PINSTECH/HPD-122

ABSOLUTE EXPOSURE DETERMINATION OF COBALT-60 GAMMA RADIATION

SYED SALMAN AHMAD
AMANAT ALI
S. D. ORFI

HEALTH PHYSICS DIVISION
Pakistan Institute of Nuclear Science and Technology
Nilore, Rawalpindi.

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Syed Salman Ahmad

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ABSTRACT

The report describes the procedure for the determination of absolute exposure for Cobalt-60 gamma radiation. A graphite cavity chamber, nominal volume of 1 cm^3, manufactured by Austrian Research Centre Seibersdorf has been used. The exposure rate at reference distance determined with the graphite chamber was compared with mean exposure rate measured with NPL-Therapy level X-ray exposure meter normalized to same date. An agreement of 0.39% was found between the two measuring systems, which seems to be very encouraging and quite satisfactory.

The work presented in this report has been carried out in Pakistan, for the first time at the Secondary Standard Dosimetry Laboratory (SSDL) of Health Physics Division PINSTECH.

1. INTRODUCTION

The free air ionization chamber is used for the absolute exposure determination in the energy range of X-rays generated at potential from ten upto few hundred kilovolts. At higher energies experimental difficulties are encountered with this instrument in fulfilling the requirement that all ionizing particles be stopped in air. To overcome these experimental problems standard laboratories have adopted another method of standardization. This alternate method employs cavity ionization chamber and is based upon the principles of Bragg-Gray theory (1).

The graphite cavity ionization chamber used for this experimental work has been manufactured by Austrian Research Centre Seibersdorf. The volume of this chamber has been determined (volumetric measurement) to be 1.0216cc by Austrian Federal Bureau of Metrology with an uncertainity of 0.1 percent. The radiometric control of volume determination was carried out by the primary standard laboratory of Austrian Research Centre Seibersdorf in Cobalt-60 gamma radiation beam traceable to the Bureau International des Poids et Measures (BIPM).

2. CHAMBER DESCRIPTION

The chamber geometry is cylindrical and both the walls and the collecting electrodes are made up of high purity graphite. The chamber has been designed to fulfil the Bragg - Gray cavity theory requirement for Cobalt-60 gamma radiation. The details of the chamber design are shown in Fig. 1 and various important dimensions of the chamber are presented in Table 1.

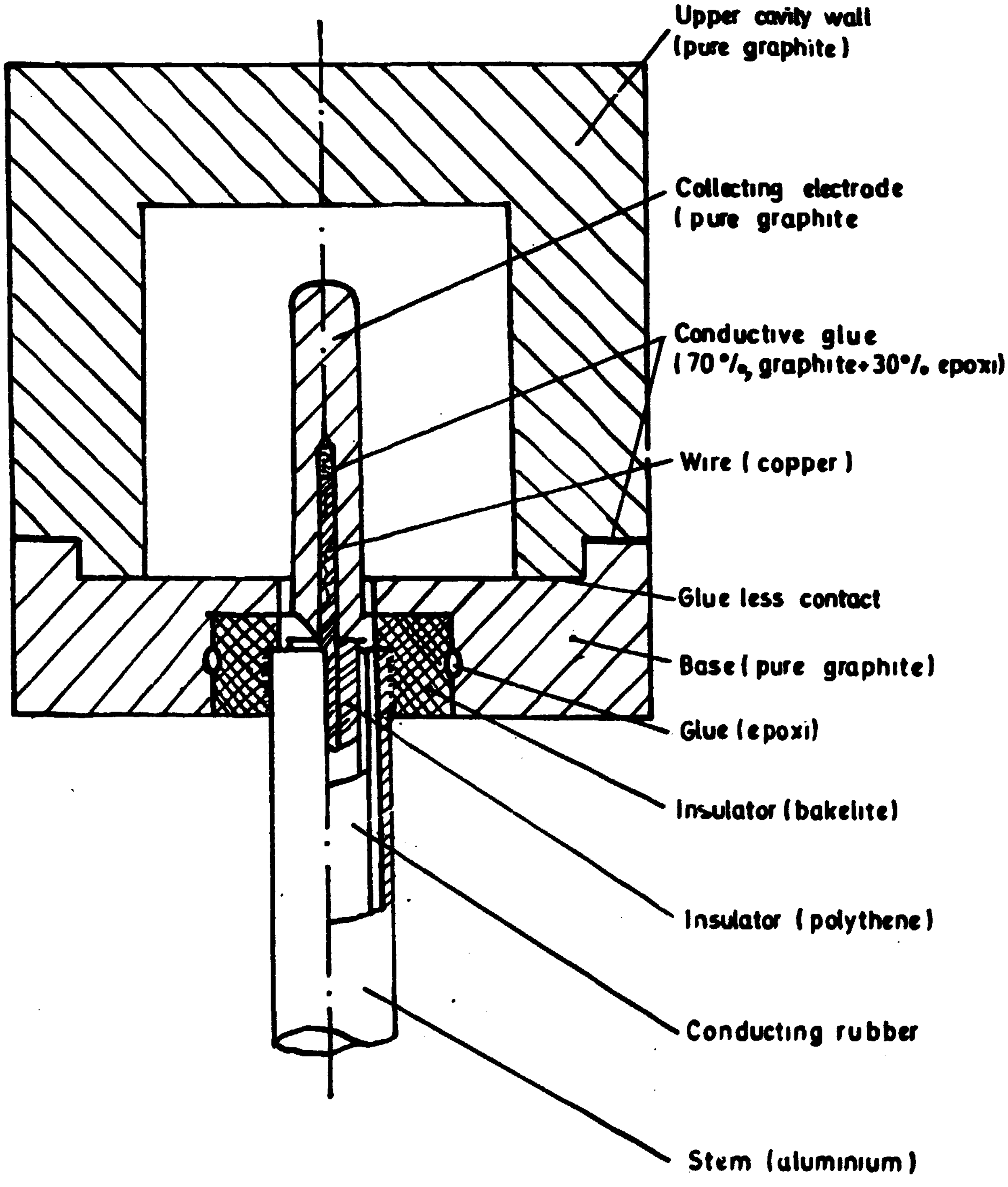


Fig. 1

Construction scheme of graphite ionization chamber Model CC-01

Table 1: Nominal dimensions of the graphite cavity chamber used.

Wall thickness (cm)	= 0.4
Height of cavity (cm)	= 1.1
Diameter of cavity (cm)	= 1.1
Diameter of collecting electrode (cm)	= 0.2
Height of collecting electrode (cm)	= 1.0
Volume of cavity (cm^3)	= 1.021_6

In order to minimize scattered radiations, the chamber stem of 4mm diameter has been made up of Aluminium.

3. IRRADIATION FACILITY

The irradiation facility consists of ELDORADO "G" Cobalt-60 teletherapy unit with source activity of about 63.24 TBq on 1.1.1986. The exposure rate at reference distance of 100 cm on a field size setting of 10 x 10 cm^2 is 27.3 R/min on 1.1.1986. The irradiation head is equipped with eight sided diapharm alongwith beam defining light. The field size can be adjusted from 2 cm x 2 cm to 15 cm x 15 cm at 55 cm from the face of source. A view of irradiation facility is shown in Fig. 2.

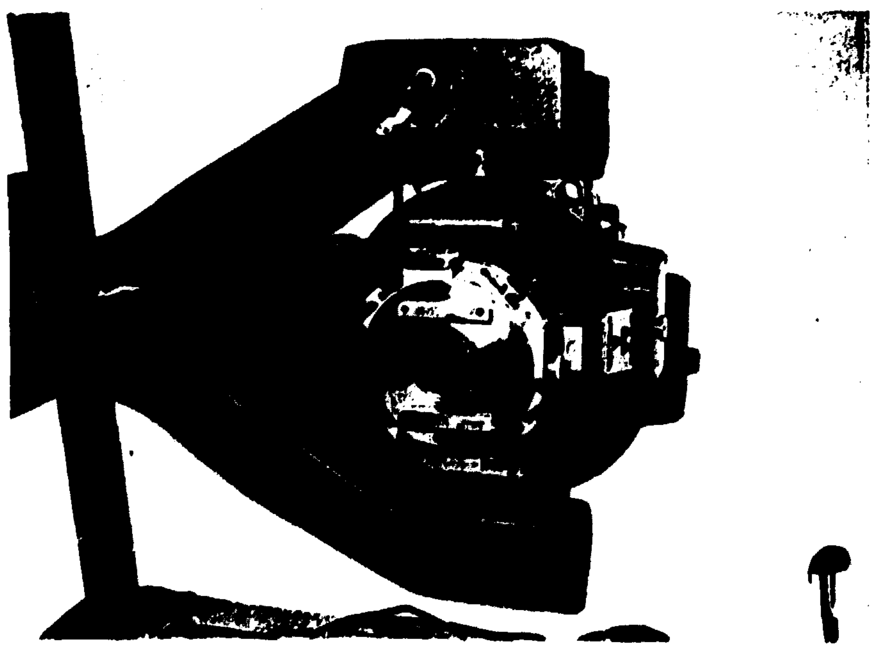


Fig. 2: Irradiation Facility

Beam uniformity measurements of Cobalt-60 gamma beam were carried out along the horizental and vertical direction with respect to beam axis using a small volume (0.1 cm^3) ionization chamber at various field sizes. It was found that the beam uniformity along the vertical direction with respect to the beam axis does not change appreciably within a distance of ± 1 cm.

4. CHARGE MEASURING ASSEMBLY

For the measurement of ionization current, Digital Current Integrator model NP-2000 shown in Fig. 3 has been used.

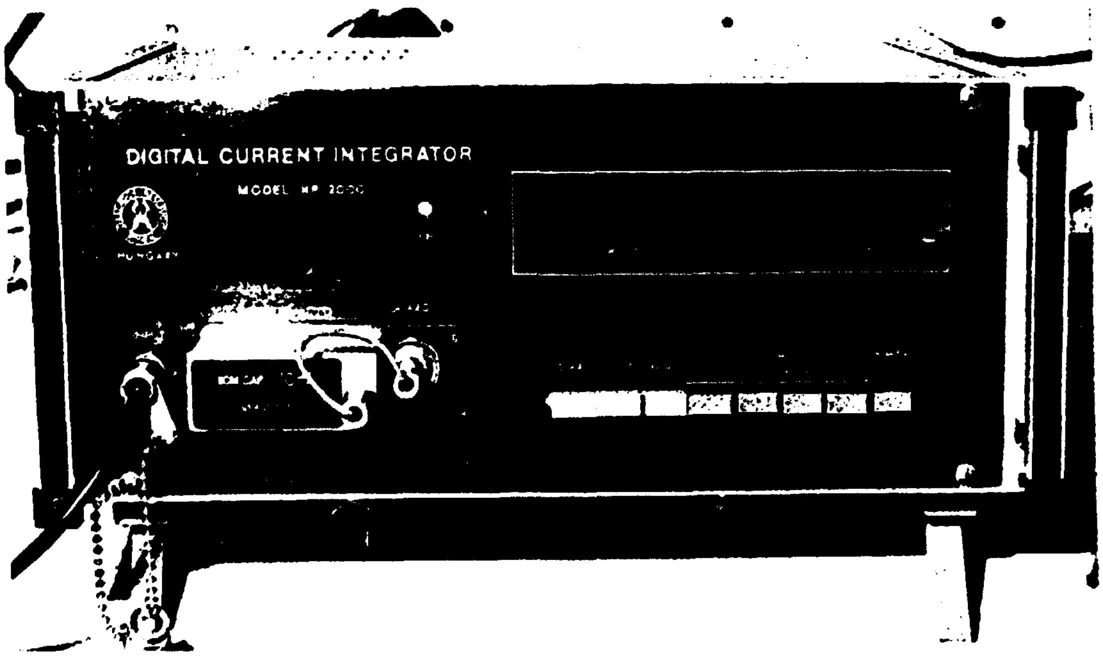


Fig. 3: Digital Current Integrator

This instrument has been designed and constructed by the Hungrian National Bureau of Measurement. The unit is capable of measuring current in the range of 10^{-15} A to 10^{-7} A, with an accuracy of ± 0.5%. The duration of current integration is measured by a time base (a crystal - controlled oscillator), with 4 digit display. The integrating voltmeter measures voltage at the interchangeable capacitor which is directly proportional to integrated current or the charge. The integrating capacitors provided with this unit have the nominal capacity of 100 PF, 1 nF, 10 nF ar.d 100 nF. The actual capacitance has been specified with an error of ± 0.1%. Integration cycle of duration 10Sec., 10C Sec., 1000 Sec., and infinity can be preselected and provision of both analogue and digital output is available with this unit.

5. EXPERIMENTAL ARRANGEMENT

Throughout the experimental work, the source to chamber distance was 100 cm. The field size at chamber position was 10 x 10 cm^2. The allignment of the chamber position in the central axis of the beam was done using laser beams and telescope. An overall view of experimental arrangement and irradiation facility is shown in Fig. 4.

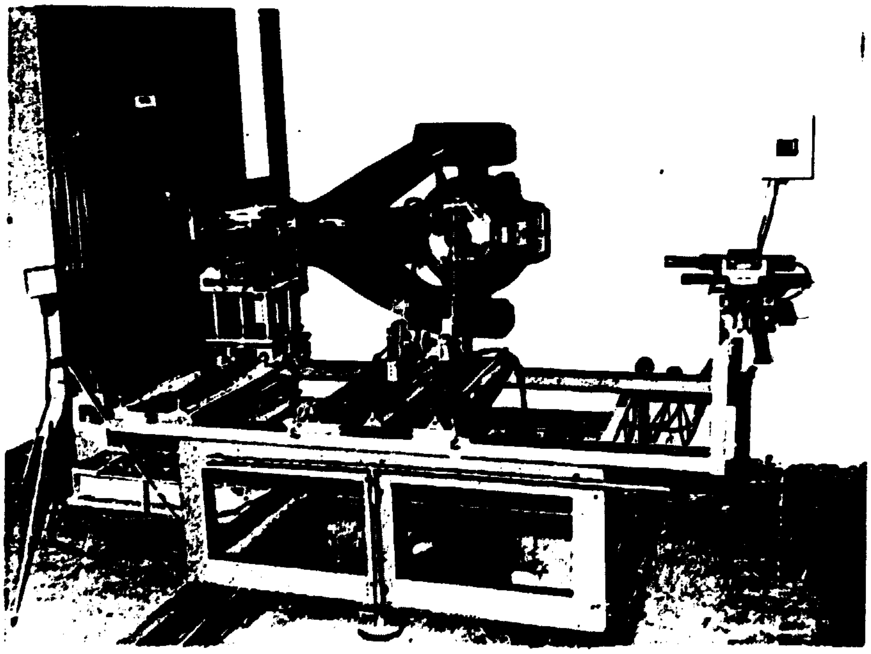


Fig. 4: Experimental Arrangement

6. DETERMINATION OF ABSOLUTE EXPOSURE

The determination of absolute exposure has been done by using the following relation (2) which is based upon the Bragg - Gray theory (3).

$$\dot{X} = \frac{1}{2.85 \times 10^{-4}} \times \frac{Q_{air}}{\rho V} \times \frac{(S/\rho)^{c}}{(S/\rho)\ air} \times \frac{(\mu en/\rho)^{air}}{(\mu en/\rho)^{c}} \times \quad \Pi K_i \text{ — (1)}$$

where 2.58 x 10^{-4} is the number of coulombs per kilogram of air produced by one roentgen, Q_{air} is the measured charge (in coulombs), V is the chamber volume m^3, ρ is the density of air in (Kg/m^3), (S/ρ) is the mass collision stopping power & ($\mu en/\rho$) is the mass energy absorbtion coefficient, ΠK_i is the product of the following corrections:

K_1 is the correction for leakage current.

K_s is the correction for loss of ionization due to recombination.

K_h is the correction for water vapours in air.

K_{st} is the correction for scattering from the chamber stem.

K_{an} is the correction for axial non-uniformity of the beam.

K_{rn} is the correction for radial non-uniformity of the beam.

K_c is the correction to zero wall thickness.

K_{CEP} is the factor which displaces the point of extrapolation from zero wall thickness to the mean center of electron production.

For determination of exposure rate equation (1) can also be written as under:

$$\dot{X} = \frac{60}{258} \times \frac{I}{V\rho} \times \frac{(S/\rho\ )^{c}}{(S/\rho\ )^{air}} \times \frac{(\mu en/\rho)^{air}}{(\mu_{en}/\rho)^{c}} \times \quad \Pi K_i \text{— } \quad (2).$$

Where I is ionization current measured with graphite cavity chamber.

6.1 Leakage Current

In the ideal case, the current measured by the electrometer system is generated exclusively by the electrons which ionize the gas in the chamber cavity. This ideal situation is not quite realized in practice since the radiation induced leakage currents in the supporting stem, connecting cables and chamber insulation, adds to the chamber reading. The contribution of leakage current was determined experimentally by performing series of measurements and was found negligible, thus $K_1 = 1.000$.

6.2 Loss of Ionization Due to Recombination

Initial and volume recombination results in the loss of ionization in the chamber cavity even at relatively high collecting voltages. The correction factor for the loss of ionization has been determined experimentally by graphical extrapolation of reciprocal current ($\frac{1}{I}$) versus reciprocal collection voltage ($\frac{1}{V}$). The graph which resulted to be linear with a regression co-efficient of 0.9976 is shown in figure 5. The experimentally determined value of the correction factor is 1.0023. It is assumed that the initial recombination is predominant over volume recombination which varies as inverse of the square of the volume and is dependent on the exposure rate (4).

6.3 Water Vapours in Air

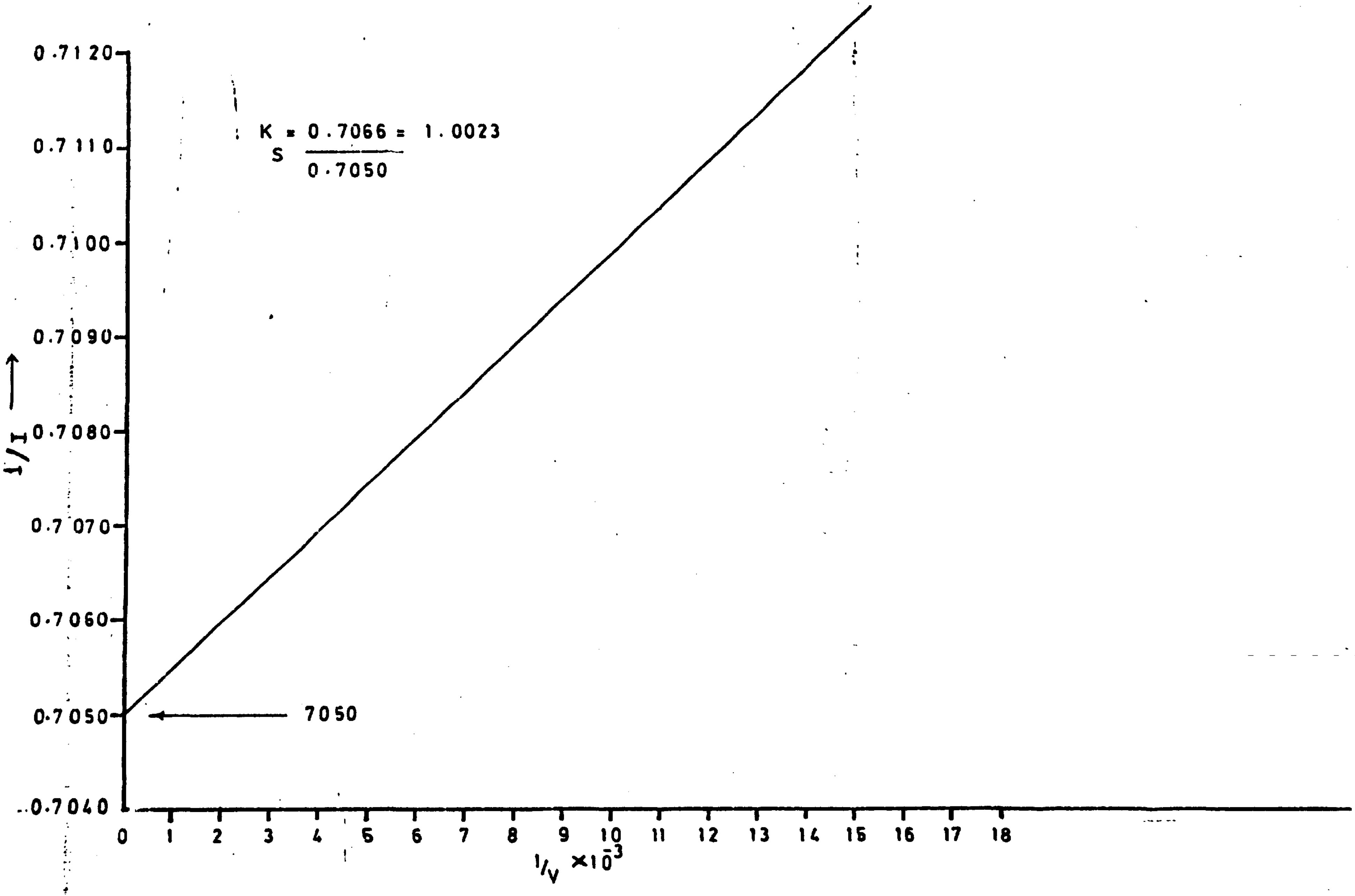
Water vapours are always present in air while the exposure is defined from the ionization of air which is implicitly supposed to be free from water vapours. For accurate measurement, a correction factor K_h is therefore required.

BIPM has proposed to use $K_h = 0.997$ if the relative humidity is below 50%. (5) Since the relative humidity varied from 45 to 55% throughout our experimental work, the value of $K_h = 0.997$ has been used in absolute exposure computation.

6.4 Scattering from the Chamber Stem

The contribution of scattered radiation from the chamber stem has been determined experimentally by using dummy stem of identical size. A series of measurements with and without additional stem revealed that the value of stem correction is smaller than the statistical uncertainties, thus $K_s = 1.000$.

FIG: 5-SATURATION CORRECTION FACTOR



6.5 Axial Non-Uniformity of the Beam

The axial non-uniformity of the beam depends upon source - chamber distance. The formula for the determination of the correction factor is available in reference (4). The presently used value of this correction factor (K_{an} = 0.997) has been taken from literature (5) for an identical size chamber being used as a primary standard for cobalt-60 gamma beam at ENEA Italy.

6.6 Radial Non-Uniformity of the Beam

Due to finite size of the source and the collimating system, the photon fluence is not rigrously constant in a plane perpendicular to the beam axis. As a result the exposure measured by the cavity chamber represents a value averaged over the chamber area. The radial non-uniformity correction must be taken into account to obtain exposure values independent of chamber size.

The beam uniformity measurements perpendicular to the beam axis were carried out using a small ionization chamber of 0.1 cm^3 volume. In a region of ± 1cm which entirely covers the chamber area, no appreciable variation of photon fluence has been detected. The factor K_{rn} has therefore, been taken as 1.000.

6.7 Wall Effect

The gamma radiation measurements in terms of exposure should be made in a small volume of air, surrounded by enough air to satisfy the condition of secondary electron equilibrium. Whereas, in actual practice, the chamber is made up of material (graphite) different from air. For absolute exposure measurement a correction for the wall effect is therefore, essential. The wall correction factor K_w can be written as:

$$K_w = K_c \cdot K_{CEP}$$

Where K_C corrects the attenuation and scattering of the radiation in the actual graphite chamber walls and K_{CEP} corrects for the mean centre of electrons productions. In actual case, secondary electrons are coming in ionization volume from different depths of the chamber wall upto equilibrium thickness.

The value of K_C has been determined by using four cylindrical caps having identical thickness but different sizes (shown in Fig. 6) in order to be fitted one inside another.

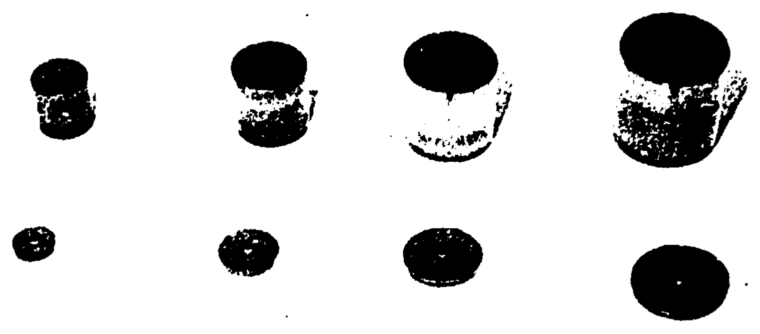
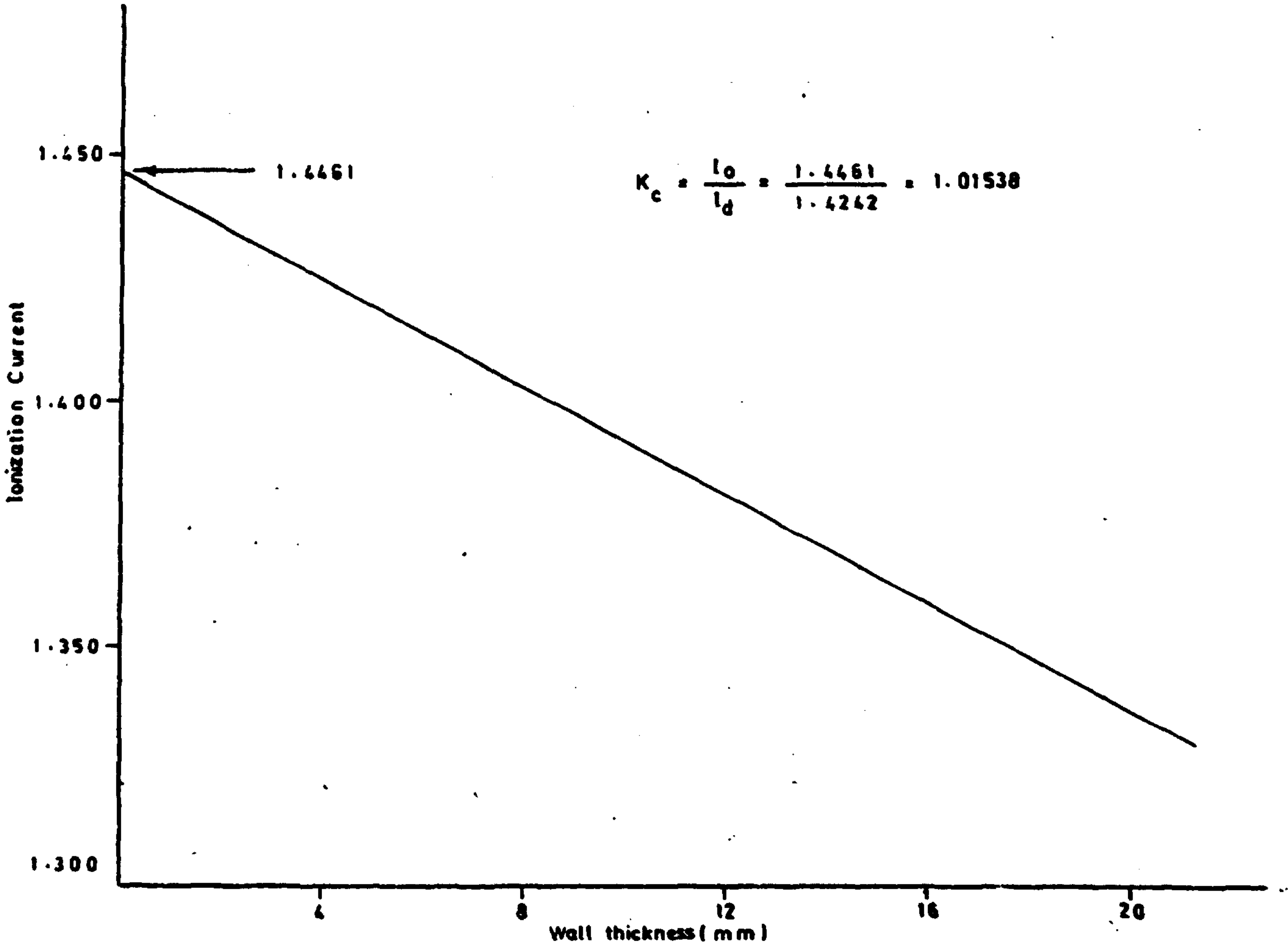


Fig. 6: Cylindrical caps.

A graph which is shown in Fig. 7 is plotted between ionization current and wall thickness. The straight line obtained by least-square calculation with a regression co-efficient of - 0.9999 is extrapolated to zero wall thickness.

$$K_C = \frac{I_C}{I} = 1.015_4$$

FIG.7. WALL CORRECTION FACTOR



where Io is extrapolated value of the current at zero wall thickness and I is the current measured with the chamber without caps.

The correction factor K_{CEP} has been estimated according to the procedure reported in reference (6) and found to be 0.997.

7. RESULTS AND DISCUSSION

The estimated values of various correction factors and physical parameters for graphite cavity chamber are presented in Table 2 & 3.

Table 2: Correction factors for the graphite chamber.

K_L	Leakage current	1.000
K_s	Saturation	1.002_3
K_h	Water vapour in air	0.997
K_{st}	Scattering of the chamber stem	1.000
K_{an}	Axial non-uniformity	1.000
K_{rn}	Radial non-uniformity	0.997
K_c	Wall thickness	1.015_4
K_{CEP}	Origin of electron Production	0.997

Table 3: Estimated physical parameters for the graphite cavity chamber

* $(S/\rho)^{c}/(S/\rho)^{air}$	: Carbon air mass collision stopping power ratio	0.9930
** $(u_{en}/\rho)^{air}/(u_{en}/\rho)^{c}$	: Air carbon mass energy absorption co-efficient ratio	0.9985
ρ	: Air density (10^{-6}Kg. m^{-3}) at reference conditions i.e. P = 101.325 KP. and T = 293.15 K°	1.2045

* The value of mass collision stopping power ratio has been taken from reference (5).

** Mass energy absorption co-efficient ratio has been estimated from the Hubbel data (7).

The uncertainties associated with the correction factors and physical parameters from exposure determination with graphite cavity chamber are presented in table (4).

Table 4: Uncertainties

ΔK_s	0.04
ΔK_h	0.05
ΔK_{st}	0.03
ΔK_{rn}	0.1
ΔK_{an}	0.1
ΔK_c	0.05
ΔK_{CEP}	0.2
$\Delta (S/\rho)c_{air}$	0.5
$\Delta (\mu_{en}/\rho)c^{air}$	0.1
ΔV	0.1
ΔI	0.1

The overall uncertainty (0.60) has been determined by taking square root of sum of squares of individual uncertainties.

Summary of the results of ionization current measurement corrected for reference conditions and normalized to 1.1.1986, with graphite cavity chamber is presented in Table 5. These measurements have been taken at both polarities and ea..h reading shown in Table 5. These measurements have been taken at both polarities and each reading shown in Table 5 is a mean of a separate series of ten measurements. The polarity effect was found to be 1.002_2.

Table 5: Summary of the results of ionization current measurements corrected for reference conditions and normalized to 1.1.86.

Date of measurement	Ionization current 10^{-10} Amp
16.1.1986	1.4252_6
19.1.1986	1.4247_4
19.1.1986	1.4245_4
19.1.1986	1.4245_4
20.1.1986	1.4237_5
20.1.1986	1.4256_5
21.1.1986	1.4246_4
22.1.1986	1.4248_5
22.1.1986	1.42512_9
23.1.1986	1.4236_4
27.1.1986	1.4232_3
28.1.1986	1.4238_6
28.1.1986	1.4244_9
	$X=1.42448_7$
	1-13
	$\%\sigma = 0.05$

By putting the values of correction factors, physical parameters and measured ionization current presented in Table 2 - 5 in exposure compautation equation (2), the exposure rate was determined to be 27.31 R/min on 1.1.1986. The exposure rate measurements carried out with NPL - therapy level X-ray exposure meter under the same conditions during the last three years were normalized to 1.1.1986. The mean value of the measurements comes out to be 27.20. The comparision of the mean value of NPL measurements with graphite cavity chamber measurement showed an agreement of 0.39%.

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