1. Introduction

About 4 new million new cancer patients are expected in Europe during 2025, according to ESTRO [1]. This represents a 16% increase compared to the diagnosed patients in 2012. Those projections reinforce the effort to develop new efficient and fast radiotherapy techniques. In this context, FLASH radiotherapy (FLASH-RT) is a new delivery mode for radiotherapy treating very high instantaneous dose rate with pulsed radiation beams. Even from around 1960 there were indications that the delivery of the ionizing radiation dose in ultra-short pulses could improve the therapeutic window respect to standard radiotherapy. During last years there is a growing interest in the clinical community about FLASH-RT due to the evidence of lower toxicity in healthy tissue keeping a similar tumour control probability (TCP) than conventional radiotherapy. In this way the so called FLASH effect would provide a new radiotherapy delivery mode with lower side effects allowing use more aggressive strategies for tumour treatment. FLASH-RT has been observed with photon and proton beams but usually most of the studies have been performed with electron beams. Although in most clinical facilities the achievable electron energies are below 20 MeV, the use of higher beam energies, even over 100 MeV, can extend the use of these modalities to deep seated tumours and boost its clinical use. Nowadays the technological advances in new accelerators and radiation delivery modalities make possible to implement this therapy in clinical practice.

2. The role of the ionization chambers

Different primary standards are considered for this new delivery modality, such as Fricke dosimetry or graphite calorimetry. For the secondary standards the project considers solutions based on ionization chambers, silicon and diamond devices or other custom solutions for the dosimetry.

Air ionization chambers are the most used secondary standards for dosimetry worldwide. International code of practice for pulsed high-energy electron-beam dosimetry recommends the use of parallel plate ionization chambers. Unfortunately for these detectors the saturation correction factor can differ substantially from unity reaching values even above 10 for some high dose per pulse deliveries. The problem of ion volume recombination that arises both from the high charge densities produced by the ionizing beam and the electric field perturbation of the chambers lead to an unreliable operation of these standards. One of the options to overcome this problem is the use of ultra-thin ionization chambers, with the corresponding assembly challenge and added effects such as electron multiplication in high electric field. We will present some results on the simulation and measurement with some commercial and custom built chambers.

The effort conducted under the collaboration will contribute to a better dosimetry understanding also at intermediate dose rate modalities such as Intra Operative Radiotherapy. The aim of this work is to develop a model that can take into account the dominant effects produced by the ionizing beam and the electric field perturbation of the chambers lead to an unreliable operation of these standards. One of the options to overcome this problem is the use of ultra-thin ionization chambers, with the corresponding assembly challenge and added effects such as electron multiplication in high electric field. We will present some results on the simulation and measurement with some commercial and custom built chambers.

Our approach to the problem is a computational-based model that solve the coupled differential equations which shape the charge transport across the air ionization chamber similar to the work of M. Gotz et al [3]. We made a step-by-step simulation: every element of the partial differential equations is executed in a infinitesimal time (usually in order of 10^{-10} s) with a dynamical time step adjust.

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\frac{\partial}{\partial t}[x, t] = R(t) - \alpha c c - \frac{\partial}{\partial E}[x, t] \frac{c}{E} c c [x, t]
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\frac{\partial}{\partial t}[x, t] = \gamma c c [x, t] - \alpha c c - \frac{\partial}{\partial E}[x, t] \frac{c}{E} c c [x, t]
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The variables \(c_1\), \(c_2\) and \(c_3\) are the positive, negative and electron carrier density along the ionization chamber respectively. \(R(t)\) is the charge liberated due to irradiation, \(\gamma\) is the electron attachment coefficient, \(\alpha\) is the recombination parameter, \(E\) the electric field and \(\mu\), the respectively mobilities. In the parameterization taken from Laitano and Gotz we have included the pressure and temperature dependency.

Whenever the chamber gap is reduced the fraction of charge collected due to free electrons is increased. Due to the much higher mobility of electrons an excess of positive charge is developed in the chamber volume close to the negative electrode. This effect is responsible of a very large electric field perturbation of the chamber, that by the reduction of the charge carrier speeds enhances a larger recombination effect.

This model can be upgraded by the addition of the electron de-attachment process altogether with the electron-positive ion recombination. Nevertheless the existing experimental parametrization of those effects indicate that their contribution can be considered marginal for most calculations of \(\alpha_{\text{sat}}\).

2.5 μs charge Plane parallel ionization chamber

Voltage = 75.469 V

Content for Advanced Markus at 452 V (p = 1.33 x 10^{12} m/s)

The European Joint Research Project UHDpulse (http://uhdpulse-expir.eu/) - Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates [2] is an international collaboration with the objective of studying this challenge providing metrological methods for dosimetry in FLASH-RT and trying to develop a Code of Practice for this radiotherapy modality.

3. The model

At the moment we are developing a Python-based code faster enough to be used in the clinical practice in order to correct the ion recombination. However, the model is still under development to accommodate an accurate parametrization of all the relevant processes of charge transport and recombination in air. Using the MELAF (Metrological Electron Accelerator Facility) at the German National Metrological Institute (PTB) different air ionization chambers have been tested in the 9 MeV electron beam with doses per pulse up to 1.8 Gy with a pulse duration of 2.5 μs. The results shown here were obtained with two Advanced Markus ionization chambers from PTW operated at 75.5 V and 452.7 V.

Although the Advanced Markus has a electrode distance of 1 mm it exhibits saturation factors in excess of 1.5 for the highest operation bias voltage of 450 V. It should be taken into account that the measurements with dose per pulse below 0.3 Gy have larger uncertainty due to the beam collimation and combined methodology with alanine dosimetry. We are working on getting data with lower uncertainty in the low and intermediate dose per pulse.

We are also developing a new ionization chamber based on the ultra-thin strategy in order to make ionization chamber a realiable devices to measure in FLASH.

4. Results

References

