Secondary standard dosimetry: Understanding the ionization chambers for the future ultra-high dose rate applications

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Disclosure

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Air vented parallel plate ionization chambers in ultra high pulse dose rate

• Conventional parallel plate ionization chambers are compromised by high ion recombination losses up to 83 % for a 2 mm electrode distance chamber at 5 Gy per pulse and 350 V bias voltage.

• Boag-like analytical ion recombination corrections factors do not reproduce the actual chamber response.


Charge carrier transport equations

Ionization chamber can be described by the following set of one-dimensional equivalent equations, similar approach used by M. Gotz et al Phys. Med. Biol. 62 8634 (2017):

\[
\frac{\partial}{\partial t} n_+ (x, t) = R(x, t) - \alpha n_+(x, t) n_-(x, t) - \frac{\partial}{\partial x} \left[ E(x, t) \mu_+ n_+(x, t) \right]
\]

\[
\frac{\partial}{\partial t} n_-(x, t) = \gamma (E) n_e (x, t) - \alpha n_+(x, t) n_-(x, t) + \frac{\partial}{\partial x} \left[ E(x, t) \mu_- n_-(x, t) \right]
\]

\[
\frac{\partial}{\partial t} n_e (x, t) = R(x, t) - \gamma (E) n_e (x, t) + \frac{\partial}{\partial x} \left[ E(x, t) \mu_e (E) n_e (x, t) \right]
\]

\[
\frac{\partial}{\partial t} E(x, t) = \frac{e}{\epsilon} \left[ n_+(x, t) - n_- (x, t) - n_e (x, t) \right] \quad \int_0^d E(x, t) dx = V
\]

\[
I = qv E_w = q \mu \frac{E}{d}
\]
Carrier Transport Parameters: Ion average mobility

Standard conditions ($P = 1013.25 \text{ hPa}$, $T = 20 \, ^\circ\text{C}$, $H = 50 \%$)

We have taken ion mobility parametrization from B. Zhang et al.

The electron attachment was taken from Boissonat Chambres d’ionisation en Protonthérapie et Hadronthérapie, Physique Médicale. Université Caen Normandie, 2015.
Simulation vs Measurements at PTB MELAF

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Towards primary and secondary standards for dosimetry in Flash radiotherapy

- 20 MeV Electron beam
- ICT Waveform
- PTB Alanine Calibration
- Dose-rate
- Simulation
- Experimental Chamber Current waveform
- Simulated Chamber Current Waveform
- Comparison

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Results: Instantaneous Induced Current

**ICT current**

- Pulse repetition frequency: 5 Hz
- Nominal beam energy: 20 MeV
- Pulse duration: 2.5 µs
- Dose per pulse: 5.74 Gy
- Nominal bias voltage: +400 V

**Ionization chamber induced current**

- Fast electron current
- Slow ion current
- End of the beam

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Results: Instantaneous Induced Current

- Instantaneous Induced Current ≈ Fast electron current
- Slow ion current
- End of the beam ≈ FEF

- Pulse repetition frequency: 5 Hz
- Nominal beam energy: 20 MeV
- Pulse duration: 2.5 µs
- Dose per pulse: 5.74 Gy
- Nominal bias voltage: +400 V

Unpublished data, do not copy or reproduce
Results: Charge Collection Efficiency

Simulation for SN1280
Simulation for SN1279
Experimental data for SN1280
Experimental data for SN1279

Advanced Markus chamber
V = 402.48 V
Δt = 2.5×10⁻⁷ s

Advanced Markus chamber
V = 201.27 V
Δt = 2.5×10⁻⁷ s

Unpublished data, do not copy or reproduce
Conclusions

• Charge carrier transport numerical simulations show promising results to model the performance of ionization chambers in ultra-high dose rate.

• This approach can still be improved. Transport parameters, such as electron attachment, need to be further studied for a more precise simulation.

• Instantaneous induced current due to charge carriers transport across the chamber is a more demanding way of benchmarking those models.

• We have created a beta version distributable simulation software. Contact Faustino.gomez@usc.es, jose.martin@usc.es.