

TITLE: Air Kerma Primary Standard: Experimental and Simulation Studies on Cs-137

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ABSTRACT: The primary standard for air kerma for the gamma radiation of Cs-137, of the Metrological Laboratory of Ionising Radiation (LMRI), is an ionisation chamber of the type CC01. This instrument was, for the first time, used to characterize the radiation field, in terms of air kerma, produced by a Cs-137 source in an irradiator Shepherd model 81, used mainly for radiation protection calibration purposes. Monte Carlo simulation studies were also made, using MCNP5. These studies intend to characterize the radiation field by simulation of the irradiator and to obtain correction factors for this ionisation chamber.

KEYWORDS: ionising radiation: primary standard; air kerma; metrology; Monte Carlo simulation

INTRODUCTION: The gamma radiation from ^{137}Cs sources is used in the Metrological Laboratory of Ionizing Radiation (LMRI) mainly for calibration and verification of radiation protection dosimeters. These dosimeters are calibrated in the operational quantities defined by ICRU [1] and are obtained from the knowledge of the air kerma [2] at a point in space, applying adequate conversion coefficients [3]. Until now the air kerma rate was obtained using a secondary standard, a ionization chamber OFZ LS-01/113 calibrated by PTB. The LMRI air kerma primary standard is a graphite-cavity ionization chamber constructed by Österreichisches Forschungszentrum (OFZ) and is used in LMRI, for the gamma radiation of ^{137}Cs for the first time.

IRRADIATION SYSTEM: The irradiation system is constituted by an irradiator from the manufacturer J. L. Shepherd & Associates, model 81, with three ^{137}Cs sources, two ^{60}Co sources and one ^{241}Am source, with different activities. The ring collimator is assembled from lead plates, with a total thickness of 35 mm (plate thicknesses of 15

mm, 10 mm, 5 mm and 5 mm, respectively), separated 20 mm from each other, with the exterior lead plate has a 2 mm copper and 3 mm aluminium plate attached together. The irradiation room as dimensions of 15 m x 6 m x 3.5 m (height) with walls made of wood.

The radiation beam profile was investigated by means of ionometric measurements and by radiographic films. At one meter, the radiation field has a diameter of 17 cm.

PRIMARY STANDARD: The LMRI primary standard in air kerma for the gamma radiation of ^{137}Cs is a cylindrical ionization chamber of the type CC01 with serial number 134, schematically presented in figure 3.

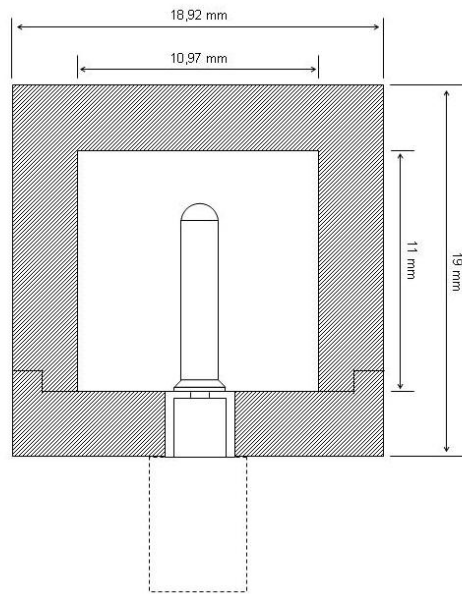


Figure 3: CC01 ionization chamber scheme.

The CC01 ionization chamber is made of graphite with a density of 1.80 g/cm^3 . The chamber wall has a thickness of 4 mm and the electrode has a diameter of 2 mm and 9 mm height. The sensitive volume of the ionization chamber is 1.0161 cm^3 obtained with an uncertainty of 0.1 % (1σ). The polarising potential is +250 V and is applied in the wall. The characteristics of the LMRI standard are shown in table 1.

Table 1: Characteristics of the CC01-134 ionization chamber

		Nominal value / mm
Chamber	Outer height	19
	Outer diameter	18.92
	Inner height	11
	Inner diameter	10.97
	Wall thickness	3.98
Electrode	Diameter	2.015
	Height	8.970
Volume	Air cavity	1.0161 cm ³
Wall	Materials	High purity moulded graphite ATJ
	Density	1.80 g.cm ⁻³
	Impurity	< 8 × 10 ⁻⁴
Insulator	PTFE Teflon	

EXPERIMENTAL RESULTS: The primary standard described above was connected to PTW UNIDOS, model 10001 with serial number 10568. Charge measurements were done for a collecting time of 600 seconds each. Measurements at four distances were made. At each distance, five measurements were done and were corrected for the leakage current. The results obtained are shown in figure 4.

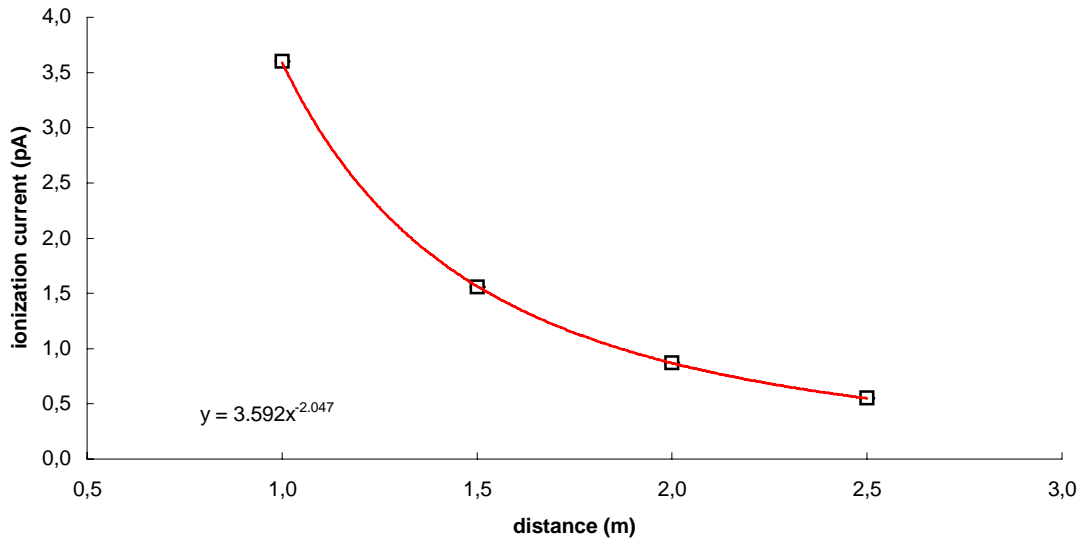


Figure 4: Experimental results as function of the distance.

DETERMINATION OF AIR KERMA RATE: The air kerma rate, \dot{K} , is obtained from,

$$\dot{K} = \frac{I}{m} \frac{W}{e} \frac{1}{1-\bar{g}} \left(\frac{\mu_{en}}{\rho} \right)_{a,c} \bar{s}_{e,a} \prod k_i$$

where I is the ionization current measured; m is the mass of air in the sensitive volume of the ionization chamber, W is the average energy spent by an electron of charge e to produce an ion pair in dry air, \bar{g} is average fraction of electron energy lost to radiative processes, $(\bar{\mu}_{en} / \rho)_{a.c}$ is the ratio of the mean mass energy absorption coefficients of air and graphite, $\bar{s}_{c.a}$ is the ratio of the mean stopping powers of graphite and air, $\prod k_i$ is the product of correction factors to be applied to the standard.

CORRECTION FACTORS: some of the correction factors were determined experimentally and are described below. All the correction factors and physical constants and associated uncertainties are shown in table 2.

Air density

The measured ionization currents have been corrected to the reference ambient temperature of 293.15 K and pressure, 101325 Pa.

Polarization

The effect of polarity in measurement was determined and a correction factor was applied in the determination of air kerma. The correction factor is obtained from

$$k_{pol} = \frac{1}{2} \left(1 + \frac{I^-}{I^+} \right)$$

Where I^- and I^+ are the currents at negative and positive polarity.

Recombination

The recombination losses were calculated by varying the polarising voltage, U , from 50 V to 400 V, in steps of 50 volt. The reciprocal of the ionization current, I , is a linear function of the $1/U$ [4]. The extrapolation of $1/I$ to $1/U=0$ gives the saturated ionization current.

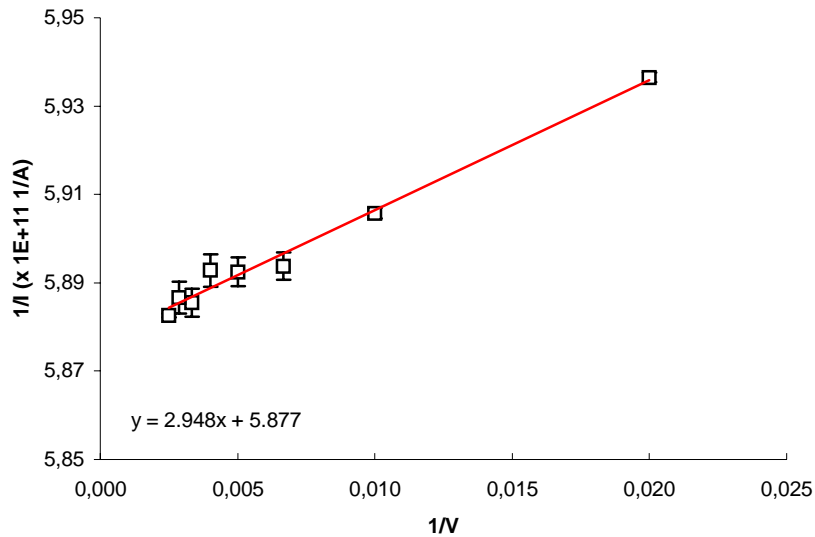


Figure 4: Results in the calculation of the recombination losses.

Stem scattering

The influence of the stem was determined experimentally using a dummy stem placed in the top of the ionization chamber in a position, opposite to the original stem.

Wall effects

Both chamber wall attenuation and scattering were calculated experimentally by the method described by Loftus and Weaver [5]. Four additional graphite caps were used, each with 4 mm thickness, and mounted in the ionization chamber. The ionization current, obtained for each graphite thickness, was exponentially fitted. The correction factor for attenuation and scattering of the wall, $k_{at} * k_{sc}$, is obtained by the ratio of the extrapolated current to zero thickness and the current of the ionization chamber without the additional caps. This value is then multiplied by the factor, k_{cep} , that takes in account the centre of electron production in the wall of the ionization chamber.

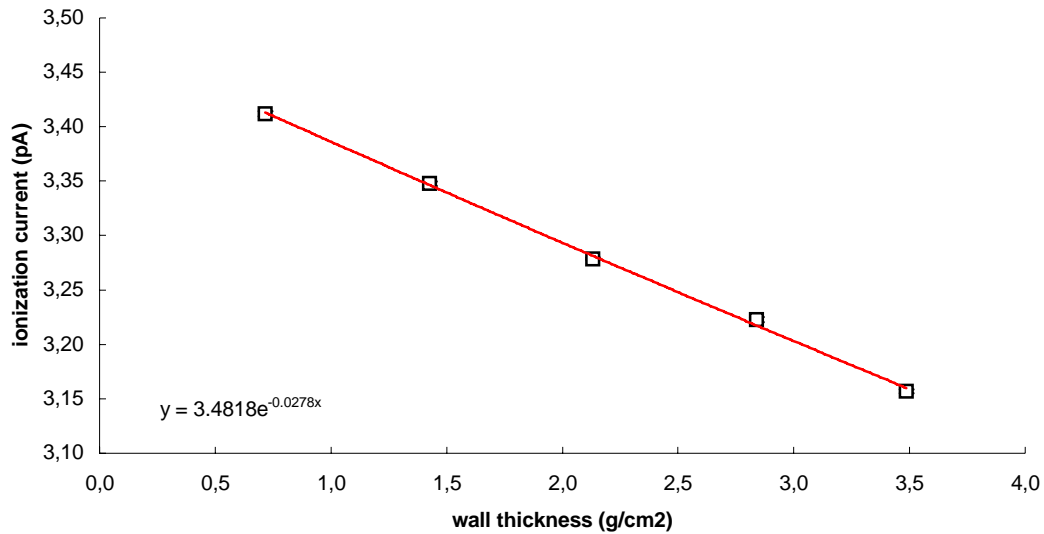


Figure 5: Ionization current plotted against wall thickness.

The results obtained for these correction factor are $k_{at} \times k_{sc} \times k_{cep} = 1.0194$. However, there is evidence that this method doesn't give the appropriate correction for wall effect and that Monte Carlo calculations are able to give correct results [6]. Due to this, the LMRI assumes the value for k_{wall} obtained by Monte Carlo calculations, made by the BEV [7]. The value used is $k_{wall} = 1.0291$. The ratio between this correction factor, obtained by Monte Carlo and experimentally is 1.010.

Axial non-uniformity

It is assumed that there is no evidence of axial non-uniformity on this chamber [8] and no correction was applied to the standard.

Radial non-uniformity

The radiation beam profile didn't show beam inhomogeneities within the area covered by the CC01 chamber. No correction for radial non-uniformity was obtained.

Table 2: Physical constants and correction factors and their estimated relative uncertainties

	value	s_i (%) ^(a)	u_i (%) ^(a)
Physical constants			
ρ_0 dry air density /kg m ⁻³	1.2930		0.01
$(\mu_m / \rho)_{a,c}$	0.9990		0.05
$\bar{S}_{e,a}$	1.0101		0.3
W/e /J C ⁻¹	33.97		0.15
\bar{g}	0.0012		0.02
Correction factors			
K_{pol} polarization	1.0004	0,01	
k_s recombination losses	1.0027	0.01	
k_h humidity	0.997		0.03
k_{st} stem scattering	0.9989	0,01	
k_{wall} wall effects	1.0291		0.03
k_{an} axial non-uniformity	1.000		0.1
k_{rn} radial non-uniformity	1.000		0.02
Measurement of $I/V\rho$			
V chamber volume /cm ³	1.0161		0.1
I ionization current /pA	3,592	0.01	0.04
Uncertainty			
quadratic summation		0.04	0.37
combined uncertainty			0,4

^(a)Expressed as one standard deviation. s_i represents an uncertainty of type A and u_i represents a type B uncertainty [10].

The air kerma rate, at 1 meter from the source, was calculated in 6,212 mGy/min with an uncertainty of 0.4% (1 σ), in 07 of December 2006. This result was compared with the previous value used in the LMRI, obtained with a secondary standard, and the agreement is quite good. The ratio between the results obtained with the primary standard and the one obtained with the secondary standard is 1.008.

MONTE CARLO SIMULATION: The MCNP5 Monte Carlo code was used in order to calculate and to confirm some experimental correction factors used experimentally in the determination of air kerma for ¹³⁷Cs. In the simulation exercises, the transport of photons and electrons has been considered (mode p e).

The photon spectrum was obtained from a simulation exercise of a real ¹³⁷Cs irradiator [9].The final result was obtained from four independent runs. For that, was used the card, DBCN, with a different control number, for each run. The number of histories

used in this exercise was $1E+8$. In the regions of interest, the results were calculated with an error lower than 2 %. The energy bin intervals were set in 5 keV. The spectrum is presented in figure 5. The scattered photon spectra component incident in the primary standard is 31%.

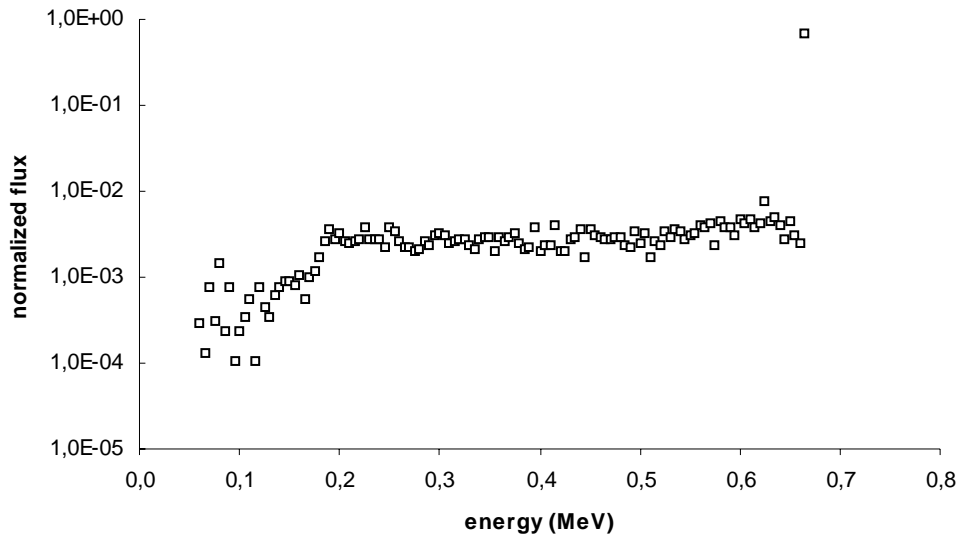


Figure 5: ^{137}Cs spectra used in the simulation exercise.

The CC01 ionization chamber was designed according to its technical specifications and the model can be seen in figure 6.

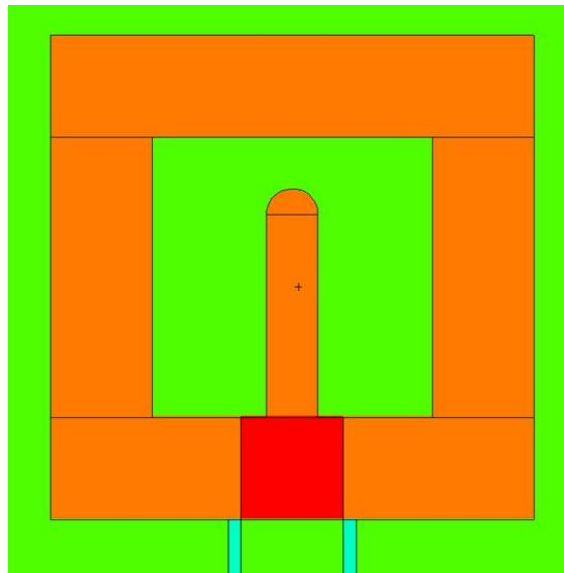


Figure 6: view of the CC01 ionization chamber used in the simulation. Orange material is graphite; red material is PTFE (Teflon); light blue is the stem in aluminium.

Stem scattering

The contribution to the determination of air kerma due to the stem was determined by Monte Carlo. A dummy stem was placed in the top of the CC01 ionization chamber and the correction factor raised from this was 0.9998 with an uncertainty of 1.6%. The number of histories used in this exercise was 1E+9. This result differs 0.1% from the experimental one, but with higher uncertainty.

CONCLUSIONS: The primary standard of air kerma, a CC01 ionization chamber, was used to obtain the air kerma rate of a ^{137}Cs source. This was successfully done and the result is in agreement with the previous reference air kerma rate, however decreasing the uncertainty from 0.9 % to 0.4% (1σ).

The simulations studies resulted in a better knowledge of the irradiation conditions and of the ionization chamber it self. Further work is needed, namely in the characterization of the LMRI irradiator to obtain the LMRI radiation beam fluence and to obtain more accurate correction factors.

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