The challenge of high dose rates for ionisation chambers

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Motivation
Ionization chamber dosimetry at UHDR beams

- Ionization chamber dosimetry based on air-filled ionization chambers is the gold standard in clinical conditions in radiation therapy
- In this field the dosimetry with ionization chambers is very well understood and the ionization chambers are available worldwide and easy to use
- The FLASH effect has been discovered and it is now attractive to use VHEE with UHDR beams in clinical practice.

**Question for this talk:** Can ionization chamber dosimetry also be used under VHEE conditions? Active monitoring of dosimetry would be essential for the clinical use of VHEE beams.

- Main problem: Recombination losses in ionization chambers at very high dose rates
  - *Peterson et al* studied ion collection efficiency with simultaneous film and chamber measurements
    - Voltage dependent
    - Dose per pulse dependent

*Peterson K., Jaccard M., Germond J.F., Bucheler T., Bachud F., Buurlea J., Vozenin M.C. and Bailat C. 2017 High dose-per-pulse electron beam dosimetry - A model to correct for the ion recombination in the Advanced Markus ionization chamber Med. Phys. 44 1157–67*
Setup
Phantom

200 MeV

ICT

Radiochromic films

YAG

Ionization chamber

Probe holder

Moveable water phantom

3.5 & 7 mm FWHM
Setup

Beam structures

<table>
<thead>
<tr>
<th></th>
<th>VERY HIGH</th>
<th>HIGH</th>
<th>MEDIUM</th>
<th>LOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trains</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>36-80</td>
</tr>
<tr>
<td>Time length of one train</td>
<td>66 ns</td>
<td>33 ns</td>
<td>16 ns</td>
<td>~ 1 fs</td>
</tr>
<tr>
<td>Time between two trains</td>
<td></td>
<td></td>
<td>1.2 s</td>
<td></td>
</tr>
<tr>
<td>Number of bunches per train</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>1-2</td>
</tr>
<tr>
<td>Time between two bunches</td>
<td></td>
<td></td>
<td>666 ps (1.5 GHz)</td>
<td></td>
</tr>
</tbody>
</table>
Measurement

Film calibration

- Film analysis: Epson 10000 XL scanner, 16 bit per color channel, no auto corrections, single channel analysis
- Film calibration with 21 MeV electron beam
Measurement

Film measurement

- Dose value was determined by averaging according to chamber diameter

3.5 FWHM

7 FWHM
Measurement

Film measurement

- Dose value was determined by averaging according to chamber diameter
Measurement
Chamber measurement

- Dose measurement with ionization chamber according to international protocols (AAPM TG 51 / TRS 398 / DIN 6800-2)

$$Dose\ to\ water = M \cdot N \cdot k_{TP} \cdot k_E \cdot k_P \cdot k_S$$

- Calibration factor for Co60 [Gy / C]
- Energy correction
- Recombination loss correction
- Temperature pressure correction
- Polarity correction
- Chamber signal [C]
Dose measurement with ionization chamber according to international protocols (AAPM TG 51 / TRS 398 / DIN 6800-2)

\[
Dose \text{ to water} = M \cdot N \cdot k_T \cdot k_E \cdot k_P \cdot k_S
\]

- **Chamber signal [C]**
- **Temperature pressure correction**
- **Recombination losses correction**
- **Energy correction**
- **Calibration factor for Co60 [Gy / C]**
- **Polarity correction**

\[
k_E = \frac{\left( s_{W,a}^\Delta \right)_{200 \text{ MeV}, 7.2 \text{ cm}} \cdot p_{200 \text{ MeV}, 7.2 \text{ cm}}}{{\left( s_{W,a}^\Delta \right)_{\text{Co60}, 5 \text{ cm}}} \cdot p_{\text{Co60}, 5 \text{ cm}}}
\]

Monte Carlo simulation (University of Oldenburg)
Dose measurement with ionization chamber according to international protocols (AAPM TG 51 / TRS 398 / DIN 6800-2)

\[ Dose\ to\ water = M \cdot N \cdot k_{TP} \cdot k_E \cdot k_P \cdot k_S \]

\[ k_E = \frac{(s_{w,a}^\Delta)_{200\ MeV,7.2\ cm} \cdot p_{200\ MeV,7.2\ cm}}{(s_{w,a}^\Delta)_{Co60,5\ cm} \cdot p_{Co60,5\ cm}} \approx 0.79 \]

Monte Carlo simulation (University of Oldenburg)
Measurement
Chamber measurement

- Dose measurement with ionization chamber according to international protocols (AAPM TG 51 / TRS 398 / DIN 6800-2)

\[
\text{Dose to water} = M \cdot N \cdot k_{TP} \cdot k_E \cdot k_P \cdot k_S
\]

- Calibration factor for Co60 [Gy / C]
- Recombination losses correction
- Energy correction
- Chamber signal [C]
- Temperature pressure correction
- Polarity correction

Experimentally determined at different number of trains
Measurement
Chamber measurement

- Dose measurement with ionization chamber according to international protocols (AAPM TG 51 / TRS 398 / DIN 6800-2)

\[ \text{Dose to water} = M \cdot N \cdot k_{TP} \cdot k_E \cdot k_P \cdot k_S \]

Calibration factor for Co60 [Gy / C]
Chamber signal [C]
Temperature pressure correction
Energy correction
Polarity correction
Recombination losses correction

Comparison to film measurement
Results

Chamber saturation at very high dose rates

- Dose measurement with ionization chamber according to international protocols (AAPM TG 51 / TRS 398 / DIN 6800-2)

\[
Dose \text{ to water} = M \cdot N \cdot k_{TP} \cdot k_{E} \cdot k_{P} \cdot k_{S}
\]

Based on Gotz et al

Results
In summary

- Ion collection efficiency of an ionization chamber was determined by comparison to film measurement.

- Ion collection efficiency was studied at CLEAR facility under different dose per train conditions and two beam sizes.

- Results comparable to theoretical calculations and previous study by Petersson et al.

- The work has shown that dosimetry via vented ionization chambers is possible at the CLEAR facility. This allows an active and directly read-out monitoring of the dosimetry during experiments.
Acknowledgement
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http://uhdpulse-empir.eu/