

# UV-LED Induced Recovery of Radiation Damage in Glass and Plastic Scintillators

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**Abstract**—Modern particle physics experiments 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. There is currently 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 a glass intended to be used as a substrate for producing new glass-based scintillators.

We find that UV-LED exposure (365 nm) is the most effective and efficient way to induce optical recovery of the glass cubes produced by AFO Research. White-light exposure only helped recovery in the green-infrared region of the electromagnetic spectrum. UV light exposure induced recovery in the entirety of the cubes transmission spectrum. We also find that UV-A light (365 nm) is effective at speeding up the recovery of plastic scintillating fibers.

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 runs in order to help the scintillating materials recover their optical properties and, at the same time, allow the detector to calibrate itself, extending the useful life of existing scintillators.

## I. INTRODUCTION

HIGH energy collider datasets improve experimental measurements by increasing the statistics of rare processes. This helps separate important signals from well-understood background processes. Any new collider experiment, if it hopes to improve our current understanding, must therefore produce more data than ever, and at a faster rate than ever. This is accomplished by increasing the beam density, or luminosity, of the collider experiment. Hinchliffe, et al, set out to quantify this requirement for any relevant future collider experiment [1], and concludes an instantaneous luminosity of  $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  to  $2 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$  is necessary to produce sufficient data to

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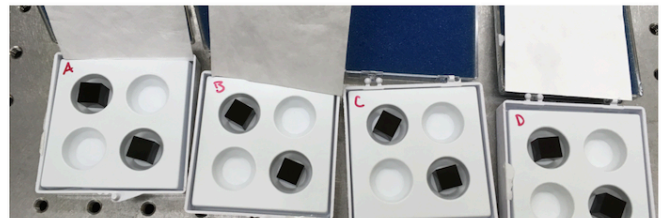


Fig. 1. Glass samples before irradiation (top) and after (bottom).

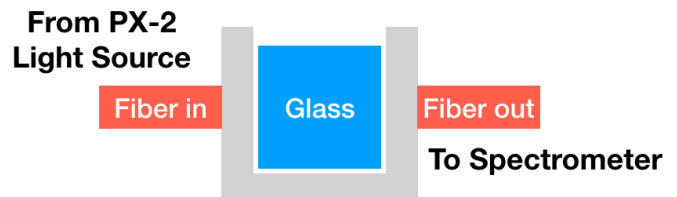


Fig. 2. Glass transmittance measurement setup.

go beyond the LHC and chase new physics at a 100 TeV pp collider.

A modern particle physics experiment therefore will produce unprecedented amounts of data. Most of this data will be background noise, consisting of well-understood processes that are not of physics interest. But while the datasets produced will be culled of these events, their histories through the detector will not be forgotten by the apparatus. Each particle leaves a mark. A history of each traverse remains behind in the scintillator tile, as a displaced electron in the substrate, a color center created that darkens the tile.

These background events, which accompany the rare events of interest, create intolerable radiation levels, each particle scarring the apparatus, leaving it darker with each track. This darkness ruins the ability for the detector to measure the

energy of the particle. The attenuation itself is a challenge for calibration to continually monitor the detector response in order to accurately reconstruct the particle energies.

Existing scintillation and light detection technologies cannot withstand these radiation fields long enough to produce useful data for the lifetime of the experiment, forcing the field of high energy physics down a path to develop radiation-tolerant technologies and strategies.

Gamma radiation most effectively damages scintillators, with high exposure to a crystal producing color centers - unpaired electrons - which absorb visible light and turn the scintillating crystal opaque, rendering them unusable [4]. After irradiation ceases, there is a period of natural recovery where the clarity of the scintillator returns. Heating crystals to high temperatures can speed this recovery process up significantly [5]. It is also known that optical bleaching can speed up the dispersion of the color centers [2].

The data reported here centers around a 5000 Ci extended cesium 137 source which can provide uniform irradiation dose rates, from 5 Gy per min to 24 Gy per minute. We exposed various samples at a rate of 24 Gy/minute for a total dose of 20 kGy, or 2 Mrads, roughly equivalent to 20 years of LHC collisions.

We investigate using newly developed UV and white LEDs as a method of bleaching color centers out of a glass. We also apply this technique to plastic scintillating optical fibers. We find that using UVA light, in particular 365 nm, is very effective at speeding up the recovery of both the glass cubes, as well as the plastic scintillators.

## II. EXPERIMENTAL SETUP

Four pairs of glass cubes were irradiated. The glass samples' transmission spectra were measured using an Ocean Optics PX-2 broad spectrum xenon light source, with usable light output of approximately 300 nm to 800 nm. Quartz optical fibers were used to transmit the light through the glass sample and measure the transmittance back to a spectrometer with a measurement range of 200 nm - 1000 nm. A 3D printed housing was used for inserting the cubes. The samples were tested before irradiation, and at 1.5 hour intervals during constant light exposure. Fig. 2 shows the optical measurement setup.

Of each pair, one was kept in the dark, and the other was kept under a circuit board with LEDs on it. The glass cube (B) was kept under 2 UVA LEDs (365 nm), glass cube (C) was kept under 1 UVA LED (365 nm) and 1 White LED (450 nm peak), glass cube (D) was kept under 2 White LEDs. Glass cube (A) was heated to 450 celsius.

The glass samples were irradiated at a rate of 24 Gy/minute for a total dose of 20 kGy, or 2 Mrad. Fig. 1 shows the near complete darkening of the cubes after exposure to radiation.

Separately, two Kuraray B2(200) [3] blue wavelength shifting fibers were exposed to 22 kGy of gamma radiation. One was kept in a dark box, the other kept under a 365 nm UVA light. The transmittance of the fiber was measured every 10 minutes during recovery using the same PX-2 light source and spectrometer. The transmittance measurements were integrated to produce integrated light intensity plots.

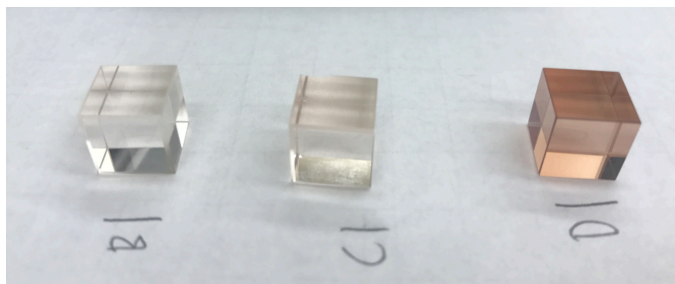


Fig. 3. Comparison of the glass cubes during the experiment. The UV LED treated cube (left most) is completely recovered while the white LED treated cube (right most) is still damaged, and the combined UV+white LED is between.

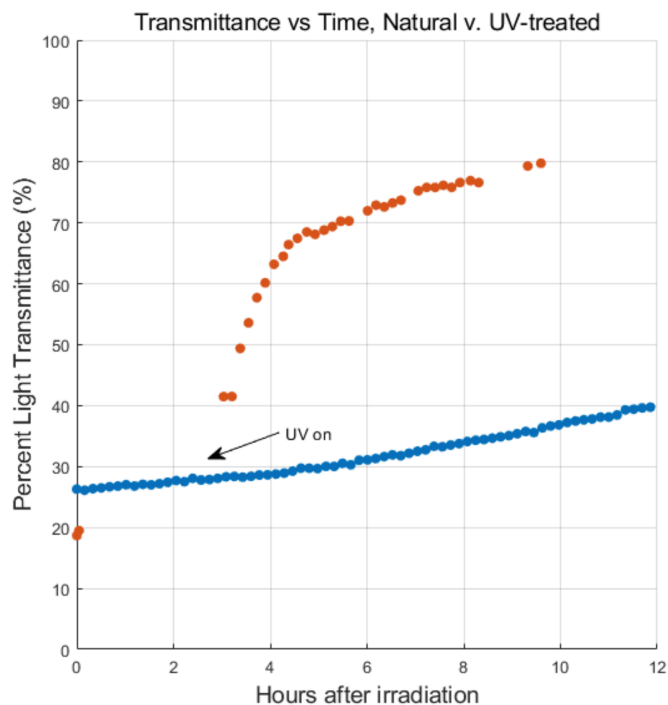


Fig. 4. Integrated spectrum over time for two identically irradiated B2(200) fibers. The blue data points are a measurement of the natural recovery, the red data points correspond to a fiber exposed to UV light.

## III. EXPERIMENTAL RESULTS

### A. Glass Cube Irradiation

We found that LEDs reduced the color centers significantly, with UVA LEDs acting faster and more thoroughly than white LEDs alone. In Fig.6, you can see in the transmission plots fully recover after just 13 hours of continuous UV LED exposure. It took approximately 4 times longer at 50 hours with one UV LED and one white LED. And while it took over 100 hours of just white LED exposure to reach maximum recovery, the maximum recovery was significantly lower than that reached with UV LEDs. This clearly demonstrates the dependence of optical bleaching on the incident wavelength, as both the UV LEDs and the white LEDs had similar intensities.

We also found that using UV LEDs returned the glass sample back fully to its original condition. Comparing the maximum

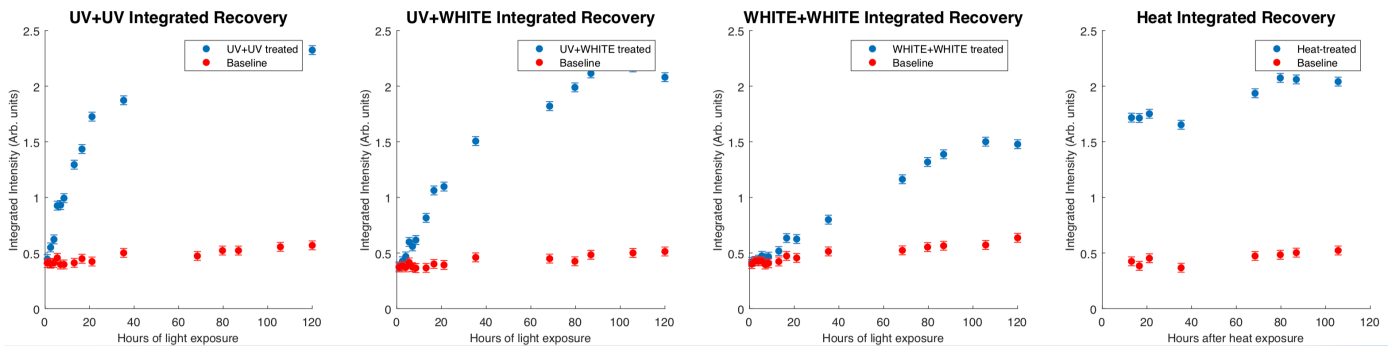


Fig. 5. Integrated spectrum (total light transmission) (blue data) vs time for the cube spectra, including the cube pairs kept in the dark (red data).

intensity levels of the recovery spectra plots in Fig.6, one can see the glass samples exposed to UV LEDs recovered more fully when compared with the white LEDs alone. The top row of these plots shows a significant difference in maximum recovery. Fig.3 starkly shows the disparity between UV and white LED treatments.

This is clear in the integrated spectrum vs. time plots shown in Fig. 5 for each irradiated cube. This figure includes the heated cube. The integrated spectrum measures the total light transmitted across the entire spectrum. More analysis will be done to characterize these measurements further, but there are two important details to note in these plots: first is the speed of recovery - heating the cube to 450 degrees celsius resulted in near complete recovery after just a few hours, though UV exposure did not take much longer. Second, the UV exposed cube (left most plot) recovered more fully than any other cube, including the heated cube. This demonstrates the power of using UV LEDs to recover the damage without the need for resorting to dramatic temperature exposures.

### B. WLS Plastic Fiber Irradiation

Comparing the results of the recovery of the irradiated plastic scintillating fibers, it was observed that the fiber exposed to UV light recovered significantly faster than the fiber left to recover naturally.

Fig. 4 demonstrates the dramatic increase in recovery rate of the B2(200) wls fiber when exposed to UV light. After irradiation, the transmittance was measured every 10 minutes, and the spectra was integrated to measure total light transmission.

At the time of this manuscript submission, recovery data was still being collected to compare maximal recovery results and will be published at a later date. Despite the limited data, the trend is clear. UV light exposure (365 nm) led to a marked increase in recovery rate, bringing the fiber to 70% of its pre-irradiation level after only 1 hour of exposure. After 12 hours of natural recovery, the fiber kept in the dark only recovered to 40%, and we predict it will maximally recover at a lower value than the UV fiber.

## IV. DISCUSSION

The main motivation for this research is to determine if there are ways to use existing scintillation products in high radiation fields. We found that not only does UV light improve the

maximal recovery level, bringing the glasses back to original condition, it also does it substantially more quickly.

We demonstrate that this technique is not limited to glasses only, but also plastic scintillating fibers.

It is therefore reasonable to conclude based on these results that UV LEDs can be incorporated into scintillation detection infrastructure to recover from radiation damage.

A few of the existing questions are: how does light intensity affect the recovery rate? Would doubling the intensity reduce recovery time? What are the intensity and wavelength limiting behaviors? It appears that doubling the intensity (2 UV LEDs vs 1 UV LED) improved the recovery rate. Where is the saturation point? Furthermore, does in situ UV exposure during irradiation provide a protective affect?

Furthermore, the intensity of the UV LED could be adjusted, and additionally used to calibrate the photodetectors, providing another strategy for radiation damage mitigation.

Finally, there is an open question of repeat irradiations. If the scintillators are left to recovery, either naturally or via UV exposure, how is the degradation of light transmission affected? Does the UV light more robustly heal the fiber? Is the recovery table, and additional radiation damage decline at a similar rate or worse? These are questions we will attempt to answer with further research.

## V. CONCLUSION

Every future high energy particle physics experiment will need to manage high radiation exposure. Existing strategies and materials will need to be improved to handle this radiation. Either more radiation tolerant scintillators or detectors need to be developed, or strategies for extending the lifetime of existing scintillator technologies will need to be developed.

With the advent of inexpensive UV LEDs, it is possible that optical bleaching using UV LEDs can be implemented into new detectors. This can aid in extending the lifetime of scintillators, while also doubling as a calibration system.

It would be interesting to study whether UV dosing during irradiation will prevent damage, and how it would effect the overall life of the scintillator.

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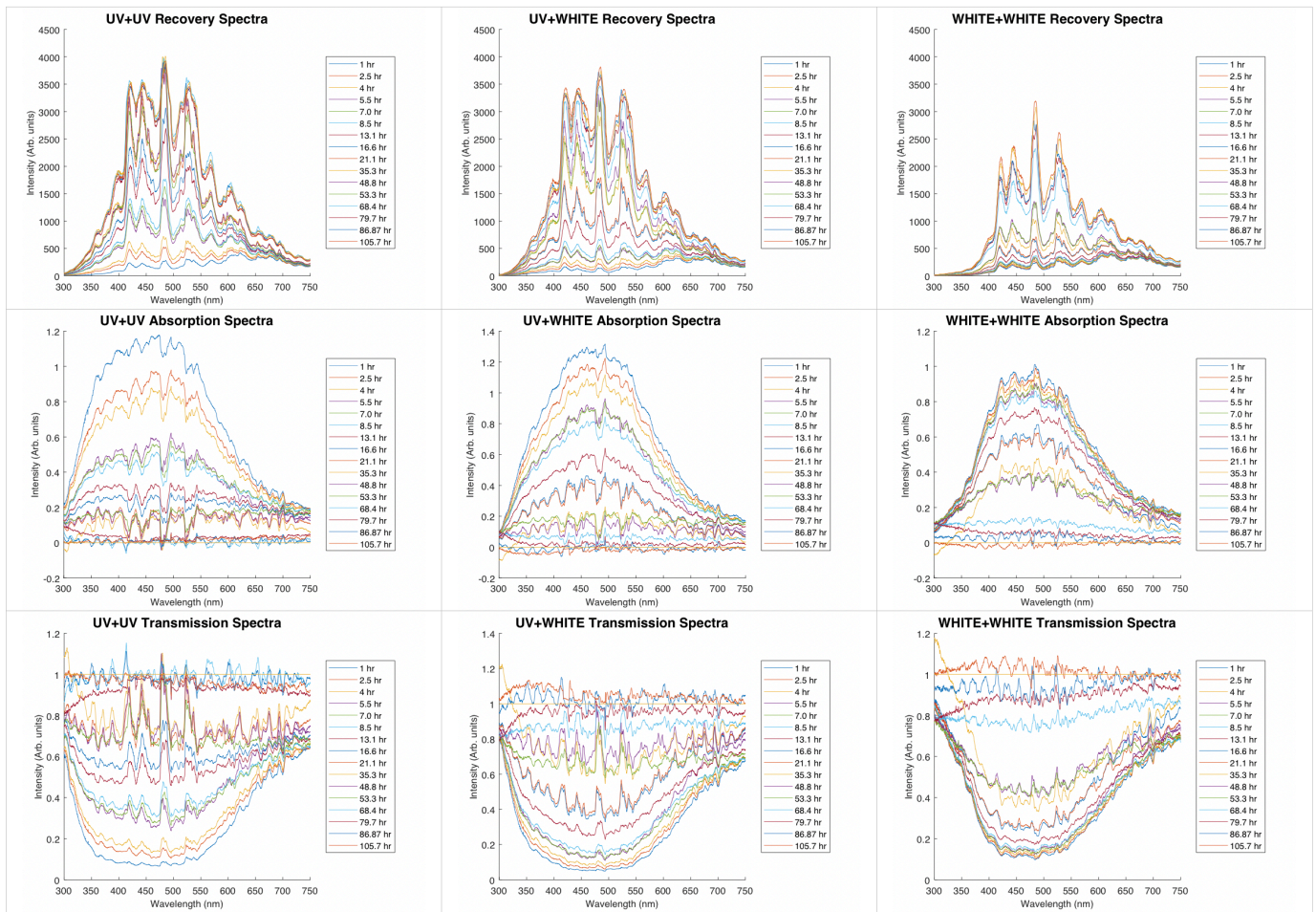


Fig. 6. Intensity (top row), absorption (middle row), and transmission (bottom row) spectra over time after irradiation. Dual UV LED setup (left column), single UV LED and single white light LED (center column), and dual white LED setup (right column).

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