Systematic Study of LED Stimulated Recovery of Radiation Damage in Optical Materials

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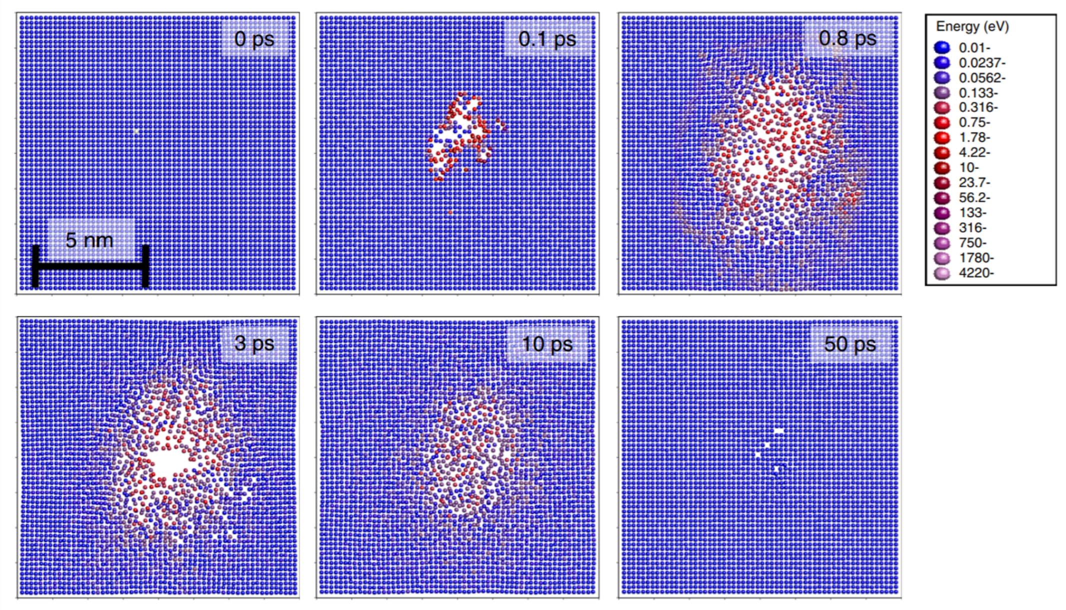
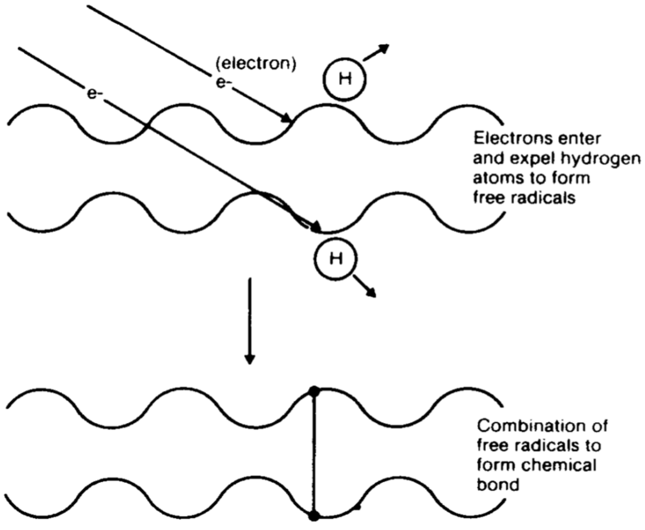
Radiation Damage

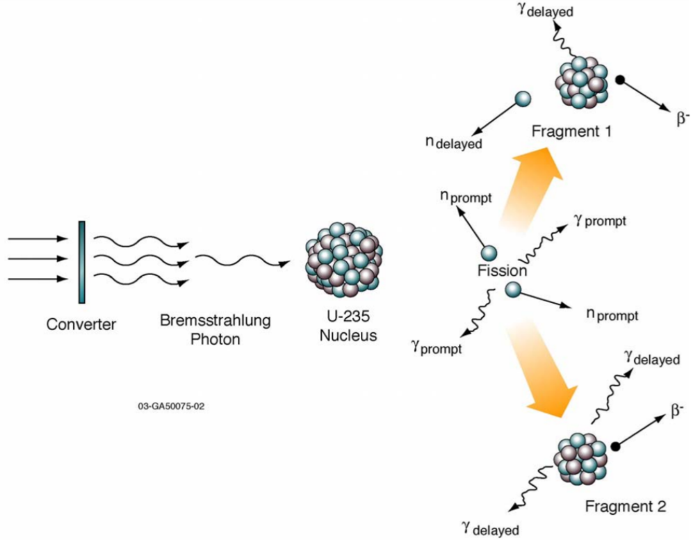
May alter the molecular structure[1]

May cause atomic cascade by knocking an individual atom[2]

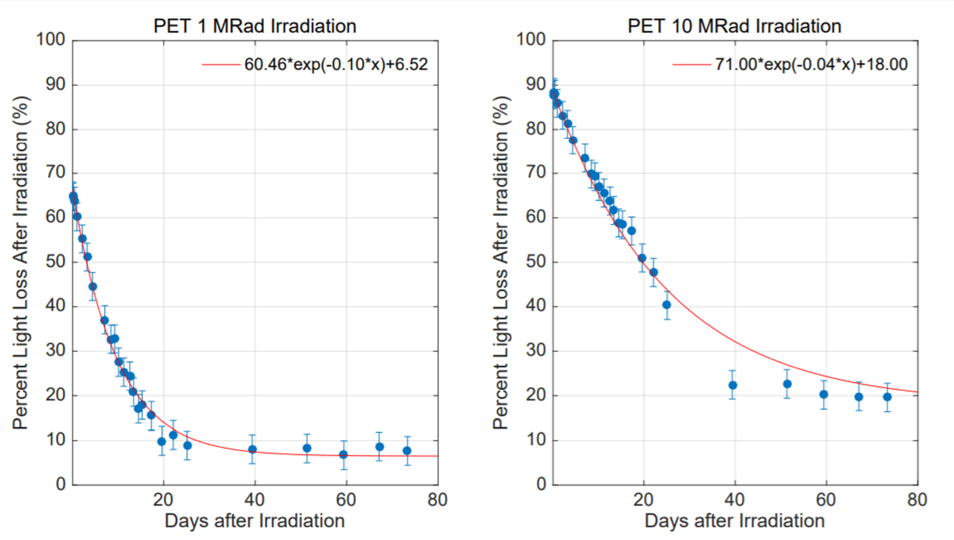
May trigger nuclear fission[3]



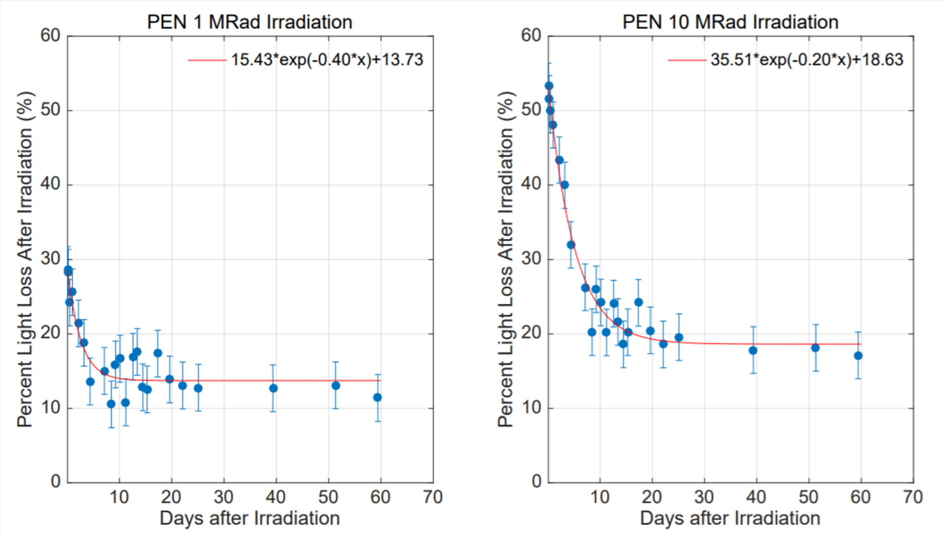




Radiation Damage and Natural Recovery of Damage on the Scintillator Materials[4]

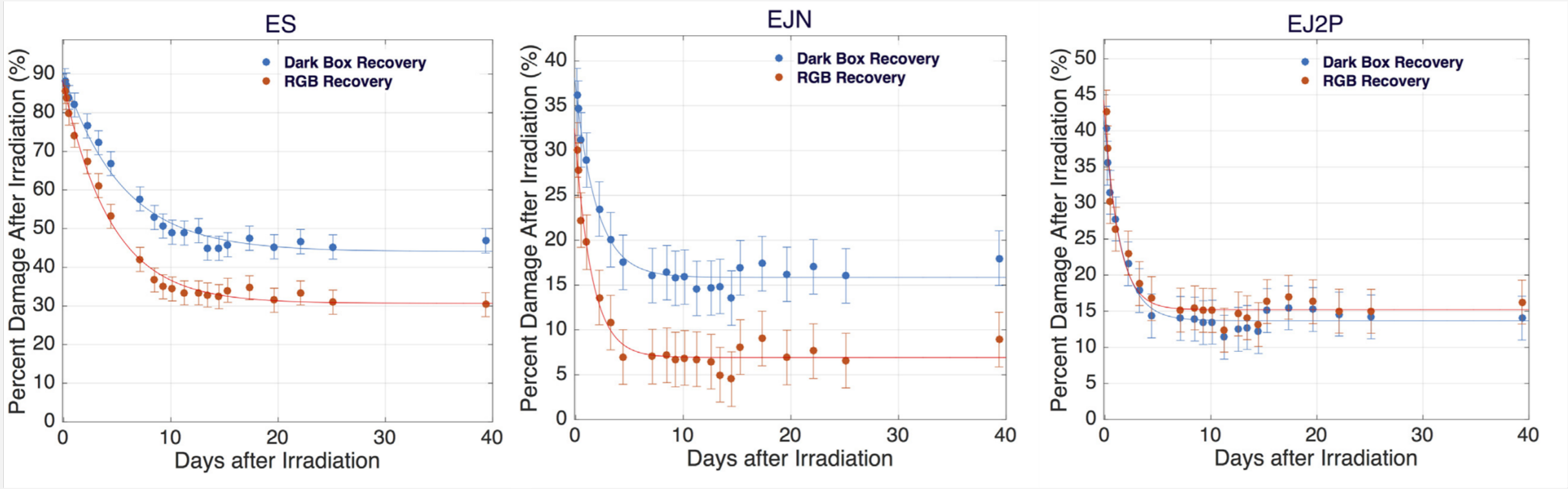


PET (polyethylene terephthalate) recovery results over 21 measurements. 1 MRad Irradiated PET (left), 10 MRad Irradiated PET (right)



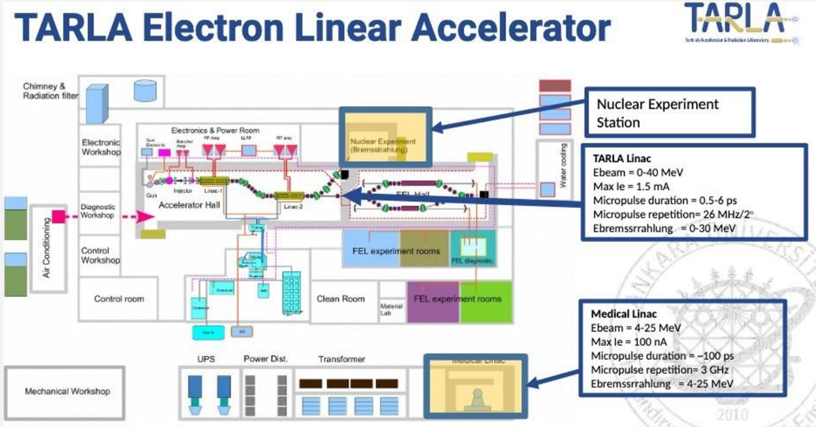
PEN (polyethylene naphthalate) recovery results over 21 measurements. 1 MRad Irradiated PEN (left), 10 MRad Irradiated PEN (right)

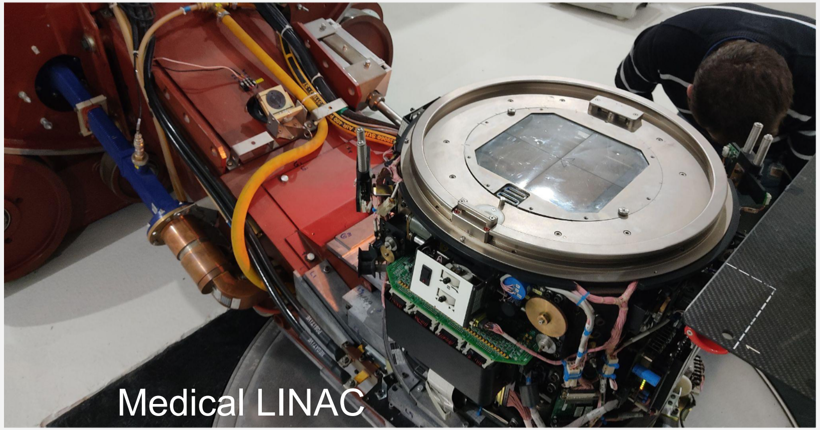
Radiation Damage and RGB LED Stimulated Recovery of Damage on the Scintillator Materials[5]

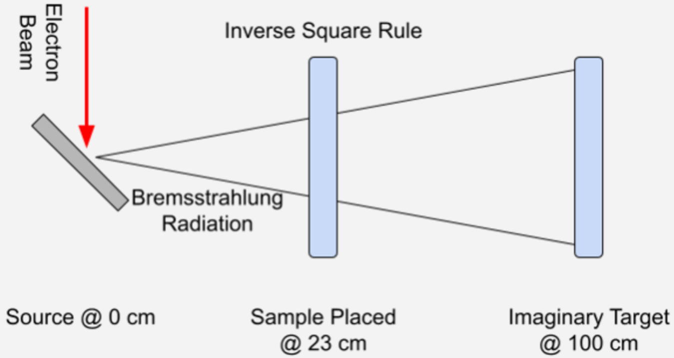


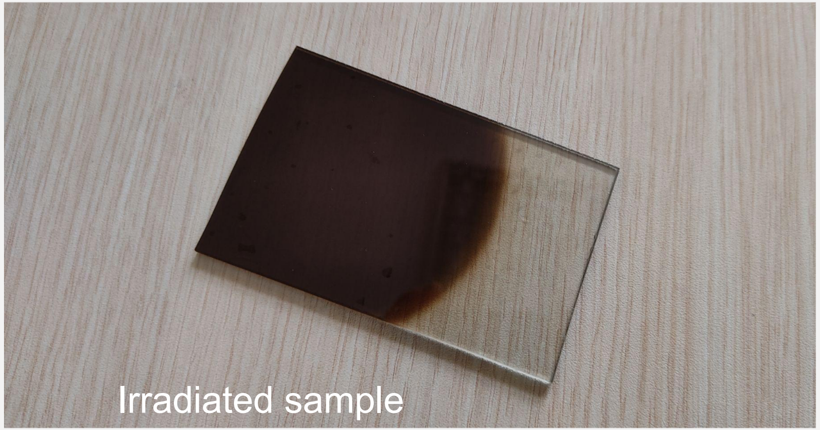
Natural (blue) and RGB LED Stimulated (red) recovery results of lab-produced ES (elastomer scintillator) (left), EJN (Eljen brand EJ-260) (middle) and EJ2P (an over-doped version of EJ-260) (right)

LED Stimulated Recovery of Radiation Damage in Optical Materials

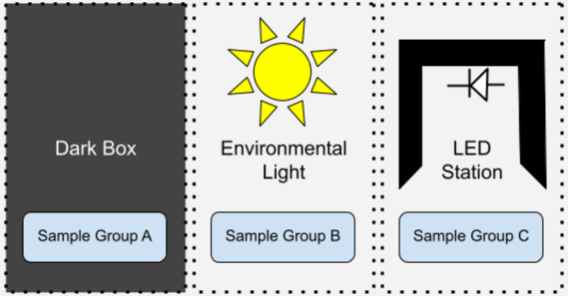


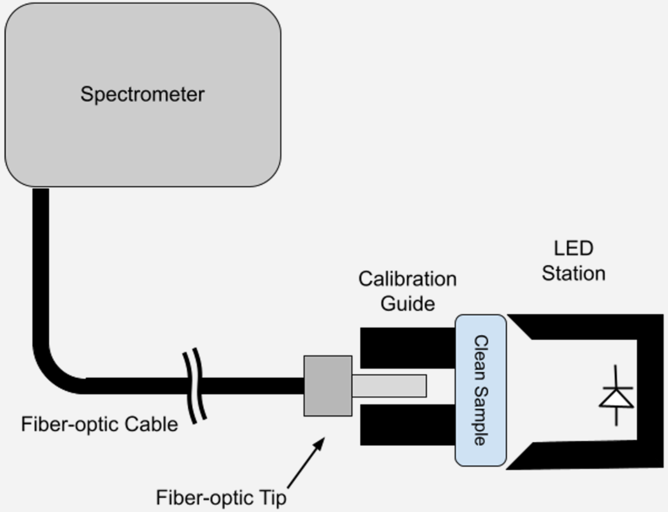






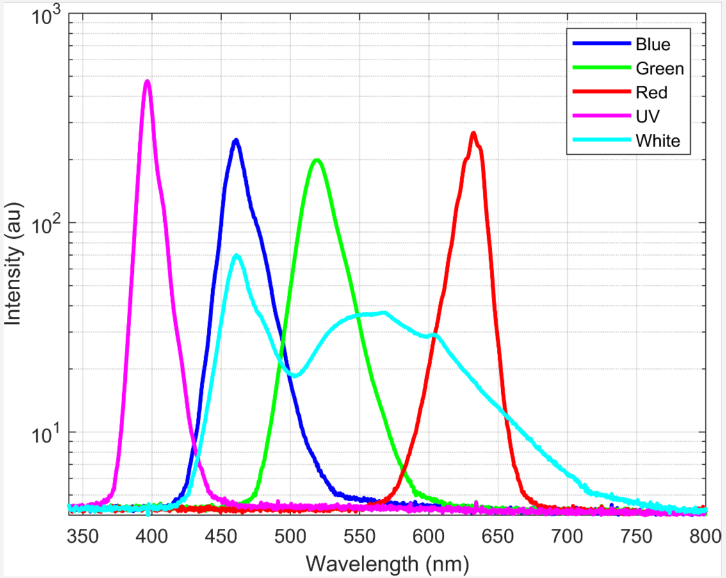
LED Recovery Station Setup and Calibration



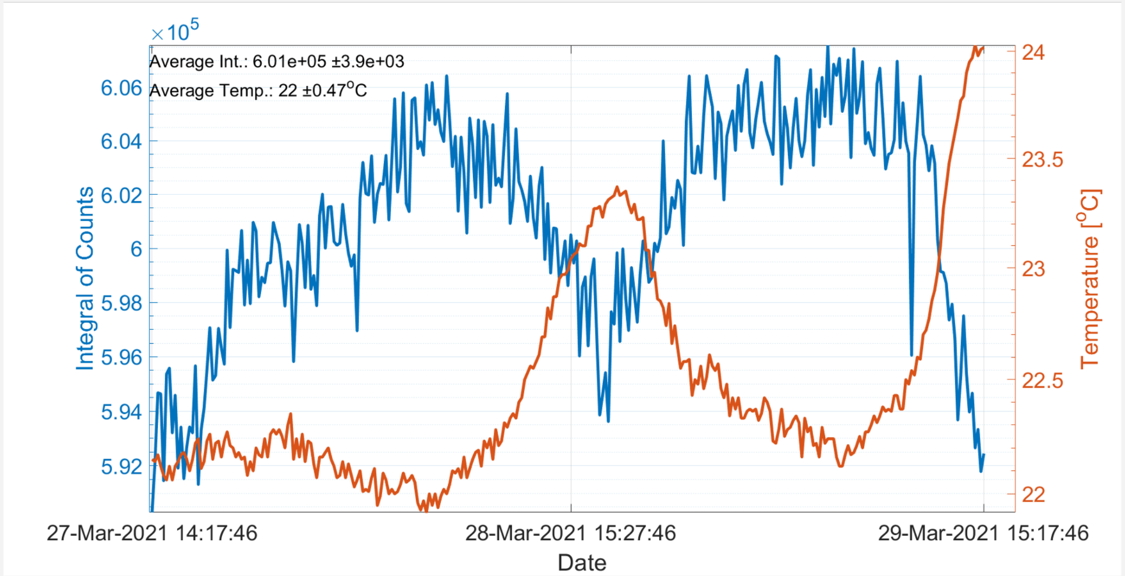


Properties of Used LEDs

All LED spectra that was used for LED station



Integral of UV LED intensity (blue) and room temperature (red) that are measured for two days



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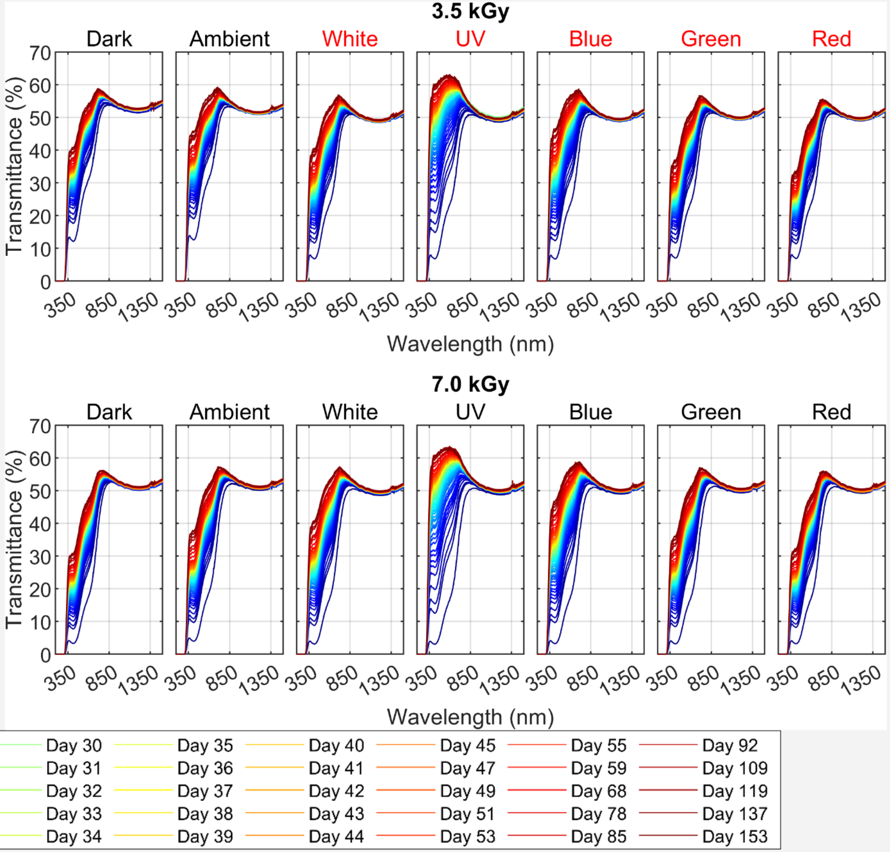
Transmittance Measurement Results (overlaid spectra)

Overlaid spectra of transparency measurements over 60 data sets

Data have been taken between 200-1500 nm range

Red titled samples have roughly 4 mm thickness, others have roughly 3 mm

Sample	Thickness (μm)
1A - 3.5 kGy Dark Box	2828 ± 13.984
1B - 3.5 kGy Ambient Light	2773 ± 10.593
1C - 3.5 kGy LED Station	3702 ± 16.193
2A - 7.0 kGy Dark Box	2789 ± 11.005
2B - 7.0 kGy Ambient Light	2749 ± 18.529
2C - 7.0 kGy LED Station	2810 ± 16.997

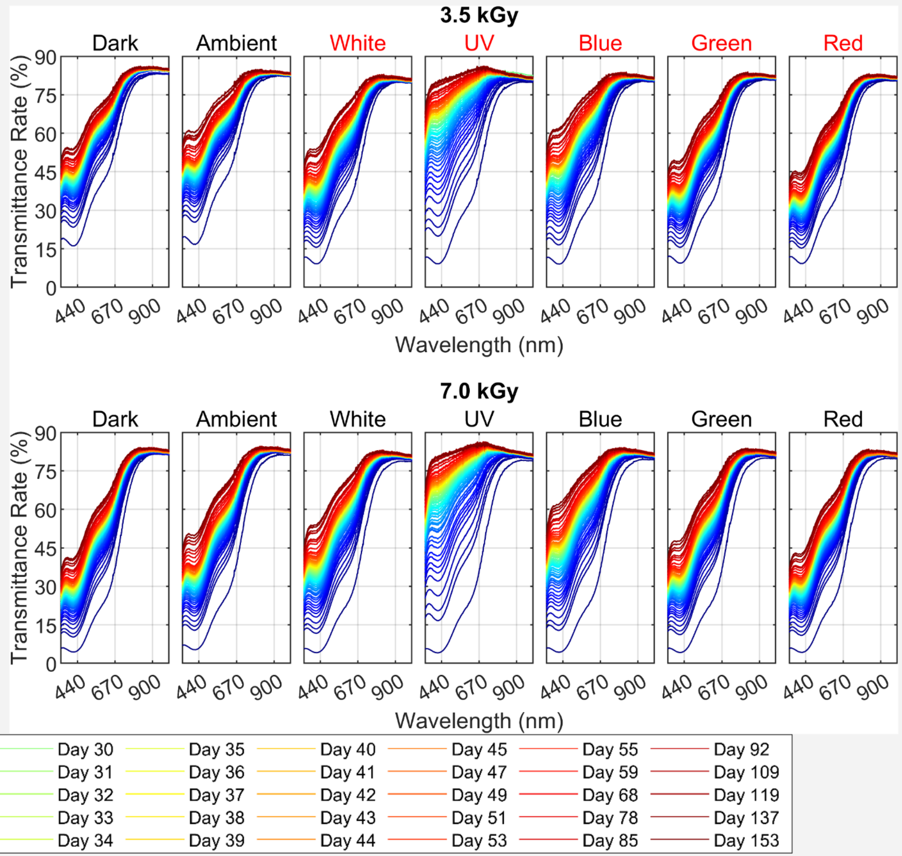


Relative Transmittance Calculations (overlaid spectra)

Overlaid relative transmittance spectra (ratio of the individual transmittance spectra to the clean sample spectrum).

Relative transmittance spectra were calculated for 340-1000 nm range, where the majority and the most relevant part of the radiation damage and recovery occurs.

Red titled samples slightly thicker than others

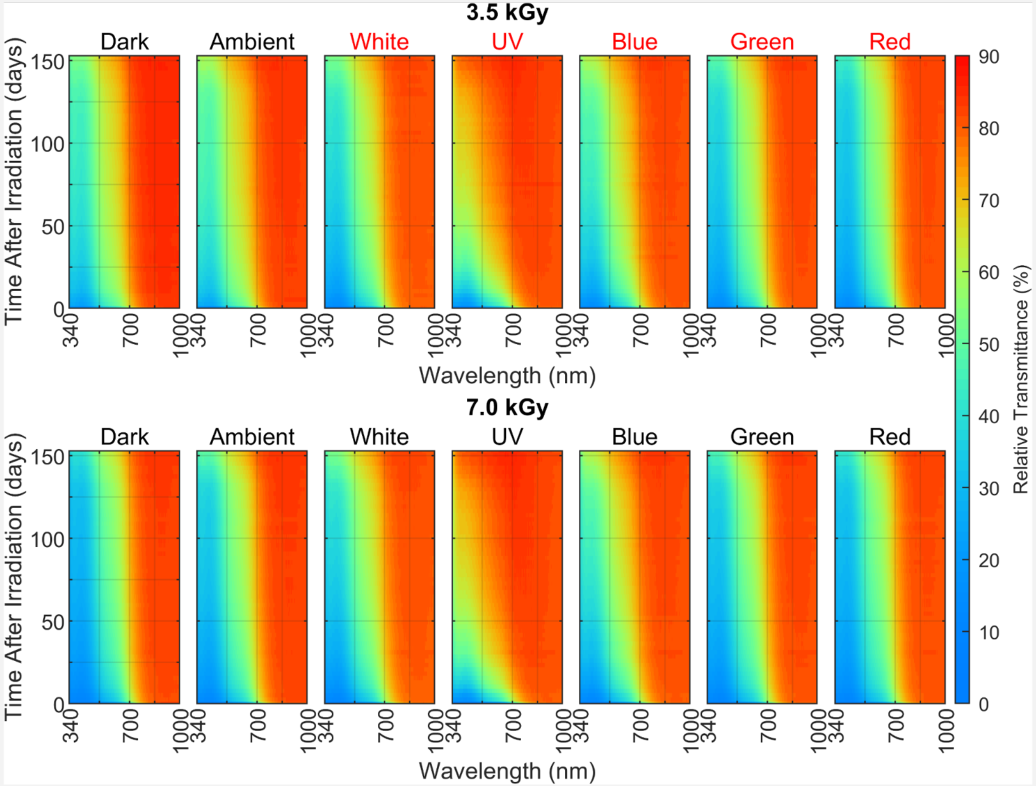


Relative Transmittance Calculations (spectral dynamics)

For UV LED stimulated recovery, the relative transmittance improves beyond 80% for the entire spectral range in the final days of the recovery.

For the other recovery modes, the 80% relative transmittance threshold lies between 500 nm and 700 nm.

The initial relative transmittance following the irradiation beyond 700 nm is around 80% and the improvement in this range is minimal for all recovery modes.

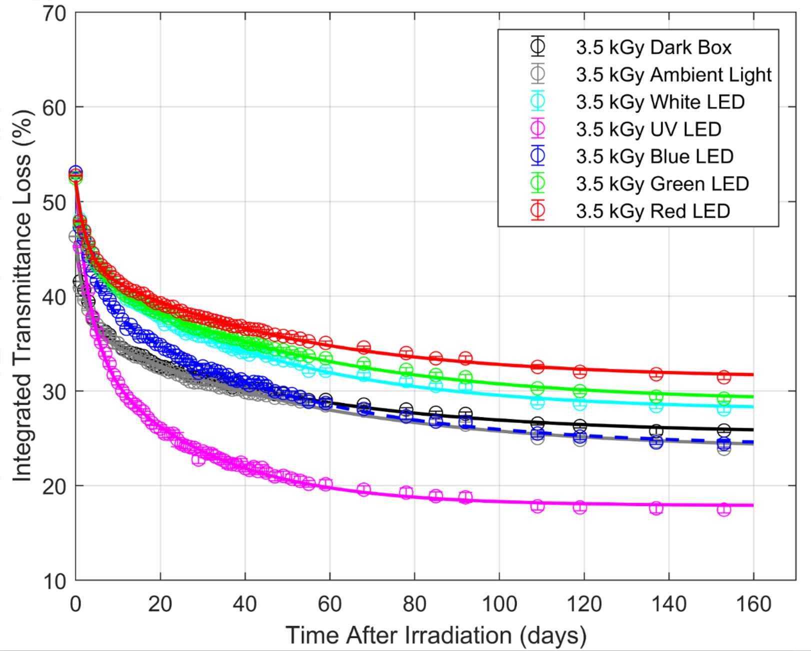


Integrated Transmittance Loss

The relative transmittance spectra were integrated in 340-1000 nm range in order to calculate the Integrated Transmittance Loss (ITL).

Fit Function: $Damage(t) = A\,exp(-t/\tau_{fast}) + B\,exp(-t/\tau_{slow}) + C$

τ_{fast}: fast component of recovery; τ_{slow}: slow component of recovery; C: permanent damage; A, B: scaling parameters



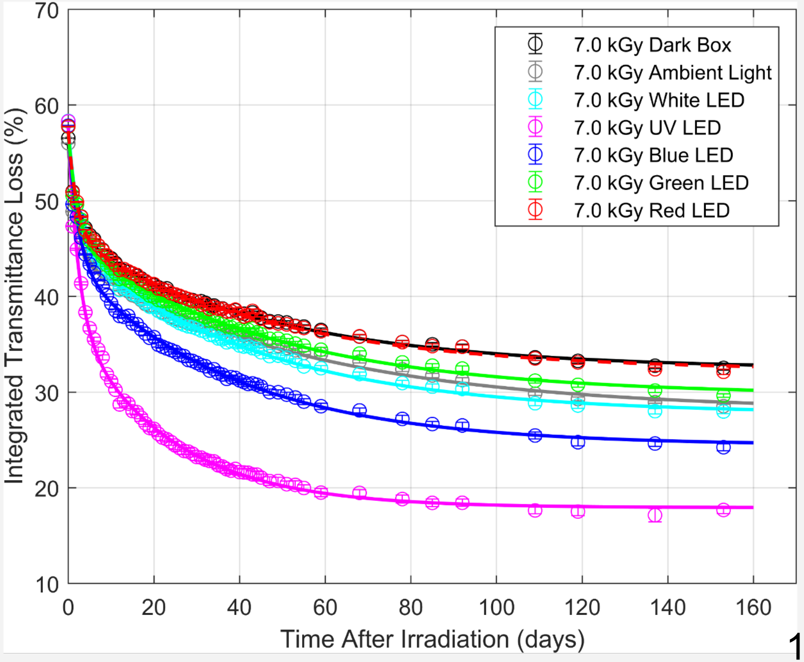


Table of Fit Parameters for the Integrated Transmittance Loss

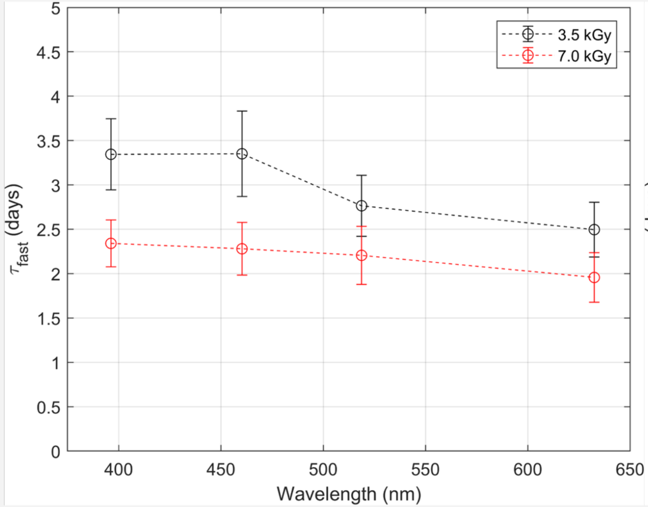
Sample	Name	A	τ fast	B	τ slow	C
3.5 kGy Dosed	Dark	9.31 ± 0.50	2.78 ± 0.31	11.07 ± 0.35	49.47 ± 4.95	25.45 ± 0.41
	Ambient	9.03 ± 0.78	2.26 ± 0.40	12.96 ± 0.56	53.65 ± 7.08	23.74 ± 0.68
	White	8.91 ± 0.71	2.74 ± 0.44	15.62 ± 0.47	44.29 ± 4.00	27.89 ± 0.48
	UV	16.91 ± 1.13	3.34 ± 0.40	17.35 ± 0.95	27.06 ± 2.56	17.88 ± 0.36
	Blue	11.47 ± 0.81	3.35 ± 0.48	16.54 ± 0.57	44.98 ± 4.71	24.13 ± 0.57
	Green	8.98 ± 0.54	2.76 ± 0.34	14.13 ± 0.38	50.65 ± 4.35	28.78 ± 0.45
	Red	8.60 ± 0.52	2.50 ± 0.31	12.35 ± 0.34	47.45 ± 4.08	31.29 ± 0.39
7.5 kGy Dosed	Dark	9.78 ± 0.64	2.53 ± 0.34	13.75 ± 0.42	46.89 ± 4.44	32.38 ± 0.47
	Ambient	11.23 ± 0.89	1.95 ± 0.31	16.19 ± 0.64	53.90 ± 6.25	28.00 ± 0.77
	White	12.02 ± 0.79	2.17 ± 0.29	17.92 ± 0.49	43.24 ± 3.47	27.72 ± 0.51
	UV	19.77 ± 1.16	2.34 ± 0.26	19.87 ± 0.88	23.14 ± 1.83	17.93 ± 0.35
	Blue	13.46 ± 0.86	2.28 ± 0.30	19.21 ± 0.53	37.80 ± 2.87	24.43 ± 0.48
	Green	11.20 ± 0.82	2.21 ± 0.33	16.15 ± 0.53	47.24 ± 4.68	29.65 ± 0.60
	Red	10.85 ± 0.76	1.96 ± 0.28	14.20 ± 0.47	45.59 ± 4.49	32.24 ± 0.52

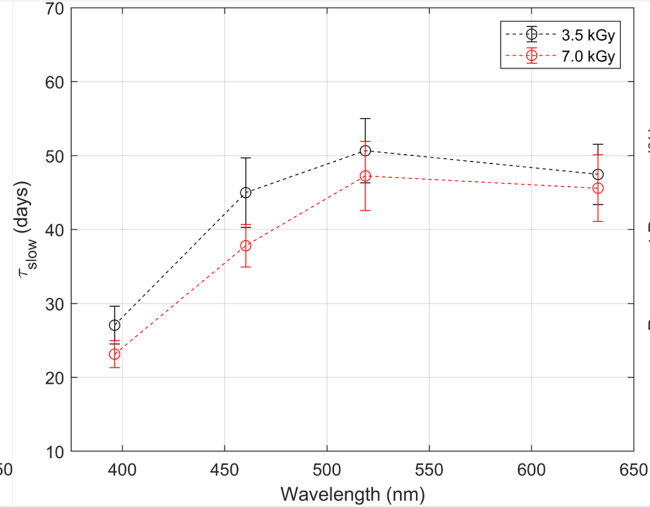
The fit function is shown like this, $Damage(t) = A\ exp(-t/\tau_{fast}) + B\ exp(-t/\tau_{slow}) + C$. At the function t is the time τ_{fast} and τ_{slow} are constants of the fast and slow recovery constants, A and B are the scaling factors of fast and slow recovery terms and C is the permanent damage [6]

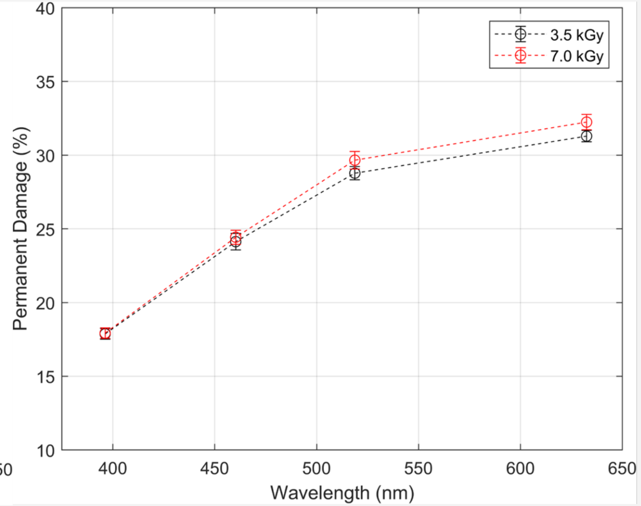
Dependence of Recovery Parameters on the Stimulating Wavelength

There is no solid relation between τ_{fast} and the wavelength of the stimulating light.

Both slow recovery time, τ_{slow}, and permanent damage, C, decrease as the wavelength of the stimulating light decreases.



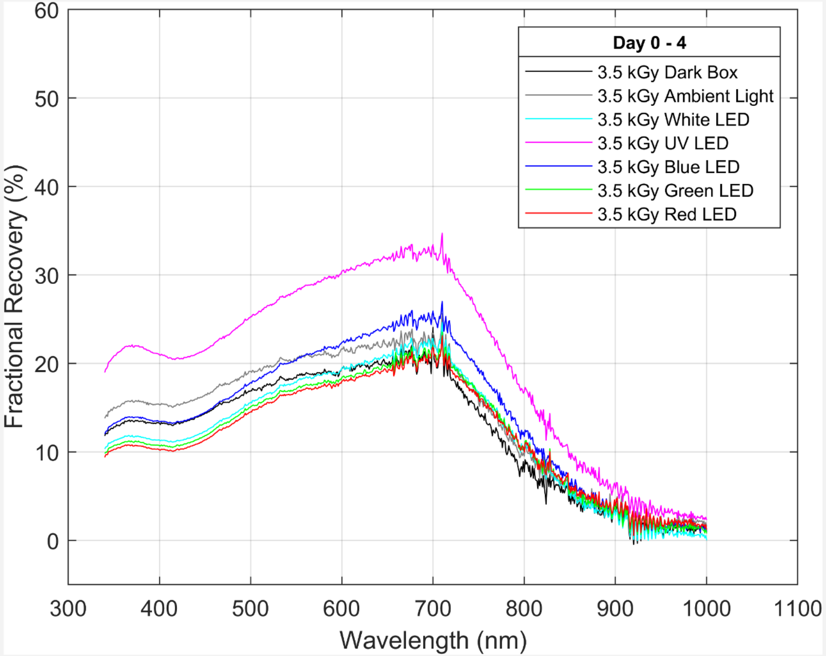


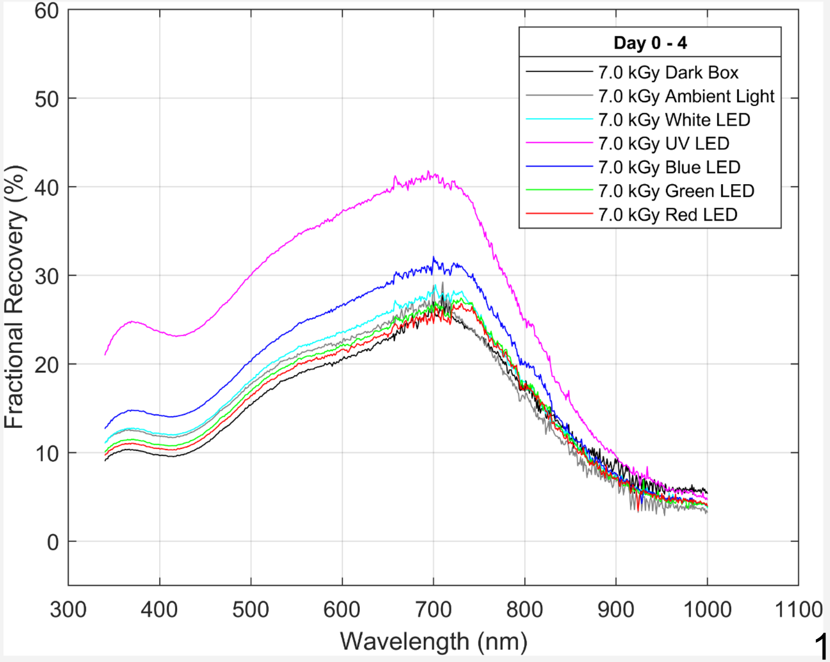


The Fractional Recovery Spectra Between 0-4th days

The spectral recovery has a characteristic shape with two major peaks, one around 360 nm and the other around 680 nm.

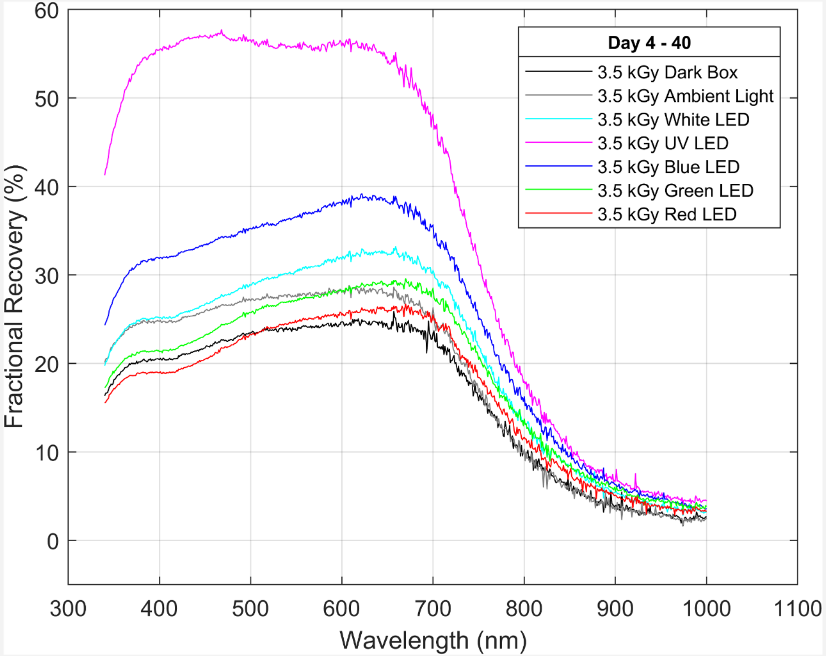
Clear ordering of UV, blue, white, green and red LED stimulation.

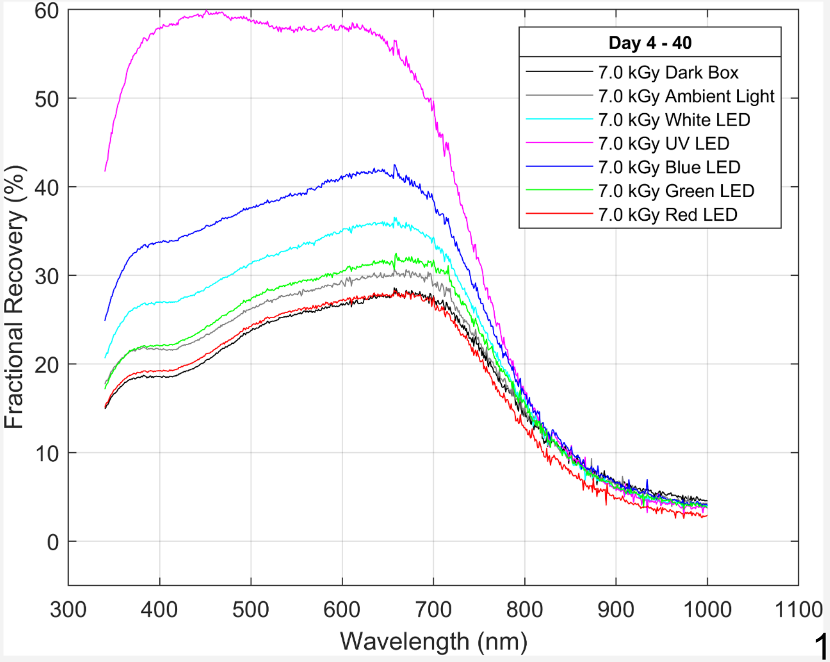




The Fractional Recovery Spectra Between 4-40th days

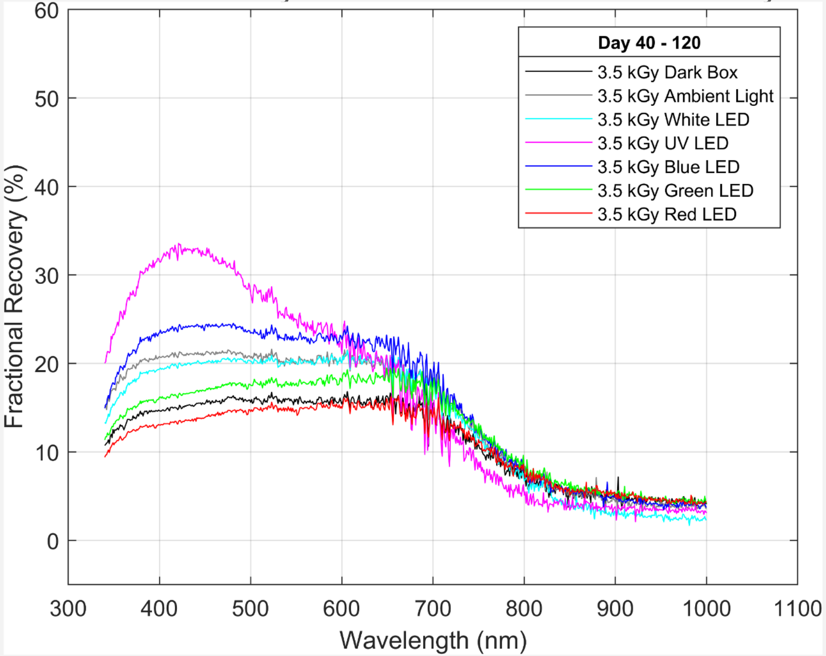
The 360 nm peak is still visible. The UV stimulated recovery has an additional and more pronounced peak around 440 nm, which extends up to 540 nm. This peak is missing in all other fractional recovery spectra including the one with the blue LED stimulation.

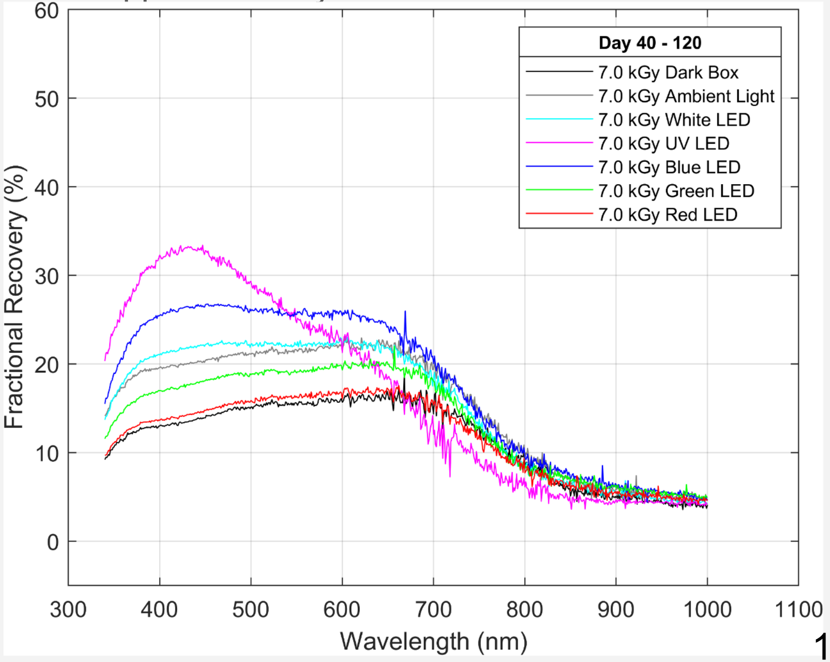




The Fractional Recovery Spectra Between 40-120th days

The 360 nm peak is not pronounced in any of the recovery regimes. The recovery in the ambient light condition dominates over the green LED stimulation in this time frame for 7.0kGy irradiation. The 440 nm peak of the UV stimulated recovery is still visible, and is the dominant feature in the recovery curves of this time frame. The 7.0 kGy fractional recovery curve of UV stimulated recovery shows a dramatic suppression beyond 540 nm.





Conclusions and Outlook

- LED stimulated recovery from radiation damage is a feasible and simple to implement technique for optical active media of radiation and particle detectors operating at high radiation environments.
- Shorter stimulating wavelengths result in faster recovery and lower permanent damage.
- There is a cut off stimulating wavelength ~500 nm above which the recovery is minimal to zero.
- The recovery characteristics of other irradiation scenarios, such as varying total dose and sample thickness, can be projected utilizing the current results.
- Next steps point towards stimulating light wavelengths in the deeper UV range.
- Plans include investigating the LED stimulated recovery characteristics of scintillators.

Reference

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