Rapport BIPM-86/14

Perturbation Correction of a Cylindrical Thimble-type Chamber in a Graphite Phantom for ^{60}Co Gamma Rays*

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Abstract

An experimental determination has been made of the perturbation correction to be applied to a graphite cylindrical (thimble type) ionization chamber. The results indicate that the magnitude of this correction increases with depth and is closely related to the size of the cavity. This makes possible the use of such a chamber as an excellent standard of absorbed dose in graphite for ^{60}Co gamma rays, as well as an appropriate transfer instrument.

1. Introduction

The determination of absorbed dose in graphite for ^{60}Co gamma rays by means of an ionization chamber located in a graphite phantom requires the knowledge of the perturbation on the photon and electron fluence made by the chamber cavity and its wall if the material or the density of the wall differs from that of the phantom.

The necessary perturbation correction factor k_p is defined [1] by the relation

$$k_p = (E/m)_o/(E/m) ,$$

where

$(E/m)_o$ is the mean specific energy imparted to air in an ideal cavity which is located in the reference plane where the absorbed dose has to be determined, and

(E/m) is the mean specific energy imparted to air in the real cavity of finite size, the geometrical center of which is conventionally placed in the same reference plane.

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* This paper is dedicated to M.-T. Niatel on the occasion of her retirement.

** On leave of absence from the Instituto de Radioproteçao e Dosimetria, CNEN, Rio de Janeiro, Brazil.

This correction is due to the fact that the real cavity disturbs the photon and the electron fluence in the phantom. It has been determined theoretically for a flat chamber [1, 2]. However, for a cylindrical chamber (thimble type) the theoretical calculation is difficult, due mainly to the geometry of the chamber.

The present work deals with the experimental determination of the perturbation correction for a thimble-type graphite chamber at different depths in a graphite phantom, in a ^{60}Co gamma-ray beam.

2. Method

For the BIPM standard, a flat cylindrical chamber, described by Boutillon and Niatel [3], the perturbation correction for different depths in a graphite phantom has been calculated by Boutillon [1]. The internal consistency of the procedure has later been confirmed by a comparison of the measurements made with four calorimeters from several national laboratories (NBS, PTB, LMRI and RIV)* [4], all performed at BIPM.

On the other hand, for the chamber studied here, the volume of the cylindrical cavity is known, and all the other correction factors needed for the measurement have been determined for the BIPM irradiation and measurement conditions.

Conventionally, the geometrical center of the chamber, both for the thimble-type chamber and for the BIPM standard, is placed in the reference plane in which the absorbed dose has to be determined. Therefore, the value of the perturbation correction for the thimble-type chamber can be determined as

$$k_{p(cyl)} = \frac{((I/m)\ \bar{s}_{C,a}\ k_{rn}\ k_p)_{BIPM}}{((I/m)\ \bar{s}_{C,a}\ k_{rn})_{cyl}} ,$$

where

I/m is the ionization current resulting from the collection of the ions produced in the mass of air of the cavity, corrected for leakage, loss of ionization due to recombination, humidity, temperature and pressure,

$\bar{s}_{C,a}$ is the mean ratio of the restricted mass stopping power of graphite to air,

k_{rn} is the correction factor for the radial non-uniformity of the BIPM beam over the chamber area. The ratio $(k_{rn})_{BIPM}/(k_{rn})_{cyl}$ has been estimated experimentally at BIPM; it varies from about 1,0029 at 5 g/cm^2 to 1,0108 at 17 g/cm^2.

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* NBS - National Bureau of Standards, USA
PTB - Physikalisch-Technische Bundesanstalt, FRG
LMRI - Laboratoire de Métrologie des Rayonnements, France
RIV - Rijks Instituut voor de Volksgezondheid, The Netherlands (now RIVM)

k_p is the perturbation correction calculated for the BIPM standard (flat cylindrical chamber).

The ionization current I_{BIPM} was measured at 5 g cm^{-2}. For the depths other than 5 g cm^{-2}, the I_{BIPM} values were taken from the curve of the current measured by the BIPM chamber versus depth, previously determined at BIPM.

The physical constants used during this work were W/e = 33,97 J C^{-1}, the average energy required to produce an ion pair, as proposed by Boutillon and Perroche-Roux [5] and recommended by CCEMRI [6]. The stopping power values for each depth were calculated by the Spencer-Attix method [7], using the recent values from the ICRU Report 37 [8] and taking into account the mean spectra of the incident radiation.

The correction for loss of recombination to be applied to the cylindrical chamber was taken from a previous measurement performed at 5 g cm^{-2} of depth in a water phantom, using a ^{60}Co beam which provides a similar current as the one used with the graphite phantom. For 250 V of collecting potential, the correction factor is 1,0022 ± 0,003.

The correction factor for humidity is 0,997, as recommended by CCEMRI [9].

3. Experimental Procedure

3.1. Description of the cylindrical cavity chamber (thimble type)

The chamber used in the present work was constructed at the Oesterreichisches Forschungszentrum Seibersdorf (OFS), of highly pure graphite (1,71 g cm^{-3}) and the volume of the cavity was measured by the Austrian Federal Office of Metrology [10].

The essential features of the chamber are given in Fig. 1 and Table 1.

The stability of the chamber had been previously checked by measuring the exposure in the BIPM ^{60}Co beam, several times during nine months. During that period the chamber has shown a long-term standard deviation of less than 0,1 % [11].

3.2. Measurement conditions

The measurements were performed in the ^{60}Co gamma-ray beam of BIPM and its measuring assembly [12]. The distance between the source and the reference plane in the graphite phantom is 100 cm. The beam size (middle of penumbra) in air is (10 x 10) cm at that distance. The graphite phantom has a density of 1,8 g cm^{-3}, a diameter of 30 cm and it is composed of two parts. First a special disc, 5 cm thick, was carefully machined in order to fit the chamber at the depth of 5 g cm^{-2}. The additional layers were taken from the BIPM phantom.

The incident beam includes scattered radiation amounting to 18 % of the unscattered radiation, in terms of energy fluence.

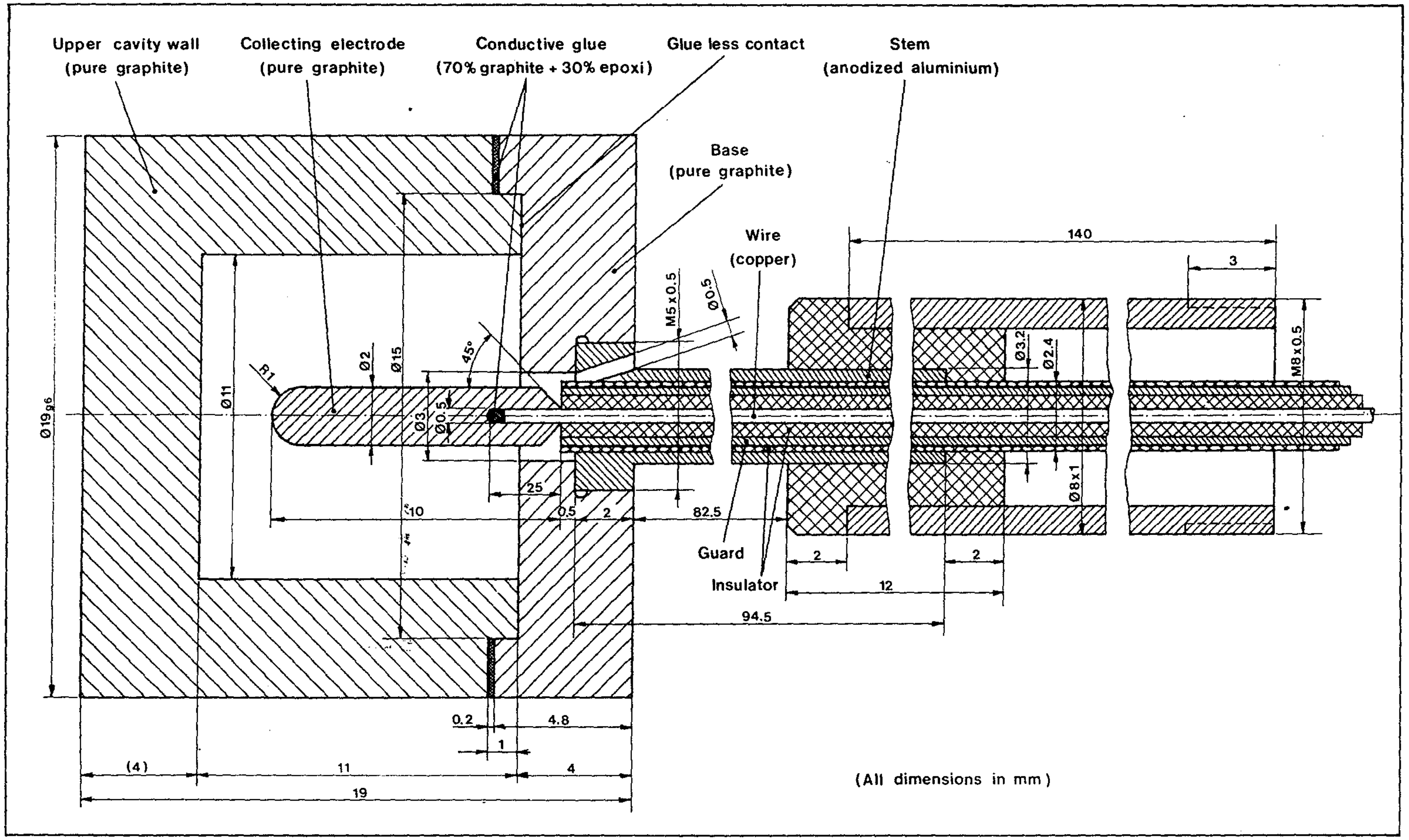

Fig. 1 - Schematic diagram of the graphite cavity chamber, including its dimentions and material specification.

The ionization current was measured for both polarities of collecting potential and averaged to eliminate possible "extracameral" effects in the chamber current. The leakage current was measured before and after each series of measurements and its relative value was normally found to be less than 0,01 %.

A calibrated thermistor was placed inside the graphite phantom near the chamber and a pressure transducer was located in the same room. Temperature and pressure were read for each measurement; the humidity used to stay fairly close to 50 %.

Table 1

Characteristics and dimensions of the IRD thimble-type chamber C001-110

Nominal outer height	(mm)	19
Nominal outer diameter	(mm)	19
Nominal inner height	(mm)	11
Nominal inner diameter	(mm)	11
Volume of cylindrical cavity*	(cm^3)	1,039
Volume of the electrode	(cm^3)	0,029 2
Additive sensitive volume**	(cm^3)	0,007 8
Sensitive volume**	(cm^3)	1,017 6
Electrode		
nominal diameter	(mm)	2
nominal length	(mm)	10
Wall and absorption caps		
wall thickness	(mm)	4
material	ultra pure graphite EK51 Ringsdorf density** 1,71 g/cm^3 impurities 150 x 10^{-6} of ash content	
Insulator	polyethylene	

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* Measured by the Austrian Federal Office of Metrology

** Data supplied by OFS [10]

4. Results and discussion

Table 2 gives the experimental results of the correction factor for the perturbation introduced by the cylindrical cavity of a thimble-type chamber and its wall, the latter consisting of the same material and nearly the same density as the phantom. The perturbation correction increases with depth when the thickness of graphite in front of the chamber is augmented, since the scattered radiation component at the reference plane increases (Fig. 2) [1]. This correction is also shown on Fig. 3 (curve A) together with the perturbation correction for the BIPM flat chamber (curve B). The differences in the magnitude of the correction between the two chambers seem to be closely related to the size of their cavities.

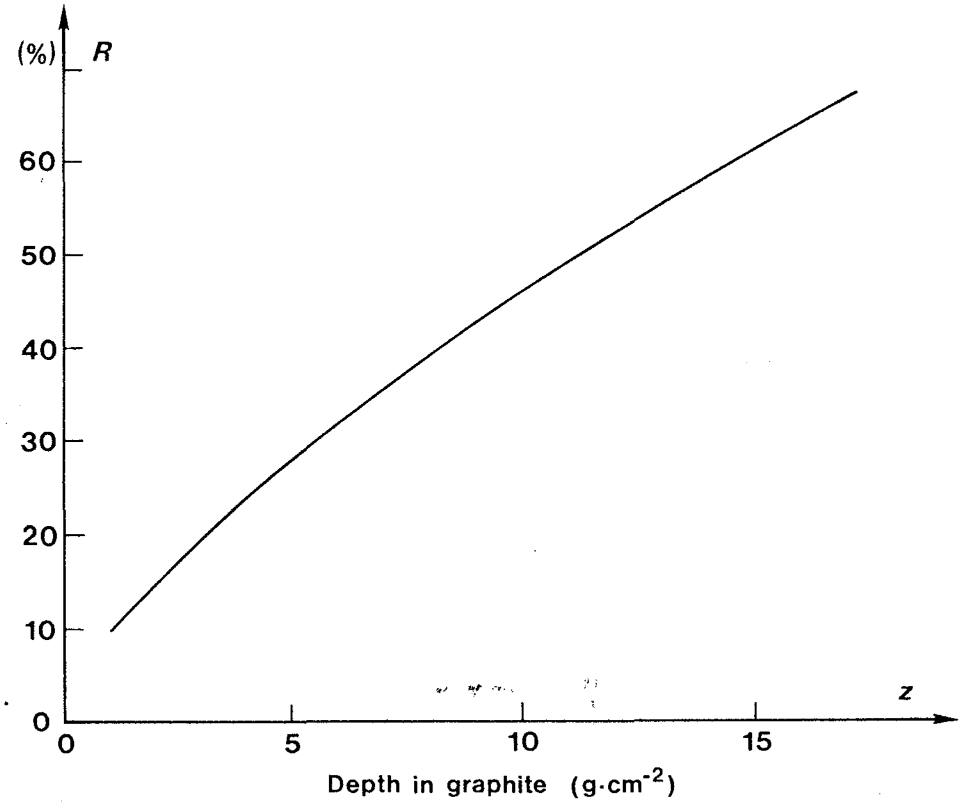

Fig. 2 - Ratio, R, of the kerma due to scattered photons to that due to primary ones, as a function of depth for a graphite phantom [1].

Table 2

Experimental values for the perturbation correction of the IRD thimble-type chamber

Depth (g/cm^2)	$(k_p)_{cyl}$*
4,0	0,9726 ± 0,0013
5,0	0,9696 ± 0,0014
9,9	0,9670 ± 0,0018
14,9	0,9640 ± 0,0018

* The uncertainty represents one standard deviation. For details see Table 3.

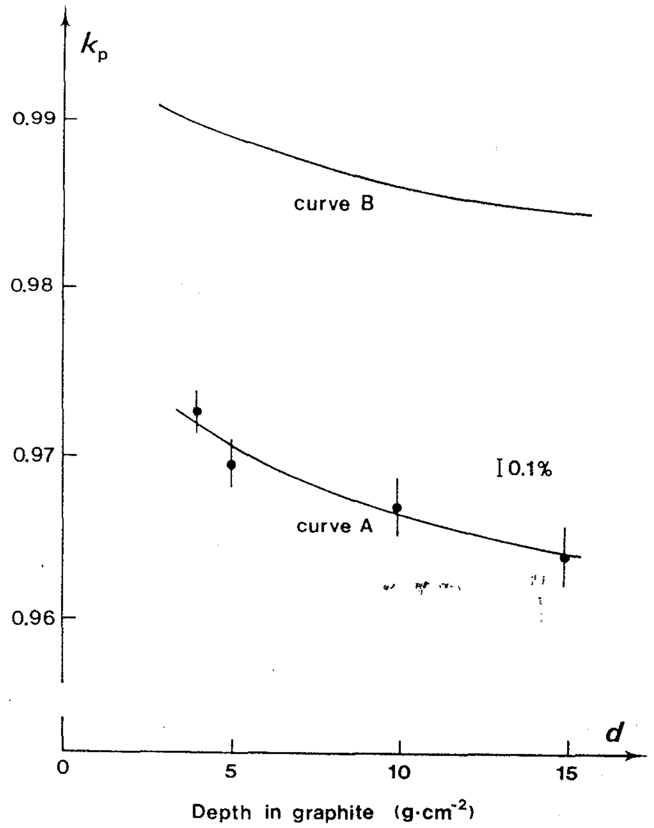

Fig. 3 - Variation of the perturbation correction with depth in graphite. Curve A represents the experimental values of the perturbation correction factor for a cylindrical thimble-type graphite chamber. Curve B shows the perturbation correction factors calculated for the BIPM standard (flat cylindrical chamber) for absorbed dose measurements in graphite [1].

The uncertainties involved in the determination of the value of k_p for the cylindrical chamber are given in Table 3. The combined uncertainty varies slightly with depth, from 0,13 % to 0,19 %. The major source of uncertainty comes from the determination of the depth in the phantom, due to the chamber positioning in the disc, and to the inherent fluctuations of density in this disc. This uncertainty has been estimated from the depth absorbed dose curve determined with the BIPM chamber. The fluctuation of density in the IRD disc was taken as the same as that measured for a BIPM disc.

Table 3

Estimated relative uncertainty in $(k_p)_{cyl}$
(standard deviation, in %)

	s_j *	u_j *
Measurement of I_{BIPM}/I_{cyl}	0,01	0,01
Volume of BIPM standard		0,03
Volume of IRD thimble-type chamber		0,03
$(\bar{s}_{C,a})_{BIPM}/(\bar{s}_{C,a})_{cyl}$		0,01
$(k_{rn})_{BIPM}/(k_{rn})_{cyl}$		0,03
$(k_p)_{BIPM}$		0,05
Interpolation on depth dose curve		0,03 to 0,04
Depth in IRD graphite disc		0,10 to 0,17
Difference between the graphite densities of BIPM and IRD discs [13]		0,02 to 0,04
Distance between source and reference plane		0,01
Quadratic sum	0,01	0,13 to 0,19
Combined uncertainty	0,13 to 0,19	

* s_i = relative uncertainty estimated by statistical methods, type A

u_j = " " " " other means, type B.

Another source of uncertainty comes from the difference between the graphite densities of the BIPM and IRD discs; this uncertainty has been estimated from Niatel [13] who has shown that, for a given depth in graphite, the measured absorbed dose varies with graphite density.

Since the volume of the cylindrical cavity was known, and the correction factors needed for the measurement were appropriately determined, and since the chamber has shown an excellent long-term stability, it was possible to measure for the first time the perturbation correction for a cylindrical thimble-type chamber.

The BIPM standard was chosen as reference for this study since it has similar characteristics as the chamber studied, which eliminates the uncertainties in the stopping power and the W values. Therefore it was possible to determine k_p with a better precision.

The results indicate that the IRD instrument can be reliably used as a very good standard for measuring absorbed dose in graphite, directly traceable to the BIPM standard. Furthermore, it may be also related to the reference value used at BIPM which is derived from the weighted mean value of the measurements of absorbed dose performed by four calorimeters and the BIPM standard during preceding comparisons.

Acknowledgments

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References

[1] Boutillon, M., Perturbation correction for the ionometric determination of absorbed dose in a graphite phantom for ^{60}Co gamma rays. Phys. Med. Biol. 28, 1983, pp. 375-388

[2] Niatel, M.-T., On the location of a flat ionization chamber for absorbed dose determination. Phys. Med. Biol. 28, 1983, pp. 407-410

[3] Boutillon, M. and Niatel, M.-T., A study of a graphite chamber. Metrologia 9, 1973, pp. 139-146

[4] Niatel, M.-T., Perroche-Roux, A.-M. and Boutillon, M., Two determinations of W for electrons in air. Phys. Med. Biol. 30, 1985, pp. 67-75

[5] Boutillon, M. and Perroche-Roux, A.-M., Re-evaluation of the W value for electrons in air. Phys. Med. Biol. 32, 1987, pp. 213-219

[6] BIPM Com. Cons. Etalons Mes. Ray. Ionisants (Section I) 1, 1985, Document CCEMRI(I)/85-8, Effect of a change of stopping power values on the W values recommended by ICRU for electrons in dry air (by M. Boutillon and A.-M. Perroche)

[7] Spencer, L.V. and Attix, F.H., A theory of cavity ionization. Radiation Research 3, 1955, p. 239

[8] International Commission on Radiation Units and Measurements, Stopping Powers for Electrons and Positrons, ICRU Report 37, 1984 (ICRU, Bethesda, MD)

[9] BIPM Com. Cons. Etalons Mes. Ray. Ionisants (Section I) 4, 1977, p. R(I) 13

[10] Duftschmid, K., (private communication) 1986

[11] de Almeida, C.E. and Niatel, M.-T., Comparison between IRD and BIPM exposure and air-kerma standards for cobalt-60 gamma rays. Rapport BIPM-86/12

[12] Allisy, A., Carnet, D., in BIPM Proc.-Verbaux Com. Int. Poids et Mesures 33, 1965, p. 55

[13] Niatel, M.-T., in BIPM Proc.-Verbaux Com. Int. Poids et Mesures 47, 1979, pp. 49-51.

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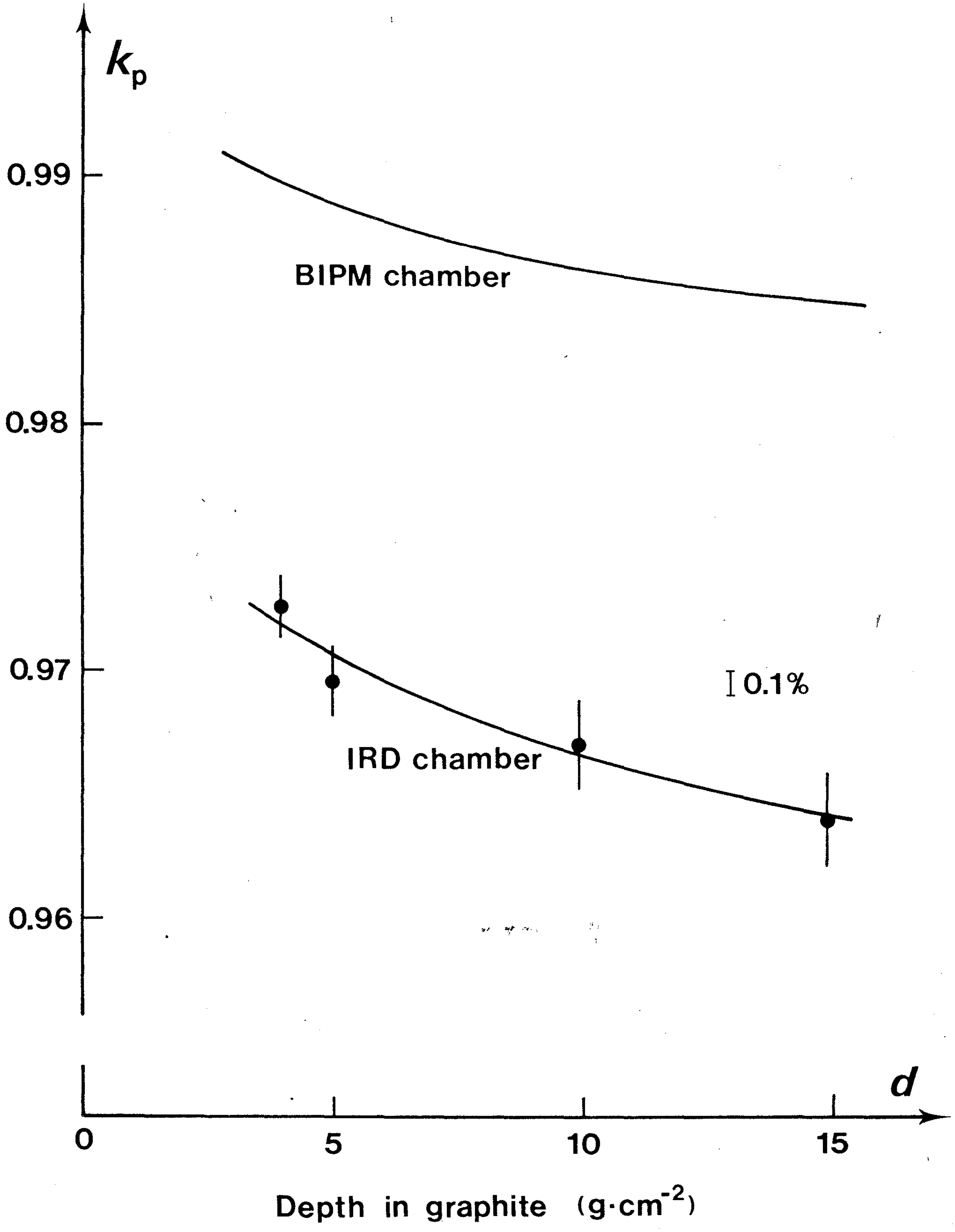
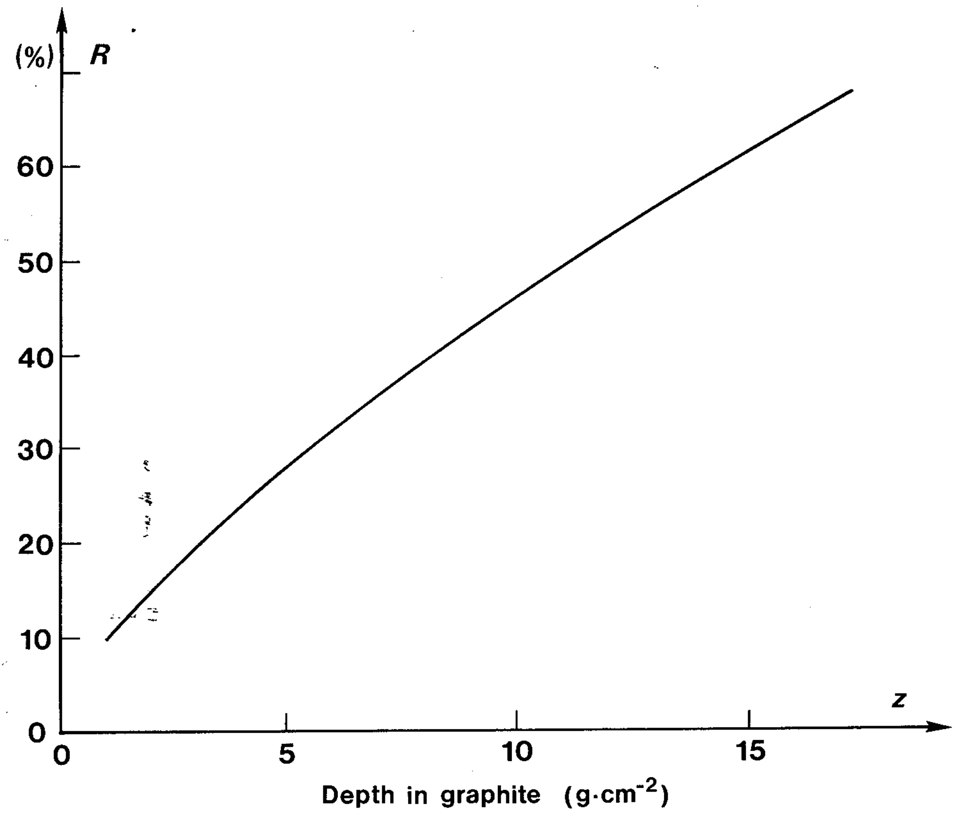


k_p
0.99
0.98
0.97
0.96
BIPM chamber
IRD chamber
0.1%
d
0
5
10
15
Depth in graphite (g·cm^{-2})

(%)
R
60
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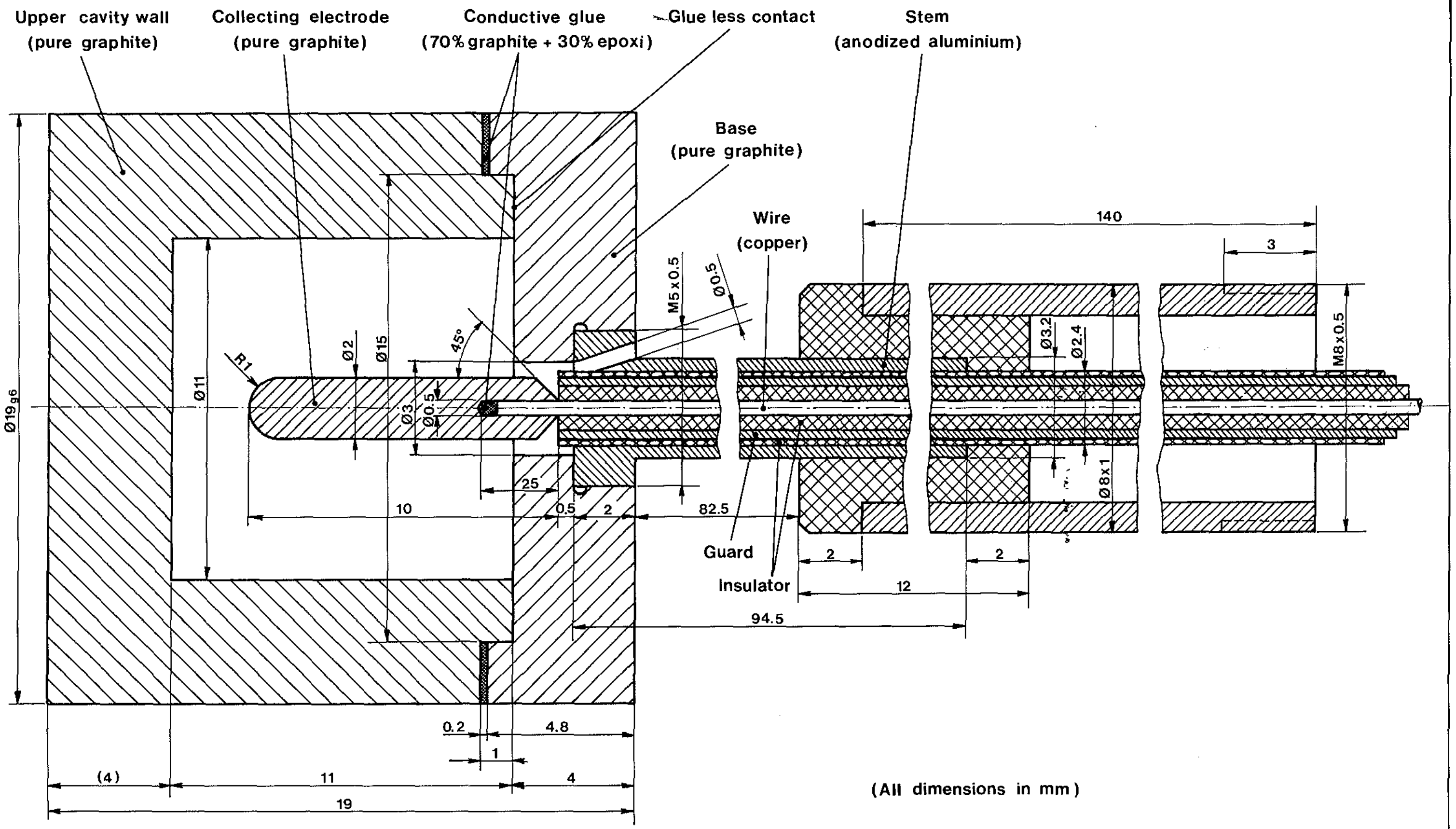
Depth in graphite (g·cm^{-2})



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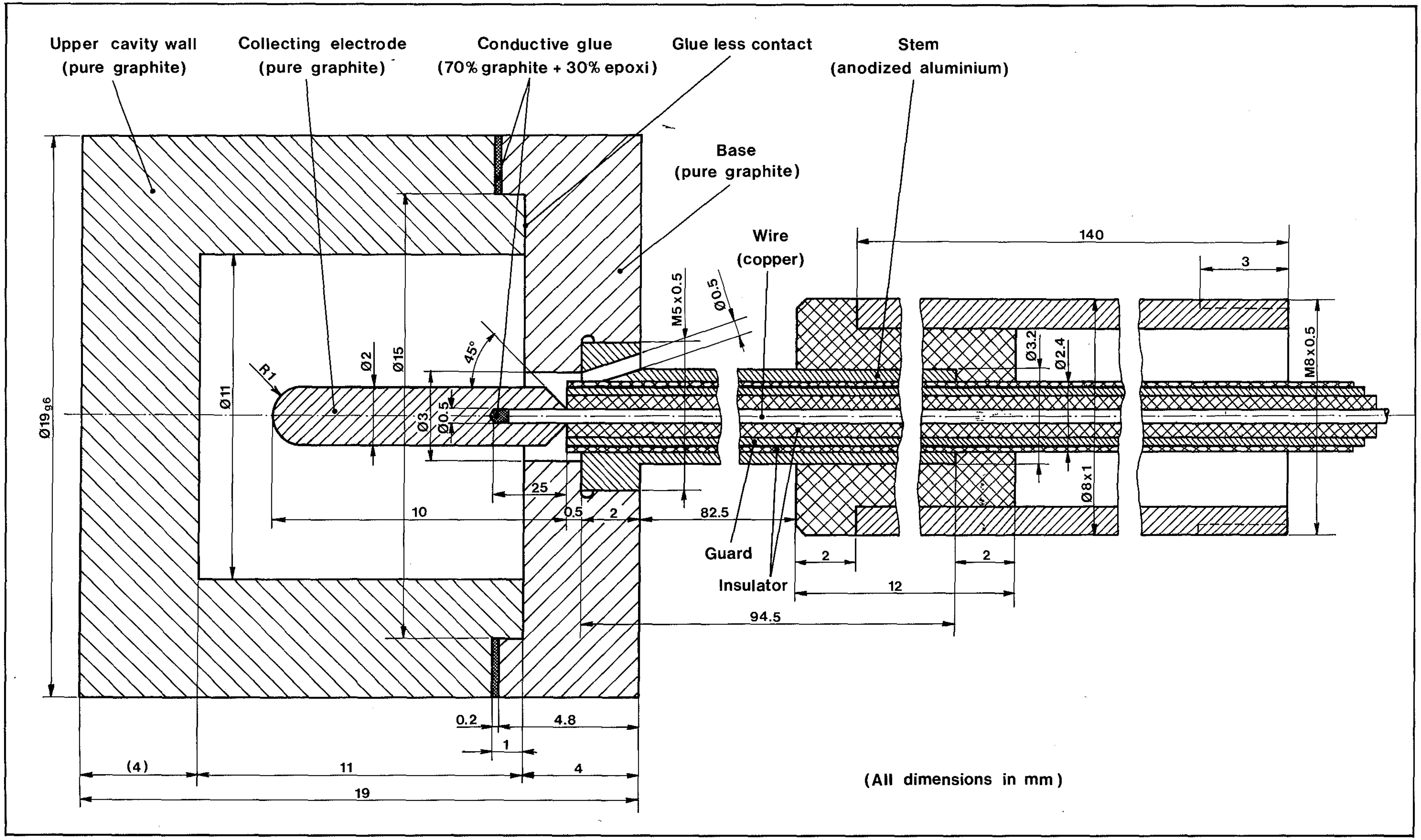

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