

Investigation of a Scintillating Fibre Detector

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Abstract

The aim of the investigation was to test the scintillation light intensity outputted from individual fibres of a scintillating fibre detector to test its effectiveness as a ion beam dosimeter. An ideal detector has uniform intensity for all fibres. The fibres were individually illuminated using a UV point source, and the scintillation light captured using a CCD camera. After analysis, a non-uniform intensity output was determined. From this, it was decided to further investigate the factors driving the non-uniform intensity output using a light microscope. Microscope images were taken of the fibre ends to assess damage and imperfections. Clear damage was visible for all fibres and statistical analysis was performed to quantitatively determine the relationship between damage and intensity. The Pearson correlation test resulted in a correlation coefficient of $r = 0.6327$, with a statistically significant hypothesis test ($p = 0.00275$) emphasising a relationship between intensity and damage. These results give evidence that the greater the damage to the fibres, the lower the intensity of the scintillation light that the fibres emit after exposure to the UV source. Finally, improvements in the manufacturing process were suggested to the LhARA team and Prof. K. Long, suggesting a diamond cutter and improved clamping method to reduce damage.

1 Method

The initial aim was to investigate variations in intensity emitted by each fibre by illuminating them individually. To illuminate each fibre, a UV LED was used. A 3D printed cap was used to ensure a point source. The cap had an aperture diameter of 1mm and was duct-taped onto the LED so that little to no light escaped. The UV LED was positioned close to each fibre, roughly 5mm, to reduce diffraction of the UV. Practically this was a difficult distance to measure due to the shape of the 3D printed frame and the measuring equipment available. Furthermore, the 3D printed frame isn't fully symmetrical so this separation was not kept completely consistent however was not expected to significantly impact the intensity of UV absorbed by each fibre. This could be further improved by using measuring equipment with a higher resolution - that is not so dependent on the human eye- to keep the distance between the source and the fibre constant as this difference contributed (however small) to the discrepancy in intensity. To measure the intensity output of each fibre, pictures of the end of the fibres were taken using a CCD camera in a dark box and analysed using python to calculate relative intensities. The focal length of CCD camera is 50.8mm, and was placed 54.0mm from the fibre ends. Since the components were screwed into the optical board, human error of bumping or moving the stands slightly was reduced and the distance between the camera and the fibre ends stayed fairly consistent throughout. However, due to removing and replacing the detector from its clamp, there is likely some variation (around 1mm) in this distance. The fibre was illuminated at the far end to assume a "worst case scenario" since the intensity of light reduces as the scintillation

light refracts through the fibre. And images capturing the scintillation light were taken at the fibre edge at the close end. Initially the voltage was set to 3.560V based on prior experimental work, however this was too high and caused the image to be oversaturated; therefore, it was lowered to 3.480V. It was also ensured that all the auto-brightness and auto-saturation settings on the CCD camera were off to ensure repeatability. From this we observed that the fibres did not output uniform intensities so our next steps were to investigate the cause. We looked at the fibres underneath a microscope and took images of each fibre edge. We then analysed these images to find the percentage area obscured in order to quantify the damage. We also took images along the length of the fibre looking at the "gluey" ends and took more data illuminating along different points along the length of the fibre. We chose a 1st fibre and 1st side on the detector which is the basis for all the data labels. Measurements were taken by illuminating fibres 1-10 with the LED shining on 'side 1' and then flipping the detector on its vertical axis and illuminating fibres 10-1 with the LED shining on 'side 2'.

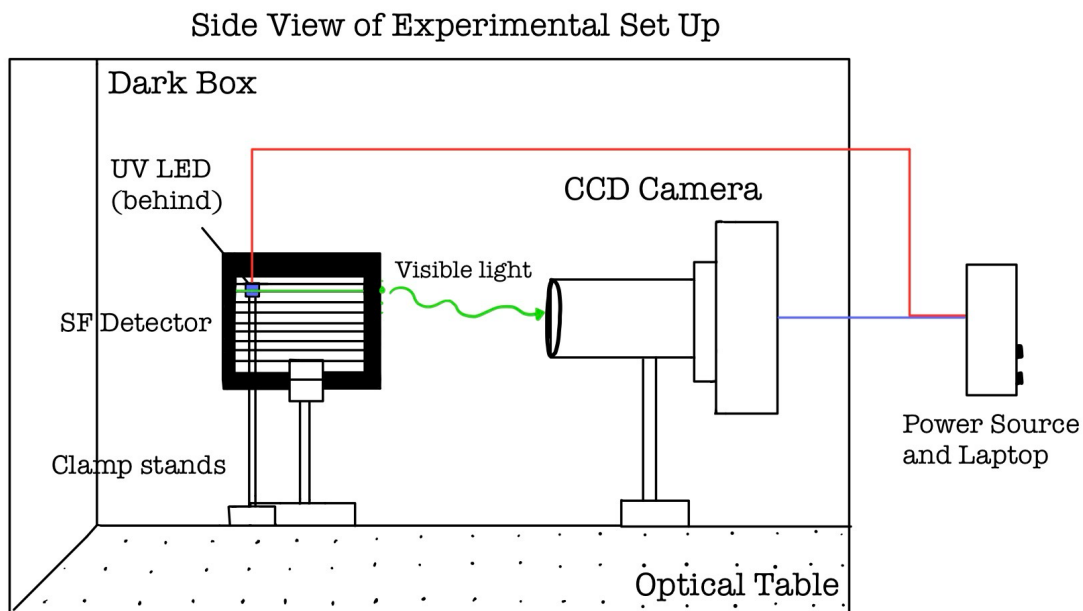
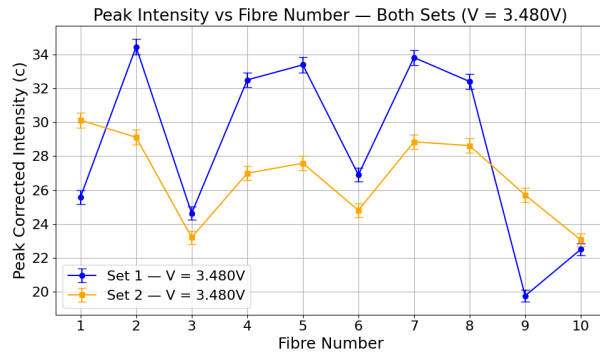


Diagram of the experimental set up. A CCD camera is directed at the ends of the fibres to capture the scintillation light. The images are saved and analysed using python. Image drawn by Isabella Matson, April 2026

2 Results and Discussion

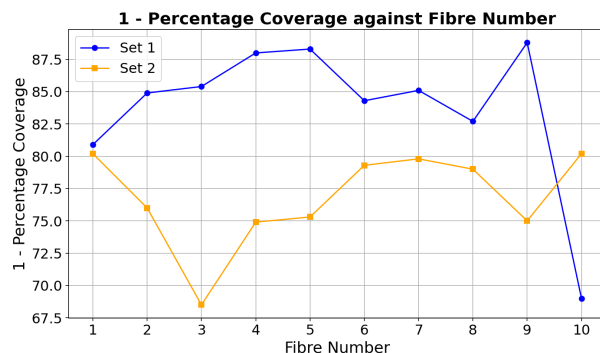
Investigating each fibre individually and plotting intensity against fibre number gave the following graph:



This graphs shows intensity emitted by each scintillating fibre plotted against fibre number. The graph was plotted in Python using Matplotlib with errorbars plotted using `plt.errorbar`. Blue shows the first side of the detector and yellow shows the second side.

This graph clearly shows that the fibres do not emit a uniform intensity, even when illuminated with the same intensity, as expected. Consequently, further investigation was needed.

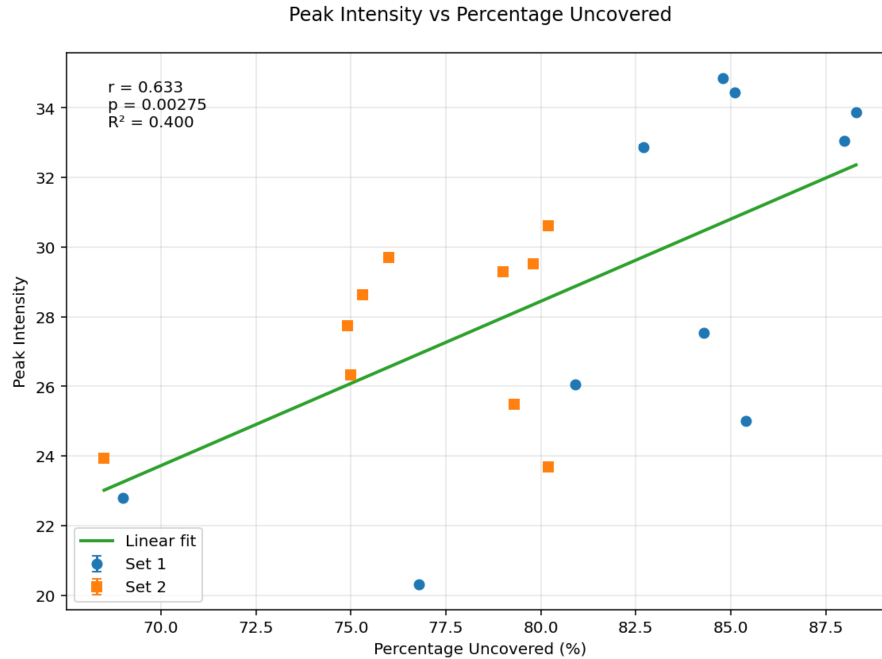
Looking at the fibre ends under a microscope and analysing the coverage/ damage gave the following results:



This graph shows the percentage of the end of the fibre that is covered plotted against fibre number. Blue shows the first side of the detector, and yellow shows the second side of the detector.

This graphs shows that the fibres do not have uniform coverage (zero coverage) as expected. The analysis of these microscope images was done using Python, which set an intensity threshold of what was considered covered and uncovered. However, the images had to be taken using a phone imaging the computer screen, due to the limitations of the microscope. Consequently, the threshold had to be changed for each image to account for glare and the auto brightness of the phone camera. This resulted in the anlysis of the coverage being subjective. In order to improve these results a better microscope could be used.

Plotting the correlation graph between Fig. 2 and Fig. 3, gives the following results:



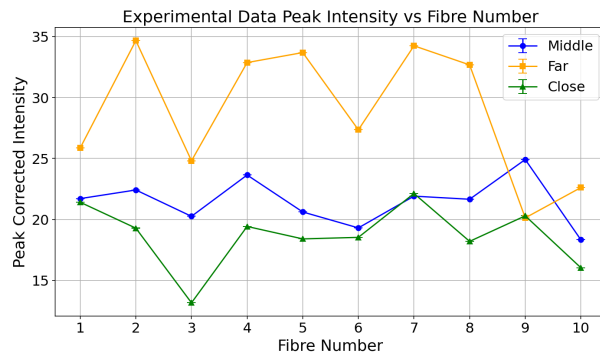
Graph of intensity of scintillation light against percentage area obscured. A positive correlation is visible and is further evidenced through statistical analysis.

Through statistical analysis of this graph and data, it was determined that there is a strong, statistically significant relationship between intensity and percentage of the circle unobscured with a correlation coefficient of 0.6327 and a p-value of 0.00275. This means that we can reject the null hypothesis that there is no relationship between intensity of scintillation light and percentage of the fibre ends obscured (indicative of damage). At a 95% confidence level, the correlation coefficient is in the range

$$[0.2642, 0.8400]$$

. This shows that the area obscured of the ends of the fibre directly impacts intensity. These obscurities are likely from the plastic case warping around the fibres due to heat and clamping. Hence perhaps the obscurity is indicative of damage to the fibre itself which may be the cause of the change in intensity. In other words, these results give evidence that the greater the damage of the fibre, the less intense the scintillation light emitted.

We also illuminated each fibre at different points along its length to give the following results:



Graph of peak intensity vs fibre number for different illumination points along the fibre.

We were unable to quantify these results any further, though the graph appears to show a correlation between where the fibre is illuminated and the intensity emitted. Alongside this we took microscope images along the fibres, these images showed significant damage along some of the fibres, in particular at the ends where the fibre had been glued to the frame. However, we were unable to quantify any of this damage.

Images are shown below of the end, and length of a fibre, to show the kind of damage we saw.

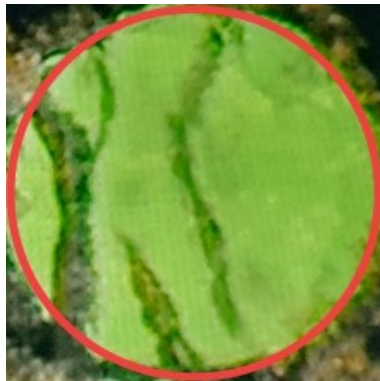


Image of the fibre ends under a microscope. Clear damage is visible. The damage is quantified by determining the area of the circle obscured by cracks and plastic casing using python.



Image of the long length of the fibre. Image shows the end of the length where the fibres had been fitted into the casing.

3 Conclusion

The aim of this project was to determine whether the scintillating fibres across this detector emitted uniform intensity. It was determined that this was not the case, and further investigations were conducted through microscope imaging. It was found that there was significant damage to the ends of the fibres. This was both due to the gluing process: further sanding of the sides of the fibre and a different sanding technique may help resolve this issue, and the make of the frame: where the frame had been joined at the corners some warping had occurred causing damage to the fibre ends and changing their shape. Microscope images of the fibre lengths were taken, showing significant damage and distortion to some of the fibres, however this could not be quantified. Looking into this further may help determine why the fibres were not illuminating a uniform intensity.

Through statistical analysis using python, it was determined - with a strong confidence level - that there was a strong positive correlation, with a pearson correlation coefficient of 0.6327, between intensity of the scintillation light and damage of the fibres. These results suggest that the scintillating fibre detector needs modifications so that variations in intensity output are predictable and repeatable and not due to internal and external fibre damage. The suggested changes hope to improve the detector to achieve this in order to be an effective dosimeter for ion beam therapy.

4 Acknowledgements

We acknowledge the use of AI - ChatGPT, Claude and Google Gemini - to assist coding the plots and graphs.

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