Evaluating the use of Silica and PMMA Optical Fibres as Proton Beam Monitors

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Abstract. Recent reports have shown both poly (methyl methacrylate) (PMMA) and silica optical fibres to be ionization quenching free, making them possibly very useful dosimeters for proton beams. In this study, the response from PMMA and silica optical fibres to therapeutic proton beams are evaluated. The light output was recorded from both optical fibres, exposed to varying dose-rates of 0.5 Gy/min to 20 Gy/min from a 235 MeV isochronous cyclotron. The PMMA optical fibre was observed to have a linear dose-rate response, and a constant light emission for a constant dose-rate exposure. However, in the case of the silica optical fibres, the light output was observed to increase during a constant dose-rate exposure. If uncorrected, this accumulated dose sensitivity observed in the silica optical fibres can result in erroneous measurements.

1. Introduction
Bare optical fibre dosimeters have recently been shown to be advantageous in proton therapy dosimetry [1]. These dosimeters are small, real-time, affordable and easily available. A major potential of these dosimeters is that the light output from the bare optical fibres has been reported to be ionization quenching free [1]. Ionization quenching is where signal degradation is observed in the Bragg peak. Uncorrected, ionisation quenching can lead to a reduced estimate of the dose in the Bragg peak.

Recently, significant changes to the emission spectrum and continuous increase in response for poly (methyl methacrylate) (PMMA) and silica optical fibres under constant dose-rate exposures, has been reported in proton beams of 16.5 MeV [2]. Similar spectral changes and an increasing response have been previously reported for silica optical fibres, but were considered to be a linear energy transfer (LET) dependence [1, 3, 4]. In this study, the dose-rate response from PMMA and silica optical fibres to proton beams of therapeutic energies are evaluated.

2. Materials and methods
A 400 \textmu m core diameter silica optical fibre (FVP400440480, Polymicro technologies, Molex, U.S.A.) and a 500 \textmu m core diameter PMMA optical fibre (SH2001, Mitsubishi Rayon Co. LTD., Tokyo, Japan) were placed at 12 cm depth in solid water. The light emitted from the optical fibres was measured using a Hamamatsu H7360-01 photon counting head (Hamamatsu, Japan). The counters
from a data acquisition card (DAQ), USB-6341 (National Instruments Inc., USA), with a time base of up to 100 MHz, was used to read the photon counter head. A customised LabVIEW™ (National Instruments Inc., USA) program was developed to interface with the USB-DAQ. The counts from the photon counting head were recorded at a sampling rate of 10 Hz. Figure 1 shows the experimental setup described.

A passive-scattering proton beam of range 14 cm (energy of 140 MeV), modulation 4 cm with a 12 cm snout was used from a 235 MeV isochronous cyclotron (Ion Beam Applications, Belgium). The dose was varied from 0.5 Gy/min to 20 Gy/min and the response of the optical fibres was evaluated.

Figure 1. Schematic of the optical fibre dosimeter setup and the experimental design.

3. Results

Figure 2 shows the response of the PMMA optical fibres as it is exposed to various dose-rates. It can be observed in figure 2a that there is an increase in light emission for increasing dose-rates. Figure 2b shows the raw signal divided by the exposed dose-rate, it can be seen that the light collected is constant under a constant exposed dose-rate, and that the signal is proportional to the exposed dose-rate. Therefore the response of the PMMA optical fibre is observed to be linear to dose-rate, as shown in Figure 2c.

Figure 3 shows the response of the Silica optical fibres as it is exposed to various dose-rates. It can be observed in figure 3a that there is an increase in light emission for increasing dose-rates and that the silica optical fibre has a more intense light emission compared to the PMMA optical fibre. Figure 3b shows the raw signal divided by the exposed dose-rate, it can be seen that the signal is somewhat proportional to the exposed dose-rate. However, the signal is not constant for a constant dose-rate and the response was observed to be sensitive to the accumulated dose in the optical fibre.
That is, that the light emitted increased as the exposure continued. This was observed at all dose-rates, however its significance increases at higher dose-rates. This dose sensitivity makes the use of silica optical fibres as proton beam monitors difficult without corrections. Figure 3c shows the effect of the dose sensitivity and how it affects the dose-rate response curve. It can be seen that, depending on

**Figure 2.** The response of the PMMA optical fibre to proton beams of varying dose-rates. a) shows the raw light collected by the photon counting head, b) shows the raw signal divided by the exposed dose-rate and c) shows the mean count rate measured with a linear curve fit.

**Figure 3.** The response of the silica optical fibre to proton beams of varying dose-rates. a) shows the raw light collected by the photon counting head, b) shows the raw signal divided by the exposed dose-rate and c) shows the mean count rate measured at 5 second intervals with a linear curve fit to the first 5 second interval.
when the count rate reading is performed from the silica optical fibre, a significantly different mean count rate will be obtained.

4. Conclusion
The results presented here show that the light emitted from silica optical fibres is accumulated-dose sensitive and hence increases as their exposure continues. This increase in light emission from silica optical fibres has been reported previously, however it was thought to be an LET dependence. If uncorrected, this will result in erroneous dose-rate measurements from silica optical fibres.

PMMA optical fibres, however, did not show this dose dependence and had a linear dose-rate response. While PMMA optical fibres are less sensitive than silica optical fibres, they may make superior proton beam dosimeters. Future work is needed to investigate the origin of the increasing light emission for the silica optical fibres.

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6. References
[1] Darafsheh A et al. 2018 SPIE BiOS 10478 7
[2] Asp J et al 2019 Physica Medica 65 15-20
[3] Darafsheh A et al 2017 Optics Letters 42 847-50
[4] Darafsheh A et al 2017 SPIE BiOS 10058 4