

**PROPOSED SPECIFICATION FOR A PRIMARY STANDARD OF AIR KERMA
FOR ^{60}Co , ^{137}Cs AND ^{192}Ir γ -RAY SOURCES**

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ABSTRACT

The three cavity chambers, the mean response of which constitutes the primary standard of air kerma for ^{60}Co and ^{137}Cs γ -rays in the United Kingdom, have been in continuous, almost daily, use at the National Physical Laboratory (NPL) since 1956.

These chambers were initially designed for use with 2 MV X-rays at therapy level air kerma rates. However since 1978 they have also been used for protection level air kerma rates, initially, with X-rays generated at 1 MV and 2 MV and more recently with ^{60}Co and ^{137}Cs γ -rays. They have been used for therapy level air kerma calibrations with ^{60}Co γ -rays since 1997 following the demise of the NPL 2 MV Van de Graaff generator.

This report describes the proposals for a new primary standard and the methods that will be used to give a better performance than the present standard when used with air kerma rates from as high as 1 Gy min^{-1} down to 10 mGy hr^{-1} . The design will also seek to ensure that the standard will be capable of providing traceable calibration for ^{192}Ir high dose rate brachytherapy sources.

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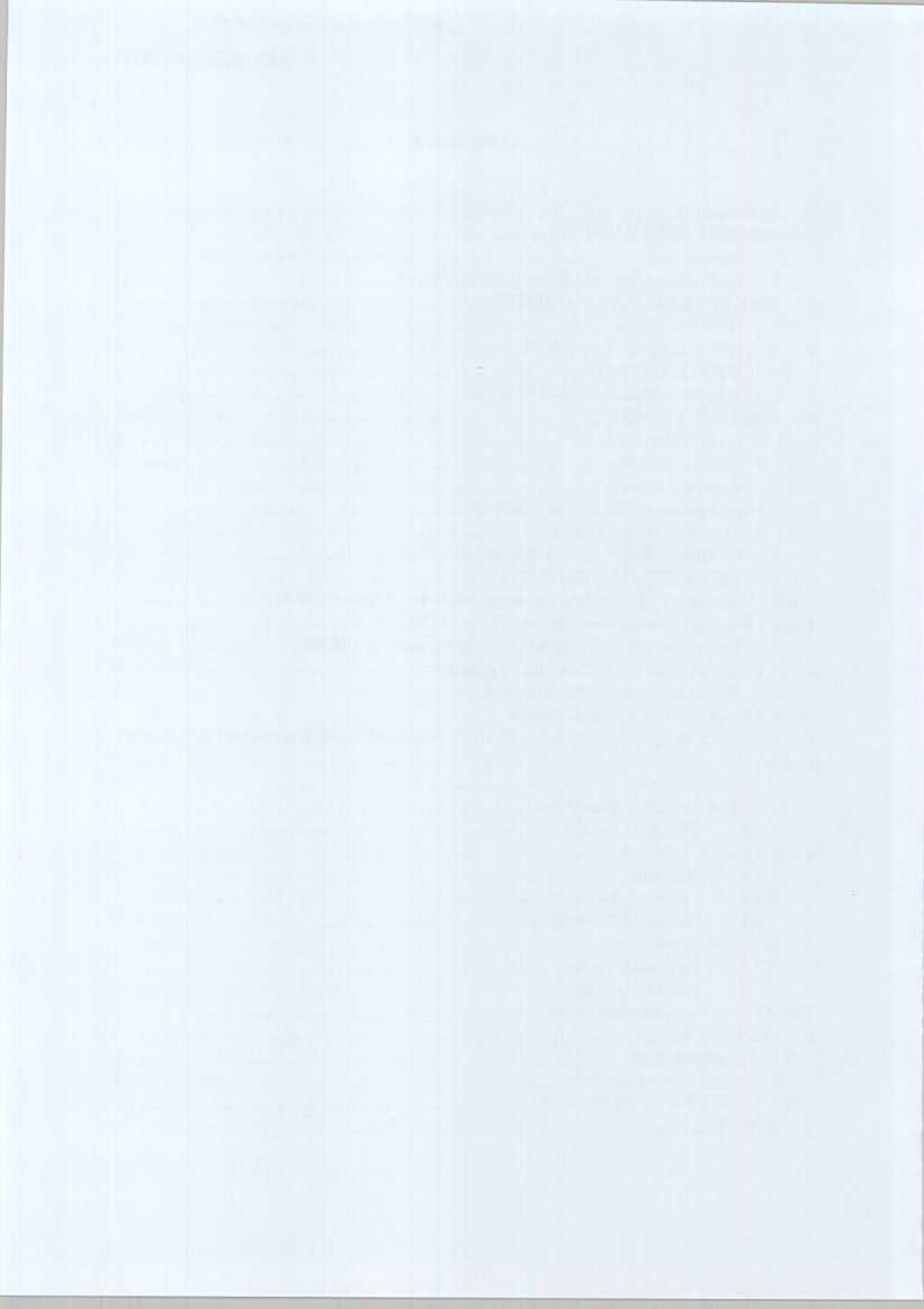
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1 INTRODUCTION

The primary standard used for high energy protection level air kerma calibrations using ^{60}Co and ^{137}Cs γ -rays was originally constructed for measurements at therapy level air kerma rates. The chambers that comprise the standard are reaching the end of their working life and will need to be replaced in the near future. An earlier report¹ examined the suitability of the present standard for protection level measurements and for use with ^{192}Ir γ -rays and identified areas that needed to be considered in designing a replacement. Further work has since been carried out and this report records the decisions that have been taken. The results of these deliberations have been incorporated into the design specification that constitutes the second part of this report.

2 PRESENT STANDARD

2.1 DESCRIPTION

The current primary standard of air kerma for ^{60}Co and ^{137}Cs γ -rays is taken as the mean response of three graphite cavity standards^{2,3}. Each chamber is of a similar construction being in the form of a right circular cylinder made of high density graphite with a volume of about 1.8 cm^3 with a cap thickness of about 3 mm. As stated these chambers were designed originally to be used with 2 MV x-rays the mean energy of which is in the region of 900 kV. The main chamber insulator is amber and the collecting electrode is graphite. The chambers are supported by an aluminium stem about 300 mm long, which is connected to earth. This has the connection for the central electrode running down the centre insulated, from the stem, by Ceresin wax. The HT connection to the cap is by a separate lead running down the outside of the stem. These connections are terminated at the end of the stem in a series 'N' connector for the collector and a BNC connector for the HT. The series 'N' is mounted in a small cast aluminium box filled with Ceresin wax, attached to the end of the stem, to eliminate any problems caused by cavities near the collector. The polarising potential of these chambers is -300 V.

2.2 DEFICIENCIES FOR PROTECTION LEVEL DOSIMETRY

These three chambers have been in continuous, almost daily, use as the national primary standard since 1956. They were initially designed for use with 2 MV x-rays at therapy level exposure rates. They were adopted as the standard for protection exposure rates with x-rays generated at 1 MV and 2 MV in 1978 and more recently air kerma at ^{60}Co and ^{137}Cs .

Because of the small volume of the chambers they are not ideally suited for use at protection level because of the high uncertainties associated with the low current collected. With maximum air kerma rates in the 300 mGy h^{-1} to 350 mGy h^{-1} the current produced by the standards is in the region of 6 pA with a leakage of about 30 fA this gives a leakage of about 0.5% of the ionisation current. Ideally the new standard should have a leakage of no greater than 0.1%. The chamber wall thickness is not thick enough for ^{60}Co γ -rays, which have a highest significant energy photon emitted at an energy of 1.33 MeV, this requires a thicker walled chamber than the current chambers.

3 PROTECTION LEVEL FACILITIES

3.1 DESCRIPTION

The irradiator for protection level calibrations^a is equipped with four ⁶⁰Co γ-ray sources the highest activity source giving an air kerma rate of approximately 350 mGy h⁻¹ at the normal calibration distance of 2 metres from the source. The irradiator also has four ¹³⁷Cs sources the maximum air kerma rate from these sources is in the region of 300 mGy h⁻¹. Each source is positioned to give a collimated circular beam with a diameter of about 400 mm at the calibration distance. A transfer standard is used to calibrate dosimeters at air kerma rates down to about 0.2 mGy h⁻¹ using the lower activity sources.

4 STANDARD FOR ¹⁹²Ir γ-RAYS

4.1 INTRODUCTION

There is a growing interest in the radiotherapy community in brachytherapy treatments. The principle nuclide used at present is ¹⁹²Ir; the highest, significant, energy photon emitted is 670 keV. NPL has a commitment to provide a calibration service for high dose rate brachytherapy.

4.2 MEASUREMENT CONDITIONS

The guidelines for brachytherapy Dosimetry⁴ define a specification quantity, reference air kerma rate (RAKR), which is the air kerma rate at 1 m from the source. Under these conditions the maximum air kerma rate is approximately 50 mGy h⁻¹ for a new high dose rate source^b, falling to only 8 mGy h⁻¹ after 6 months when the source at NPL is normally replaced.

5 PRIMARY STANDARD

5.1 CAVITY STANDARD

Measurements carried out at NPL⁵ have demonstrated that the sensitivity of the present therapy-level primary standard cavity chambers is inadequate for the γ-ray air kerma rate available even from high dose rate brachytherapy sources at convenient source to chamber distances.

5.2 FREE AIR CHAMBER

Measurements have been made with the 300 kV primary standard free air chamber⁶. While the sensitivity of the chamber is more appropriate for the air kerma rates available, the size of some correction factors, especially ion loss (more than 100%) and front face penetration (greater than 30%), and the large uncertainties in others rule out the use of this standard.

^a Multi-source Irradiation Unit, Mainance International Ltd, Waterlooville, Hants

^b MicroSelectron-HDR, Nucletron UK Ltd, Tattenhall, Chester

5.3 FUTURE STANDARD

Measurement has shown that the existing NPL primary standard chambers are inadequate for use with ^{192}Ir γ -rays. Since a large-volume, thick-walled cavity standard is required for measurement with these beams it is recommended that the proposed ^{60}Co and ^{137}Cs γ -ray protection-level cavity standard is designed to be suitable also for use with ^{192}Ir γ -ray beams.

6 DESIGN REQUIREMENTS FOR THE STANDARD

6.1 THEORETICAL CONSIDERATIONS

Bragg-Gray cavity theory normally has to be taken into account in designing a cavity chamber for the measurement of air kerma. The theory effectively requires or assumes:

- (a) that charged particle equilibrium exists in the absence of the cavity;
- (b) (i) that the cavity does not disturb the charged particle fluence or its distribution in energy and direction, and (ii) as a corollary to (i) that charged particle production in the cavity is negligible or no different from that in an equal mass of surrounding medium;
- (c) that the mass stopping power ratio does not vary with energy;

and

- (d) that the secondary charged particles lose energy by a process of continuous slowing down, ie by a large number of very small energy loss events.

The Monte Carlo code (EGSnrc) will be used for the calculation of the correction factors for the primary standard chambers. This makes no assumptions about the chamber obeying Bragg-Gray cavity theory but relies solely on modelling individual interactions. Thus, as a result of using this modelling technique, it is not necessary that the cavity chambers meet the above requirements of cavity theory.

6.2 CORRECTIONS AND UNCERTAINTIES

The design of the standard should be such as to minimise the magnitude of any corrections applied to it and the overall uncertainty in the realisation of the measurement quantity. Although it is not necessary to meet the requirements of cavity theory it is desirable that materials used in the construction of the standard should, as far as possible, be air equivalent to minimise the corrections applied.

6.3 MEASUREMENT QUANTITY

The recommendation of the British Committee on Radiation Units and Measurements (BCRU) and the present code of practice in the United Kingdom⁷ is that air kerma should be used for photon Dosimetry in air; any new primary standard should therefore realise air kerma.

6.4 SUMMARY OF PRINCIPAL RECOMMENDATIONS OF REPORT CIRM36

The recommendations of report CIRM36 concerning the design of the standard are summarised in Table 1 below.

Table 1 Principal recommendations of Report CIRM36

Parameter		Recommendation
Type of standard		Thick-walled cavity chamber
Volume		Up to 100 cm ³
Design		Review designs of other primary standards
Wall thickness		690 mg cm ⁻²
Measurement quantity		Air kerma
Radiation beams	Sources	⁶⁰ Co, ¹³⁷ Cs and ¹⁹² Ir γ -rays
	Minimum dose rate	10 mGy h ⁻¹ or less
	Minimum beam diameter	At least 200 mm, preferably 500 mm
Polarising potential		Capable of being used with at least 1000 V

6.5 REQUIREMENTS ESTABLISHED SINCE PUBLICATION OF CIRM36

Following the publication of CIRM36 two formal review meetings have been held and other informal discussions. Experimental and computational work has been carried out to further refine the design requirements; the results of this work are summarised in Table 2.

Table 2 Further and revised design requirements

Parameter	Requirement
Minimum beam diameter	230 mm – implies a minimum clear stem length of at least 200 mm
Chamber configuration	Spherical
Number of chambers	Minimum of 4
Chamber volumes	5, 10, 30, 100 cm ³ (preferably 2 of each)
Chamber and electrode material	High purity extruded graphite Impurity less than 40 ppm
Thin wall option	One 100 cm ³ chamber to have thinner, 350 mg cm ⁻² thick wall plus 350 mg cm ⁻² thick build up shell

6.6 DECISIONS TO BE MADE AT DESIGN

A number of aspects of the standard are best considered as part of the engineering stage of the design process and so should be left unresolved at present, see Table 3.

Table 3 Engineering design decisions

Design aspect	Decision required	Comments
Stem construction	Material	Carbon fibre-reinforced epoxy aluminium
	Coaxial/triaxial	Coaxial – external HT lead Triaxial – inner screen
	Stem insulation	Ceresin wax Polymer (eg PCTFE, Lucentine) Chamber insulator
	Signal conductor material	Carbon fibre Copper Aluminium
Cable (signal and HT)	Hard-wired or detachable	Hard wired preferred
	Coaxial/triaxial	Triaxial preferred
	Cable manufacturer	
	Connectors	
	Signal	BNC/TNC, depending on cable
	HT	depending on cable
Main insulator	Material	Amber, peek TM , Sapphire or pctfe

7 ENGINEERING SPECIFICATION FOR A PRIMARY STANDARD OF AIR KERMA FOR HIGH ENERGY γ -RAYS

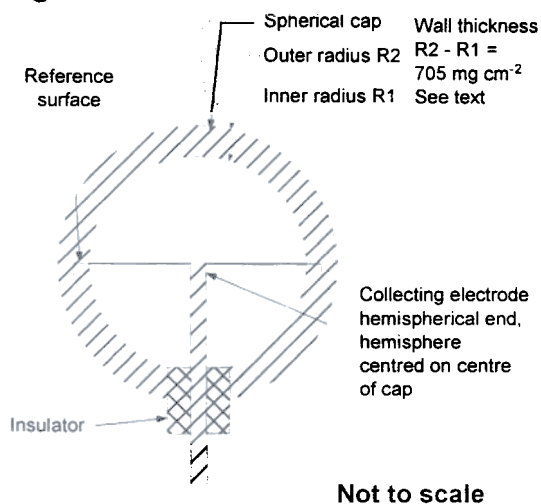
7.1 INTRODUCTION

The primary standard is intended for the measurement of air kerma for γ -rays emitted from ^{60}Co , ^{137}Cs and ^{192}Ir . It will consist of a number of thick-walled ionisation chambers of differing volumes, the mean response of all of the chambers being taken as the standard. This specification is in three parts, the first relating to the design of the ionisation chambers themselves, the second to the construction of the supporting stem(s) and electrical connections. The final section defines the requirements for ancillary items that are required for evaluating the performance of the standard.

7.2 THE IONISATION CHAMBERS

7.2.1 Chamber format

Figure 1 General format of chamber



The general format of the chambers is illustrated in Figure 1; chamber volumes are listed in Table 1. Two chambers of each size are required.

Table 4 Cavity volumes

Nominal cavity volumes/cm ³
5
10
30
100

It is essential that precautions be taken to minimise surface contamination of all chamber components and that diamond or ceramic tipped tools are used to machine them. The cap shall be manufactured as two mating hemispheres, joined with a push fit or screw thread only, without use of other fixing materials. The joint shall be machined to minimise cavities in the assembled cap, no cavity shall occur with a volume of more than 0.1% of the internal volume of the cap. The reference surfaces for mating the two hemispheres shall be the join surfaces inside the cavity; the gap between hemispheres at the outside shall not be greater than 0.02 mm. The total combined volume of all cavities will be no greater than 0.1% of the internal volume of the cap.

Materials

The wall and collecting electrode shall be machined from high purity (40 ppm impurity or less) high density graphite. The insulator shall be made from one of the following peekTM, amber, sapphire and pctfe, part of this project shall be the testing of each of these insulators to ascertain their suitability for this task. No other material may be used in the construction of the chamber or in the immediate vicinity ie within 5 mm of the cavity; beyond this distance other materials may be used but kept to the minimum possible, particularly if they have an atomic number greater than 13 (aluminium).

Cap wall thickness

The wall of the cap shall have a superficial thickness ($R_2 - R_1$, see Figure 1) of 0.705 g cm^{-2} with an uncertainty of $-0\% +0.1\%$ (but see later, Wall study chamber)

$t_s = t_p$

where

t_s = superficial thickness, g cm^{-2}

t = actual thickness, cm

ρ = density of the material concerned, g cm^{-3} .

As an example, if the graphite has a density of 1.8 g cm^{-3} then the actual thickness t required to give a superficial thickness t_s of $0.705 \text{ g cm}^{-2} = 0.705/1.8 = 0.39 \text{ cm}$.

The wall thickness will have to be adjusted to suit the density of the graphite actually used for manufacture, and machining tolerances adjusted to take account of the uncertainty in the density.

Electrode dimensions

The central electrode shall have a hemispherical end and its length shall be such as to place the centre of the hemisphere at the centre of the chamber. The diameter of the electrode shall be $3 \text{ mm} \pm 0.1\%$.

7.3 THE STEMS

Stem construction

The purpose of the stem is to support the chamber in the radiation beam and to make the necessary electrical connections while interfering as little as possible with the beam. It therefore needs to be constructed of low atomic number material ($Z = 13$ (aluminium) or less) with the minimum amount of material necessary to support the chamber stably with the stem horizontal when fixed in a mounting bracket outside the beam. The same stem design shall be used for each chamber.

The stem shall be electrically conducting and will be earthed when the chamber is in use. An electrically screened connection must be made to the collecting electrode of

the chamber and a second connection supplied for the polarising potential (up to 1000 V) to be applied to the cap.

An essential feature of the electrical connection to the central (collecting) electrode is that there shall be no significant air cavities (volume > 0.01 % of the chamber volume) close to the signal lead that might give rise to a spurious ionisation current.

7.3.2 Electrical connections

The electrical connections to the chamber may be made either with a triaxial low noise cable or with two separate screened cables, one for the signal (low noise) the second for the HT (1000 V). If triaxial cable is employed the central conductor will be used for the signal, the inner screen will be earthed and the outer screen will carry the chamber HT (up to 1000 V). At least 3 m of cable shall be permanently attached to the chamber (stem) so that any connectors may be placed outside the radiation beam and shielded from the radiation if necessary.

The cable(s) may be taken up the stem to the vicinity of the chamber subject to meeting the requirements for atomic number and spurious cavities. Alternatively the signal cable may be terminated at the end of the stem remote from the chamber and a signal lead taken up the centre of the stem provided it is suitably insulated and cavity free.

Table 5 Possible connector types

Signal connector	HT connector
TNC	...
BNC	SHV

8 ANCILLARY ITEMS

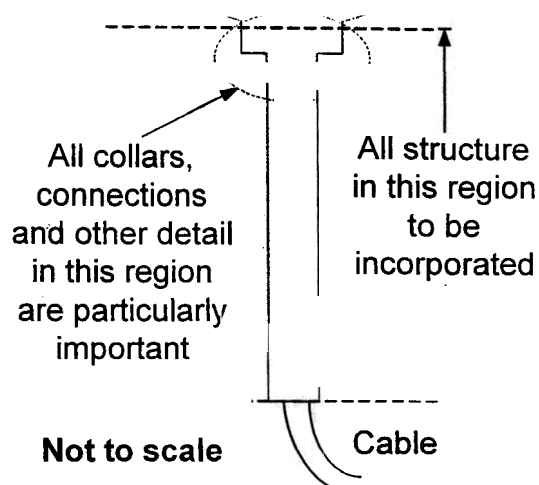
8.1 DUMMY STEM

A dummy stem is required that shall be manufactured to the same design as that used for the chambers up to a point equal to the cap wall thickness from the interior of the cavity; the dummy stem shall include any collars, electrical connections, etc, and use the same materials see Figure 2.

8.2 WALL STUDY CHAMBER

A further chamber is required of the same general construction, including stem, as those described above, with a volume of 100 cm³; the only difference is that the wall thickness

Figure 2 Dummy stem



should be 350 mg cm^{-2} . In addition it is required to have two additional removable nesting spherical shells with thicknesses of 350 mg cm^{-2} and 700 mg cm^{-2} respectively. Each shell shall fit the closely round the chamber with radial gaps of no more than 0.1 mm. The shells shall be machined from the same batch of graphite as that used for the chamber.

8.3 INSULATOR TEST RIG

To test the suitability of the two materials to be used for the insulator a rig is needed to test the insulating properties of of the insulators listed above. A number of test insulators, of all materials, will need to be manufactured for use in this rig.

9 REFERENCES

1. Angliss, R.F. and Moretti C.J., *Review of Requirements for a Primary Standard of Air Kerma for ^{60}Co and ^{137}Cs γ -Rays at Protection Level Air Kerma Rates*, NPL Report CIRM 36 (March 2000)
2. Angliss, R.F., *private communication*, 21 November 2000
3. Moretti, C.J., *private communication*, 1 June 2001
4. Joint BIR/IPSM Working party, *Recommendations for Brachytherapy Dosimetry*, December 1992
5. Nutbrown, R.F. and Sander, T., *Corrections to Air Kerma Rate Measurements from a ^{192}Ir High Dose Rate Brachytherapy Source to Free Space Conditions*, NPL Report CIRM 39 (August 2000)
6. NPL workbooks
7. BCRU (1982), *Use of Air Kerma for Photon Dosimetry in Air*. Memorandum from the British Committee on Radiation Units and Measurements. Br. J. Radiol. (55) pp. 375-377.