Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Radiation Damage and Recovery Mechanisms in Scintillating Fibers

To cite this article: J Wetzel *et al* 2022 *J. Phys.: Conf. Ser.* **2374** 012121

Journal of Physics: Conference Series **2374** (2022) 012121 doi:10.1088/1742-6596/2374/1/012121

Radiation Damage and Recovery Mechanisms in Scintillating Fibers

J Wetzel[1,2], Y Onel[1], B Bilki[1,3], N Bostan[1], O Koseyan[1], E Tiras[1,4] and D Winn[5]

[1]The University of Iowa, Iowa City, IA, USA
[2]Augustana College, Rock Island, IL, USA
[3] Beykent University, Istanbul, Turkey
[4] Erciyes University, Kayseri, Turkey
[5] Fairfield University, Fairfield, CT, USA

E-mail: james-wetzel@uiowa.edu

Abstract. Optical scintillating bers lose their transparencies when exposed to radiation. Nearly all studies of radiation damage to optical bers so far only characterize this darkening with a single period of irradiation. Following the irradiation, bers undergo room temperature annealing, and regain some of their transparencies. We tested the irradiation-recovery characteristics of scintillating fibers in four consecutive cycles. In addition, three optical scintillating bers were irradiated at 22 Gy per minute for over 15 hours, and their transmittance were measured each minute by pulsing a light source through the bers. Here, we report on the in-situ characterization of the transmittance vs radiation exposure, allowing future applications to better predict the lifetime of the scintillating bers.

1. Introduction

Particle physics experiments of the near future have unprecedented needs for radiation tolerant components. Particle detectors broadly use scintillators to generate optical signals in proportion to the energy of passing particles. Radiation damages a scintillator, producing color centers which absorb and attenuate light within the scintillator, reducing its performance. Currently, there is a major effort underway to develop new radiation tolerant scintillators and readout strategies for modern experiments.

One strategy is to take advantage of the natural recovery of a moderately damaged scintillator. We investigate whether being exposed to bright light can enhance the recovery of various scintillators.

Our previous results indicated that UV-LED exposure (365 nm) is the most effective and efficient way to induce optical recovery of the scitillators from radiation damage. White-light exposure only helps the recovery in the green-infrared region of the electromagnetic spectrum whereas UV light exposure induced recovery in the entirety of the spectrum. We also find that UV-A light (365 nm) is effective at speeding up the recovery of plastic scintillating fibers [1, 2].

UV-LED mediated recovery techniques are a possible solution to speed up radiation damage recovery in detectors. A UV-LED calibration system inside a detector could be turned on between experiment data taking runs in order to help the scintillating materials recover their

Journal of Physics: Conference Series **2374** (2022) 012121 doi:10.1088/1742-6596/2374/1/012121

optical properties and, at the same time, allow the detector to calibrate itself, extending the useful life of existing scintillators.

For the case of scintillating fibers on the other hand, LED stimulated recovery might not be feasible to implement in large-scale collider detectors. In order to investigate the effect of natural recovery in a dark environment, we irradiated different kinds of optical fibers in successive campaigns and monitored the recovery process for an extended period of time.

In addition, we performed an in-situ measurement of radiation damage in the optical fibers and obtained the dynamic maps of the radiation damage in the spectral region of 400 nm 800 nm.

Here, we report on the in-situ characterization of the optical transmittance vs. radiation exposure, and the recovery from radiation damage in successive irradiations for scintilating/wavelength shifting fibers, allowing future applications to better predict the lifetime of their active media.

2. Irradiation Facility And Experimental Setup

The optical fiber samples were irradiated by using 6000 Ci ^{137}Cs Gamma source at the University of Iowa RadCore Facility. Figure 1 shows a picture of the irradiation hall. We used two acrylic tables that are 8 cm and 18 cm away from the radioactive source and the dose rate and integrated dose can be calculated and simulated accurately. Figure 2 shows the Fluka [3] simulations of the gamma source and the sample holders.

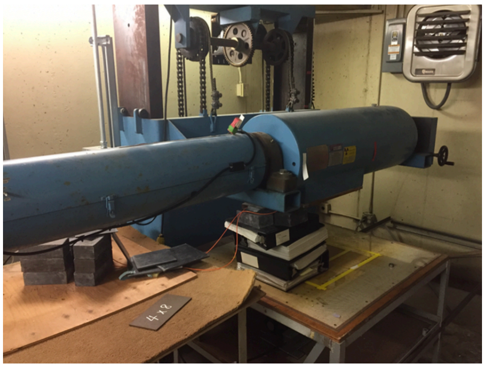

Figure 1. Picture of the irradiation hall at the University of Iowa RadCore Facility.

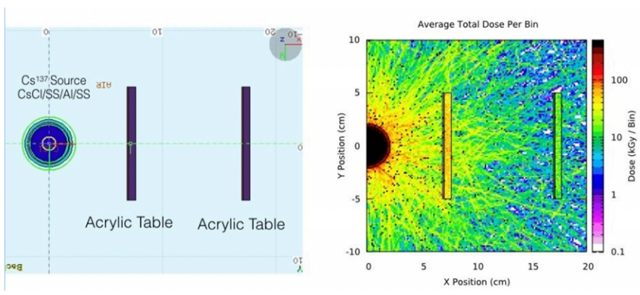

Figure 2. The displays from the Fluka simulation of the radioactive source and the sample holders.

The samples were prepared and characterized at the High Energy Physics Laboratory of the University of Iowa before and after the irradiation. The equipment used can be summarized as:

- Dark boxes: Light-tight enclosures with cable feedthroughs.
- Xenon light source: A fiber-coupled, broad spectrum light source used in transmission tests.
- OceanOptics two channel spectrometer: For the measurement of spectral response between 400 nm and 800 nm.

3. In-Situ Measurement of Radiation Damage In Optical Fibers

We used three different optical fibers for both the in-situ measurement of radiation damage and the successive irradiation and recovery tests. Emission of these fibers were centered in blue, green and orange regions of the visible spectrum. The dose rate for the irradiations was kept constant at 22 Gy/min. Figure 3 shows the transmission spectra of the blue fiber as a function of irradiation duration. The majority of the damage is in the blue region and it manifests itself within minutes of irradiation. The damage in the red-infrared region remains above 50% for the entire duration of the irradiation and it is dramatic below 520 nm. It is also observed that the transmission peak at 480 nm disappears and a new peak at 540 nm emerges. However, the blue-end of this peak gets damaged quite fast to yield less than 5% transmission after approximately 10 hours of irradiation. There are also spectral regions with slightly less pronounced damage compared to their spectral neighborhood, around 600 nm and 650 nm.

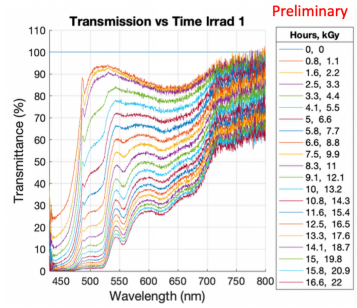

Figure 3. The transmission spectra of the blue fiber as a function of irradiation duration.

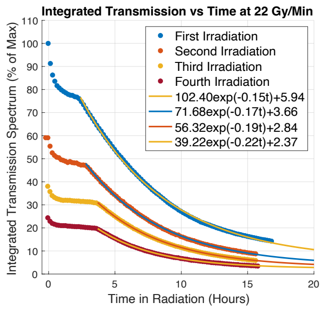

Figure 4. The integrated transmission vs. time for the four consecutive irradiation campaigns for the blue fiber.

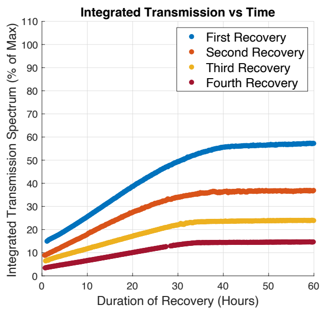

Figure 5. The transmission spectra integrals as a function of duration of recovery for the blue fiber.

The transmission spectra were then integrated for the spectral region of 400 nm to 800 nm, and the trend of this integral was monitored in-situ. Figure 4 shows the integrated transmission vs. time for the four consecutive irradiation campaigns for the blue fiber. After approximately four hours of irradiation which corresponds to approximately 5 kGy, the integrals can be fit to the sum of an exponential and a constant. As expected, the initial and final damages are higher for successive irradiations. The time constants for the damage are between 4.5 hr to 6.7 hr, decreasing with successive irradiations. Therefore, the radiation damage is faster for the previously damaged fibers. The fibers were also monitored for natural recovery in dark boxes (see next section). Therefore the initial damage of consecutive irradiations is much higher that the final damage of the previous campaign.

4. Recovery from Radiation Damage In Optical Fibers

The same set of three fibers were also investigated for their recovery properties from radiation damage. Figure 6 shows the absolute transmission spectra of blue (left), green (middle) and orange (right) fibers as a function of time following the first irradiation campaign. The blue fiber exhibits the largest amount of recovery from radiation damage reaching 95% of its initial peak intensity, but the peak is displaced from 540 nm to 618 nm. The amount of recovery in the green fiber is dramatically high compared to the other fibers. The orange fiber recovers approximately 85% of the radiation damage.

In total four irradiation campaigns were performed. Figure 5 shows the transmission spectra integrals as a function of duration of recovery for the blue fiber. The fiber recovers to 58%, 38%, 24% and 15% after the first, second, third and fourth irradiation campaigns respectively.

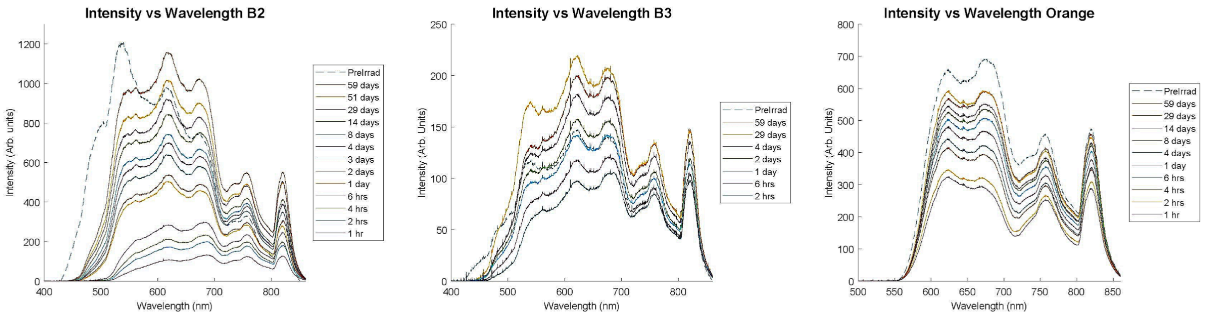

Figure 6. The absolute transmission spectra of blue (left), green (middle) and orange (right) fibers as a function of time after the first irradiation campaign.

5. Development of Radiation-Hard Wavelength Shifting Fibers

We already validated the coating of quartz fibers with pTp with in-house methods. We have also identified ZnO:Ga (1-4%) [4] and CeBr3 [5] as outstanding scintillators for radiation-hard wavelength shifting fiber applications.

We also probed the technique of filling quartz capillaries with soft WLS materials. We produced quartz capillaries with anthracene and tested a bunch of 7 fibers in the 80 GeV electron beam yielding 8-9 photoelectrons. The results obtained with capillaries filled with 3HF [6] indicate that future implementations should employ larger size capillaries.

Recently, we used a Pt- cured silicon capillary (2.3 mm outer diameter, 1 mm inner diameter) in place of the quartz capillaries, and a silicon gel conveying 3HF as the WLS core. The WLS fiber was placed through the center hole of three 2.5 cm 2.5 cm 5 mm blue scintillator tiles. The fiber was parallel to the beam and was coupled to a silicon photomultiplier (SiPM) at the downstream side. Using the wire chamber profiles, the muons passing through the tiles and 1 mm away from the SiPM/fiber were selected and the response to 150 GeV muons was measured. Figure 7 shows the charge distribution. The distribution is fit to Gaussian + Landau. The mean for the Gaussian and the most probable value for the Landau functions are constrained to be identical, denoted as in Figure 7. The mean response to MIPs corresponds to approximately 20 photons.

Figure 8 shows the picture of two different capillaries coupled to a square scintillator and the free parts illuminated with a UV light. Both capillaries have silicone gel doped with 3HF as the core material. The larger diameter fiber is a silicon capillary and the smaller diameter fiber is Teflon AF capillary. The preliminary investigation indicates that these options are quite promising in terms of wavelength shifting properties and radiation hardness.

6. Conclusions

Optical fibers are excessively used in High Energy Physics experiments to carry scintillation light from the scintillators to the photon sensors. Their response to the repeated exposure provides an important information for the experiments. The darkening and recovery curves of the optical fibers provide such information about the annealing process. The investigation of in-situ recovery mechanisms is critically important for the future experiments. We investigated the in-situ radiation damage of optical fibers with the emission peaks in the blue, green and orange region of the visible spectrum. The time constants for the radiation damage are measured to be between 4.5 hr to 6.7 hr, decreasing with successive irradiations. The recovery from the damage ranges from approximately 60% for the first irradiation campaign to approximately 15% for the fourth campaign.

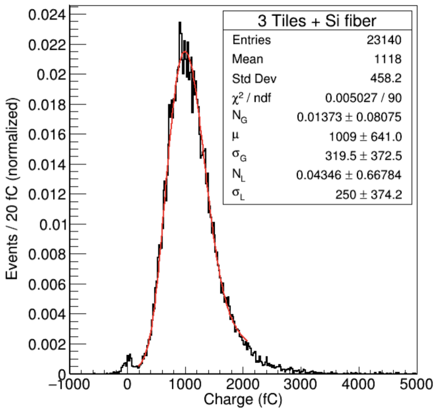

Figure 7. The charge distribution and the fit to Gaussian + Landau for the response of the 3 tiles + fiber assembly to 150 GeV muons.

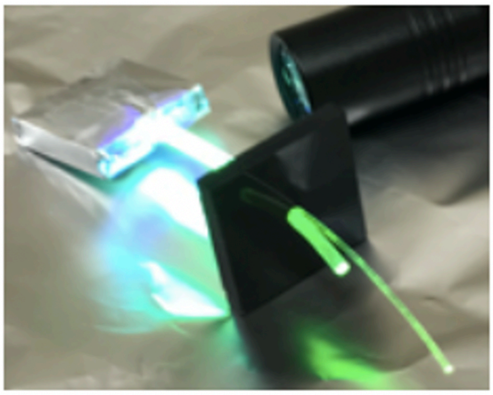

Figure 8. The picture of silicone (large) and Teflon AF (small) capillaries filled with silicone gel doped with 3HF.

In parallel to the studies on radiation damage and recovery mechanisms, the search for radiation-hard wavelength shifting fibers should continue on all grounds. The production of the radiation-hard fibers in larger quantities should be followed by the investigation of their radiation damage and recovery properties.

7. Acknowledgements

We acknowledge the staff at the University of Iowa College of Medicine and Holden Comprehensive Cancer Center Radiation and Free Radical Research (RFRR) Core for radiation services.

References

[1] J. Wetzel, et.al. JINST 11 P08023, 2016.
[2] J. Wetzel, et.al., Nucl. Instrum. Meth. B395, 13-16, 2017.
[3] G. Battistoni, et.al., Annals of Nuclear Energy, 82, 10, 2015.
[4] S.E. Derenzo, et.al., Nucl. Instr. and Meth. A 486, 214, 2002.
[5] https://www.berkeleynucleonics.com/cerium-bromide
[6] A. Bross, et.al., Nucl. Instr. and Meth. A 327, 337, 1993.