# REPORT TO THE CCRI SECTION I ON THE (2001-2003) RE-DETERMINATION OF THE AIR-CAVITY VOLUME FOR THE Co-60 GAMMA-RAY AIR-KERMA STANDARD AT THE ENEA-INMRI

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## Introduction

The air-kerma standard for Co-60 gamma rays at the ENEA-INMRI is a graphite cylindrical ionisation chamber of the OMH type. The volume determination of this chamber was made about twenty years ago and that data was used in the relevant international comparisons so far performed with this standard. The early analysis on which that previous volume determination was based has been recently more thoroughly examined resulting in the need to revise it. It also resulted that the original value of the chamber volume was not correct and had to be changed.

## Methods

A schematic of the ENEA-INMRI standard chamber cross section is reported in Figure 1 where the small region of the air-cavity volume in the bottom part around the collecting electrode is denoted as the region A. It was recently just this small volume region (about 0.9% of the total cavity volume) to be re-considered in the determination of the total volume of the chamber cavity. When in the past years the chamber volume was initially determined, the region A was excluded from the effective cavity volume. At that time it was concluded, on the basis of some previous evaluations, that the charge collection in the region A did not result to contribute significantly to the total collected charge. The reasons of neglecting such a volume/charge contribute were recently re-analysed and the conclusion was that they have to be considered not grounded. A more thorough analysis of the electric field strength in the region A was made in this respect. Accordingly the air-cavity volume of the standard chamber was re-calculated by including this time also the small volume contribution due to the region A.
Specific measurements were then made to support experimentally this new result on chamber volume determination. To this end and to assess more accurately the procedure so far used for the cavity volume determination six cylindrical ionisation chambers were built. The details of these six chambers are reported in Figure 2 and Table 1. Three of these chambers (A, B and C, in Table 1) were made different from each other both in shape and dimensions. The other three chambers (D, E and F, in Table 1) have size and shape comparable with each other (similar to the OMH type and hence to the present ENEA-INMRI air-kerma standard). The purpose of the three different chambers was mainly to check experimentally the influence of the region A, having a constant volume, on the charge collected by chambers of different size. Absolute air-kerma measurements in a Co-60 gamma beam were then made by each of these chambers. If, as supposed in the past, the region A had a negligible influence on the total collected charge, the value of the air-kerma would not depend on the cavity volume only if in its calculation the region A is not accounted for. The construction of the other three chambers similar to each other and to the present ENEA-INMRI standard, aimed at improving experimentally the reproducibility in chamber construction and the accuracy in volume determination. To this end absolute air-kerma measurements were made by these chambers (as well as with the three chambers of different size referred to above) after carefully determining for each of them the cavity volume and the relevant $K_{wall}$ factor. For the present study the $K_{wall}$ factor of each of the six chambers considered was determined by (EGSnrc) Monte Carlo calculation.

**Results**

The results of the present investigation are summarised by the curves shown in Figure 3. From the analysis of these results it clearly appears that the small volume (the region A, in Fig 1) traditionally neglected in the previous determinations of the air cavity volume, had instead to be included in that volume.

If the region A could be neglected in the chamber volume, the air- kerma values determined by chambers with equal volume of the region A but different total cavity volume, should not vary if the region A is not accounted for in determining the total cavity volume. Variable air-kerma values, decreasing down to 0.7%, are instead obtained (see curve ***a*** in Fig 3) when they are determined by chambers with increasing cavity volumes in which the region A is neglected in the total volume calculation. On the other hand if the region A is included in the cavity volume computation, nearly constant air-kerma values (within 0.13%) are obtained when they are determined by chambers with different total cavity volume (see curve ***b*** in Fig 3). As a consequence of these results the cavity volume of the ENEA-INMRI air-kerma standard was revised by adding the small volume of the region A that for this chamber was known since the time it was built. Because of this change the reference air-kerma values as determined in the previous intercomparison have to be revised. Accordingly the ratio $K_{ENEA}/K_{BIPM}$ referring to the last comparison should be decreased by about 0.9%.

For all of the six ionisation chambers referred to above a more accurate method to determine the cavity volume was set up. To this end mechanical tools and gauges more suitable and accurate than those adopted in the past years were used. As pointed out above the main objective of these new chambers was to check and improve the reproducibility in chamber construction (hence reducing the uncertainty associated to the chamber volume). The results of Co-60 air-kerma measurements by all these chambers, the volume of which includes the region A, are shown in Figure 4. It was reported in Figure 4 also the analogous data referring to the two cavity chambers (chambers C1 and C3) that have been traditionally used in the air-kerma international comparisons (in particular those with the BIPM). The results in Figure 4 show that the data relevant to the chamber C3 is an outlier and the only likely reason of that is that the chamber volume originally determined (more than 20 years ago) for this chamber is uncorrect. The other six of new construction chambers give rather close results within 0.2%. If also the old C1 chamber is included in this comparison the agreement is less satisfactory but anyway within 0.3%.

These results will be accounted for in the choice of the new Co-60 air-kerma standard chamber(s) that, after a new international comparison, will replace the existing one.

As far as the present standard (chamber C1) is concerned, the following revisions have been accordingly made: a) revision of the chamber volume increasing it by about 0.9%, b) increase from 0.14% to 0.2% the uncertainty assigned to the volume determination to account for the deviation shown in Figure 4 for this chamber. The relevant data are reported in Table 2 where the other chamber C1 parameters that have been revised in the time (1983-2003) are also reported (Table 2a). In Table 2b the consequent changes on the Cs-137 air-kerma standard are shown as this standard is based on the Co-60 and medium-energy x-ray air-kerma standards.

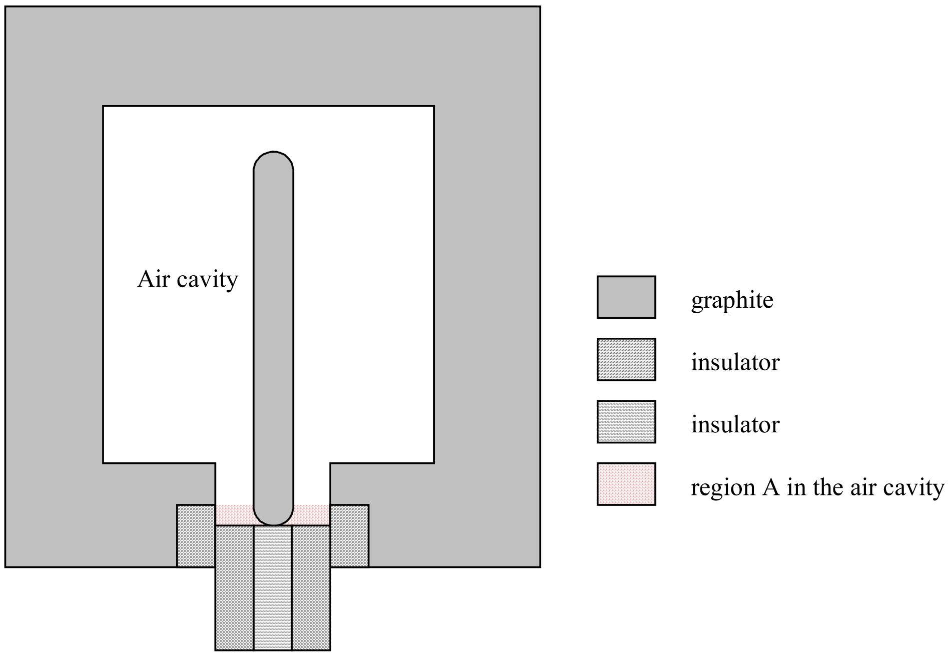



Figure 1. Cross section of the ENEA-INMRI standard cavity chamber showing the small region A (in the cavity volume) the role of which in the measured charge was analysed in the present study.

Table 1. Characteristics of the six cylindrical ionization chambers considered in the present analysis.

| | Chamber code | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| **Chamber dimensions (mm)** | | | | | | |
| Inner diameter | 7.98 | 10.87 | 16.01 | 11.00 | 11.00 | 11.00 |
| Inner length | 15.98 | 10.86 | 7.97 | 11.02 | 10.97 | 11.03 |
| Wall thickness | 2.97 | 2.99 | 3.00 | 3.88 | 3.99 | 3.97 |
| Central electrode diameter | 1.96 | 1.99 | 1.99 | 1.98 | 2.00 | 2.00 |
| Central electrode length | 14.98 | 10.07 | 7.01 | 10.00 | 10.12 | 10.13 |
| Volume ($cm^3$) | 0.772 | 0.988 | 1.598 | 1.032 | 1.022 | 1.029 |
| **Chamber material** | | | | | | |
| Wall and central electrode | Graphite (1.75 g $cm^{-3}$) | | | | | |

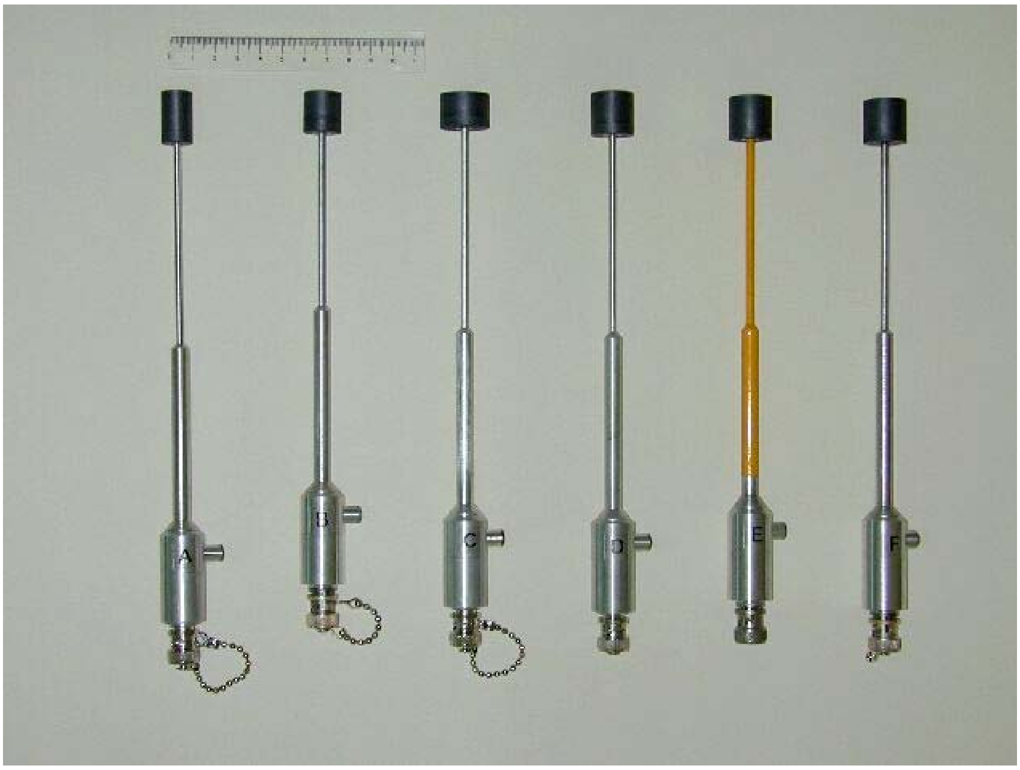
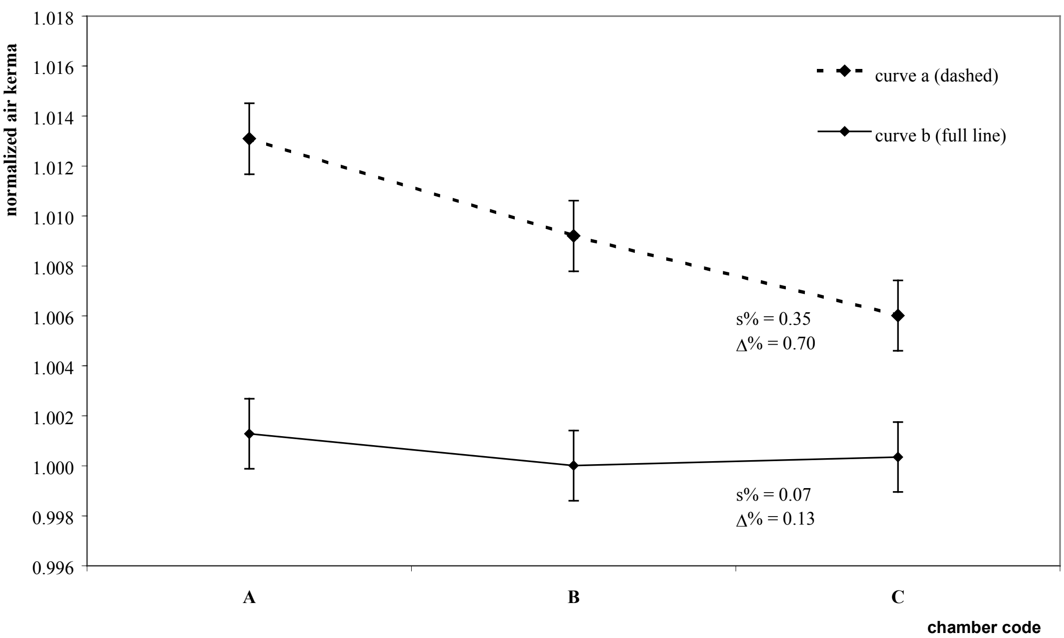



Figure 2. Photo of the six cavity chambers used in the present study. From left the chambers with code: A, B,C,D,E and F, respectively (see Table 1).

Figure 3. Curve a (dashed): air kerma values determined by the different ion chambers (A, B and C, see Table 1) the volume of which was calculated without accounting for the small volume region A (see Fig. 1). Curve b (full line): air kerma values determined by the different ion chambers (A, B and C, see Table 1) the volume of which includes the small volume region A (see Fig. 1). The data are normalized to the air-kerma value relevant to the chamber B in curve b.



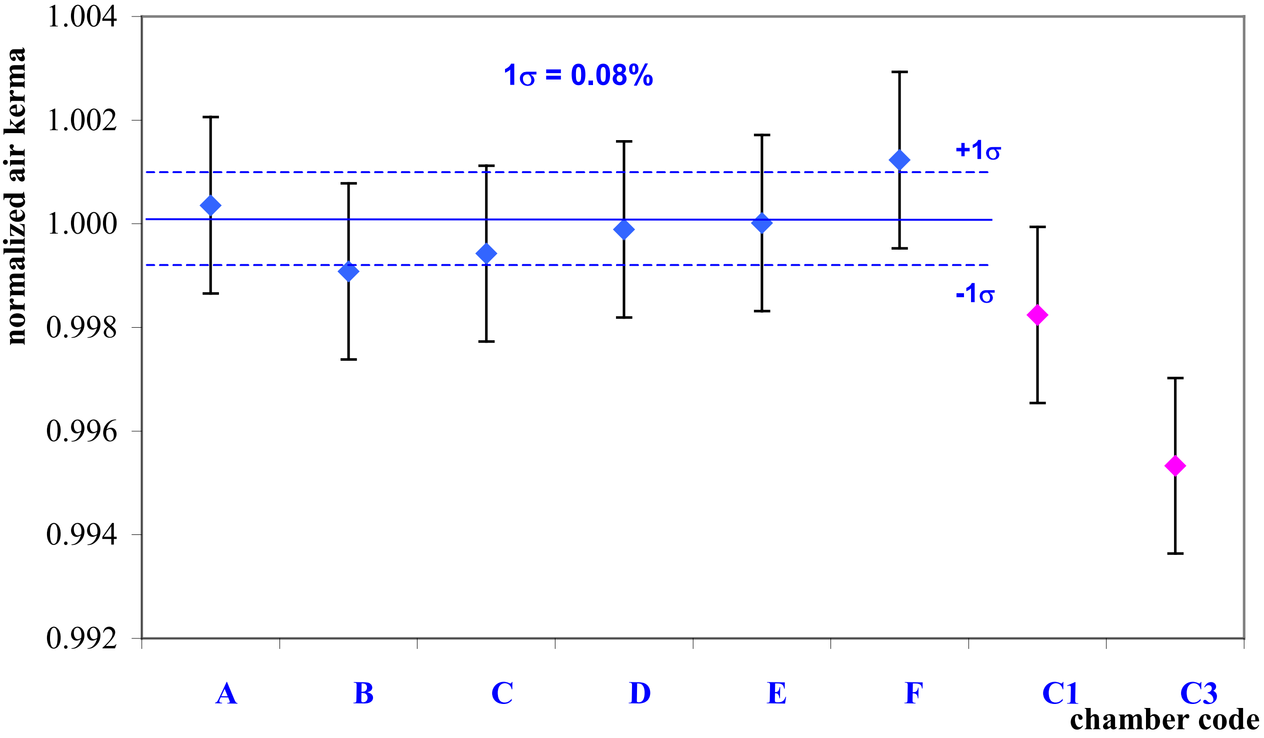



Figure 4. Co-60 air kerma values determined by the six new cavity chambers (code A, B, C, D, E, F) recently built at the ENEA-INMRI. The Co-60 air kerma values determined by the present ENEA-INMRI standard chamber (C1) and another similar chamber (C3) are also reported. The volume of chamber C3 resulted to be uncorrect. All of the data are normalized to the mean air-kerma value obtained from the six new chambers (code A, B, C, D, E, F)

Table 2a. Physical constants and correction factors revised in the period 1983-2003 at ENEA-INMRI for the cavity chamber air kerma standard in Co-60 beam.

| | | **Value** | | | |
|---|---|---|---|---|---|
| | | 1983 | 1998 | 2001 | 2003 |
| **Physical constants** | | | | | |
| $\mathbf{s_{c,a}}$ carbon to air restricted mass stopping power ratio (Δ = 20 keV) | | 1.0070 | **1.0007** | 1.0007 | 1.0007 |
| **Correction factors** | | | | | |
| $k_c$ | wall attenuation and scatter | 1.015 6 | 1.0160 | | |
| $k_{CEP}$ | mean origin of electrons | 0.997 2 | 0.9972 | | |
| $k_{wall}$ | wall effects correction | | | **1.0220** | 1.0220 |
| $k_{rn}$ | beam radial non-uniformity | 1.000 | | | |
| $k_{an}$ | Beam axial non-uniformity | 0.997 | | | |
| $k_{pn}$ | point source non-uniformity[(2)] | | **1.0001** | 1.0001 | 1.0001 |
| $k_{npn}$ | non-point source effects | | **1.000** | 1.000 | 1.000 |
| **Chamber Volume** (chamber no.C1) | | 1.022 2 | 1.022 2 | 1.022 2 | **1.031 2** |
| | $\mathbf{K_{ENEA}/K_{BIPM}}$ | **0.9994** | **1.0038** | **1.0127** | **1.0039** |

[(1)] determined at the ENEA air-kerma.
[(2)] this factor corrects for beam axial and radial non-uniformity due to a point source.

Table 2b. Data relevant to the ENEA-INMRI transfer chamber for air-kerma measurement in Cs-137 beam. The revision of the data in the years are consequent to the revision on the Co-60 air kerma standard from which Cs-137 air kerma standard is derived.

| | 1998 | 2001 | 2003 |
|---|---|---|---|
| $F_{ENEA}$ (Gy/C) (*) | 1.021 $10^6$ | 1.025 $10^6$ | 1.021 |
| **$K_{ENEA}/K_{BIPM}$** | 0.994 | 0.998 | 0.994 |

(*) Calibration coefficient for the Cs-137 air-kerma transfer chamber