Project Title: Femtosecond radiobiology with very high energy electron beams

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Type of Project: EXPERIMENTAL

Helpful existing knowledge: 1st or 2:1 BSc or MSci degree in physics or related subjects

Funding status: Funded

Project Description

A fundamental understanding of biological response to ionising radiation requires disentangling an intricate web of processes and mechanisms, typically spanning more than twenty orders of magnitude in time, starting with ionisation and the generation and diffusion of radicals (from a few to hundreds of femtoseconds after irradiation), through the chemical reactions inducing DNA damage and repair (from picoseconds up to minutes after irradiation), and ending with the macroscopic effects induced by the biological response of the cells and tissues (emerging even years after irradiation) [1]. Within this complex and structured response, the primary role of radiation is typically completed within femtoseconds after entering the cells, mainly by inducing ionisation and production of radicals. Protracted irradiation implies that considerable energy deposition still occurs during the subsequent biomolecular damage and repair mechanisms. Radiation can thus significantly interfere with signalling channels and repair processes; for example, it is known that radiation delivered after the solvation of the electron (>500 fs) can induce its excitation, thus altering its reactivity [2]. This is a known issue in radiotherapy that cannot be addressed with conventional methods and it has been highlighted by the international research community as a key area of research [3].

To experimentally decouple physical response from secondary effects of radiation, it is necessary to develop radiation sources able to deliver Gy-scale doses in a single delivery over femtosecond timescales. In a series of pioneering experiments in collaboration with the Patrick G. Johnston Centre for Cancer Research (PGJCCR) at QUB and the National Physical Laboratory (NPL), we demonstrated that such doses can be delivered by electron beams accelerated by high-power lasers [4,5] reaching unprecedented dose-rates in excess of 10^{13} Gy/s. Our proof-of-concept demonstration has already provided intriguing hints of significantly different biological response of cells, including a high relative biological effectiveness and a reduction in tumour radioresistance [5], effects that are not observed at picosecond timescales [6,7].

Following on these exciting preliminary results, we have partnered with the Istituto Nazionale di Ottica (INO) in Italy, to carry out the first systematic and detailed study of the in-vitro response of biological cells to radiation delivered by plasma-accelerated electron beams over femtosecond timescales in a single fractionation, resulting in unprecedented average dose-rates exceeding 10^{13} Gy/s. The student will join an interdisciplinary collaboration working at the forefront of radiobiology, at unprecedented durations (femtoseconds) and dose-rates (>10^{13} Gy/s). The student will design and carry out interdisciplinary experiments using laser-accelerated electron beams at the facilities provided by INO, QUB, and at the Central Laser Facility (CLF) in the UK. The collection of extensive experimental datasets of this kind will be pivotal in advancing our understanding of the micro-physics involved in radiobiological response, will enable benchmarking and improving Monte-Carlo radiation codes such as Geant4-DNA and TOPAS-nBio, and will provide the necessary platform to progress to future pre-clinical studies, including in-vivo irradiation.

Useful references

[1] G. E. Adams, Rad. En. Bio. 17, 95 (1980)

[2] P. J. Low et al, Nat. Comm. 13, 7300 (2022)

[3] T. Freeman Phys. World online resource: https://physicsworld.com/a/radiotherapy-innovation-optimize-the-physics-but-dont-ignore-the-biology/ (2021)

[4] K. Poder et al., Phys. Rev. Lett. 132, 195001 (2024)

[5] C. McAnespie et al., Arxiv:2409.01717 (2024)

[6] C. McAnespie et al., Int. J. Radiat. Oncol. Biol. Phys. 118, 1105 (2024)

[7] C. McAnespie et al., Phys. Rev. E 110, 035204 (2024)