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

J. Cardoso, L. Santos, C. Oliveira

Workshop on “Absorbed Dose and Air Kerma Primary Standards”, Paris, 9, 10, 11 May, 2007
SUMMARY:

i. The primary standard
ii. The irradiation room
iii. Experimental results
iv. Simulation exercise
v. Conclusions
THE PRIMARY STANDARD

CC01 graphite-cavity ionization chamber

Constructed by the Österreichisches Forschungszentrum (ÖFZ), Austria
# THE PRIMARY STANDARD

## CC01 graphite-cavity ionization chamber

Constructed by the Österreichisches Forschungszentrum (ÖFZ), Austria

<table>
<thead>
<tr>
<th>Nominal value / mm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chamber</strong></td>
<td></td>
</tr>
<tr>
<td>Outer height</td>
<td>19</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>18.92</td>
</tr>
<tr>
<td>Inner height</td>
<td>11</td>
</tr>
<tr>
<td>Inner diameter</td>
<td>10.97</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>3.98</td>
</tr>
<tr>
<td><strong>Electrode</strong></td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>2.015</td>
</tr>
<tr>
<td>Height</td>
<td>8.970</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td></td>
</tr>
<tr>
<td>Air cavity</td>
<td>1.0161 cm³</td>
</tr>
<tr>
<td><strong>Wall</strong></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>High purity moulded graphite ATJ</td>
</tr>
<tr>
<td>Density</td>
<td>1.80 g.cm⁻³</td>
</tr>
<tr>
<td>Impurity</td>
<td>&lt; 8 × 10⁻⁴</td>
</tr>
<tr>
<td><strong>Insulator</strong></td>
<td>PTFE Teflon</td>
</tr>
</tbody>
</table>

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THE PRIMARY STANDARD

CC01 graphite-cavity ionization chamber
Constructed by the Österreichisches Forschungszentrum (ÖFZ), Austria

Voltage applied to CC01: +250 V

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THE IRRADIATION ROOM

Irradiation room I: 15 m x 6 m x 3,5 m (height)

Walls made of wood

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THE IRRADIATION ROOM

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THE IRRADIATION ROOM

Irradiator

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THE IRRADIATION ROOM

Colimator

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 cooper and 3 mm aluminium plate attached together.
THE IRRADIATION ROOM

The radiation beam profile was investigated by means of ionometric measurements and by radiographic films.

Dimensions of the radiation field:
17 cm diameter, at 1 meter from the source.
THE IRRADIATION ROOM

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EXPERIMENTAL RESULTS

Primary standard connected to PTW UNIDOS 10001

Charge measurements were done for a collecting time of 600 seconds

Measurements at four distances were done

At each distance, five measurements were made
EXPERIMENTAL RESULTS

The results with CC01 chamber

\[ y = 3.592x^{-2.047} \]
EXPERIMENTAL RESULTS

Results:

Measured current: 3.592E-12 A

SD: 5.990E-16 A

Leakage current: 2.292E-15 A
EXPERIMENTAL RESULTS

Determination of air kerma rate

The air kerma rate is obtained from,

$$\dot{K} = \frac{I}{m} \frac{W}{e} \frac{1}{\overline{g}} \left(\frac{\mu_{en}}{\rho}\right) \prod k,$$

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,
- $\overline{g}$ is average fraction of electron energy lost to radiative processes,
- $\left(\frac{\mu_{en}}{\rho}\right)$ is the ratio of the mean mass energy absorption coefficients of air and graphite,
- $\overline{s}_{\overline{g}}$ is the ratio of the mean stopping powers of graphite and air,
- $\prod k$ is the product of correction factors to be applied to the standard.

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EXPERIMENTAL RESULTS

Determination of air kerma rate

<table>
<thead>
<tr>
<th>Physical constants</th>
<th>value</th>
<th>$s_i$ (%) (a)</th>
<th>$u_i$ (%) (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$, dry air density /kg m$^3$</td>
<td>1.2930</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$(\mu_a / \rho)_\alpha$</td>
<td>0.9990</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>$S_{\gamma}$</td>
<td>1.0101</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>$W / e$ /J C$^{-1}$</td>
<td>33.97</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>$g$</td>
<td>0.0012</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correction factors</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{pol}$ polarization</td>
<td>1.0004</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$k_s$ recombination losses</td>
<td>1.0027</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$k_h$ humidity</td>
<td>0.997</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>$k_{st}$ stem scattering</td>
<td>0.9989</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$k_{wall}$ wall effects</td>
<td>1.0291</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>$k_{an}$ axial non-uniformity</td>
<td>1.000</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>$k_{rn}$ radial non-uniformity</td>
<td>1.000</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement of $I/V \rho$</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$V$ chamber volume /cm$^3$</td>
<td>1.0161</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>$I$ ionization current /pA</td>
<td>3.592</td>
<td>0.01</td>
<td>0.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>quadratic summation</td>
<td>0.04</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>combined uncertainty</td>
<td></td>
<td>0.37</td>
<td></td>
</tr>
</tbody>
</table>

(a)Expressed as one standard deviation. $s_i$ represents an uncertainty of type A and $u_i$ represents a type B uncertainty.

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Correction factors

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 $1/U$. The extrapolation of $1/I$ to $1/U=0$ gives the saturated ionization current.

$$y = 2.948x + 5.877$$

$k_s = 1.0027$
EXPERIMENTAL RESULTS

Correction factors

Wall effects

Both chamber wall attenuation and scattering were calculated experimentally by the method described by Loftus and Weaver.

\[ k_{at} \cdot k_{sc} \cdot k_{cep} = 1.0194 \]
EXPERIMENTAL RESULTS

Correction factors

Wall effects

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.

Due to this, the LMRI assumes the value for $k_{\text{wall}}$ obtained by Monte Carlo calculations, made by the BEV (Witzani, J. Monte Carlo calculation of the wall correction factors for the air kerma standards of the BEV for $^{137}$Cs and $^{60}$Co $\gamma$-rays. CCR(I)/03-11)

$$k_{\text{wall}} = 1.0291$$

The ratio between this correction factor, obtained by Monte Carlo and experimentally is 1.010
EXPERIMENTAL RESULTS

Determination of air kerma rate

The air kerma rate, at 1 meter from the source, was calculated in 6,212 mGy/min with an uncertainty of 0.4% (1σ), in 07 of December 2006.

The ratio between the results obtained with the primary standard and the one obtained with the secondary standard (OFZ LS-01, calibrated at PTB) is 1.008.
SIMULATION EXERCISE

MCNP5 simulation code

The transport of photons and electrons has been considered (mode p e)
SIMULATION EXERCISE

Photon spectra

The scattered photon spectra component incident in the primary standard is 31%.


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SIMULATION EXERCISE

Ionization chamber
SIMULATION EXERCISE

Stem scattering

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, for the first time in LMRI, 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% (1 $\sigma$).

The simulations studies resulted in a better knowledge of the irradiation conditions and of the ionization chamber itself. Further work is needed.
THANK YOU!

THE END