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► To cite this version:

Marco Cavallone, Patrik Gonçalves Jorge, Raphaël Moeckli, Claude Bailat, Alessandro Flacco, et al.. Determination of the ion collection efficiency of the Razor Nano Chamber for ultra-high dose-rate electron beams. Flash radiotherapy and particle therapy conference 2022, Nov 2022, Barcelona, Spain. , 49, pp.4731 - 4742, 2022. hal-04305562

HAL Id: hal-04305562

<https://hal.science/hal-04305562>

Submitted on 24 Nov 2023

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Determination Of The Ion Collection Efficiency Of The Razor Nano Chamber For Ultra-high Dose-rate Electron Beams

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Context:

The clinical transfer of **ultra-high dose-rate (UHDR, >50 Gy/s)**, or FLASH, radiation therapy (RT) requires the development of **accurate and practical tools for online dosimetry**.

Ionization chambers remain the gold-standards in RT but show non-negligible ion recombination at such dose rates, imposing the use of **ion recombination models for UHDR irradiations**. **Small volume size** may be an interesting characteristic to **limit the charge recombination effects**. In that context, we investigated the charge collection behavior in UHDR pulses of the **IBA Razor™ Nano Chamber (RNC)**, having the **smallest available sensitive volume** (3 mm³).

Materials and Methods:

The **RNC ion collection efficiency (ICE)** was determined under an **UHDR electron beam, on the Oriatron eRT6** (PMB-Alcen, France) experimental accelerator (~5-6 MeV electrons).

Three simultaneous dose measurements:

RNC charge (with Dose 1 IBA electrometer), **beam current transformer (BCT)** and dose-rate independent **Gafchromic™ EBT3 films** (used as dose reference).

Corrections: RNC charge Q is corrected by the $k_{T,P}$ and the BCT signal. Dose-per-pulse (DPP) at RNC position (1.5 cm) is the film dose (RW3 surface) corrected for PDD difference (k_F).

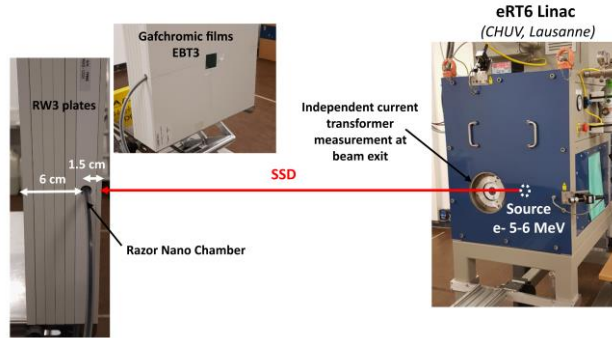


Figure 1: Experimental irradiation setup. Right: eRT6 Oriatron's picture. Left: RW3 water equivalent phantom with inserted RNC (at 1.5 cm depth) and EBT3 films placed at the phantom surface for simultaneous reference dose measurements. SSDs used of 2, 0.5, 0.3, and 0.2 m.

Parameters: DPP: from **0.01 to 30 Gy**.

Pulse durations: 1 and 3 μ s. Frequency: 10 Hz. Three measurements per condition and two independent experimental campaigns performed.

ICE calculation:

The ICE was determined separately for the two pulse durations. It was calculated as:

$$ICE(DPP) = \frac{Q}{Q_{sat}}(DPP) = \frac{1}{N_{RW3,el\ eRT6} \left[\frac{Gy}{nC} \right] \cdot k_{T,P}} \cdot DPP [Gy]$$

Where Q is the charge collected by the RNC and Q_{sat} is the saturation charge, i.e. the charge without recombination determined by linear fit of $Q=f(DPP)$ at SSD of 2m ($Q < 20$ pC, negligible recombination).

ICE model: An empirical logistic model was used to fit the RNC ICE measurements:

$$ICE(DPP) = \left(1 + \left(\frac{DPP}{\gamma} \right)^\alpha \right)^\beta$$

where α , β , and γ are fitting parameters (Pettersson *et al.*, 2017). The **uncertainty on ICE fit** ranged from 1-8% and was determined with a Monte Carlo approach including uncertainties on film dose, k_F and RNC repeatability.

Results:

The total corrected RNC charge is plotted as a function of the DPP in Figure 2, separately for the two pulse duration, and the corresponding calculated ICE, using the experimentally determined Q_{sat} , are shown in Figure 3.

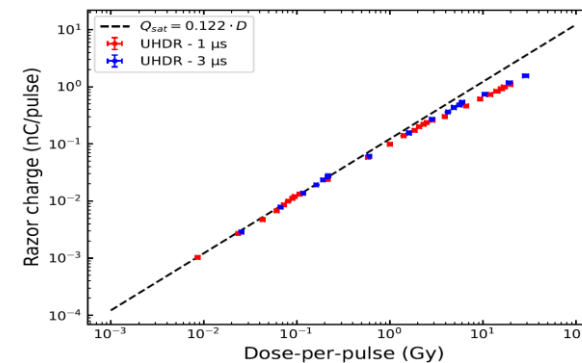


Figure 2: RNC charge response as a function of the DPP. Two series at pulse lengths of 1 μ s (red dots) and 3 μ s (blue dots), with DPP ranging from 0.01 to 30 Gy. The black linear dashed curve represents the saturation charge Q_{sat} . The uncertainty on DPP is of 5% and that on the RNC charge is of 0.43%.

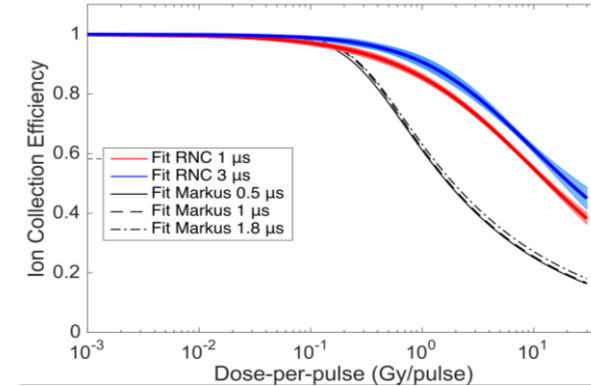


Figure 3: ICE of the RNC as a function of the DPP, for pulse lengths of 1 μ s (red curve) and 3 μ s (blue curve), fitted with the logistic recombination model. The uncertainties are represented by the shaded region around the main curves. The RNC ICE results are compared with those of the Markus Advanced chamber of PTW as published by Pettersson *et al.*, Med. Phys. 2017

The **RNC ICE decreases as the DPP increases above 0.2 Gy** and stays **higher than 85 and 55% for DPP of 1 and 10 Gy**, respectively. The Advanced Markus chamber results in lower efficiencies with 60 and 25% at same DPP. However, the **RNC shows a higher sensitivity to the pulse duration**, suggesting a higher sensitivity to the dose rate within the pulse.

Conclusions:

The results confirmed that the small sensitive volume of the RNC ensures higher ICE compared with larger chambers, which makes it a promising online dosimetry tool for FLASH RT. The proposed recombination model allows corrections up to DPP of 30 Gy.