 5 and their uncertainties in Table 6. We note that the uncertainties on k_a and k_{dec} do not contribute to the uncertainty on the ratio R_d since both terms appear explicitly in $(\dot{D}_d)_{IRA}$ or implicitly in $(\dot{D}_d)_{BIPM}$, with very similar numerical values.

Thus, the values of the absorbed dose determined by the two standards are, within their uncertainties, in good agreement.

The result of the comparison at the reference depth of 5 g cm^{-2} is

$$R_5 = 0{,}997\,6\,. \tag{5}$$

Figure 2 shows the results of the IRA-BIPM comparison and of the comparisons of absorbed dose to graphite performed at BIPM with other national laboratories [10]. At the reference depth of 5 g cm^{-2}, the weighted mean of the absorbed dose to graphite measured by the BIPM ionometric standard and by the calorimeters of the national laboratories is 0,08 % lower than the BIPM ionometric value alone.

5. Conclusion

The agreement between the standards of absorbed dose to graphite of IRA and BIPM is good at all the depths used in the comparison, considering the uncertainties. The results agree well with those of other comparisons in this field and show the good quality of the IRA standard of absorbed dose to graphite.

Table 1

Physical constants and correction factors entering in the BIPM ionometric determination of the absorbed dose rate in graphite at 5,00 g cm^{-2}, and estimated relative uncertainties* (1σ, in %)

				s_i	u_j
Physical constants					
	air density at STP	(kg m^{-3})	1,293 0		0,01
	$\bar{s}_{c,a}$		1,003 0		0,2
	W/e	(J C^{-1})	33,97		0,15
Corrections factors					
	k_{rn} radial non-uniformity		1,003 2		0,03
	k_p perturbation correction		0,989 6		0,05
	k_{dist} depth in graphite		1,000 6		0,01
**	k_z air compressibility		1,000 2		-
**	k_s recombination losses		1,001 6	0,004	0,01
**	k_h humidity		0,997		0,03
Measurement of I/vρ					
	v volume	(cm^3)	6,787 3		0,03
	I ionization current, corrections concerning ρ (temperature, pressure)			0,01	0,02
Uncertainty on $(\dot{D}_5)_{BIPM}$	quadratic sum			0,01	0,26
	combined uncertainty			0,26	

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

** These correction factors are applied to the measured ionization current.

Table 2

Characteristics of the IRA graphite calorimeter

Core			
	diameter	(mm)	16,00
	length	(mm)	3,00
	mass	(g)	1,086 2
	graphite density	(g cm^{-3})	1,82
Gap widths			
	gap 1	(mm)	0,5
	gap 2	(mm)	0,5
	gap 3	(mm)	1,0
	gap 4 (in air)	(mm)	≈ 0,1
Depth from the surface of the entrance window to the middle plane of the absorber		(g cm^{-2})	0,92
Phantom			
	diameter	(mm)	280
	length	(mm)	≈ 125
	graphite density	(g cm^{-3})	≈ 1,82

Table 3

Quantities, correction factors and estimated relative uncertainties (1σ, in %) in IRA calorimetric measurement of the absorbed dose rate in graphite, $\dot{D}_{cal}$

			s_i	u_j
Measured quantity				
ΔV	variation of the potential at the bridge output during an irradiation run		0,07	
S_D	sensitivity of the bridge		0,01	0,22
Δ_t	duration of irradiation		0,07	0,01
Correction factors				
	impurities	1,000 0		0,20
	heat loss (temperature gradients)	1,000 0		0,01
	heat defect	1,000 0		0,10
	electrical power loss in leads	1,000 0		< 0,01
	depth of point of measurement	1,000 0		0,10
k_{gap}	vacuum and air gaps	1,002 0 to 1,007 2*		0,08
	homogeneity of graphite	1,000 0		< 0,01
	entrance foil attenuation	1,000 0		0,01
k_{bs}	lack of graphite thickness behind the reference plane	1,001 0		0,01
	diameter of the phantom	1,000 0		0,01
k_{an}	axial non-uniformity	1,000 0		< 0,01
k_{rn}	radial non-uniformity (in the BIPM beam)	1,000 2 to 1,001 2*		0,01
Uncertainty on $\dot{D}_{cal}$				
	quadratic sum		0,10	0,34
	combined uncertainty		0,35	

* See details in Table 4.

Table 4

Absorbed dose rate measurement with the IRA graphite calorimeter

Depth ($g\ cm^{-2}$)	Date	Correction factors k_{rn} *	k_{gap} **	Nb. of runs	$\dot{D}_{cal}$ *** ($mGy\ s^{-1}$)	k_{dec}	k_a	$(\dot{D}_d)_{IRA}$ on 1989-01-01 ($mGy\ s^{-1}$)	σ (%)
3,03	1989-11-23	1,000 2	1,002 0	18	11,637	1,124 7	1,007 0	13,180	0,29
5,00	1989-11-22	1,000 2	1,003 2	25	11,035	1,124 3	1,006 9	12,492	0,42
5,00	1989-11-28	1,000 2	1,003 2	18	10,997	1,126 7	1,007 0	12,476	0,15
5,00	1989-11-30	1,000 2	1,003 2	10	10,997	1,127 5	1,007 0	12,486	0,15
8,03	1989-11-24	1,000 4	1,004 7	18	9,988	1,125 1	1,006 8	11,314	0,15
10,00	1989-11-27	1,000 6	1,005 4	18	9,297	1,126 3	1,006 8	10,542	0,14
16,03	1989-11-29	1,001 2	1,007 2	19	7,264	1,127 1	1,006 6	8,241	0,23

* Taken from [6].

** Taken from [8].

*** The $\dot{D}_{cal}$ values are referred to the day of measurement at 12 h UT.

Table 5

Comparison of IRA and BIPM absorbed dose rates to graphite versus depth in graphite

Depth d ($g\ cm^{-2}$)	$(\dot{D}_d/\dot{D}_5)_{BIPM}$	$(\dot{D}_d)_{BIPM}$ * ($mGy\ s^{-1}$)	$(\dot{D}_d)_{IRA}$ * ($mGy\ s^{-1}$)	f_ρ	R_d	
3,03	1,056 0	13,201	13,180	0,999 5	0,997 9	
5,00	1,000 0	12,500	12,492	0,999 0	0,998 4	
5,00	1,000 0	12,500	12,476	0,999 0	0,997 1	0,997 6**
5,00	1,000 0	12,500	12,486	0,999 0	0,997 9	
8,03	0,904 6	11,308	11,314	0,998 1	0,998 6	
10,02	0,840 0	10,501	10,542	0,996 3	1,000 2	
16,03	0,653 9	8,174	8,241	0,992 9	1,001 0	

* The $(\dot{D}_d)_{BIPM}$ and $(\dot{D}_d)_{IRA}$ values are referred to 1989-01-01, 0 h UT.

** Weighted mean.

Table 6

Estimated relative uncertainties on $R_d = (\dot{D}_d)_{IRA}/(\dot{D}_d)_{BIPM}$ at depth d
(1σ, in %)

	s_i	u_j
Determination of $(\dot{D}_d)_{BIPM}$		
ionometric measurement of absorbed dose rate in graphite, at 5,00 g cm^{-2} (see Table 1)	0,01	0,26
interpolation on BIPM depth dose curve, $(\dot{D}_d/\dot{D}_5)_{BIPM}$	-	0,02 to 0,05
Determination of $(\dot{D}_d)_{IRA}$		
calorimetric measurement of absorbed dose rate in graphite, $\dot{D}_{cal}$ (see Table 3)	0,10	0,34
Comparison conditions		
factor f_ρ due to the difference in densities of IRA and BIPM graphite discs	-	0,05
measurement of distance from source to detectors	-	0,03
Comparison result		
$R_d = (\dot{D}_d)_{IRA}/(\dot{D}_d)_{BIPM}$		
quadratic sum	0,10	0,43
combined uncertainty	0,45	

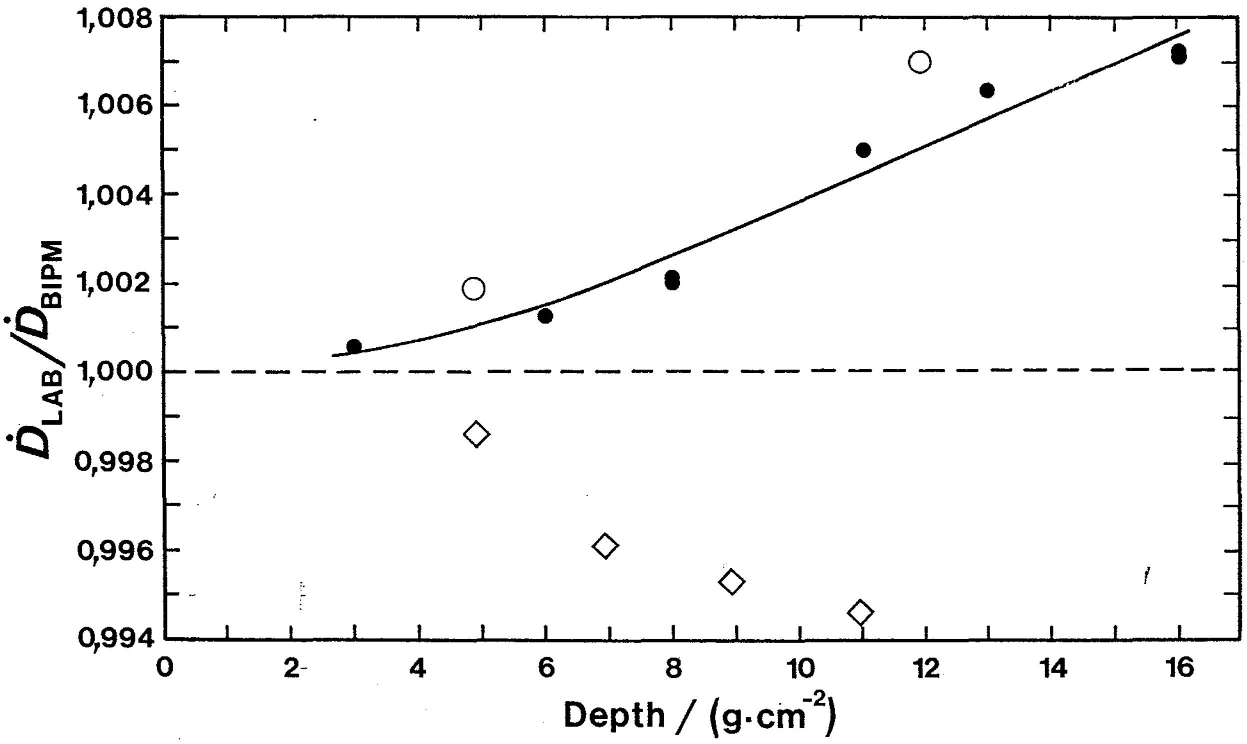

Fig. 1 - Effect of the density of the graphite discs on the absorbed dose value. $\dot{D}_{LAB}$ is the absorbed dose rate measured by the BIPM standard when the graphite discs of the laboratory LAB are placed in front of the BIPM standard.

Laboratory :	● IRA	O RIVM	◊ NIST	– – – BIPM
ρ_c (g cm^{-3}) :	≈ 1,82	≈ 1,85	1,64 to 1,70	1,74 to 1,80

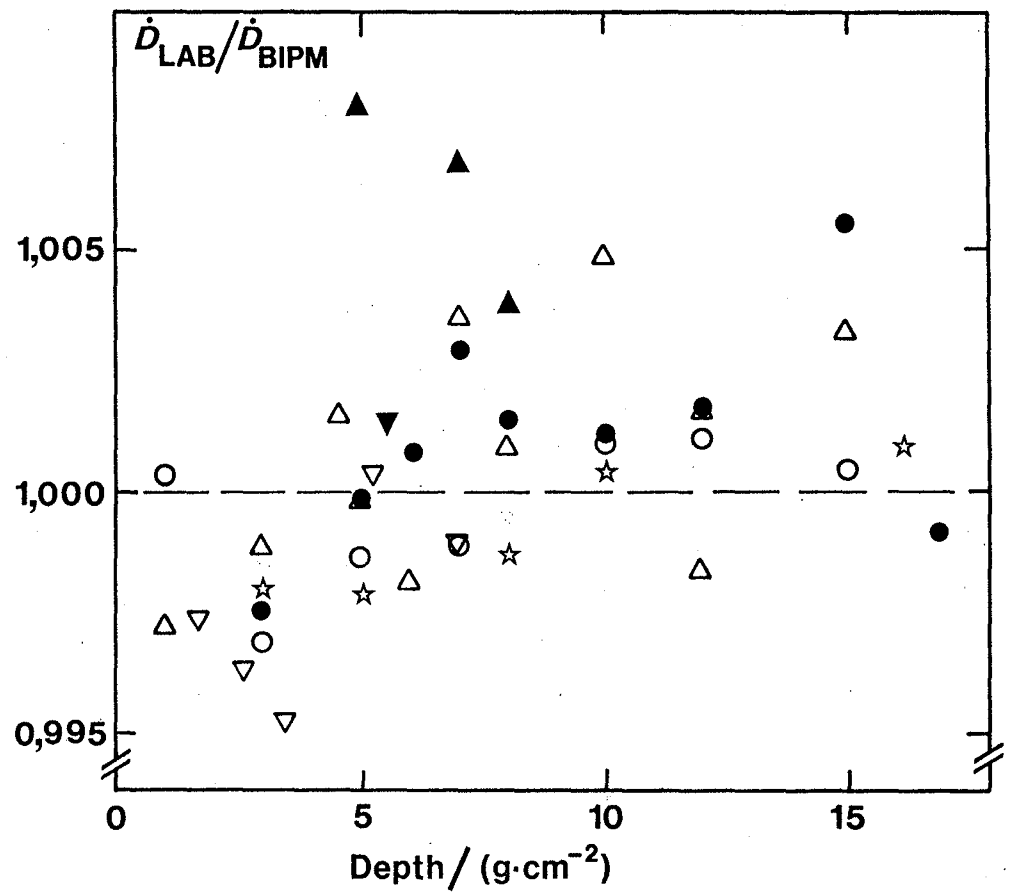

Fig. 2 - Comparisons of absorbed dose to graphite performed at BIPM.
Ratio of the absorbed dose rate to graphite $\dot{D}_{LAB}$ and $\dot{D}_{BIPM}$ measured with the calorimeters of the national laboratories and with the BIPM ionometric standard, respectively.

Symbol	○	●	▲	△	▽	▼	☆	——
Laboratory	NIST	LMRI	PTB	RIVM	OMH	NPL	IRA	BIPM
Date	1977	1977	1977	1979	1986	1987	1989	-
σ (%)	0,07	0,17	0,35	0,11	0,35	0,18	0,35	0,26

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