Comparison of the standards of absorbed dose to graphite of the OMH 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 Országos Mérésügyi Hivatal and the Bureau International des Poids et Mesures has been performed at depths from 1.76 to 7.08 g cm^{-2}. The ratio of the absorbed dose rates determined by each standard is 0.999 4 at the reference depth of 5 g cm^{-2}.

1. Introduction

The OMH standard is a graphite heat-loss compensated four-body calorimeter, of the type developed by S.R. Domen (National Institute of Standards and Technology, USA). It is described in [1] and its main characteristics are given in Table 1. The measurements took place at the BIPM in October 1986.

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) [2]:

- 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 and ionization chamber) were placed in the reference plane.

The comparison was made at the reference depth, and also at other depths ranging from 1.76 to 7.08 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

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

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 graphite. I is corrected for humidity (k_h), for ion recombination (k_s) and for air attenuation (k_a) between the source and the front face of the phantom and for the decay of ^{60}Co. The I values refer to an evacuated path length between source and phantom, and are given below at the reference date of 1986-01-01 (the half life used 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 [3];

$\bar{s}_{c,a}$ is the weighted mean ratio of the stopping powers for carbon and air [3];

k_p is the perturbation correction factor of the BIPM cavity chamber [4];

k_{rn} is the correction factor for the radial non-uniformity of the ^{60}Co beam over the surface of the BIPM standard [5];

k_{dist} is the ratio of the absorbed dose rate 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 OMH calorimetric measurements at BIPM.

Numerical values

$$\frac{I}{m} = 117.48\ \mu\text{A kg}^{-1}, \quad \text{on 1986-01-01, 0 h UT},$$

$$(\dot{D}_5)_{BIPM} = 3.976\ 0\ \text{mGy s}^{-1}, \quad \text{on 1986-01-01, 0 h UT.}$$

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 2.

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

$$(\dot{D}_c)_{BIPM} = (\dot{D}_5)_{BIPM} \frac{\dot{D}_d}{(\dot{D}_5)_{BIPM}}, \tag{2}$$

where

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

$\dot{D}_d/(\dot{D}_5)_{BIPM}$ is the ratio of the absorbed dose rate in graphite at depth d and at 5.00 g cm^{-2}, determined from the well established BIPM experimental curve of the absorbed dose, versus depth.

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

c) OMH calorimetric determination of absorbed dose rate to graphite

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

$$(\dot{D}_c)_{OMH} = \dot{D}_{cal}\ k_{dec}\ k_a, \tag{3}$$

where

$\dot{D}_{cal}$ is the absorbed dose rate, at depth d, measured at BIPM with the OMH calorimeter, and not corrected for decay and air attenuation between source and phantom. The correction factors entering in the determination of $\dot{D}_{cal}$ are given in Table 3 and the values of two of them (k_6 for the radial non-uniformity of the BIPM beam over the surface of the core of the calorimeter and k_9 for the effects of the gaps) are given in Table 4.

k_{dec} is the correction factor for the ^{60}Co decay to refer the $\dot{D}_{cal}$ measurements to 1986-01-01, 0 h UT.

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

The calorimetric measurements have been performed with the OMH graphite discs placed in front of the calorimeter. The density and the thickness of the OMH discs have been carefully measured in the laboratory where they have been manufactured. Their density (1.76 g cm^{-3}) is very close to 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 OMH phantoms, due to possible changes in graphite density [7], is considered as negligible.

The uncertainty on $\dot{D}_{cal}$ is given in Table 3 and the $(\dot{D}_c)_{OMH}$ values are given in Table 4 for depths ranging from 1.76 to 7.08 g cm^{-2}.

4. Results

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

$$R_d = \frac{(\dot{D}_c)_{OMH}}{(\dot{D}_c)_{BIPM}} . \qquad (4)$$

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 $(\dot{D}_c)_{OMH}$ or implicitly in $(\dot{D}_c)_{BIPM}$, with very similar numerical values.

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

The result of the comparison at the reference depth of 5 g cm^{-2} is obtained by a linear interpolation between the R_d values at 3.53 and 5.32 g cm^{-2}. The resulting value is

$$R_5 = 0.999\,4. \qquad (5)$$

Figure 1 shows the results of the OMH-BIPM comparison and of the other comparisons of absorbed dose to graphite performed at BIPM with national laboratories. All the results are revised values taking into account the gap correction in the calorimeters [6] and the radial non-uniformity of the BIPM beam [5].

A reference value, at 5 g cm^{-2}, of the absorbed dose to graphite is determined from the results of the six comparisons performed at BIPM; it is given by the weighted mean of the absorbed dose to graphite measured by the BIPM ionometric standard and the six calorimeters. The ratio, k_{ref}, of this mean value to the BIPM ionometric one is equal to 0.999 2.

5. Conclusion

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

Table 1

Characteristics of the OMH graphite calorimeter

Type : heat-loss compensated four-body calorimeter.

Phantom : graphite, $\rho = 1.760$ g cm^{-3}
⌀ 300 mm x 215 mm.

Core : graphite, $\rho = 1.79$ g cm^{-3}
⌀ 20 mm x 2.75 mm.

Effective point of measurement: 6.5 mm from the mylar window surface on the axis of the cylindrical lucite chamber.

Effective graphite depth from the mylar window surface to the effective point of measurement: 0.88 g cm^{-2}.

Core mass:	effective	1 547.7 mg
	graphite	1 541.9 mg
	epoxy resin	3.3 mg
	mylar	0.1 mg
	polystyrene	0.86 mg
	copper (wires) and thermistors	0.72 mg.

Table 2

Physical constants and correction factors entering in the 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
Correction 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		0.03
** Z/Z_o	(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 in cm^3)	6.787 3		0.03
I	(ionization current)		} 0.008	0.01
corrections concerning ρ	pressure, temperature			} 0.01
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 3

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

			s_i	u_j
Measured quantity				
P_{el}	Electrical calibration power		0.03	0.15
m	Mass of the absorber/core		-	0.02
α_{rad}	Temperature sensitivity (by radiation)		0.20	-
α_{el}	Temperature sensitivity (by electrical energy)		0.20	-
Δt_{rad}	Irradiation time period		-	-
Δt_{el}	Calibration time period		-	0.03
Correction factors for				
k_1	Impurities	0.999 5	-	0.08
k_2	Heat loss (temperature gradients)	1.000 0	-	0.05
k_3	Heat (caloric) defect	1.000 0	-	-
k_4	Electrical power loss in leads	0.999 4	-	0.01
k_5	Axial non-uniformity	1.000 0	-	0.02
k_6	Radial non-uniformity (in the BIPM beam)	1.000 3 to 1.000 6	-	0.01
k_7	Distance		-	- *
k_8	Depth of point of measurement	1.000 0	-	0.02
k_9	Vacuum and air gaps	1.001 3 to 1.005 5	-	0.08
k_{10}	Homogeneity of graphite	1.000 0	-	0.02
k_{11}	Entrance foil attenuation	1.000 0	-	-
Uncertainty on $\dot{D}_{cal}$				
	quadratic sum		0.28	0.20
	combined uncertainty		0.35	

* The uncertainty on the distance used at BIPM is given in Table 6.

Table 4

Absorbed dose rate measurement with the OMH graphite calorimeter

Depth ($g\ cm^{-2}$)	Date	Correction factors k_6 *	k_9 **	Number of runs	$\dot{D}_{cal}$ *** ($mGy\ s^{-1}$)	k_{dec}	k_a	$(\dot{D}_c)_{OMH}$ on 1986-01-01 ($mGy\ s^{-1}$)	σ (%)
1.76	1986-10-06	1.000 3	1.005 5	25	3.865	1.105 4	1.007 1	4.303	0.25
2.64	1986-10-03	1.000 3	1.004 5	27	3.791	1.104 2	1.007 0	4.215	0.20
3.53	1986-10-02	1.000 3	1.001 3	25	3.712	1.103 8	1.006 9	4.126	0.26
5.32	1986-09-30	1.000 4	1.002 4	30	3.547	1.103 0	1.006 9	3.940	0.16
	1986-10-08	1.000 4	1.002 4	25	3.535	1.106 2	1.006 9	3.938	0.20
7.06	1986-10-01	1.000 6	1.003 1	30	3.347	1.103 4	1.006 8	3.718	0.26

* Taken from [5].

** Taken from [6].

*** The $\dot{D}_{cal}$ values are referred to the day of measurement at 12 h 00 UT.

Table 5

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

Depth d ($g\ cm^{-2}$)	$\frac{\dot{D}_d}{(\dot{D}_5)_{BIPM}}$	$(\dot{D}_c)_{BIPM}$ * ($mGy\ s^{-1}$)	$(\dot{D}_c)_{OMH}$ * ($mGy\ s^{-1}$)	$R_d = \frac{(\dot{D}_c)_{OMH}}{(\dot{D}_c)_{BIPM}}$	
1.76	1.084 7	4.313	4.303	0.997 7	
2.64	1.063 7	4.229	4.215	0.996 7	
3.53	1.042 6	4.145 5	4.126	0.995 3	
5.00	1.000 0	3.976	-	0.999 4**	
5.32	0.990 4	3.938	3.940	1.000 5	1.000 3
"	"	"	3.938	1.000 0	
7.08	0.936 2	3.722	3.718	0.998 9	

* The $(\dot{D}_c)_{BIPM}$ and $(\dot{D}_c)_{OMH}$ values are referred to 1986-01-01, 0 h UT.

** Interpolated value (see Section 4).

Table 6

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

	s_i	u_j
1. Determination of $(\dot{D}_c)_{BIPM}$		
Ionometric measurement of absorbed dose rate in graphite, at 5.00 g cm^{-2} (see Table 2)	0.01	0.26
Interpolation on BIPM depth dose curve, $\dot{D}_d/(\dot{D}_5)_{BIPM}$	-	0.03*
2. Determination of $(\dot{D}_c)_{OMH}$		
Calorimetric measurement of absorbed dose rate in graphite, $\dot{D}_{cal}$ (see Table 3)	0.28	0.20
3. Comparison conditions		
Difference in densities of OMH and BIPM graphite discs	-	0.03
Measurement of distance from source to detector	-	0.03
4. Comparison result		
$R_d = (\dot{D}_c)_{OMH}/(\dot{D}_c)_{BIPM}$ quadratic sum	0.28	0.33
combined uncertainty	0.43	

* This value applies to depths above 3.53 g cm^{-2}. At lower depths the uncertainty increases: its value is 0.09 % at 1.76 g cm^{-2}.

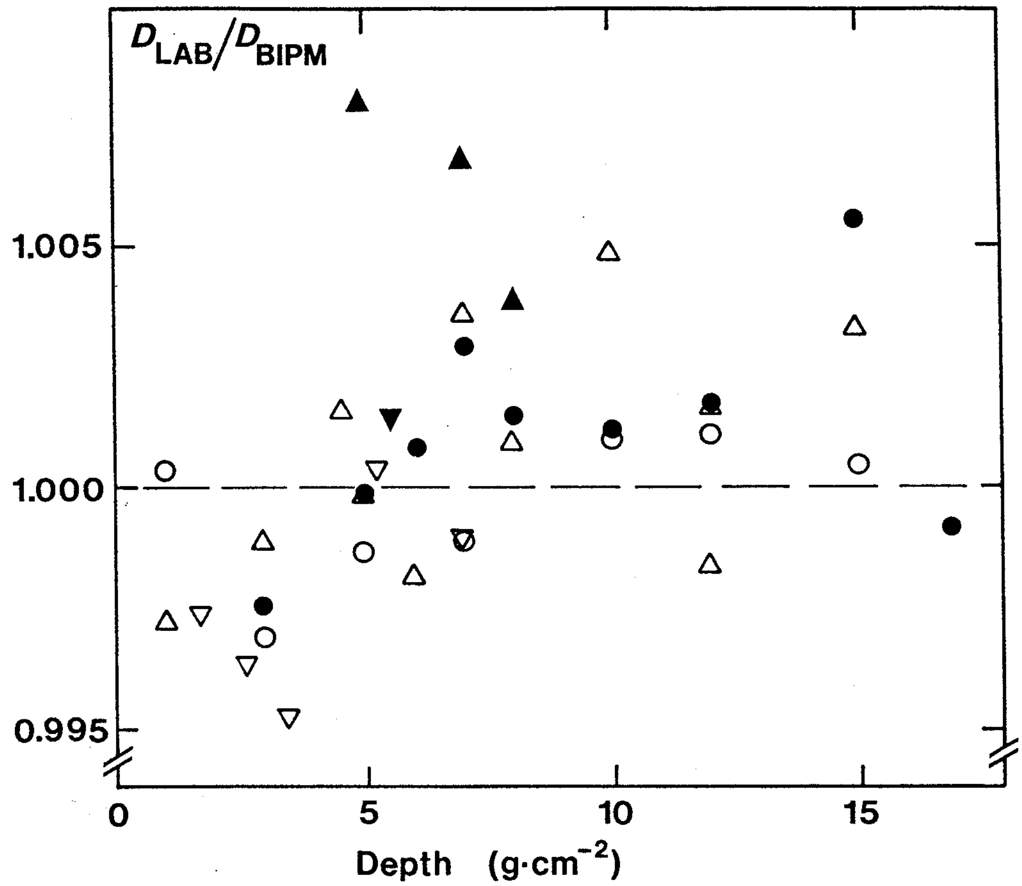

Figure 1 - Comparisons of absorbed dose to graphite at BIPM.

Ratio of the absorbed doses to graphite D_{LAB} and 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	BIPM
Date	1977	1977	1977	1979	1986	1987	
σ (%)	0.07	0.17	0.35	0.11	0.35	0.18	0.26

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