Suitability of noble gas-filled ionization chambers for dosimetry of electron FLASH radiotherapy

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Purpose: Ultrahigh dose rate (or FLASH) radiotherapy widens the therapeutic window of radiotherapy treatments by achieving a higher normal tissue sparing than conventional dose rates. Reference dosimetry using air-filled ionization chamber is especially challenging for electron FLASH (eFLASH) where the high instantaneous dose rates lead to significant recombination effects. Noble gases are better suited for reference ionization chambers due to their negligible electronegativity, which results in electron-ion recombination as the only mechanism for incomplete charge collection. The electron drift towards the anode results in a net positive space charge near the cathode perturbing the electric field across the electrodes. The reduction in the total electric field near the anode leads to electron-ion recombination that needs to be investigated. The aim of this work was to create a charge carrier transport model to study the magnitude of the charge collection efficiency (CCE) for noble-gas filled ionization chambers under eFLASH conditions.

Methods: Coupled 1D partial differential equations describing charge carrier transport of electrons and cations in helium, neon, and argon gases were solved using the Runge-Kutta 4 numerical method considering the change in the total electric field using the Poisson equation. The electron drifty velocity, ion mobility, W/e, and electron-ion recombination coefficients were extracted from existing literature for noble gases. A parallel-plate ion chamber geometry was assumed with a plate separation of 1 mm. CCE and polarity were calculated for pulsed beams with dose-per-pulse (DPP) ranging from 1-20 Gy with a pulse duration of 0.5 microseconds. Applied voltages of 150 V and 300 V were considered since these values are typically used for conventional air-filled ion chambers.

Results: All polarity results were noted to be unity. Figure 1 displays the electric field across the electrodes at various times. Figure 2 shows the CCE for the noble gases with both 150 V and 300 V applied voltages. Lowest recombination was found for helium with the lowest CCE of 0.994. Significant recombination was calculated for neon and argon gases even for the 300 V bias.

Conclusions: Helium gas was found to be best suited to minimize recombination effects in eFLASH irradiations.

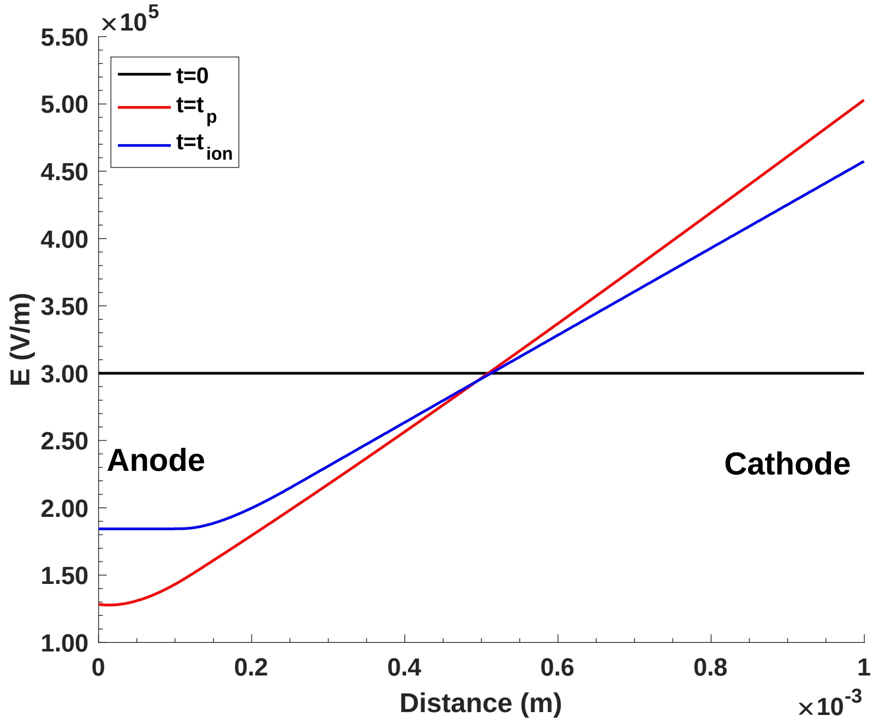

Figure 1. Electric field across the electrodes applied with a 300 V bias at $t = 0$, $t = t_p$, and $t = t_{ion}$ where t_p is the pulse duration and t_{ion} is the time at which only cations remain in the sensitive volume.

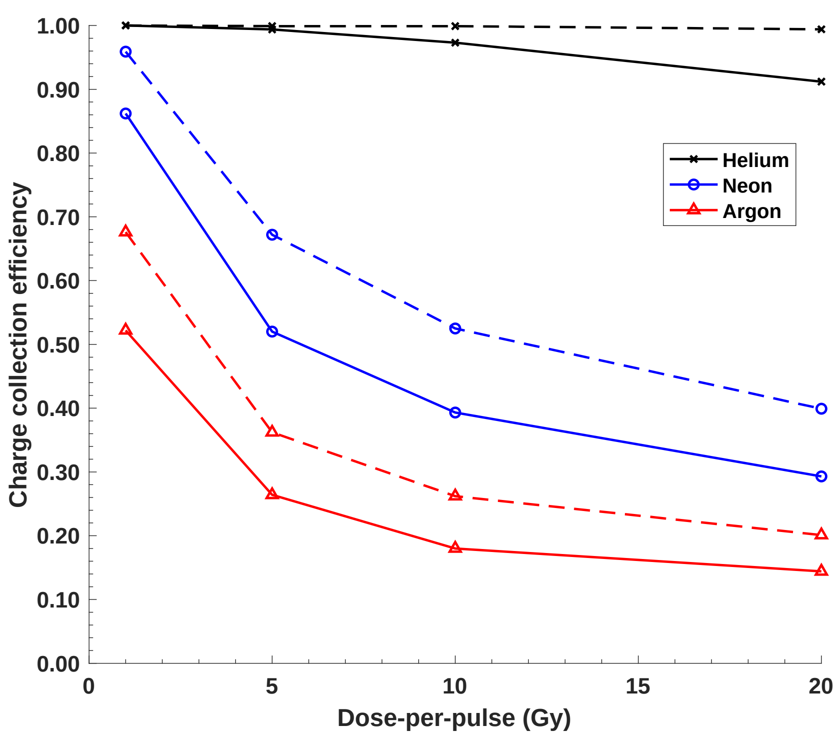

Figure 2. Charge collection efficiency (CCE) for helium, neon, and argon gases at applied voltages of 150 V (solid line) and 300 V (dash line).