Review of Requirements for a Primary Standard of Air Kerma for ^{60}Co and ^{137}Cs γ-Rays at Protection Level Air Kerma Rates

R F Angliss and C J Moretti
Centre for Ionising Radiation Metrology

March 2000

Abstract

The three cavity chambers which comprise the primary standard of air kerma for ^{60}Co and ^{137}Cs γ-rays are reaching the end of their working life. A new primary standard suitable for use at protection level air kerma rates is proposed to replace them and the main parameters which must be addressed in the design are identified. Recommendations are made for further work needed to inform the design process.

ISSN 1369-6793

Authorised by Dr Martyn Sené
Head of the Centre for Ionising Radiation Metrology

National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW

CONTENTS

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. With the introduction of absorbed dose standards and calibration services at therapy level dose rates based upon them the demand for therapy level air kerma calibration with ^{60}Co γ-rays is expected to decrease over the next 5 years. As a consequence it seems sensible that the replacement standard is optimised for the measurement of air kerma at protection level rates where it seems unlikely that there will be a demand for absorbed dose measurements for the foreseeable future. This report examines the suitability of the present standard for protection level measurements and identifies areas which will need to be considered in designing a replacement.

2. PRESENT STANDARD

2.1 DESCRIPTION

The present primary standard of air kerma for ^{60}Co and ^{137}Cs γ-rays comprises three nominally identical graphite-walled cylindrical cavity ionisation chambers each with a volume of about 1.8 cm^3; their mean response is taken[1,2,3]. The chambers, which were designed specifically for the measurement of 2 MV X-rays at therapy-level air kerma rates and for the calibration of therapy level secondary standards, have been in use for therapy level calibrations since 1954. The standard has also been used since 1978 for the protection level calibration service, initially with X-rays generated at 1 and 2 MV and subsequently with ^{60}Co and ^{137}Cs γ-rays.

2.2 DEFICIENCIES FOR PROTECTION LEVEL DOSIMETRY

The principal difficulty in the use of the therapy level primary standard for calibration at protection level air kerma rates arises from the low ionisation current due to the relatively low sensitivity; air kerma rates are 200 times less than the standard was designed for. In addition, because the chambers are of an unguarded design, that is to say that they have the full chamber polarising potential across the main insulator to the collecting electrode, they have a relatively large leakage current. As a consequence of the low ionisation current the leakage current in the primary standard chambers, while acceptable for therapy level measurements, becomes a large correction and leads to an undesirable increase in the uncertainty of measurement for protection level air kerma rates. The difficulty of measurement makes the standard unsuitable for routine use in protection level calibrations. Instead, a transfer standard is calibrated periodically at the maximum air kerma rate available from the irradiator, at one metre focal distance, and then used to calibrate the secondary standards at the normal distance of two metres from the source.

3. PROTECTION LEVEL FACILITIES

3.1 DESCRIPTION

The irradiator for protection level calibrations[a] is equipped with four ^{60}Co γ-ray sources, the one with the highest activity giving an air kerma rate of approximately 25 mGy h^{-1} at two metres from the source, the normal calibration distance, and four ^{137}Cs sources giving a similar maximum air kerma rate. Each source can be positioned to give a collimated circular beam in the irradiation room with a diameter of about 400 mm at the normal calibration distance. By employing the lower activity sources the transfer standard may be used to calibrate dosemeters at air kerma rates down to about 0.2 mGy h^{-1}.

4. STANDARD FOR ^{192}Ir γ-RAYS

4.1 INTRODUCTION

There is growing interest in the radiotherapy community in brachytherapy treatments. The principal nuclide used at present is ^{192}Ir; the highest energy photon emitted, 610 keV (see Table A1), requires the use of a thick-walled cavity chamber. NPL has a commitment to provide a calibration service for high dose rate brachytherapy.

4.2 MEASUREMENT CONDITIONS

The guidelines for brachytherapy dosimetry[4,5] 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 air kerma rate is approximately 45 mGy h^{-1} for a new high dose rate source[b], falling to only 8 mGy h^{-1} after 6 months when the source normally has to be replaced.

4.3 PRIMARY STANDARD

4.3.1 Cavity standard

Measurements carried out at NPL[6] have demonstrated that the sensitivity of the present therapy-level primary standard cavity chambers is inadequate for the γ-ray air kerma rates available even from high dose rate brachytherapy sources at convenient source to chamber distances.

4.3.2 Free air chamber

Measurements have been made with the 300 kV free air primary standard. 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

---

Multi-source Irradiation Unit, Mainance International Ltd, Waterlooville, Hants
MicroSelectron-HDR, Nucletron UK Ltd, Tattenhall, Chester

penetration (greater than 30%), and the large uncertainties in others rule out the use of this standard.

4.3.3 Future standard

Measurement has shown that existing primary standards are inadequate for use with ^{192}Ir γ-rays. Since a large-volume, thick-walled cavity standard is required for the 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.

5. REQUIREMENTS FOR A NEW STANDARD

5.1 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. [7]

The Monte Carlo code (EGS4) will be used for the calculation of the correction factors for the primary standard. 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.

5.2 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.

5.3 MEASUREMENT QUANTITY

The recommendation of the British Committee on Radiation Units and Measurements (BCRU)[8] and present practice in the United Kingdom is that air kerma should be used for photon dosimetry in air; any new primary standard should therefore realise air kerma.

5.4 RADIATION BEAMS

The standard should be optimised for the measurement of γ-rays emitted from sources of ^{60}Co, ^{137}Cs and ^{192}Ir, at air kerma rates of 10 mGy h^{-1} with beams of not less than 200 mm diameter, preferably up to 500 mm diameter.

5.5 ELECTRICAL

5.5.1 Polarising potential

The chamber should be designed to minimise the polarising potential needed, it is recommended that potentials greater than 1 kV should be avoided if possible.

5.5.2 Insulation

Electrical insulation for the chamber polarising potential should be sufficient for applied potentials of at least twice the normal applied polarising potential. Insulation for the collecting electrode should be as high as can be achieved, preferably greater than 10^{15} Ω, and in any case not less than 10^{14} Ω.

5.5.3 Leakage current

The leakage current presently achieved with the primary standard is 40 fA or less, the leakage current for the present electrometers (Keithley Model 642) is typically less then 10 fA; modern instruments (eg Keithley 6430) can achieve considerably less than this figure. The design of the standard should be such as to achieve as low a leakage current as possible, preferably no more than that from the electrometers in use for the calibration services, ie no greater than 10 fA.

5.5.4 Chamber Format

The format or shape of the chamber needs to be optimised to reduce to a minimum uncertainties in the realisation of the quantity. Factors which need to be considered are presented in Table 1. The wall thickness of the cavity should be that needed for the highest energy photons to be measured, ^{60}Co γ-rays; this requires walls with a superficial density of at least 690 mg cm^{-2} to ensure full electronic equilibrium[9]. The volume of the chamber should be as small as possible consistent with adequate sensitivity, a volume of between 50 and 100 cm^3 would be suitable. The lowest leakage currents are obtained with guarded chambers, if possible such a design should be used. Consideration should be given to constructing several chambers with different formats so as to minimise in each one a particular source of uncertainty and to help identify systematic uncertainties. The standard would then be the mean response of the set of chambers as at present.

Table 1 Parameters affecting uncertainty in the standard

Parameter	Method of minimising the uncertainty		See para
Electric field uniformity	Design of chamber	Consider guarded field design	6.1.2 6.1.3
Monte Carlo modelling	Design of chamber	Simplicity of design	6.1.1 6.3
	Selection of materials	Air equivalent materials Ensure required data are available for selected materials	6.2.1
Air-equivalence of chamber materials (including purity)	Selection of materials	Graphite walls and electrode Review insulator materials Study effect of impurities with MC modelling	6.2.1 6.2.2
Leakage current	Design of chamber	Guarded chamber	6.1.1
	Selection of materials	Review insulator materials	6.2.2
Determination of mass of air in chamber (volume of cavity)	Design of chamber	Design for ease of dimensional metrology Coincidence of electric field with mechanical volume	6.3 6.1.2 6.1.3
Density of wall material (uncertainty)	Selection of materials	If necessary measure density of wall material	6.2.1
Scatter from chamber supports, etc	Design of chamber	Minimise extraneous material	6.1.1
Ion recombination effects	Design of chamber	Ensure optimum field strength throughout chamber volume	6.1.2 6.1.3

6. FURTHER WORK

6.1 DESIGN

6.1.1 Other designs

The design of the primary standards of other laboratories should be reviewed to provide guidance into the solution of some of the problems likely to be encountered; if appropriate the laboratories should be approached for further information.

6.1.2 Calculation of electric field distribution

A key parameter is likely to be the influence of electric field non-uniformity on the effective collecting volume of the chamber and hence the uncertainty of the standard. Methods of calculating electric field distribution in the chamber should be investigated so that such an analysis can inform the design process.

6.1.3 Electric field optimisation

Alternative designs should be investigated with a view to minimising electric field non-uniformity without increasing unacceptably other sources of uncertainty.

6.2 MATERIALS

6.2.1 Composition

The effects of composition or purity of material used for the chambers on the uncertainties in the calculated corrections should be investigated to ensure that appropriate specifications are included in the design brief.

6.2.2 Insulators

Moulded amber is used as the insulator in the present standard. A review of possible insulating materials should be undertaken to determine whether there are more appropriate materials that could be used for the collecting electrode insulation. Experimental evaluation of any potential replacement materials should be considered where appropriate or necessary.

6.3 METROLOGY

The dimensional metrology of potential formats for the chambers should be reviewed in consultation with the Dimensional Metrology Section of the Centre for Basic, Thermal Metrology and Length Metrology. Methods of determining chamber volume, their applicability to the materials likely to be employed in the construction and the likely resultant uncertainties in the volume could influence the design(s) finally selected.

7. REFERENCES

1 Barnard, G. P. (1964). Standardisation of ionisation chambers for megavolt X-rays. *Phys. Med. Biol.* **9**: 287-294.

2 Barnard, G. P. and A. R. S. Marsh (1960). The stopping power correction for graphite cavity-chambers used with 2 MV X-rays. *Phys. Med. Biol.* **4**: 33-42.

3 Barnard, G. P., A. R. S. Marsh, et al. (1964). Studies of cavity ionisation chambers with megavolt X-rays *Phys. Med. Biol.* **9**: 295-319.

4 BCRU (1984). Specification of brachytherapy sources. *Br. J. Radiol.* **57**: 941-942.

5 BIR (1993). Recommendations for brachytherapy dosimetry, report of the joint working party of the BIR and the IPSM. *British Institute of Radiology, London.*

6 Nutbrown and Sander, *Corrections to air kerma rate measurements from a ^{192}Ir high dose rate brachytherapy source free to space conditions*, NPL report CIRM 39, August 2000

7 Greening, J R, *Fundamentals of Radiation Dosimetry*, Bristol, Adam Hilger Ltd, 1985, second edition. p 82

8 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**: 375-377.

9 Hubbell, J. H. (1982). Photon mass attenuation and energy-absorption coefficients from 1 keV to 20 MeV. *Int. J. Appl. Radiat. Isot.* **33**: 1269-1290.

Appendix 1 Nuclide γ-ray Energies

Table A1 Nuclides to be used with the standard

Nuclide	Principal photon energies* kV	Relative probability %
^{60}Co	1170	100
	1332	100
^{137}Cs	662	100
^{192}Ir	206	3.8
	296	34.6
	309	35.8
	317	100
	468	57.5
	485	3.8
	589	5.4
	604	9.7
	613	6.3

* Only energies with a relative probability greater than 1% are included