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Background and Aims: Understanding the chemical phase is essential for interpreting the effects of radiation, particularly in the context of ultra-high dose rates. Oxygen depletion measurements provide a sensitive proxy for changes in radiochemistry, as oxygen consumption is directly linked to radical formation in aqueous solutions. The addition of radical scavengers such as sodium nitrate ($NaNO_3$, scavenging solvated electrons) and the variation of beam parameters enable more detailed insight into these processes.

Methods: Time-resolved measurements of oxygen partial pressure were performed using a FirestingPro OXR-UHS 430 sensor (PyroScience GmbH) in a cuvette containing (≈ 200 µl) of water with varying concentrations (0–1000 µM). Each sample was irradiated repeatedly with 20 Gy per irradiation in the entrance channel, and oxygen depletion was determined from the change in oxygen concentration during irradiation. Experiments were conducted using protons (48–221 MeV/u) and carbon ions (86–430 MeV/u). Conventional dose rates ranged from 0.06 to 2.36 Gy/s, while ultra-high dose rates (UHDR) reached 75–127 Gy/s.

Results: The results showed that oxygen depletion induced by both proton and carbon-ion irradiation decreased in the presence of and further declined with successive re-irradiations. This effect arises from the suppression of – reactions, which promotes formation and its subsequent reaction with radicals to regenerate, thereby reducing net oxygen depletion. Over 6 irradiations with protons, oxygen depletion changes from 0.089 to 0.053 %oxsat per Gy at a concentration of 250 µM, from 0.084 to 0.036 %oxsat per Gy at 1000 µM and decreases from 0.108 to 0.090 %oxsat per Gy in pure water. During carbon-ion irradiation, oxygen depletion stabilizes at ~0.045 %oxsat per Gy after the first irradiation at 3 different energies, indicating reduction of LET dependency by $NaNO_3$ and a delay in the mentioned oxygen regeneration.

Conclusions: Time-resolved oxygen monitoring combined with targeted radical scavenging provides an effective approach for characterizing radiochemical processes during irradiation. enables specific investigation of contributions within the radiochemical reaction network. The method is readily extendable to other scavengers, irradiation modalities, and chemical conditions, offering a flexible framework for systematic radiochemistry studies.

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E-POSTER VIEWING PHYSICS: NEW APPROACHES (E.G. ULTRA-HIGH DOSE RATE, SPATIALLY FRACTIONATED THERAPY) 10-06-2026 08:00 - 19:30

EP209 / #436

EXPERIMENTAL VALIDATION OF A CHERENKOV-BASED SUB-MICROSECOND BEAM MONITORING DEVICE FOR ULTRA-HIGH DOSE RATE ELECTRON BEAMS IN FLASH RADIOTHERAPY

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Background and Aims: FLASH Radiotherapy is a novel technique that delivers radiation using ultra-high dose rate (UHDR) beams. It has shown reduced side effects while maintaining tumour control. However, technological barriers remain before clinical implementation, including the lack of suitable beam monitoring, as ionization chambers saturate and lack sub-microsecond resolution. We present a solution based on the Cherenkov effect. Cherenkov emission is prompt and expected to be free from saturation. Our concept uses a thin in-beam Cherenkov radiator coupled to fast photodetectors. We expect to achieve sub-microsecond temporal resolution without saturation effects. In this contribution, we present the design and testing of a prototype beam monitoring device for UHDR electron beams inspired by this concept.

Methods: We select a fast photodetector for the prototype, the silicon photomultiplier (SiPM). The chosen models provide rise and fall times on the order of tens of nanoseconds. Glass is selected as the radiator material, as it enables Cherenkov emission in the clinical electron energy range. The SiPM is coupled to the radiator and read out with fast electronics. The system will be exposed to electron beams at different dose rates. Cross-calibration will be performed using reference detectors under conventional radiotherapy conditions, representing the first steps toward testing under FLASH beams.

Results: We expect to present the device's temporal resolution and an assessment of its dynamic range. The time response will be evaluated relative to a reference detector. We expect it to be in the sub-microsecond range due to the prompt Cherenkov emission, SiPM response time, and fast electronics. Additionally, the device will provide an integrated particle count per time interval, allowing the linearity of the response with dose to be assessed.

Conclusions: FLASH-RT is an emerging cancer treatment technique facing a roadblock due to the lack of suitable beam monitoring. We present the development and experimental testing of a prototype monitoring system intended for FLASH beam usage, designed to provide sub-microsecond temporal resolution. These results constitute the first step toward validation under FLASH conditions, a prerequisite for clinical implementation of the therapy.

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E-POSTER VIEWING PHYSICS: NEW APPROACHES (E.G. ULTRA-HIGH DOSE RATE, SPATIALLY FRACTIONATED THERAPY) 10-06-2026 08:00 - 19:30

EP210 / #783

WEIGHTING TRACK SUPERIMPOSITIONS IN ULTRAHIGH DOSE RATE EXPERIMENTS REPORTING A FLASH EFFECT: A COMBINED CHEMICAL TRACK STRUCTURE-STOCHASTIC ANALYSIS

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Background and Aims: Among the most investigated hypotheses for a radiobiological explanation of the FLASH effect in radiotherapy, intertrack recombination between chemical species produced by particle tracks arriving within a close spatiotemporal regime, associated with elevated dose rates, has been proposed as

a potential driver of damage quenching. The extent of such proximity is intrinsically determined by the temporal modulation of the beam, besides the radical diffusion. In this work, we introduce an analytical framework that expresses track spatiotemporal closeness directly from the beam structure, accounting for stochasticity to identify the proximity scales relevant for modeling and characterizing FLASH-relevant irradiation conditions.

Methods: Track arrivals are modeled as a spatiotemporal Poisson random measure, assuming statistical independence in time and spatial uniformity over the irradiated field, to account for the effect of stochastic fluctuations. The time-dependent intensity is constructed directly from irradiation parameters (dose, dose rate, LET, target density, and size) and extended to include explicitly pulsed delivery through periodic macro/micro-pulse structures. Closed-form expressions are derived for the expected number of tracks within a prescribed spacetime proximity window, using autocorrelation functions of the pulse structure.

Results: The proposed model provides explicit criteria linking beam temporal structure to track proximity statistics. Micro-pulse structure influences track coincidence only at times shorter than the micro-pulse period, while at longer times the behavior converges to that of the macro-pulse envelope. Similarly, macro-pulse effects vanish when observation times exceed the pulse repetition period, recovering the continuous-beam limit (Figure 1). The analytical predictions for population heterogeneous chemistry were coupled with multi-track simulations performed with an extended version of TRAX-CHEM to assess the impact of track coincidence on heterogeneous chemical stages (Figure 2). TRAX-CHEM simulations confirm that, under realistic UHDR conditions, intertrack interactions at the heterogeneous chemistry scale are generally negligible, becoming appreciable only for low-LET radiation combined with exceptionally high instantaneous dose rates.

Conclusions: This work establishes a quantitative framework connecting beam delivery parameters to multiscale track interaction probabilities. By identifying the temporal and spatial regimes where intertrack effects are relevant, the model provides practical guidance for simplifying or refining radiation damage simulations and clarifies the role of beam structure in UHDR scenarios.

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E-POSTER VIEWING PHYSICS: NEW APPROACHES (E.G. ULTRA-HIGH DOSE RATE, SPATIALLY FRACTIONATED THERAPY) 10-06-2026 08:00 - 19:30

EP211 / #706

A NEW COMBINED APPROACH FOR RADIOTHERAPY TREATMENT: PROTONS AND FAST NEUTRONS

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Background and Aims: Current radiotherapy regimens using proton beam treatment have become routine practice worldwide. Nevertheless, approaches to overcome radioresistance and improve treatment outcomes and quality of life remain under discussion. During the last decade, at A. Tsyb MRRC, Obninsk, Russia, more than 1,200 patients have undergone proton therapy, primarily for head and neck cancer. Additionally, another area of active research at our center is the application of fast neutron therapy using compact neutron generators suitable for installation in a standard therapeutic room. We are currently initiating a novel project to explore the potential of combining highly precise proton treatment with highly effective fast neutrons and to investigate this approach as a human radiotherapy modality.

Methods: The "Prometheus" proton therapy facility (AO "Protom", Protvino) will be used as the proton treatment source. The novel NG-24 facility (N.L. Dukhov VNIIA, Moscow), producing 14.8 MeV neutrons with collimator-based shielding, will be investigated as the neutron source. Both facilities are already installed and operational at A. Tsyb MRRC, Obninsk, and are maintained by qualified staff. Both facilities are equipped with in-house treatment planning systems supporting Monte Carlo engines and graphics processing unit acceleration for computationally intensive operations. An interference radiobiological model for both modalities is currently under active development.

Results: The clinical trial protocol is currently under review by the institutional Ethics Committee. The anticipated trial initiation is mid-2026, with a one-year follow-up period. The expected enrollment is 20 patients. The primary endpoint is the frequency and severity of early and late adverse reactions; the secondary endpoint is the incidence of in-field local recurrences.

Conclusions: Conventional radiation techniques have nearly reached their limits, while the primary interest of the radiotherapy community remains strongly focused on novel approaches that may ultimately allow an increase in tumor response rates while improving safety. In this context, the proposed combined contribution of precisely targeted protons and non-homogeneous but highly effective fast neutrons may result in notable progress in the treatment of oncological diseases. Overall, this can drive a new era of a multimodal particle therapy treatment.

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EP212 / #261

ROBUSTNESS OF LET-OPTIMIZED MULTI-ION THERAPY FOR BONE AND SOFT TISSUE SARCOMAS

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Background and Aims: Multi-ion radiotherapy with carbon, oxygen and neon ions aims to improve treatment results by increasing dose-averaged linear energy transfer (LETd) in the target. First clinical trial of multi-ion radiotherapy for bone and soft tissue sarcoma (BSTS) is being conducted at National Institutes for Quantum Science and Technology. We evaluated the robustness of multi-ion therapy against setup and range errors for BSTS.

Methods: Numerical phantoms were created using in-house treatment planning software to simulate the patient's body (Fig. 1).