Calibration of pencil type ionization chambers at various irradiation lengths and beam qualities

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The pencil chamber is a thin cylindrical ionization chamber with active length of 100 mm (or higher)

- Partial irradiation
- The response of the active volume is (must be) uniform along its entire axial length

The associate dosimetric quantity:

Air kerma-length product, $P_{KL}$ in mGy•cm
(mGy•mm, μGy•m)

However, some old dosimeter models read in mGy or mR
For the last decades, pencil chambers have mainly been used in computed tomography (CT) dosimetry.

However, they become inappropriate in new CT modalities - technologies (MDCT).

The standards of CT dosimetry and methods are being reviewed – other types of detectors are proposed.

Pencil chambers may be withdrawn (?), soon (?)

Before that …
the pencil chambers will remain in use

Furthermore,
Pencil chambers are used for dose measurement in other applications, like dental, cone and fan beams, etc.
Aim of this work
• to address special topics on pencil chamber calibration
• to present calibration results & performance characteristics of pencil chambers

The work was conducted at the SSDL Ionizing Radiation Calibration Laboratory of the Greek Atomic Energy Commission (IRCL/GAEC)
• member of IAEA/WHO SSDL network, 2000
• member of EURAMET, 2001
• ISO 17025 accreditation, 2003
**Method A: Partial irradiation of the sensitive volume**

IAEA TRS 457

Partial irradiation of the sensitive volume

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Film for chamber calibration set up
**Method A: Partial irradiation of the sensitive volume**

IAEA TRS 457

![Diagram of partial irradiation](image)

\[ N_{PKL} = \frac{K_i \cdot L}{M} \]

- \( L \): measured length, so known (+uncertainty)
- \( N_{KL} \) according to \( P_{KL} \) definition
- Scattered radiation from “slit” apertures

**Method B: Total irradiation of the sensitive volume**

\[ N_{PKL} = \frac{K_i \cdot L}{M} \]

- \( L \): nominal (rated) length - Not measured
- No “slit” aperture – less scattered radiation
Three irradiation geometries

**GOOD:** \( A_1 = 50 \text{ mm dia} + A_2 = 33.5 \times 33.5 \text{ mm} \)

**MEDIUM:** \( A_1 = 50 \text{ mm dia}, \text{ only} \)

**POOR:** No additional apertures

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**TEST**
PTW 31014 therapy **pin point** ionization chamber
(0.015 cm\(^3\) & 2 mm dia)

Three irradiation geometries

**GOOD:** \( A_1 = 50 \text{ mm dia} + A_2 = 33.5 \times 33.5 \text{ mm} \)

**MEDIUM:** \( A_1 = 50 \text{ mm dia}, \text{ only} \)

**POOR:** No additional apertures

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**SLITs:** 10 – 20 – 30 – 50 – 80 – 100 mm width

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\( P_{KL}^{\text{ref}} = K_i \cdot L \)

Under “good” geometry \( K_i \) is the same
Conclusions:

• The set-up geometry affects the reference $P_{KL}^{\text{ref}}$ determination.
• If “good” geometry is not achieved, associated $k_w$ correction factors may be introduced: $P_{KL}^{\text{ref}} = K_i \times k_w \times L$
• The associate uncertainty of $k_w$ is $\sim 0.6 \%$ ($k=1$)

* Normalization to “open field” (without the slit)
2. Residual signal, $R_0$


- The residual signal, $R_0$ originates from scattered radiation (from the slit mainly)
- The chamber reading, $R$ and the irradiation length, $L$ should be proportional.
- The extrapolation of the $R=f(L)$ intercepted the ordinate axis at a positive value $R_0$

TEST

Several pencil chamber tested: PTW (TM 30009)
RADCAL (20x5-3CT), RTI (DCT 10),
VICTOREEN (660-6, 500-100),

SLITs: 10 – 20 – 30 – 50 – 80 – 100 mm width
## 2. Residual signal, $R_0$

### Examples:

![Graph showing chamber readings and irradiation length](image)

<table>
<thead>
<tr>
<th>Chamber model</th>
<th>Residual signal (A.U.)</th>
<th>% residual to actual signal @ 100 mm slit</th>
<th>% residual to actual signal @ 50 mm slit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTW TM 3000</td>
<td>0.060</td>
<td>1.0%</td>
<td>1.9%</td>
</tr>
<tr>
<td>RADCAL 20x5-3CT</td>
<td>0.067</td>
<td>1.2%</td>
<td>2.2%</td>
</tr>
<tr>
<td>RTI DCT 10</td>
<td>0.053</td>
<td>0.8%</td>
<td>1.6%</td>
</tr>
<tr>
<td>VICTOREEN 660-6</td>
<td>0.141</td>
<td>2.5%</td>
<td>4.4%</td>
</tr>
</tbody>
</table>

Uncertainty ~1.0 – 1.5 % (k=1), depending on the “case”
2. Residual signal, $R_0$

![Graph showing the relationship between irradiation length (mm) and chamber reading with fitted lines and residuals for different calibration types.]

- **Radcal 2026**
  
  $y = 0.076x + 0.007$  
  Residual: $0.20\%$

- **Radcal 3036**
  
  $y = 0.057x + 0.021$  
  Residual: $0.55\%$

- **Radcal 2026(2)**
  
  $y = 0.054x + 0.015$  
  Residual: $0.70\%$
2. Residual signal, $R_0$

Conclusions:

- $R_0$ depends on “experiment set up”, especially on the shape of slit edges.
- $R_0$ depends on the chamber type & performance.
- $R_0$ has not the same value for pencil chambers of the same model / type.

$R_0$ measurement tests:

- The chamber spatial homogeneity and
- The repeatability of the calibration procedure.

Example of “poor” spatial homogeneity performance.
2. Residual signal, $R_0$

Conclusions:

$R_0$ should be determined for each chamber, since deviations up to few % may be recorded.

In calculation of the calibration coefficients, the residual signal $R_0$ should be subtracted from the chamber signal, $M$

$$N_{P_{KL}} = \frac{K \cdot L}{(M - R_0) \cdot k_{PT}}$$

The $N_{PKL}$ is obtained at 50 mm irradiation length (50% chamber rated length).
3. Energy dependence of response

TEST

Several pencil chamber were calibrated at RQT and RQR series (IEC 61267) PTW, RADCAL, RTI, VICTOREEN (FLUKE)
3. Energy dependence of response

Examples:

- **Radcal**
  - $N_k$ (mGy/R)
  - $HVL / mm Al$
  - RQR
  - RQT

- **RTI**
  - $N_{k,LP}$ (mGy cm / mGy cm)
  - $HVL / mm Al$
  - RQR
  - RQT

- **500 -100**
  - $N_k$ (mGy/ mGy)
  - $HVL / mm Al$
  - RQR
  - RQT

- **500-200**
  - $N_k$ (mGy/ µC)
  - $HVL / mm Al$
  - RQR
  - RQT
CALIBRATION
Beam quality : RQT9 (120 kV, HVL=8.41 mm Al, F: 3.55 mm Al + 0.25 mm Cu)

23 commercial dosimeters with pencil chambers were calibrated:

PTW (TM 30009) : $P_{KL}$ in mGy·cm

RADCAL 3cc (20x5-3CT series) : Kair mGy & mR (none measured the $P_{KL}$ !)

RTI (DC10) : mGy·cm, $\mu$Gy·m

VICTOREEN / FLUKE (660-6, 500-100, 500-200) :

$P_{KL}$ in mGy·cm, $\mu$Gy·m OR $K_{Air}$ in mGy OR $X$ in mR OR $pC$
### 4. Calibration

All dosimeters were calibrated in terms of $P_{KL}$ in mGy cm / reading

![Bar chart showing distribution of $P_{KL}$ readings for different dosimeters.](Image)

<table>
<thead>
<tr>
<th><strong>All chambers</strong></th>
<th><strong>PTW</strong></th>
<th><strong>RADCAL</strong></th>
<th><strong>RTI</strong></th>
<th><strong>VICTOREEN</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean $N_{PKL}$ (± sd)</td>
<td>0.982±0.117</td>
<td>0.983±0.009</td>
<td>0.934±0.089</td>
<td>0.899±0.030</td>
</tr>
<tr>
<td>Median</td>
<td>0.976</td>
<td>0.984</td>
<td>0.923</td>
<td>0.896</td>
</tr>
</tbody>
</table>

** For comparison reasons, the mR readings were converted to Kair using the of $8.76 \times 10^{-3}$ mGy/mR conversion factor while the $x10^{-2}$ factor was omitted.
## 5. Comparison of the two calibration methods

<table>
<thead>
<tr>
<th>Chamber</th>
<th>$N_{PKL}$ (Method A) Partial irradiation mGy cm / reading</th>
<th>$N_{PKL}$ (Method B) Total irradiation mGy cm / reading</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radcal</td>
<td>1.01 ± 0.04</td>
<td>1.00 ± 0.03</td>
<td>-1.19%</td>
</tr>
<tr>
<td>Radcal</td>
<td>0.97 ± 0.04</td>
<td>0.99 ± 0.03</td>
<td>2.36%</td>
</tr>
<tr>
<td>Radcal</td>
<td>1.07 ± 0.04</td>
<td>1.06 ± 0.03</td>
<td>1.30%</td>
</tr>
<tr>
<td>Radcal</td>
<td>0.99 ± 0.04</td>
<td>0.97 ± 0.03</td>
<td>-2.17%</td>
</tr>
<tr>
<td>Radcal</td>
<td>0.98 ± 0.04</td>
<td>0.97 ± 0.03</td>
<td>-1.08%</td>
</tr>
<tr>
<td>Victoreen</td>
<td>1.30 ± 0.05</td>
<td>1.32 ± 0.03</td>
<td>-1.29%</td>
</tr>
<tr>
<td>Victoreen</td>
<td>1.09 ± 0.04</td>
<td>1.07 ± 0.03</td>
<td>-1.38%</td>
</tr>
</tbody>
</table>
CONCLUSIONS

Pencil chambers, although ionization chambers, may have significant *energy dependence of response*, so must be calibrated at beam qualities close to those that are used.

The *residual signal* should be investigated for each chamber during calibration.

Calibration should be performed under “Good *Geometry*” or appropriate correction factors should be applied.

Correct interpretation of the dosimeter “*measuring quantity*” and the calibration coefficient units is necessary.
I thank you for your attention