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JOINT AAPM | COMP MEETING

Impact of Pre-irradiation on Quenching in Optical Fibres: Proton Therapy Dosimetry

Francesca Sogus[1,2]; S. Usherovich[1]; F. Fricano[3]; S. Girard[3]; G. Dehnel[1,2]; C. Bélanger-Champagne[1], C. Hoehr[1,2]
[1]TRIUMF (Vancouver), [2]The University of British Columbia (Kelowna), [3]Laboratoire H. Curien (Saint-Étienne, France).

ABSTRACT

Scintillating optical fibre dosimeters offer high spatial resolution for proton therapy dosimetry but suffer from quenching in high-LET regions, reducing their response at the Bragg peak and necessitating repeated calibrations.

This work investigates X-ray pre-irradiation as a strategy to mitigate quenching in CeTb-doped optical fibres. Two sets of fibres were pre-irradiated to accumulated doses between 0 and 1.7 MGy and characterized in a 74 MeV proton beam at the TRIUMF Proton Therapy Research Centre, using the Bragg peak-to-plateau ratio as a quenching indicator.

The peak-to-plateau ratio increased with pre-irradiation dose, from ~2.8 (pristine) to a maximum of 3.44, following an exponential saturation behaviour. Compared to the reference ratio of 3.7 obtained with an ionization chamber (Markus chamber), quenching was reduced but not fully eliminated.

The saturation of the conditioned response suggests that a stable, reproducible calibration is attainable with pre-irradiated fibres.

Alternative dopants or longer doped sections may enable complete quenching removal, opening the path toward a linear, LET-independent calibration for fibre-based proton dosimetry.

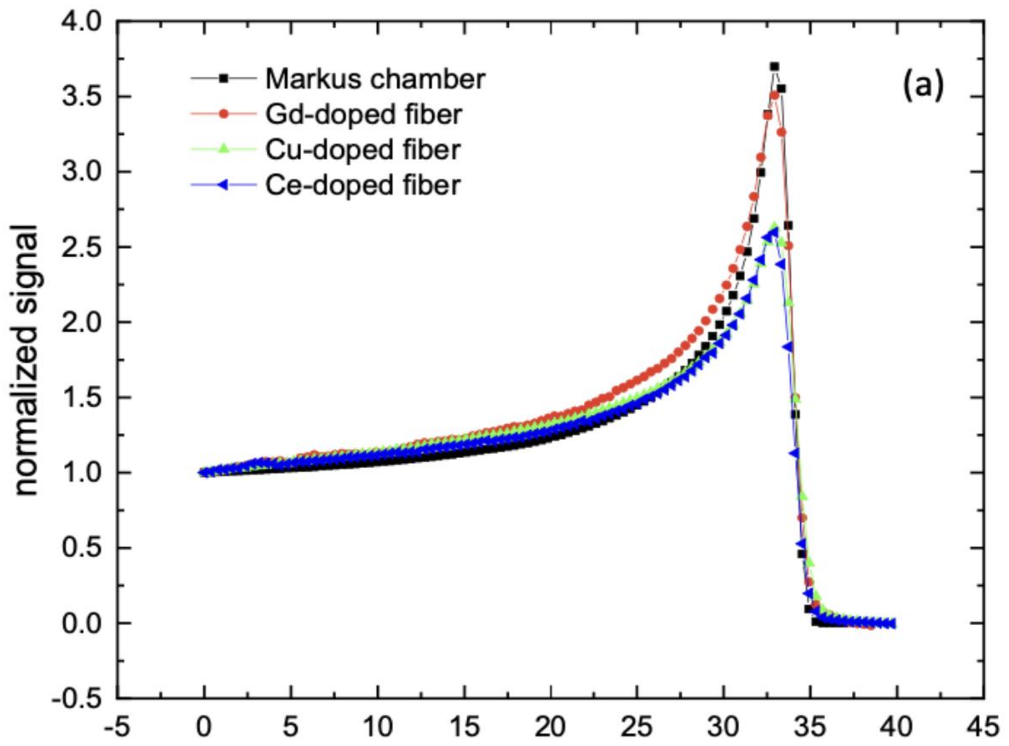
CONTACT

Francesca Sogus, MSc
TRIUMF
4004 Wesbrook Village, Vancouver, Canada
fsogus@triumf.ca
fsogus@student.ubc.ca

Cornelia Hoehr, PhD
TRIUMF
4004 Wesbrook Village, Vancouver, Canada
choehr@triumf.ca

INTRODUCTION

Proton therapy is a powerful cancer treatment modality that delivers highly localized radiation doses while sparing surrounding healthy tissues, thanks to the characteristic Bragg peak in the proton depth-dose profile. A variety of detectors are used in proton dosimetry, each with specific advantages and limitations. Scintillating optical fibres detect ionizing radiation through Radiation Induced Luminescence (RIL): incident protons excite charges that recombine at intrinsic or dopant sites, emitting visible light, proportionally to the absorbed dose. Optical fibres offer high spatial resolution, but are affected by quenching in high LET regions, i.e. the Bragg peak.[2]



Objective: Pre-irradiation of doped optical fibres induces new luminescence centres and other radiation-induced defects, which can reduce quenching by saturating non-radiative recombination sites, while opening new luminescence ones[1]. The goal of this work was to assess how different pre-irradiation levels affect the Bragg peak response of inorganic doped optical fibres, using the peak-to-plateau ratio as a quenching indicator.

METHODS AND MATERIALS

Samples: sets of CeTb-doped optical fibres, pre-irradiated to 0, 50, 250, 400 kGy and 1 MGy (set A), 0, 50, 260, 370 kGy and 1.7 MGy (set B).

Beam: 74 MeV, 8 nA proton beam (Proton Therapy Research Centre, TRIUMF)

Setup:

- Fibres in water phantom, aligned at isocentre;
- 3D motorized stage for positioning;
- Signal: transport fibre, photodetector (MPPC).

Ten CeTb-doped fibres were tested. After centering (x*, y*, z=0), each fibre was scanned continuously along the z-axis, from 0 to 43 mm, recording Bragg peak signals with 100 ms gate time.

Analysis:

- Background subtraction (20 s);
- Current normalization and entrance plateau normalization;
- Three runs were aligned using peak position, and averaged;
- Quenching metrics: peak-to-plateau ratios from averaged runs.

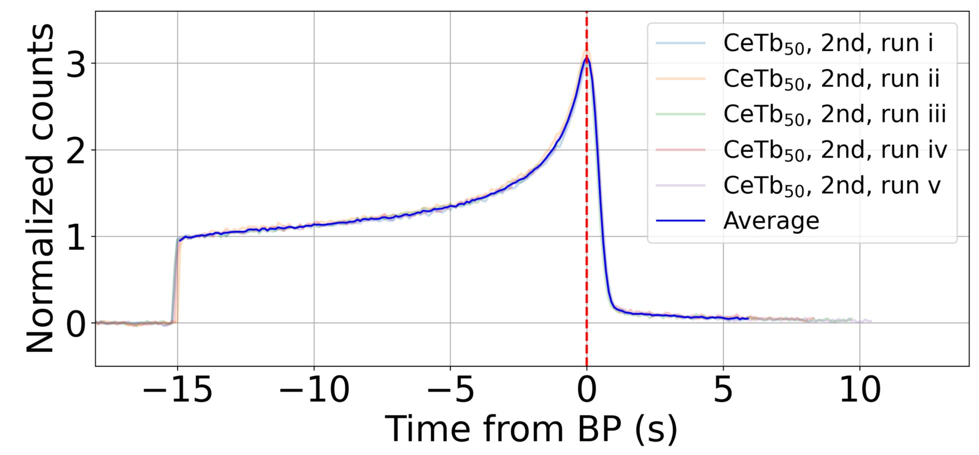
RESULTS

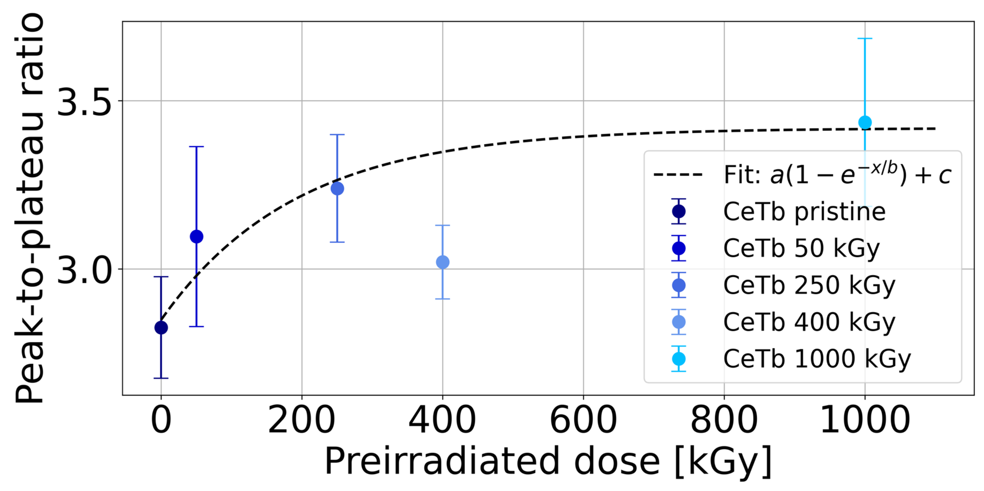
An exponential saturation model was fitted to the dose vs peak-to-plateau ratios data:

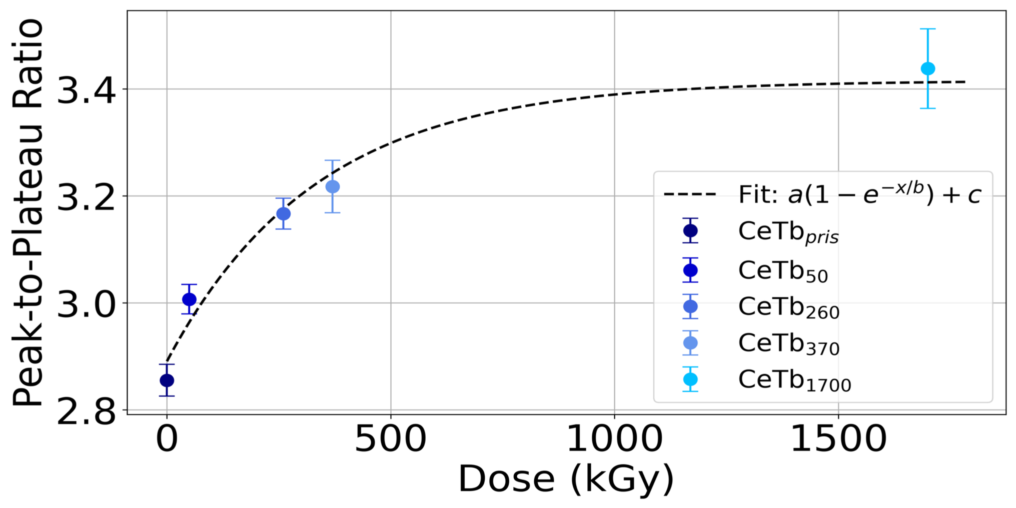
$$y = a\left(1 - e^{-\frac{x}{b}}\right) + c$$

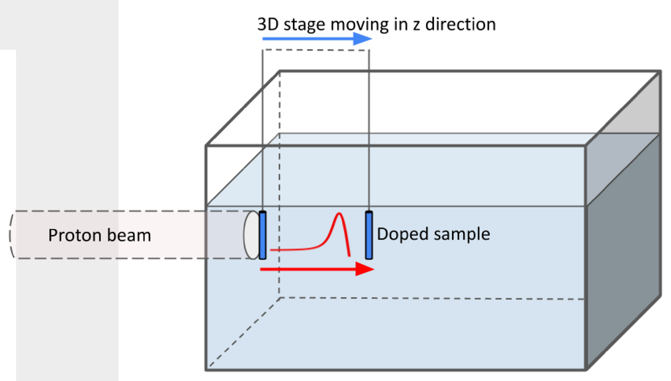
The peak for set A increased from 2.83 (pristine) to 3.4 (1 MGy), for set B from 2.86 (pristine) to 3.44 (1.7 MGy).

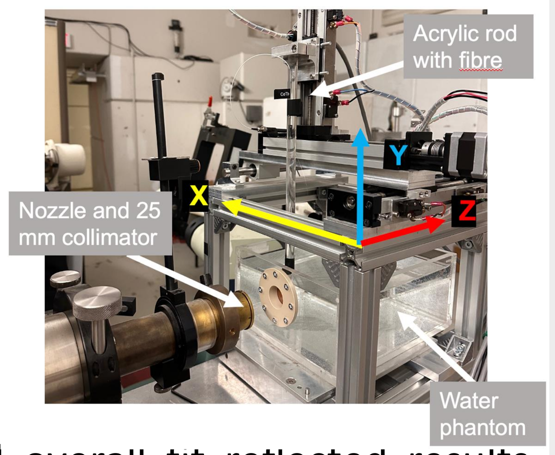
$a_A = (0.6 \pm 0.3)$	$b_A = (190 \pm 240)\ kGy$	$c_A = (2.84 \pm 0.14)$
$a_B = (0.52 \pm 0.08)$	$b_B = (330 \pm 90)\ kGy$	$c_B = (2.89 \pm 0.02)$







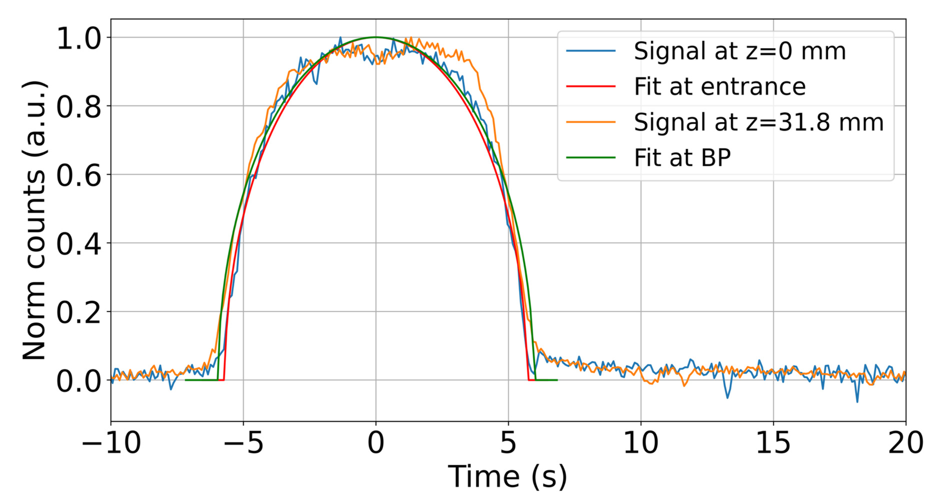




Results were combined and overall fit reflected results from Set B.

$a = 0.53 \pm 0.08$	$b = 330 \pm 90$ kGy	$c = 2.89 \pm 0.02$

Vertical and horizonal beam profiles were analyzed, confirming good symmetry and beam divergence estimate of (1.1 ± 0.3)°.



DISCUSSION

- Quenching arises when the local ionization density in high-LET regions exceeds the radiative capacity of the available luminescence centres, such that a fraction of the deposited energy is dissipated through non-radiative channels rather than emitted as scintillation light;[3]
- X-ray pre-irradiation generates additional radiation-induced luminescence centres, increasing the trap density of the fibre. With more centres available, a larger fraction of the deposited energy can be converted radiatively before the onset of quenching; the ionization density at which the luminescent response saturates is shifted upward, and the under-response at the Bragg peak is reduced;
- In both datasets, the peak-to-plateau ratio increases with accumulated pre-irradiation dose, reaching a maximum of 3.44 (compared to ~2.8 for the pristine fibre);
- A reference Bragg peak measured with a Markus chamber yields a peak-to-plateau ratio of 3.7, indicating that quenching was not fully eliminated;
- This shortfall may be attributable to the limited length of the doped section (1 cm); previous studies have reported full recovery of the 3.7 ratio with longer samples (2 cm);[1]
- Nonetheless, the existence of a stable plateau in the conditioned response implies that a robust, reproducible calibration is attainable, and that deliberate pre-irradiation constitutes a viable conditioning strategy. Even in this regime, however, the calibration remains non-linear and dependent on LET and particle energy, since residual quenching persists.

CONCLUSIONS

- The experimental results support the hypothesis that pre-irradiation reduces quenching, increasing the peak-to-plateau ratios in CeTb-doped optical fibres;
- Because of quenching, repeated energy and dose calibrations are required under proton irradiation, while a stable quenching response would instead permit a robust calibration, requiring only periodic verification;
- Alternative dopants (Gd, N, Ce) or a longer doped length (>1 cm) could raise the peak-to-plateau ratio toward the maximum (~3.7), effectively eliminating quenching. This could lead to a linear, LET-independent calibration;
- Future work could involve the study of SOBP responses and the FLASH effect, as well as a quantification of RIA-induced loss of SNR[4].

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