Ion collection efficiency (CCE) in ultra-high dose per pulse electron beams

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No, nothing to disclose
Ultra-high dose rate means that ion recombination is very large.

Do not follow current model (Boag).

Alanine can be used to measure the ion recombination.

Bourgouin et al., DOI: 10.3389/fphy.2020.567340
Dose equation

\[ D_w = M \cdot k_{R50} \cdot N_{D,w}^{Co} \]
Dose equation

\[ D_w = M \cdot k_{R50} \cdot N_{D,w}^{Co} \]

- Dose
- Beam quality correction factor
- Charge
- Cobalt calibration factor
- Measurement
Dose equation

Dose

\[ D_w = M \cdot k_{R50} \cdot N_{D,w}^{Co} \]

Beam quality correction factor

Cobalt calibration factor

\[ M = (Q_{raw} \cdot Q_{leak}) \cdot k_{sat} \cdot k_{elec} \cdot k'_{elec} \cdot k_{pol} \cdot k_{TP} \cdot k_{field} \]
Charge measurement equation

Raw meas. - leakage

\[ M = (Q_{\text{raw}} \cdot Q_{\text{leak}}) \cdot k_{\text{sat}} \cdot k_{\text{elec}} \cdot k'_{\text{elec}} \cdot k_{\text{pol}} \cdot k_{\text{TP}} \cdot k_{\text{field}} \]
Charge measurement equation

Raw meas. - leakage

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Saturation effect
Charge measurement equation

Raw meas. - leakage calibration +

\[ M = (Q_{\text{raw}} \cdot Q_{\text{leak}}) \cdot k_{\text{sat}} \cdot k_{\text{elec}} \cdot k'_{\text{elec}} \cdot k_{\text{pol}} \cdot k_{\text{TP}} \cdot k_{\text{field}} \]

Saturation effect
Charge measurement equation

\[ M = (Q_{\text{raw}} \cdot Q_{\text{leak}}) \cdot k_{\text{sat}} \cdot k_{\text{elec}} \cdot k'_{\text{elec}} \cdot k_{\text{pol}} \cdot k_{TP} \cdot k_{\text{field}} \]

- Raw meas. - leakage
- Saturation effect
- Electrometer calibration + Polarity effect
Charge measurement equation

\[ M = (Q_{\text{raw}} \cdot Q_{\text{leak}}) \cdot k_{\text{sat}} \cdot k_{\text{elec}} \cdot k'_{\text{elec}} \cdot k_{\text{pol}} \cdot k_{TP} \cdot k_{\text{field}} \]

- Raw meas. - leakage
- Electrometer calibration +
- Saturation effect
- Polarity effect
- Temperature pressure
Charge measurement equation

\[ M = (Q_{\text{raw}} \cdot Q_{\text{leak}}) \cdot k_{\text{sat}} \cdot k_{\text{elec}} \cdot k'_{\text{elec}} \cdot k_{\text{pol}} \cdot k_{TP} \cdot k_{\text{field}} \]

Raw meas. - leakage
Electrometer calibration +
Temperature pressure
Saturation effect
Polarity effect
Non-homogeneity of beam profile
Charge measurement equation

\[ M = (Q_{\text{raw}} \cdot Q_{\text{leak}}) \cdot k_{\text{sat}} \cdot k_{\text{elec}} \cdot k'_{\text{elec}} \cdot k_{\text{pol}} \cdot k_{\text{TP}} \cdot k_{\text{field}} \]

\[ \downarrow \]

\[ M = Q'' \cdot k_{\text{sat}} \]

\[ D_w = M \cdot k_{R50} \cdot N^{C_0}_{D,w} \]
Dose $k_{sat}$ equation

$$k_{sat} = \frac{D_w}{Q'' \cdot k_{R_{50}} \cdot N_{D,w}^{Co}}$$
Dose \( k_{\text{sat}} \) equation

Dose to water estimated from Alanine calibration

\[
k_{\text{sat}} = \frac{D_w}{Q'' \cdot k_{R_{50}} \cdot N_{D,w}^{Co}}
\]
Dose $k_{sat}$ equation

Dose to water estimated from Alanine calibration

$$k_{sat} = \frac{D_w}{Q'' \cdot k_{R50} \cdot N_{D,w}^{Co}}$$

Calculated by Monte Carlo
Measurement set-up

- Metrological Electron Accelerator Facility (MELAF) at PTB, Germany

- Tests carried out at 20 MeV, 5 Hz PRF, pulse width of 2.5 μs
- Dose varied between 0.1 Gy and 6.3 Gy per pulse
- Beam current monitor; Integrating Current Transformer (ICT)
Detectors

- Alanine was evaluated using the PTB’s Alanine/SPR system
- 6 parallel plate ionization chamber models
  - 6 Advanced Markus (gap of 1.0 mm)
  - 4 Roos (gap of 2.0 mm)
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  - 3 PPC40 (gap of 2.0 mm)
  - 2 NACP02 (gap of 2.0 mm)
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  - 2 NACP02 (gap of 2.0 mm)
  - 2 SNC350p (gap of 2.0 mm)
Charge collection efficiency

Dose per pulse (Gy)

Bias 300 V

- PPC05
- Advanced Markus
- PPC40
- Roos
- SNC350p
- NACP02

Charge collection efficiency

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Charge collection efficiency

Error bar: intra-type variation

Bias 300 V

- PPC05
- Advanced Markus
- PPC40
- Roos
- SNC350p
- NACP02

Charge collection efficiency (CCE) vs. Dose per pulse (Gy)

- 0.6 mm
- 1.0 mm
- 2.0 mm

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Charge collection efficiency

~200 V/mm

- PPC05, 125 V
- Advanced Markus, 200 V
- PPC40, 400 V
- Roos, 400 V
- SNC350p, 400 V
- NACP02, 400 V
Reproducibility

Bias 300V
- Advanced Markus (01)
- Advanced Markus (02)
- PPC40 (01)
- PPC40 (02)
- NACP02 (01)
- NACP02 (02)
Relative Measurement (not corrected)

Error on $R_{50}$
- min 0.4 cm -> 0.1% off on $k_{R_{50}}$
- max 1.1 cm -> 0.4% off on $k_{R_{50}}$

Normalized value

Depth (cm)

2 Gy per pulse, 300 V
Relative measurement (not corrected)

Error on $z_{\text{ref}}$
- min 0.4 cm -> 0.4%
- max 1.1 cm -> 1.1%

2 Gy per pulse, 300 V
Relative measurement (corrected)

Variation of $R_{50} = 0.2$ cm

2 Gy per pulse, 300 V
Conclusion

➢ Absolute dosimetry
  – Intra-type variations up to 10 %

➢ Polarity effect
  – up to 10 %

➢ Electrometer used in current mode
  – Test yours!

➢ Relative measurement
  – $k_{sat}$ as to be used even for relative measurement
  – Published model work, good enough
A FLASH moment of silence

Advanced Markus Drowned

Roos Weep

Water tank tomb
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http://uhdpulse-empir.eu/