Calibrations of high-dose rate and low-dose rate brachytherapy sources

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Content

- Calibration of $^{192}\text{Ir}$- and $^{60}\text{Co}$-HDR sources
- Calibration of $^{125}\text{I}$- LDR sources
- Anisotropy measurements
- Short overview on PTB activities concerning calibrations in terms of absorbed dose rate to water
Calibration of $^{192}$Ir- and $^{60}$Co-HDR brachytherapy sources in terms of the reference air kerma rate (or air kerma strength)

- lead box
- secondary standard
- afterloader
- industrial robot
Determination of the RAKR \((K_{a, 1 \text{ m}})\) using the „multiple distance“ method

Model: \(Y = K_{a, 1 \text{ m}}/(d-d_0)^2\)

\[
\begin{align*}
K_{a, 1 \text{ m}} & = 0.04076 \pm 3.3147 \times 10^{-6} \\
d_0 & = 0.00107 \pm 0.00004
\end{align*}
\]
Calibration of the PTB-secondary standard for $^{192}$Ir radiation

$$M(E_{\text{max}}) = \frac{1}{C} \int_{0}^{E_{\text{max}}} \varphi(E_{\text{max}}, E) \cdot r(E) dE$$

- response curve measured with X-ray qualities
- solving the integral equation
- response curve for monoenergetic radiation
- interpolation + weighted mean
- $^{192}$Ir - emission lines
- $^{192}$Ir - emission probabilities
- narrow X-ray spectra including special series
- calibration factor for $^{192}$Ir-spectrum
Verification of the calibration method by measurements with a Bragg-Gray chamber

- Graphite-pancake chamber
- PTB’s primary standard for $^{137}\text{Cs}$- and $^{60}\text{Co}$-gamma-radiation (HRK 3)
- Primary realization of the air kerma according to the Bragg-Gray principle
- Wall correction factors for $^{192}\text{Ir}$-radiation determined with MCC (EGS-NRC)
- Calibrations of a $^{192}\text{Ir}$-source with the secondary standard and the Bragg-Gray chamber HRK 3 agree within 0.5%
### Uncertainty budget according to the GUM

<table>
<thead>
<tr>
<th>reason of the uncertainty</th>
<th>u [%]</th>
<th>index [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>secondary standard calibration</td>
<td>0,50</td>
<td>29,8</td>
</tr>
<tr>
<td>ionization current measurement (reproducibility)</td>
<td>0,14</td>
<td>2,3</td>
</tr>
<tr>
<td>background (leakage) current</td>
<td>0,07</td>
<td>0,6</td>
</tr>
<tr>
<td>source to chamber distance</td>
<td>0,20</td>
<td>4,8</td>
</tr>
<tr>
<td>chamber offset</td>
<td>0,46</td>
<td>25,2</td>
</tr>
<tr>
<td>incomplete ion collection</td>
<td>0,20</td>
<td>4,8</td>
</tr>
<tr>
<td>attenuation in air</td>
<td>0,30</td>
<td>10,7</td>
</tr>
<tr>
<td>air density correction</td>
<td>0,05</td>
<td>0,3</td>
</tr>
<tr>
<td>influence of scattered radiation</td>
<td>0,30</td>
<td>10,7</td>
</tr>
<tr>
<td>source anisotropy</td>
<td>0,30</td>
<td>10,7</td>
</tr>
<tr>
<td>data fitting</td>
<td>0,03</td>
<td>0,1</td>
</tr>
<tr>
<td>combined uncertainty (k=1)</td>
<td>0,92</td>
<td></td>
</tr>
<tr>
<td><strong>U(k=2)</strong></td>
<td>1,8</td>
<td></td>
</tr>
</tbody>
</table>
PTB offers the following calibrations in terms of reference air kerma rate:

- Calibration of clinical HDR brachtherapy sources, $^{192}\text{Ir}$ and $^{60}\text{Co}$.
- Calibration of suitable ionization chambers for $^{192}\text{Ir}$ and $^{60}\text{Co}$ radiation (Krieger phantom with thimble chamber).
- Calibration of well type ionization chambers with $^{192}\text{Ir}$ and $^{60}\text{Co}$ brachytherapy sources.
Calibration of $^{125}\text{I}$- (and $^{103}\text{Pd}$)- LDR brachytherapy sources in terms of reference air kerma rate (or air kerma strength)

the new PTB’s primary standard for low dose rate brachytherapy sources, a large volume extra-polation chamber (GROVEX)
Schematic of the GROVEX measuring system

- 5 mm Pb shutter
- high voltage electrode
- potential rings
- 5 mm Pb
- 0.1 mm Al
- 30 cm
- 0 - 20 cm
- guard electrode
- measurement electrode 10.0 mm Ø
Front and back view of the GROVEX

- Shutter
- Collector electrode and guard ring
- Potential rings
- Source position
- High-voltage electrode (hidden from view)
Realization of the reference air kerma rate by means of the extrapolation chamber technique:

\[
K_\delta = \frac{\left( \frac{\bar{W}}{e} \right)_{\text{air}}}{\rho_{\text{air}} A_{\text{eff}} (1 - g_{\text{air}})} \left( \frac{d(kI)}{ds} \right) \prod k_i
\]

\[
\left( \frac{\bar{W}}{e} \right)_{\text{air}} = 33.97 \text{ eV}
\]

\[
\rho_{\text{air}} = 1.2046 \text{ kg/m}^3
\]

\[
A_{\text{eff}} = 7754 \pm 11 \text{ mm}^2
\]

\[
\frac{d(kI)}{ds} \text{ is the increment of corrected ionization current per increment of the chamber volume}
\]

\[
k_i \text{ are corrections to the entire measurement}
\]
Correction factors

- Nearly all correction factors are energy dependent
- Therefore, for each type of source the spectral distribution has to be measured

<table>
<thead>
<tr>
<th>Proportion of counts in silver lines</th>
<th>0%</th>
<th>5%</th>
<th>10%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product of correction factors</td>
<td>1.0546</td>
<td>1.0578</td>
<td>1.0601</td>
<td>1.0658</td>
</tr>
</tbody>
</table>
Uncertainty budget of the GROVEX according to the GUM

<table>
<thead>
<tr>
<th>Reason of the uncertainty</th>
<th>$u$ [%]</th>
<th>index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionization current measurement (reproducibility)</td>
<td>0,5</td>
<td>32,6%</td>
</tr>
<tr>
<td>Electrode separation</td>
<td>0,06</td>
<td>0,4%</td>
</tr>
<tr>
<td>Air density and humidity</td>
<td>0,05</td>
<td>0,3%</td>
</tr>
<tr>
<td>Electrode area</td>
<td>0,5</td>
<td>33,0%</td>
</tr>
<tr>
<td>Source-to-measurement point distance</td>
<td>0,035</td>
<td>0,2%</td>
</tr>
<tr>
<td>Incomplete ion collection</td>
<td>0,03</td>
<td>0,1%</td>
</tr>
<tr>
<td>Attenuation in the Al-filter</td>
<td>0,5</td>
<td>27,8%</td>
</tr>
<tr>
<td>Attenuation in the entrance window</td>
<td>0,12</td>
<td>1,7%</td>
</tr>
<tr>
<td>Attenuation and scatter between source and entrance window</td>
<td>0,12</td>
<td>1,7%</td>
</tr>
<tr>
<td>Attenuation and scatter in the chamber volume</td>
<td>0,12</td>
<td>1,7%</td>
</tr>
<tr>
<td>Source holder</td>
<td>0,06</td>
<td>0,4%</td>
</tr>
<tr>
<td>combined uncertainty ($k=1$)</td>
<td>0,9</td>
<td></td>
</tr>
<tr>
<td><strong>Uncertainty $U(k=2)$</strong></td>
<td><strong>1,8</strong></td>
<td></td>
</tr>
</tbody>
</table>
Intercomparisons

GROVEX / PTB-primary standard for air-kerma PK100

<table>
<thead>
<tr>
<th>PTB Beam Code</th>
<th>chamber current reading ($\times 10^5$ Gy/C)</th>
<th>Measured air kerma rate per monitor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GROVEX</td>
<td>PK100</td>
</tr>
<tr>
<td>A20</td>
<td>1.735</td>
<td>1.751</td>
</tr>
<tr>
<td>A25</td>
<td>1.738</td>
<td>1.747</td>
</tr>
<tr>
<td>A30</td>
<td>1.685</td>
<td>1.692</td>
</tr>
<tr>
<td>A40</td>
<td>1.658</td>
<td>1.659</td>
</tr>
</tbody>
</table>

GROVEX (PTB) / VAFAC (UW) / WAFAC (NIST)

<table>
<thead>
<tr>
<th>Seed</th>
<th>PTB $S_K$ (cGy cm$^2$ h$^{-1}$)</th>
<th>UW $S_K$ (cGy cm$^2$ h$^{-1}$)</th>
<th>NIST $S_K$ (cGy cm$^2$ h$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{103}$Pd (model 200) No.1</td>
<td>26.307</td>
<td>26.389</td>
<td>26.40</td>
</tr>
<tr>
<td>$^{103}$Pd (model 200) No.3</td>
<td>26.327</td>
<td>26.380</td>
<td>26.44</td>
</tr>
<tr>
<td>$^{103}$Pd (model 200) No.10</td>
<td>27.973</td>
<td>26.951</td>
<td>26.90</td>
</tr>
<tr>
<td>$^{125}$I (model 6711) No.1</td>
<td>17.288</td>
<td>17.138</td>
<td>17.16</td>
</tr>
<tr>
<td>$^{125}$I (model 6711) No.2</td>
<td>12.191</td>
<td>12.226</td>
<td>12.25</td>
</tr>
<tr>
<td>$^{125}$I (model 6711) No.3</td>
<td>17.093</td>
<td>17.053</td>
<td>17.18</td>
</tr>
</tbody>
</table>

Anisotropy measurements

HDR sources  LDR sources
Anisotropie von HDR-Quellen

$^{192}$Ir

$^{60}$Co
Radial (left) and polar anisotropy (right) of two BEBIG seeds

S.17 seed

S.16 seed
Calibration of brachytherapy sources in terms of absorbed dose rate.

- Air kerma strength
- Reference air kerma rate
- MCC
- TG 43

Absorbed dose rate to water, $D_w$ (1 cm)

Today vs. Future
Calibration of brachytherapy sources in terms of absorbed dose rate.

- Air kerma strength
- Reference air kerma rate
- MCC
- TG 43
- Absorbed dose rate to water, $D_w (1 \text{ cm})$

Today, in the future.
Absorbed dose rate to water in 1 cm distance from the source is already determined for two $^{192}$Ir-HDR sources:

a) GammaMed 12i
b) Microselectron Classic

First well type chamber has been calibrated (BEV)
Schematic of the GROVEX II measuring system for the realization of absorbed dose to water

A first $^{125}\text{I}$ source (BEBIG S16) has been calibrated
PTB offers:
- Calibration of HDR and LDR sources in terms of reference air kerma rate
- Calibration of suitable ionization chambers (for example in a Krieger phantom) and well type ionization chambers

The source calibration certificate contains information on the anisotropy of the source.

Development of primary standards for absorbed dose rate to water are in progress.

Two HDR sources and one LDR source have been already calibrated in terms of absorbed dose rate to water.

First well type chamber has been calibrated in terms of absorbed dose rate to water for $^{192}$Ir radiation.
Thank you for your attention