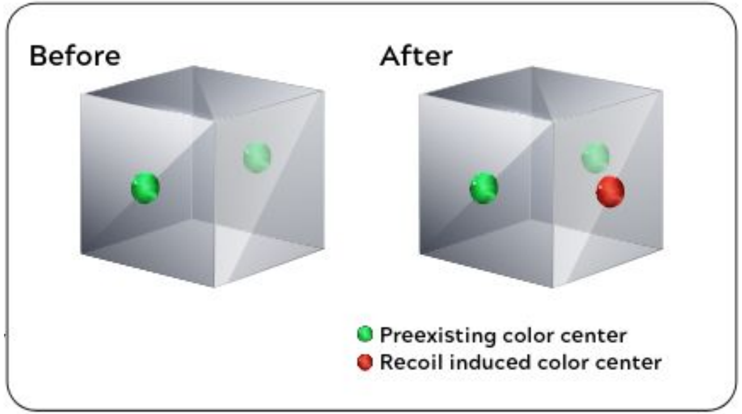
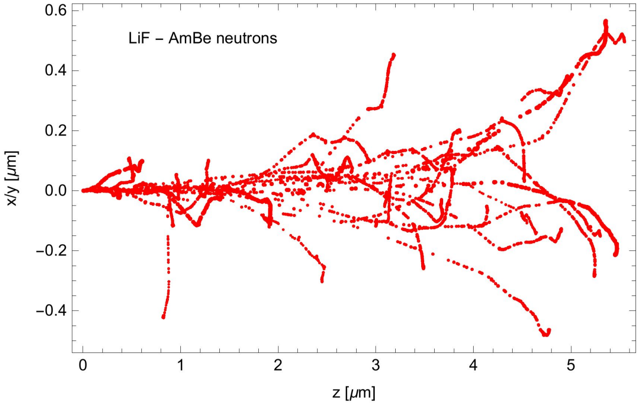
PALEOCCENE

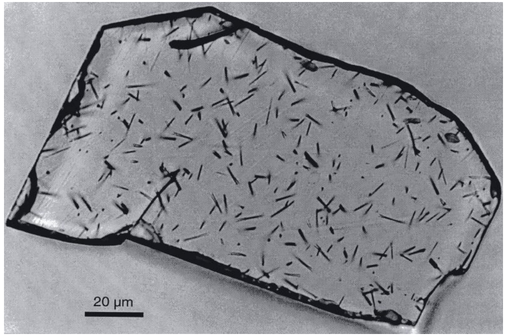
Keegan Walkup (December 13th)

What is Paleoccene?





B. K. Cogswell, A. Goel, and P. Huber, "Passive Low-Energy Nuclear-Recoil Detection with Color Centers," Phys. Rev. Applied 16, 064060 (2021), 2104.13926



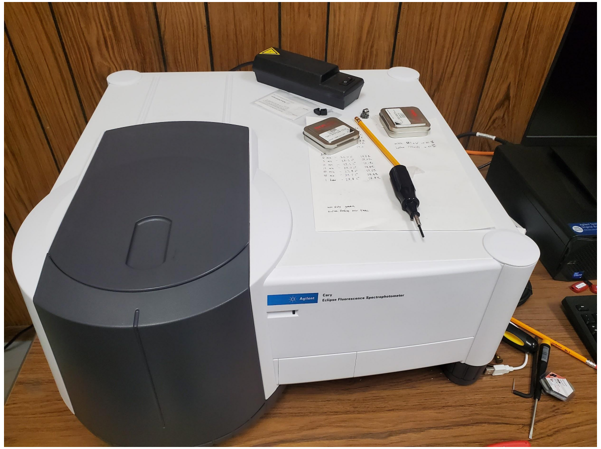
A. J. W. Gleadow *et al.*, Rev. Mineral. Geochem. 48, 579 (2002)

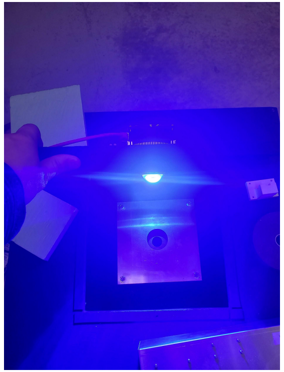
NSF/J. Yang

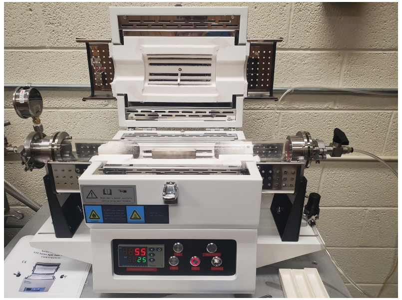
Passive Low-Energy Nuclear-Recoil Detection with Color Centers.

What are we doing at Virginia Tech?

- Detecting rare events requires a clear understanding of the crystals we plan on turning into detectors.
- Our lab is focused on sample irradiation and the bulk properties of crystal samples such as diamond, sapphire, CaF2 and LiF.
- Other collaborators take these samples and look at individual tracks.







Radiation Sources

- We use a 100 mCi Cobalt pellet inside a lead shield (20cm) as a gamma source.
- We use a 100 mCi AmBe source inside a borated HDPE shield as a neutron source. Am241 x-rays shielded by 5mm of lead.
- Samples undergo changes within minutes under gamma irradiation and hours in the neutron irradiation

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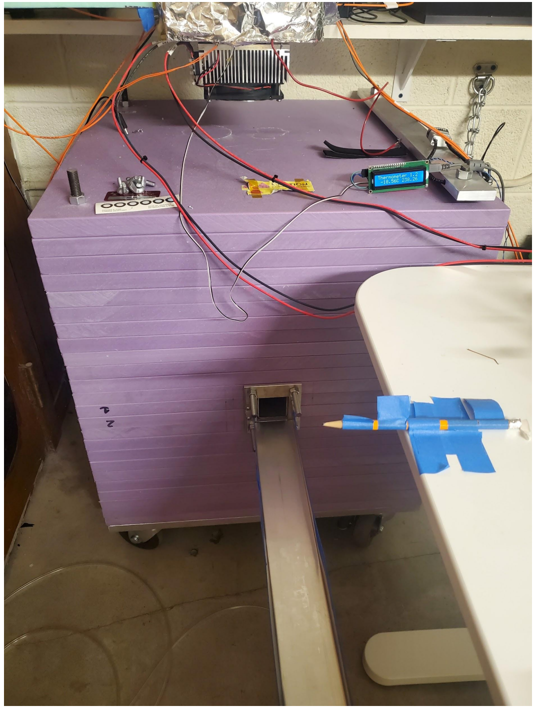
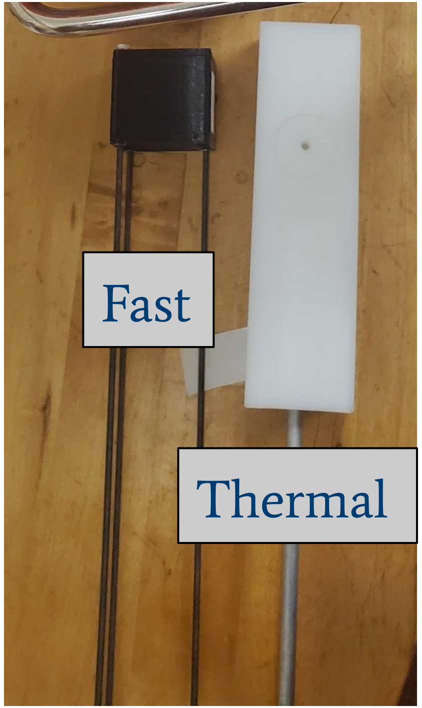
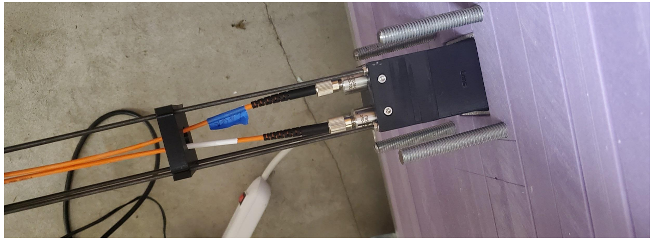




Fiber optics measurement system



Splitter

This splits the pulse in two for laser and secondary SiPM monitoring.

Laser

A 450 nm laser is pulsed at 20 kHz.

Laser Filter

450/10 nm filter to get rid of non-laser light

Sample

The sample is placed in a holder designed to be inserted into radiation environments.

Fluorescence Filters

A 500> nm longpass filter is used to get rid of stray laser light. An additional 600/10 nm filter is used upstream.

Measurement

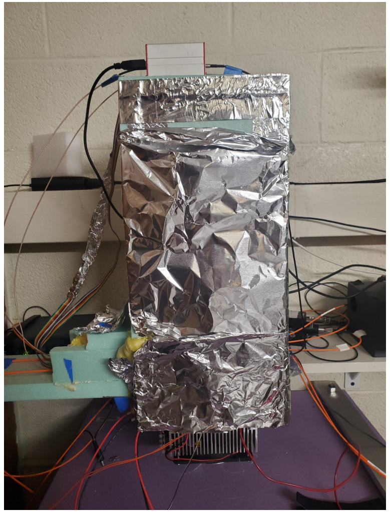
Measurement is triggered at a 20kHz rate in sync with laser pulses.

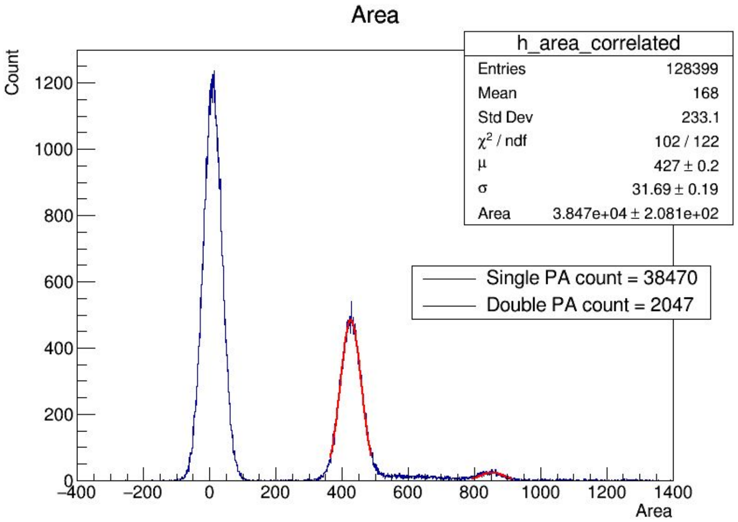
Monitoring

A neutral density filter is used to reduce the laser light and send it off to a monitoring SiPM

Data taking in radiation

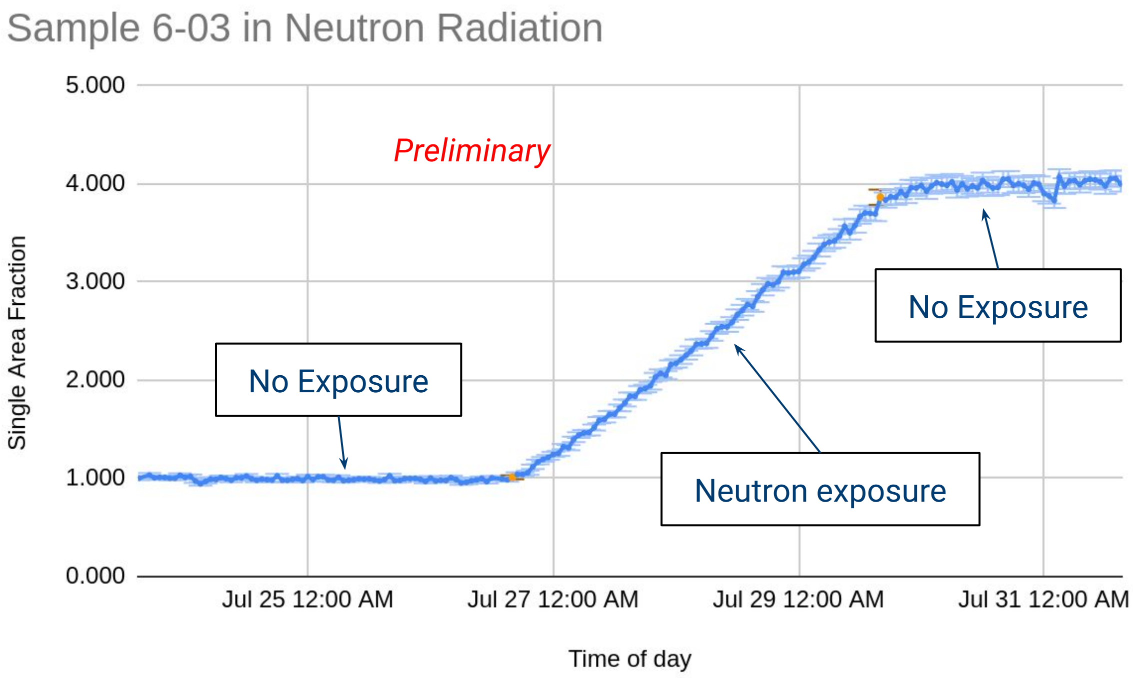
- Data taking occured in sync with the 20 kHz laser pulse and was separated into pulse correlated and uncorrelated bins to catch both fast and slow fluorescence lifetimes.
- We employed a standard ON-OFF subtraction run in 200 second alternating intervals over the course of an hour per run.
- Great effort was bent towards SiPM noise reduction, including refrigeration, noise isolation and software corrections.





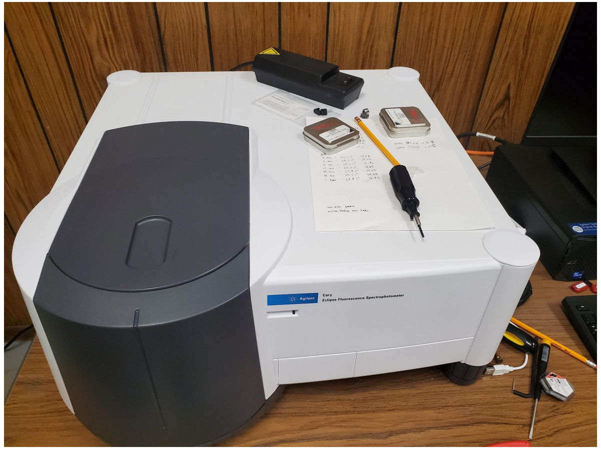
LiF sample in neutron radiation.

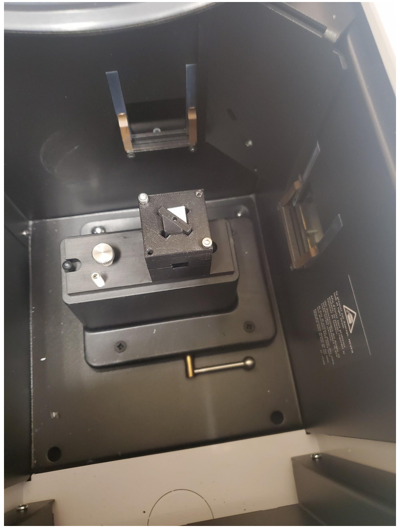
- We have successfully measured neutron radiation induced color-centers in LiF in-situ.
- This measurement verifies linear behaviour at a low neutron dose.



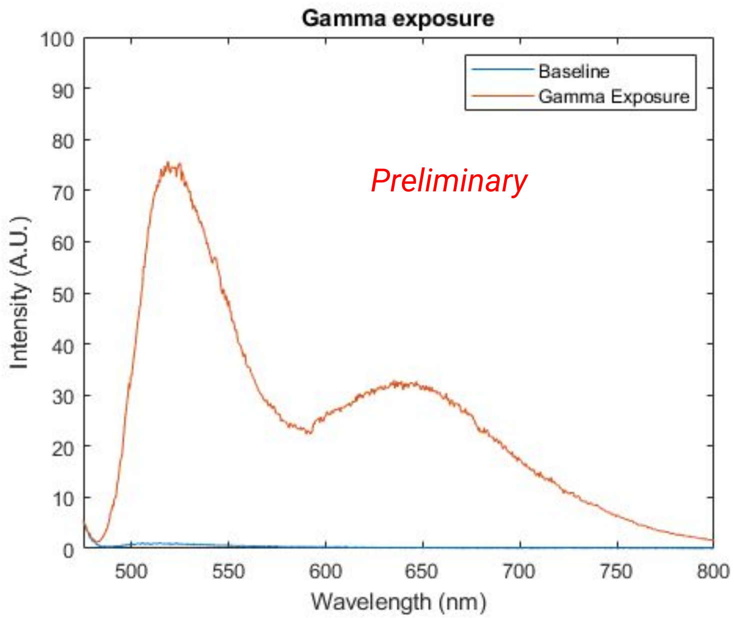
Spectroscope

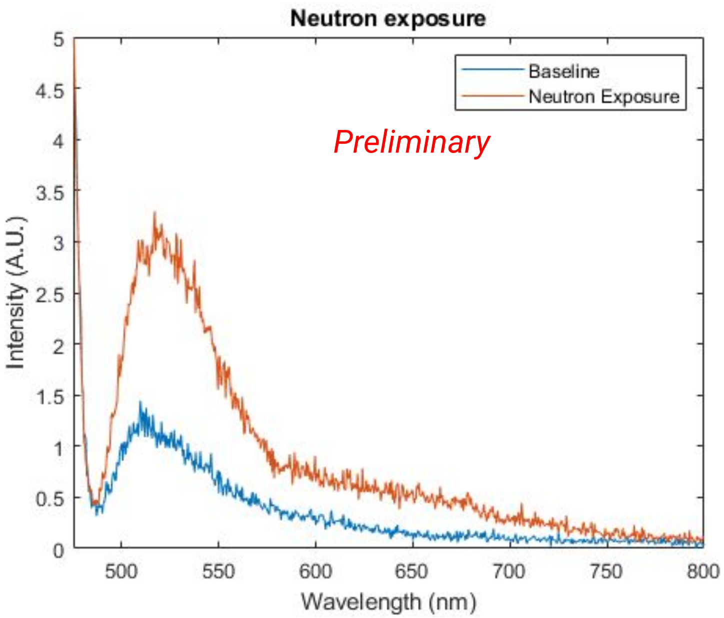
- For measurements outside of radiation, we use a commercial spectroscope.
- With the spectroscope, we can scan both input and output frequencies to hone in on color center species.
- This allows us to easily measure fluorescent spectra.





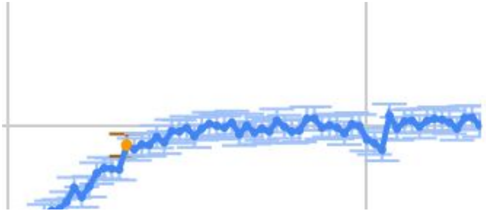
Gamma and Neutron Spectra



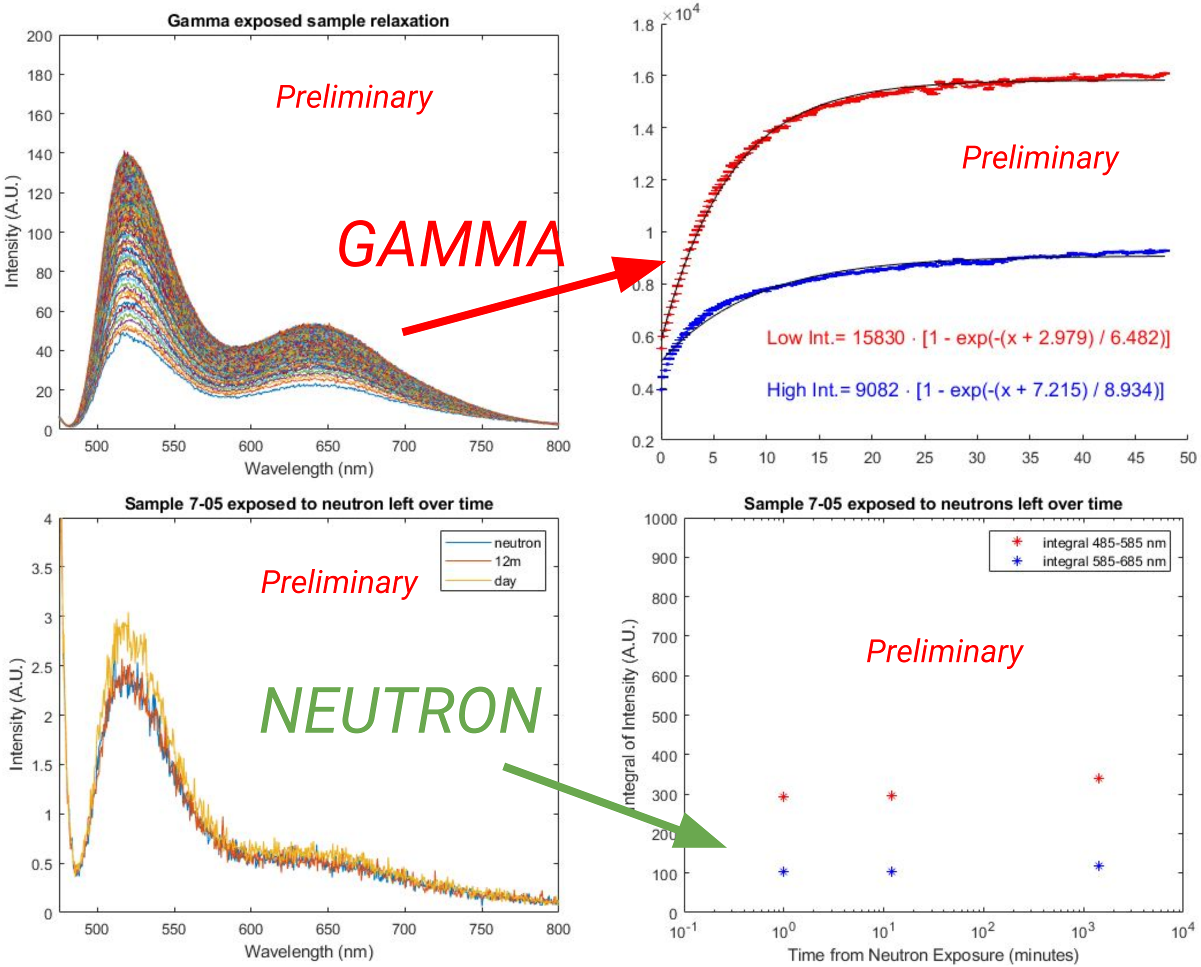


- Gamma exposed samples have a noticeable increase in the 600-700 nm region

Relaxation time

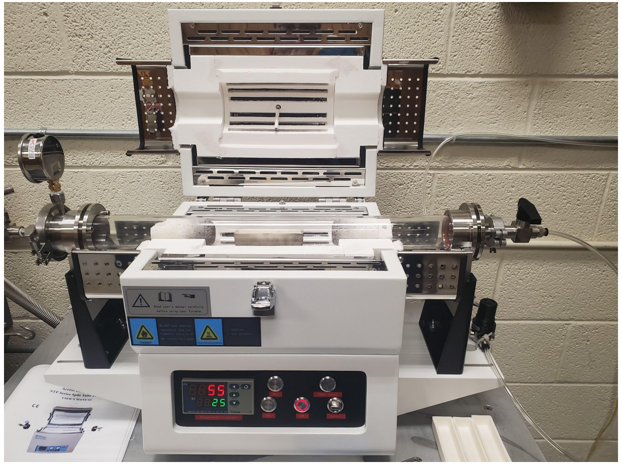


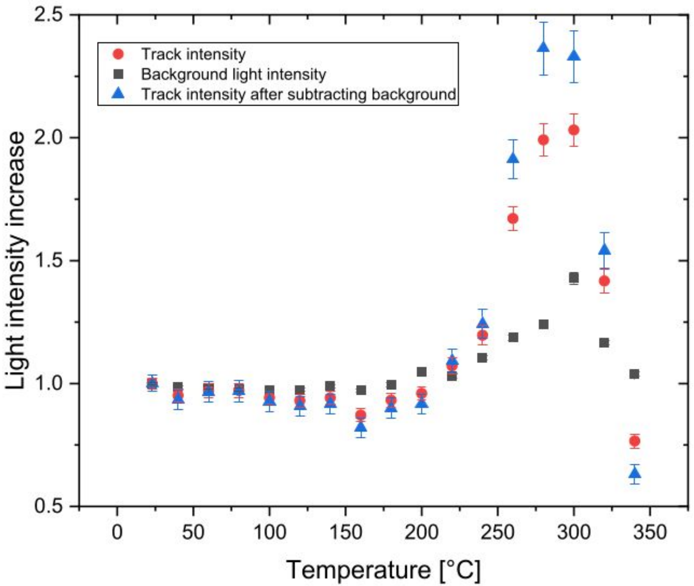
- Post exposure, there is a relaxation time before the fluorescence reaches its maximum intensity.
- This is far more pronounced in the gamma exposed samples than the neutron exposed samples.



Annealing

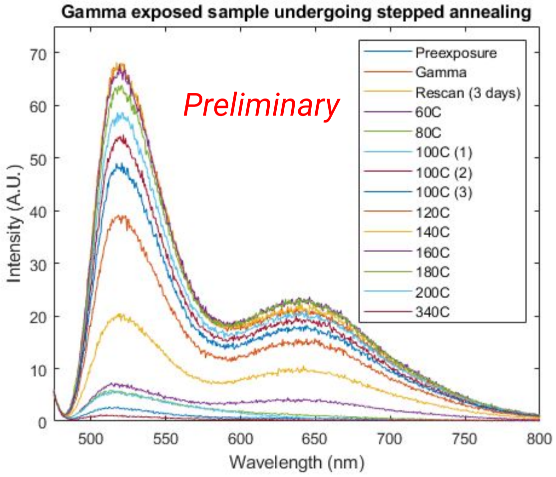
- Relaxation time suggests some internal energy dependent color center formation.
- We annealed exposed LiF samples in a vacuum oven in two hour chunks to investigate.
- Previous work with alpha irradiated LiF samples predicted an enhancement in light intensity within certain temperature ranges.

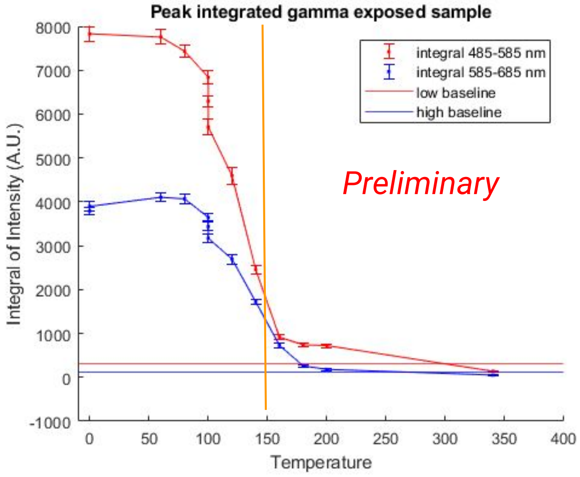


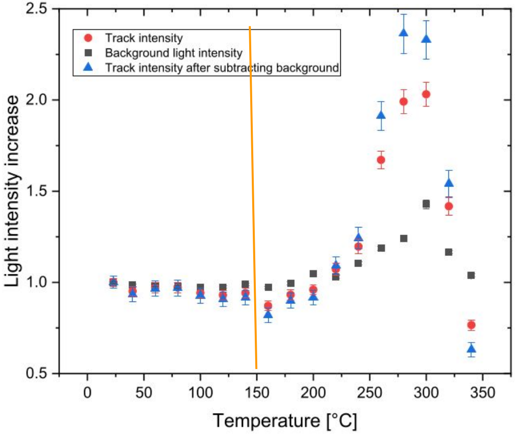


M. Sankowska, P. Bilski, B. Marczewska, "Thermal enhancement of the intensity of fluorescent nuclear tracks in lithium fluoride crystals," Radiation Measurements 157, 106845 (2022), https://doi.org/10.1016/j.radmeas.2022.106845.

Gamma annealing at different temperatures



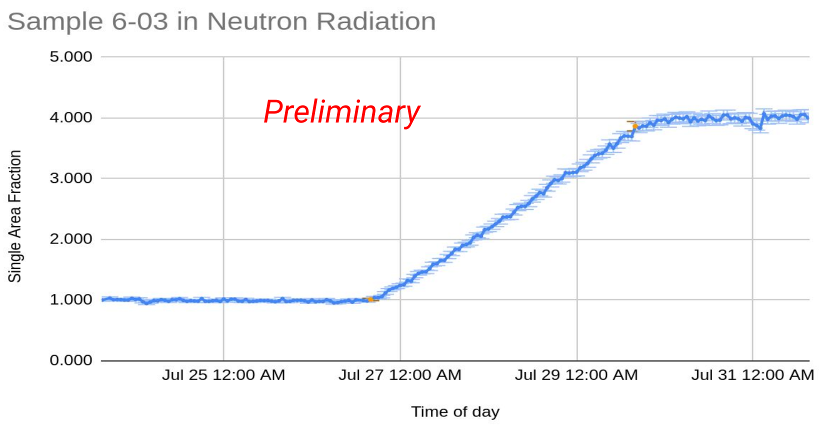


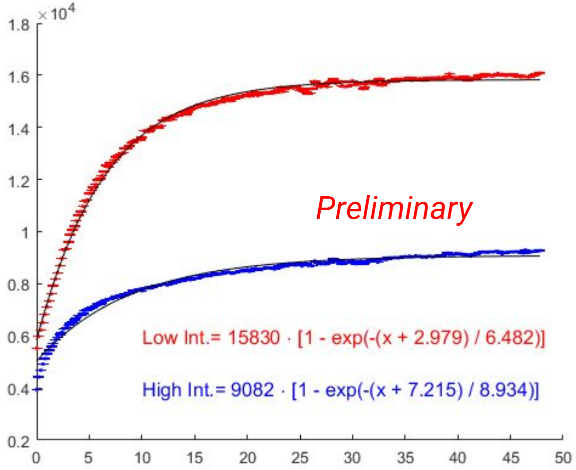


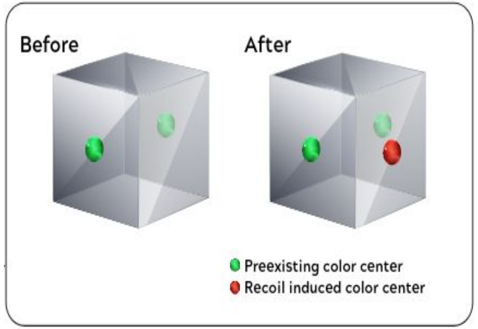
- A different LiF crystal was exposed to a half-hour of gamma radiation, then was annealed in 2 hour intervals at steadily increasing temperatures.
- For now, we see no dramatic increase in fluorescence.

Summary

- We use crystals as passive detectors for nuclear recoils
- Even without individual track resolution our lab is capable of studying interesting macroscopic properties of samples.

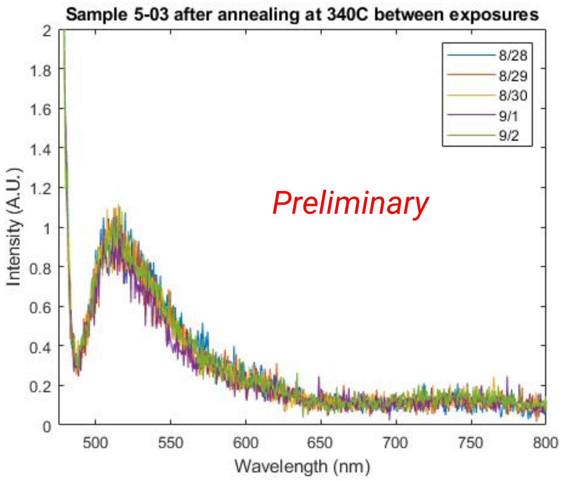


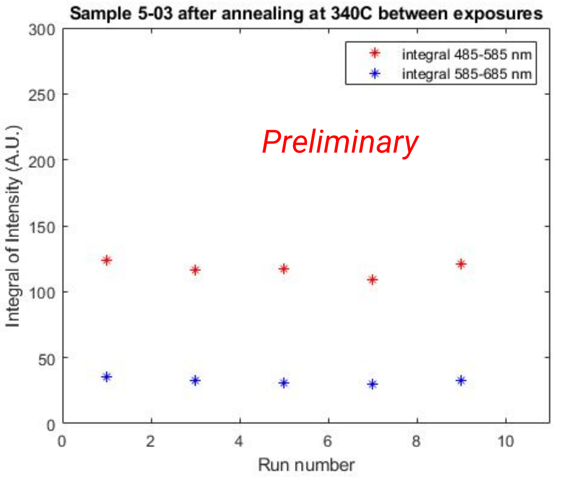




Is there history?

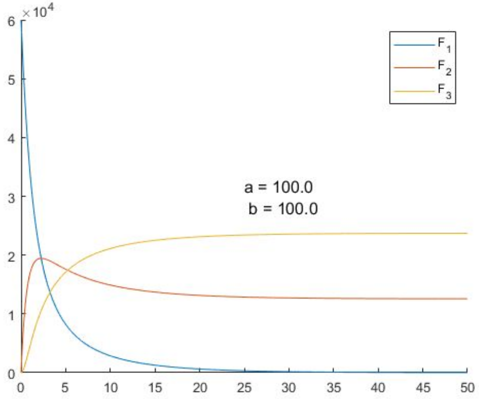
- Re-exposing the sample to gamma irradiation, then annealing at 340C shows that the sample can be reset to a baseline
- This allows us to reuse samples.

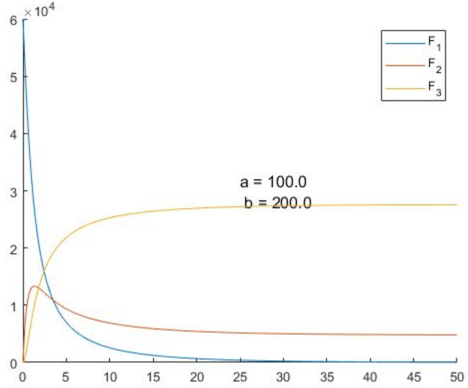


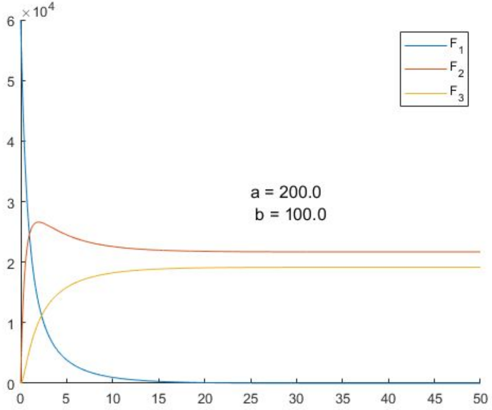


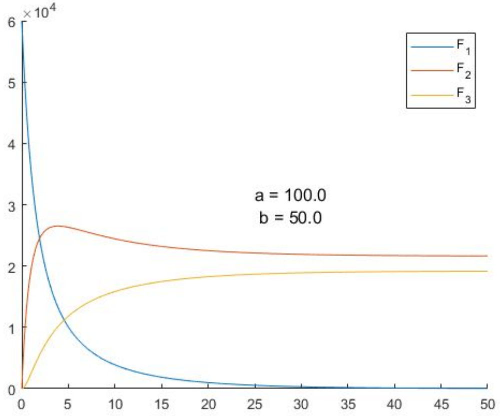
Kinetic Gas Model?

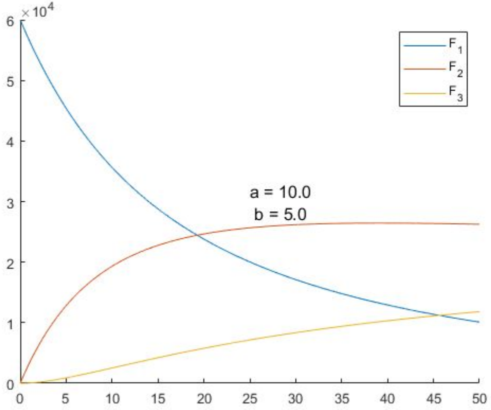
$$[F1]' = -a[F1][F1] - b[F1][F2]$$
$$[F2]' = +a[F1][F1] - b[F1][F2]$$
$$[F3]' = +b[F1][F2]$$



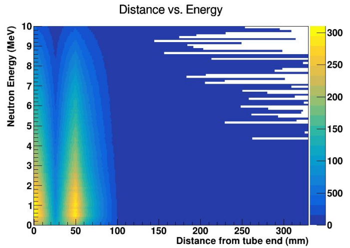


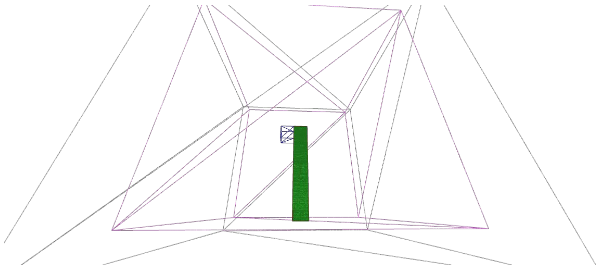


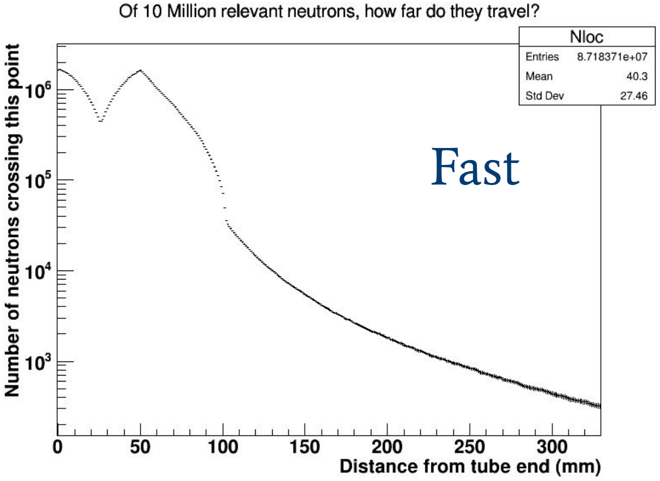


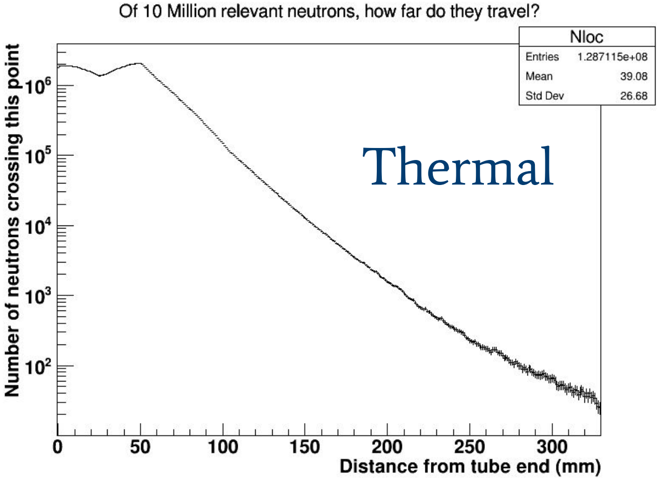


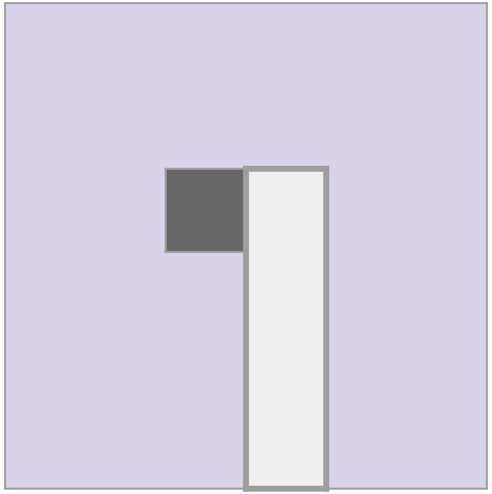
Neutron simulation







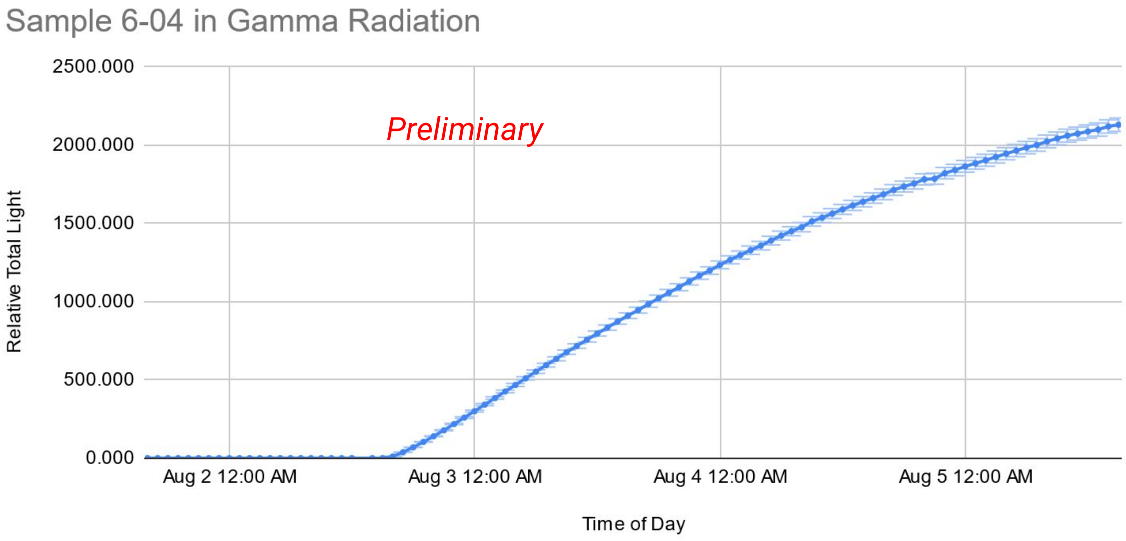




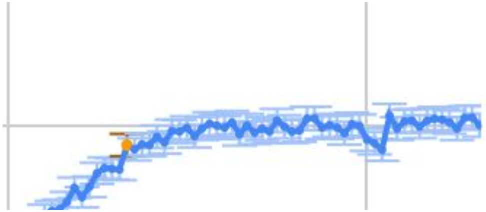
- Simulation allows us to estimate fast and thermal neutron doses.

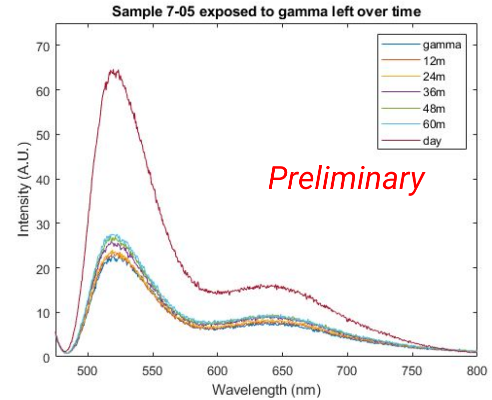
LiF sample in gamma radiation.

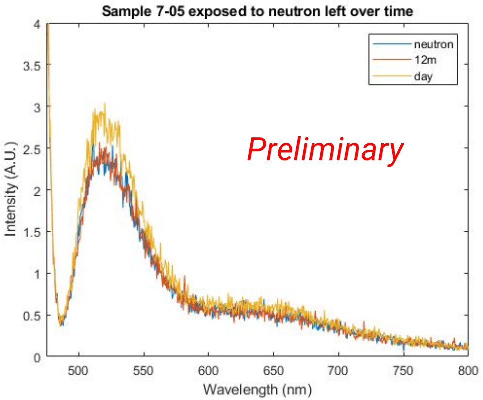
- Gamma radiation results in a much more rapid production of color-centers in LiF.
- The slight curvature is due to some light being out of measurement range at higher values.

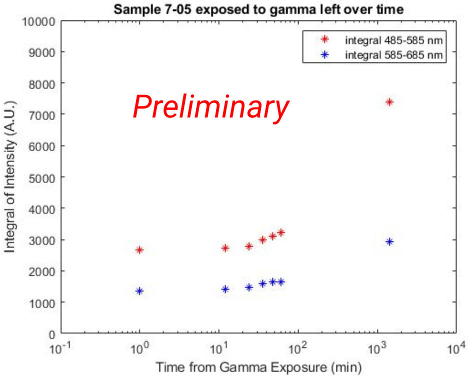


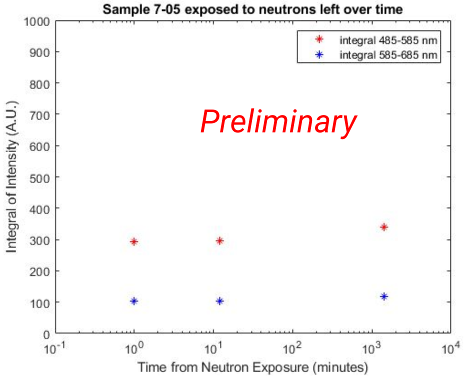
Relaxation time











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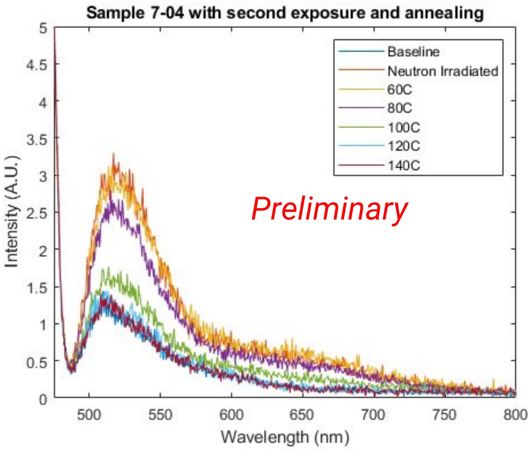
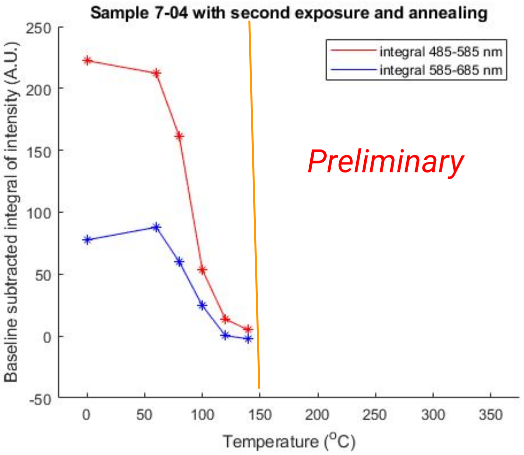
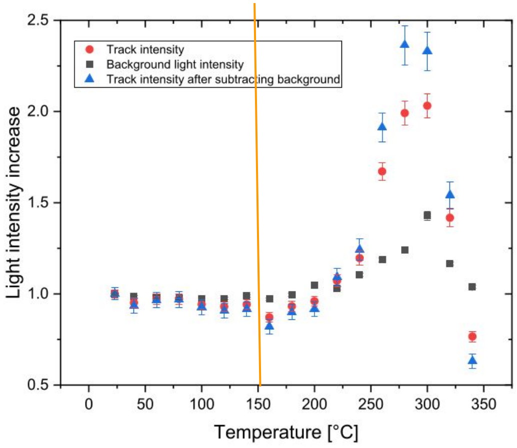
Neutron Annealing

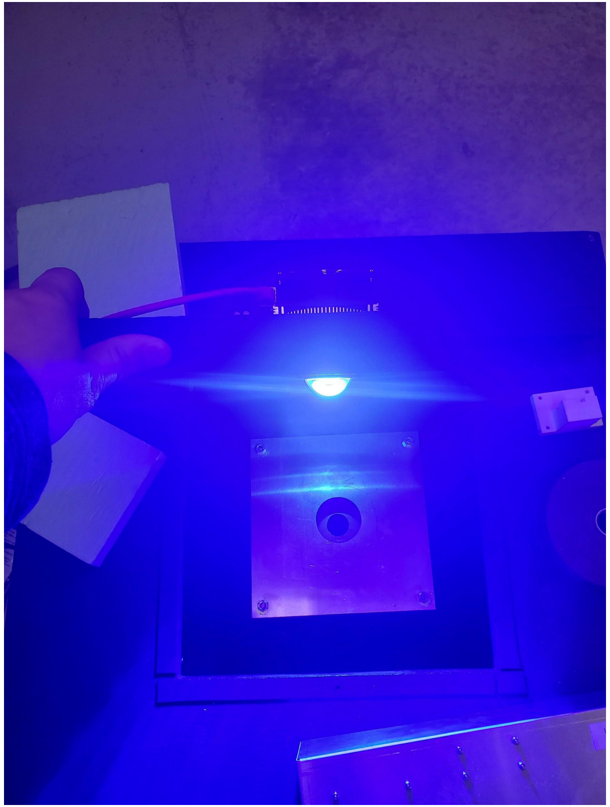






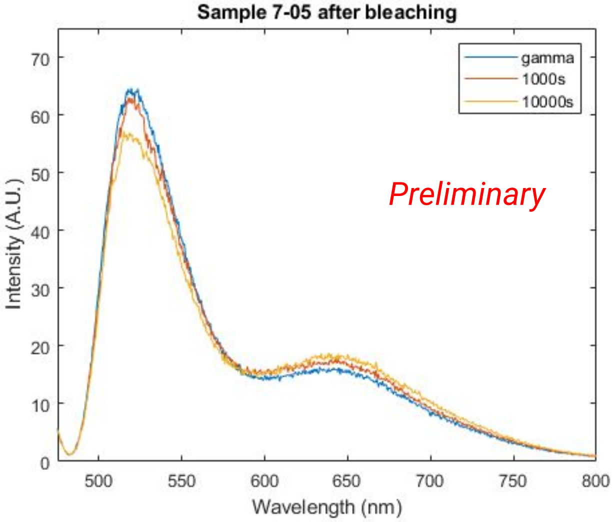
- A fresh sample was exposed to fast neutrons, then annealed and exposed again
- Surprisingly, even annealing at the low temperature of 120C resulted in a reset to baseline
- The alpha exposed sample in literature report no significant change up to 200C

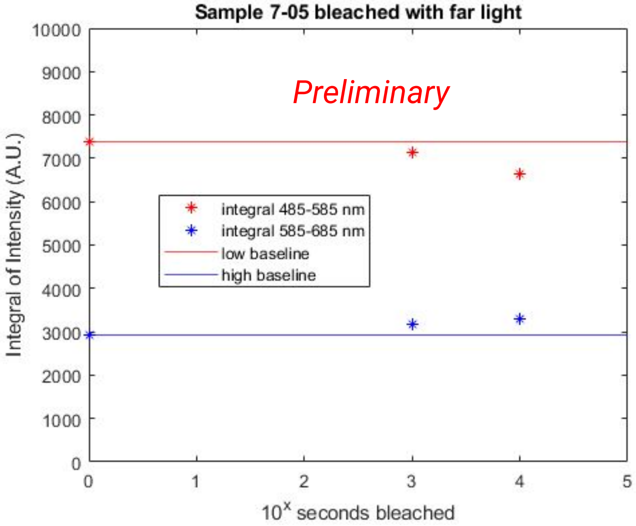
Bleaching



- Another method capable of resolving individual tracks within the sample is light sheet microscopy.
- As the name suggests light sheet microscopy uses a high intensity light.
- Samples scanned under this method were observed to undergo “bleaching”, which we investigated using an LED light.

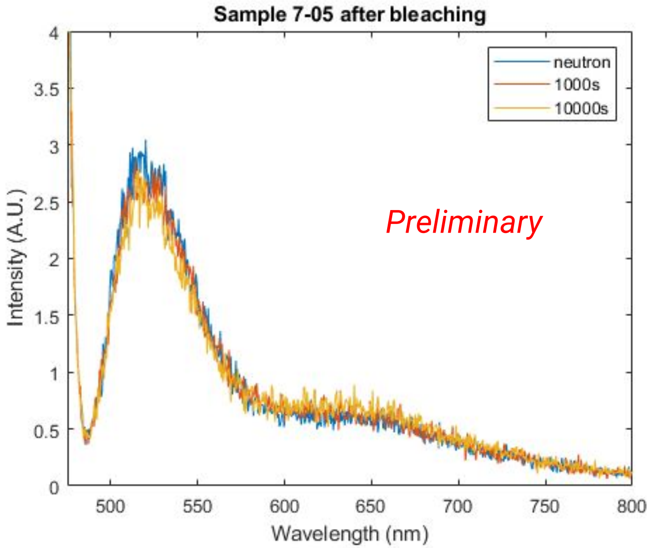
Gamma bleaching

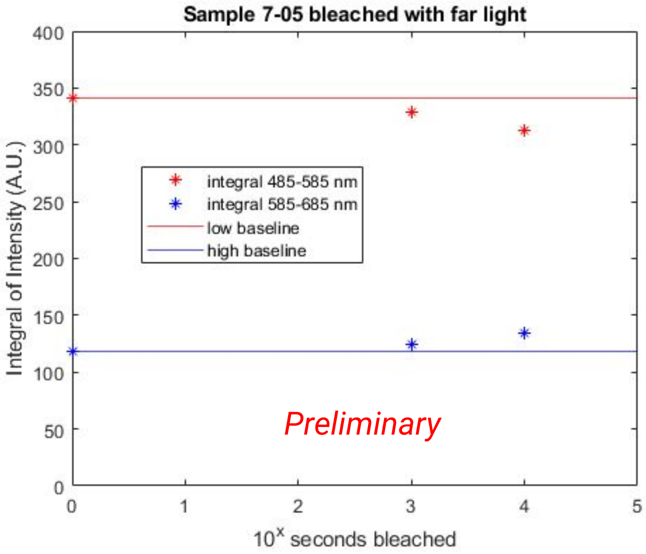




- Gamma exposed sample was subjected to bleaching with an estimated flux of 42 mW/cm^2
- There is a visible shift from low wavelength to high wavelength.
- Bleaching appears to have a small effect on fluorescence at this level.

Neutron bleaching

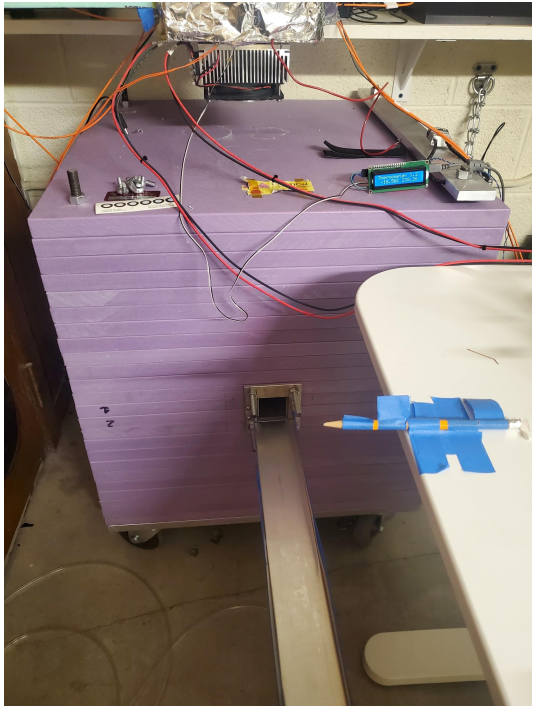


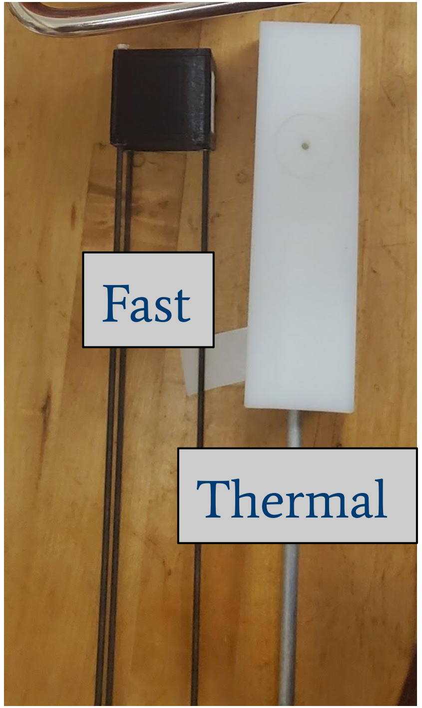


- The same bleaching was performed after neutron exposure with similar results
- The mesoSPIM achieves a much higher photon flux and there bleaching needs to be carefully managed (see a future talk by G. Araujo)

Neutron radiation

- We cut a tube into the bulky borated HDPE shielding to allow for safe sample exposure.
- We use a ‘open’ sample holder to get fast neutron radiation and a closed HDPE plug holder to get thermal neutron radiation.





Outline

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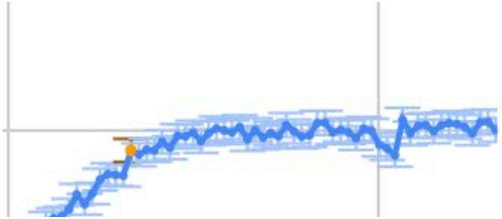
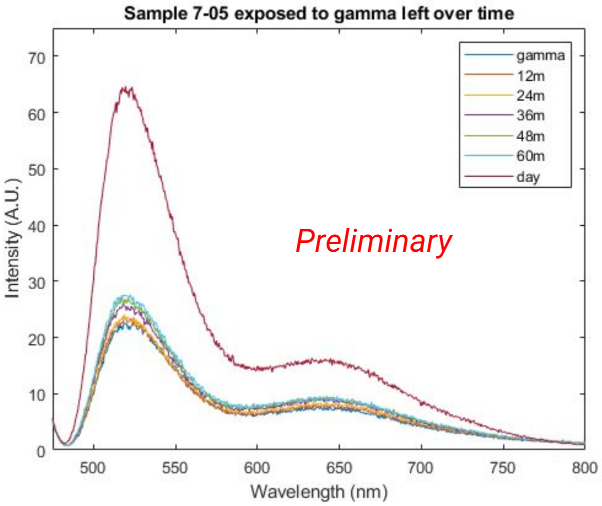
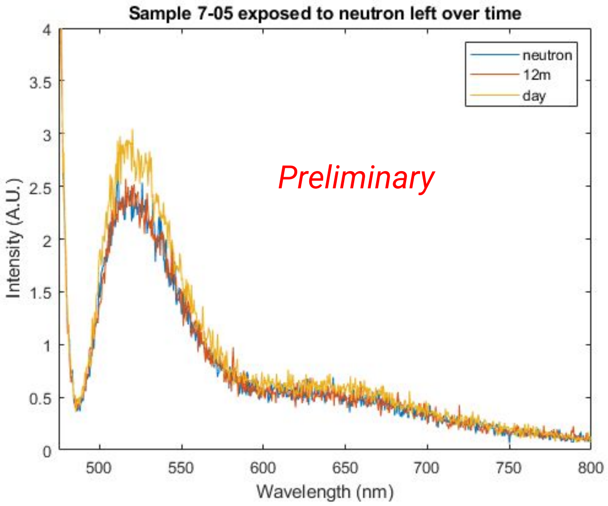
- 19-20 Bleaching results

Relaxation time

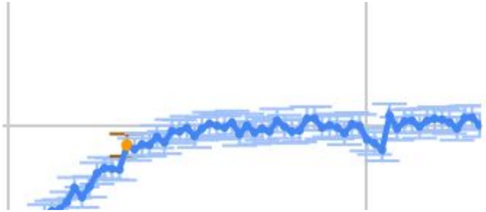


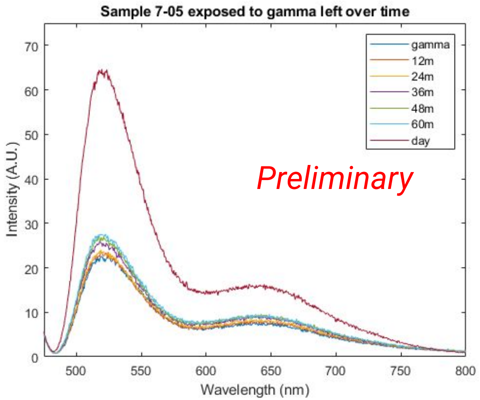


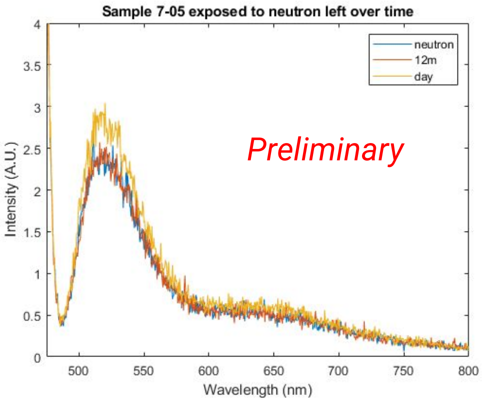


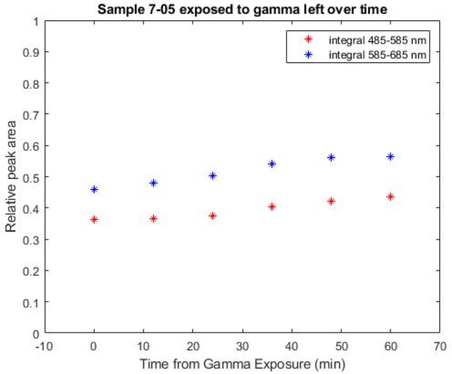
- Post exposure, there is a relaxation time before the fluorescence reaches its maximum intensity.
- This is far more pronounced in the gamma exposed samples than the neutron exposed samples.

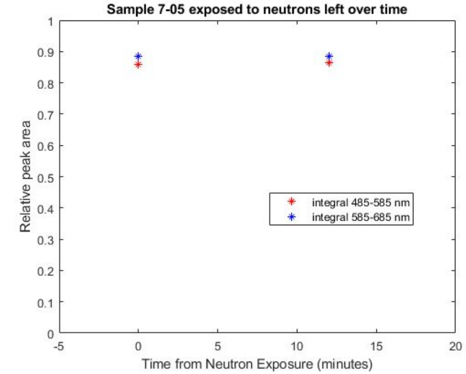
Relaxation time





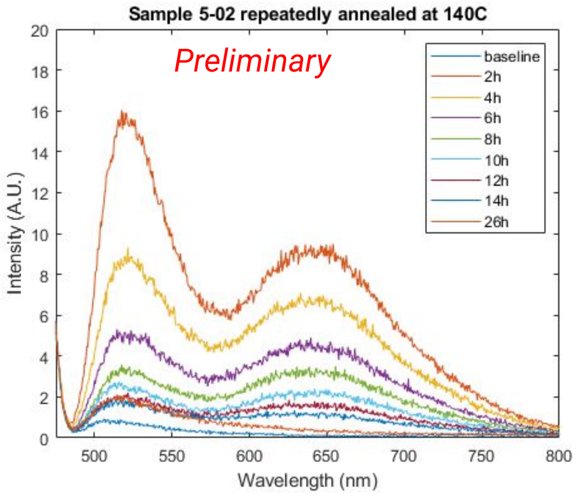


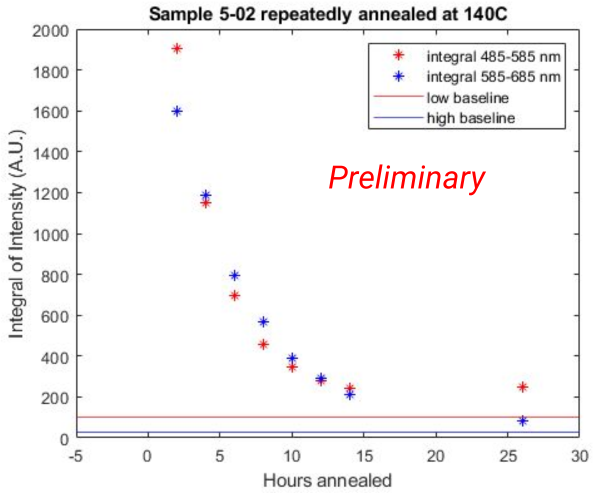




- Post exposure, there is a relaxation time before the fluorescence reaches its maximum intensity.
- This is far more pronounced in the gamma exposed samples than the neutron exposed samples.

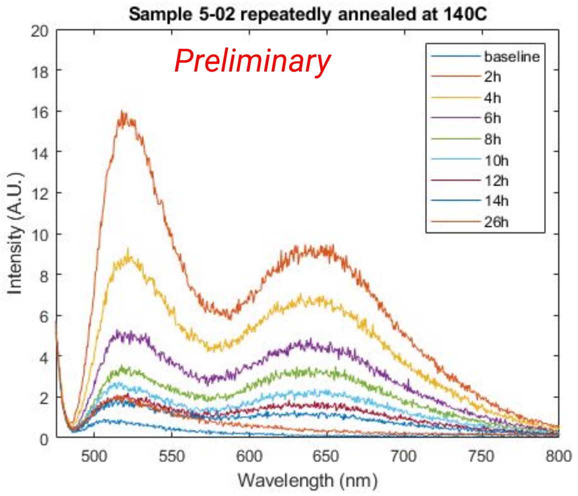
Repeated low temperature annealing

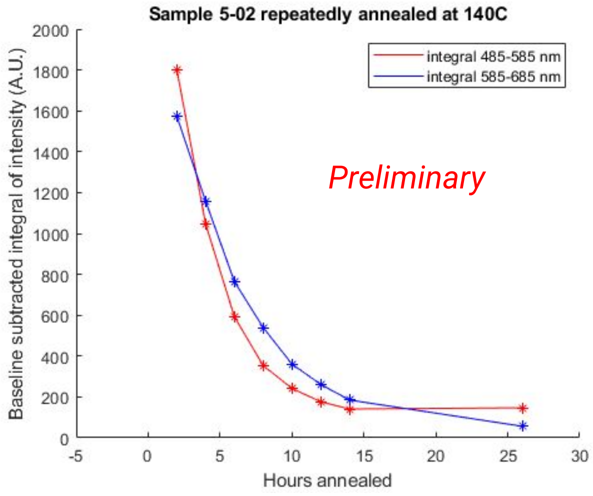




- I exposed the LiF sample to a half hour of gamma radiation then annealed at low temperature.
- The change in intensity from a repeated temperature suggests time-dependent process.
- The spectral peaks undergo separate changes.

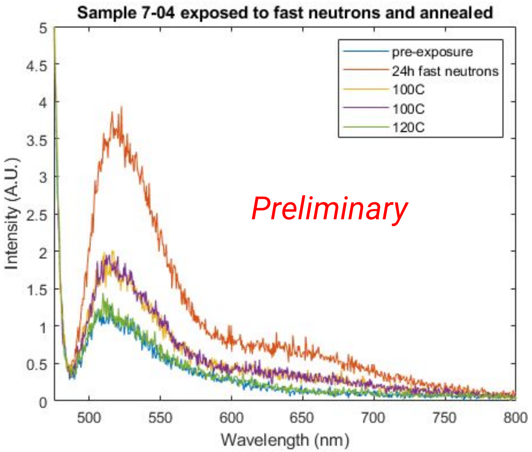
Same temperature annealing

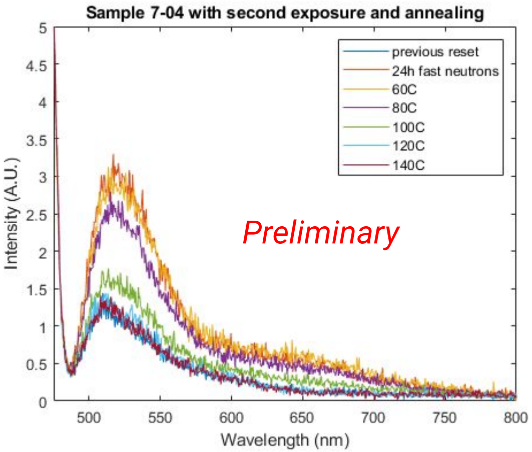


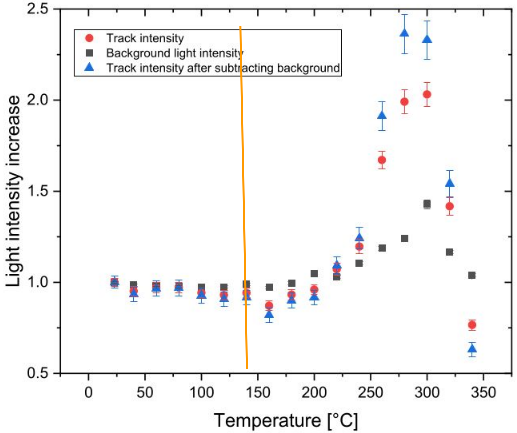


- I exposed the LiF sample to a half hour of gamma radiation then annealed at the same low temperature.
- The change in intensity from a repeated temperature suggests time-dependent process.
- The spectral peaks undergo separate changes.

Neutron Annealing

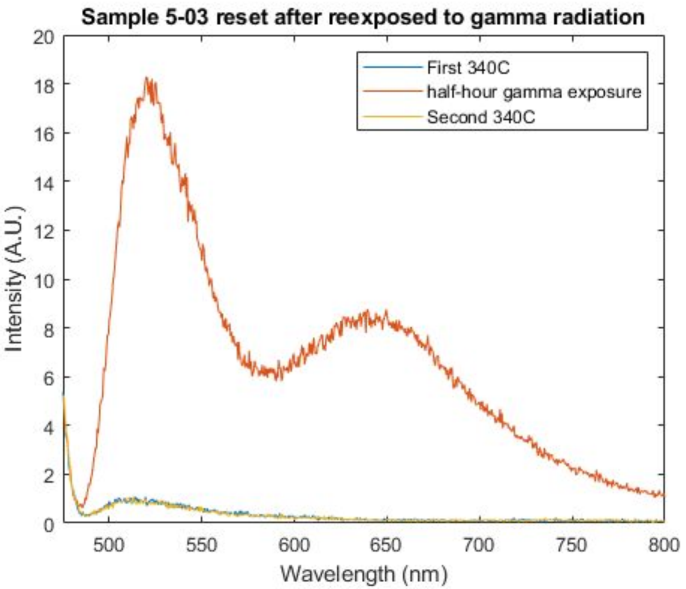


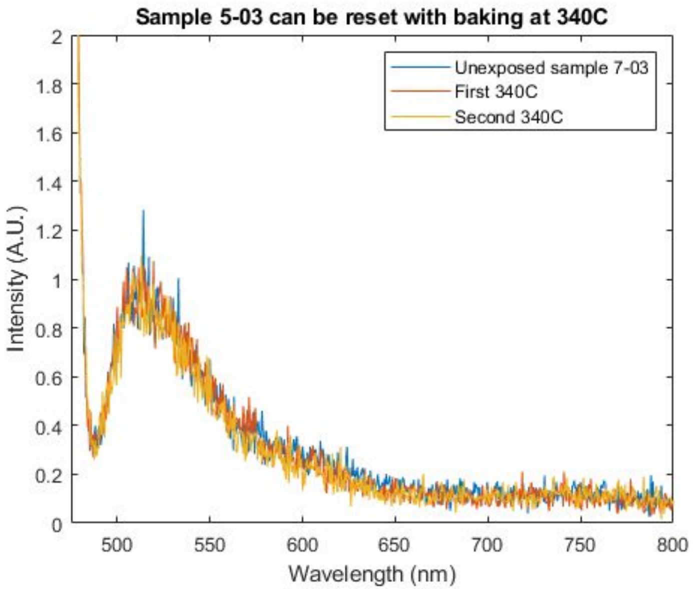




- A fresh sample was exposed to fast neutrons, then annealed and exposed again
- Surprisingly, even annealing at the low temperature of 120C resulted in a reset to baseline
- The alpha exposed sample in literature report no significant change up to 200C

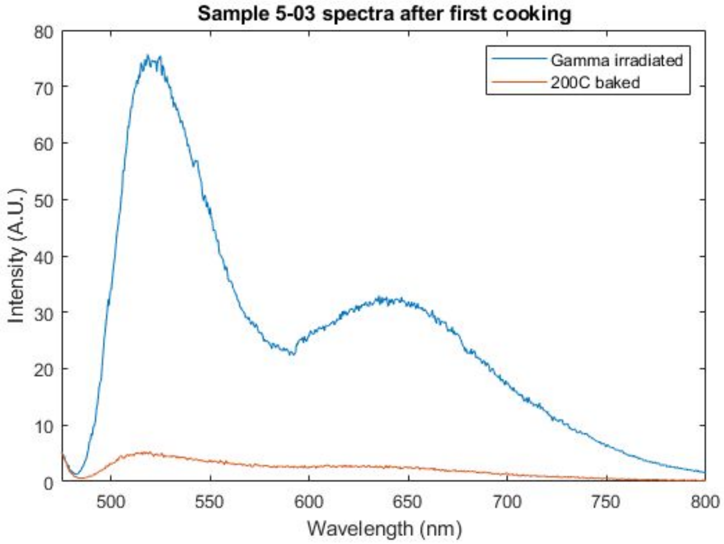
Is there history?

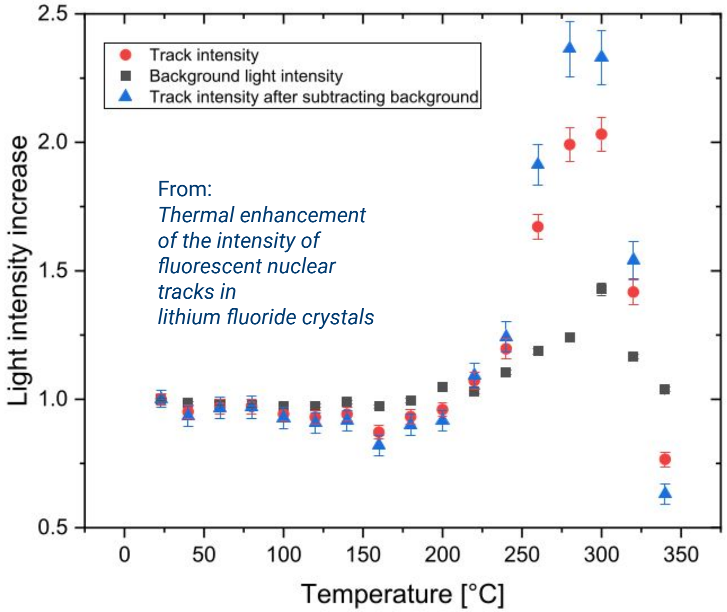




- The spectra after annealing is comparable to a separate, unexposed sample.
- This allows us to reuse samples.

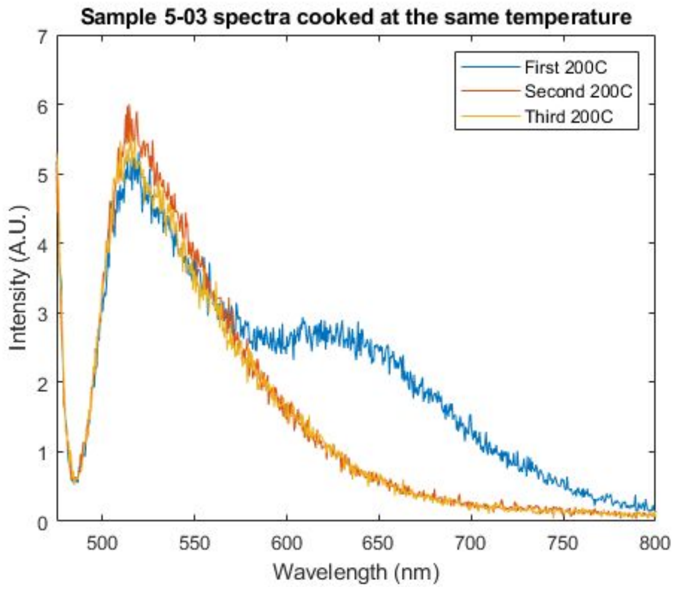
First Annealing

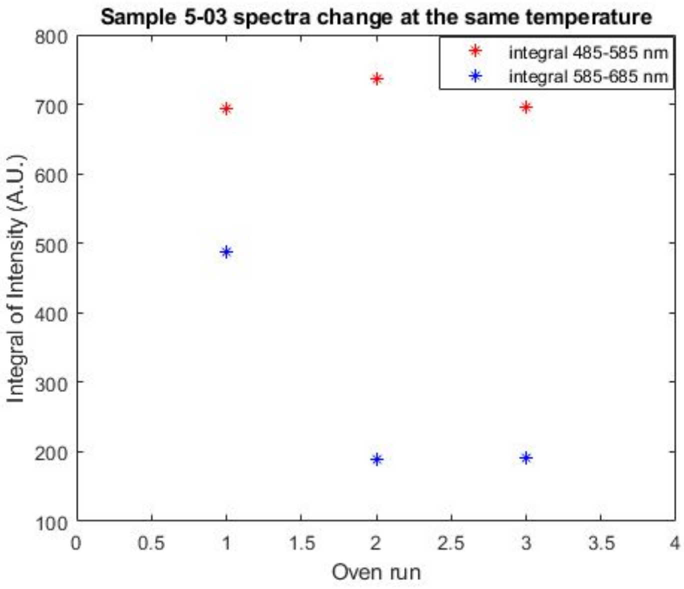




- Annealing at 200C shows severe reduction in light intensity
- Previous work with alpha exposed LiF sample showed slight increase at 200C

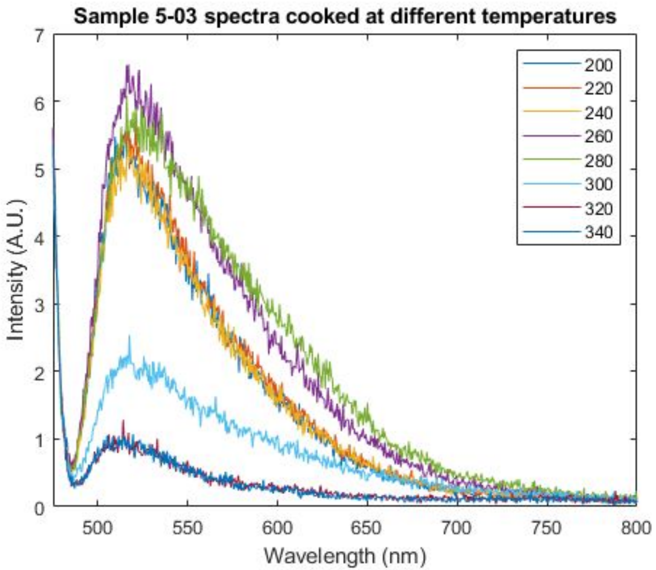
Annealing at the same temperature

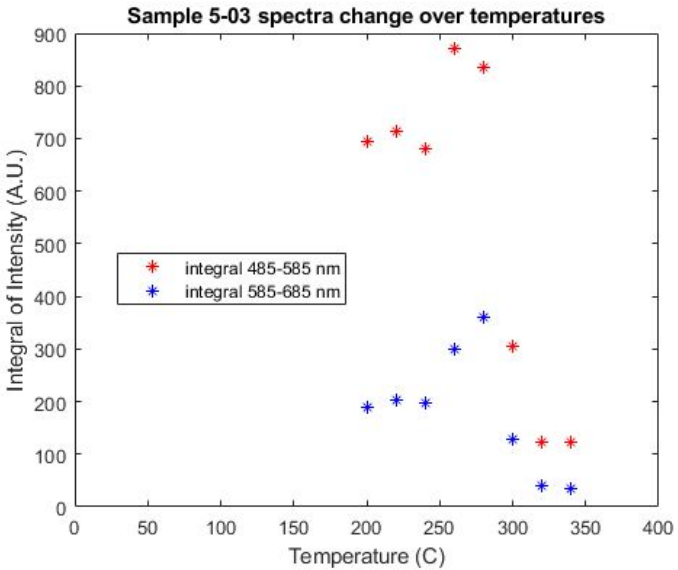




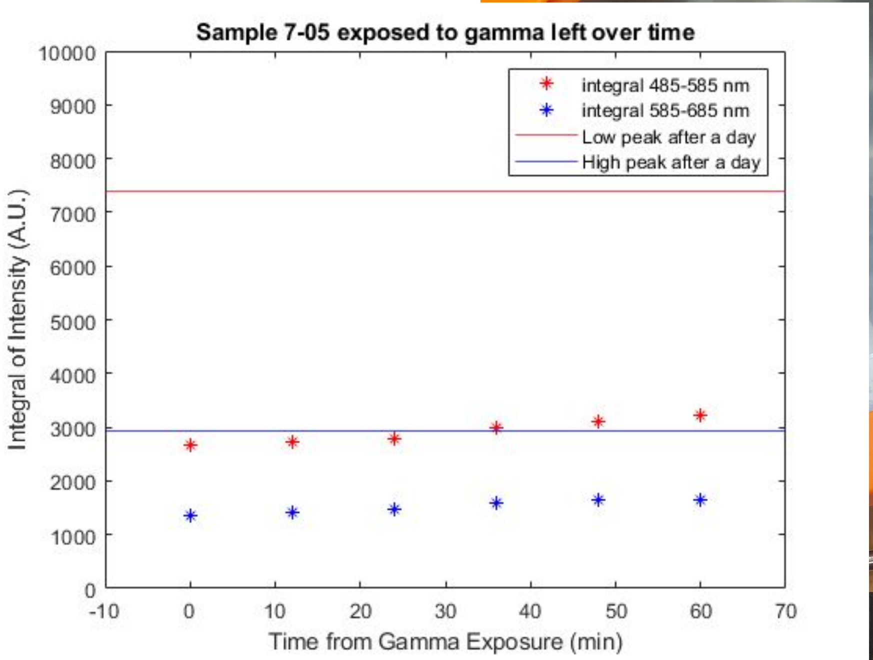
- Annealing at 200C again reduces the high wavelength peak without reducing the low wavelength peak much.
- A third annealing at 200C shows minimal change to the spectra.

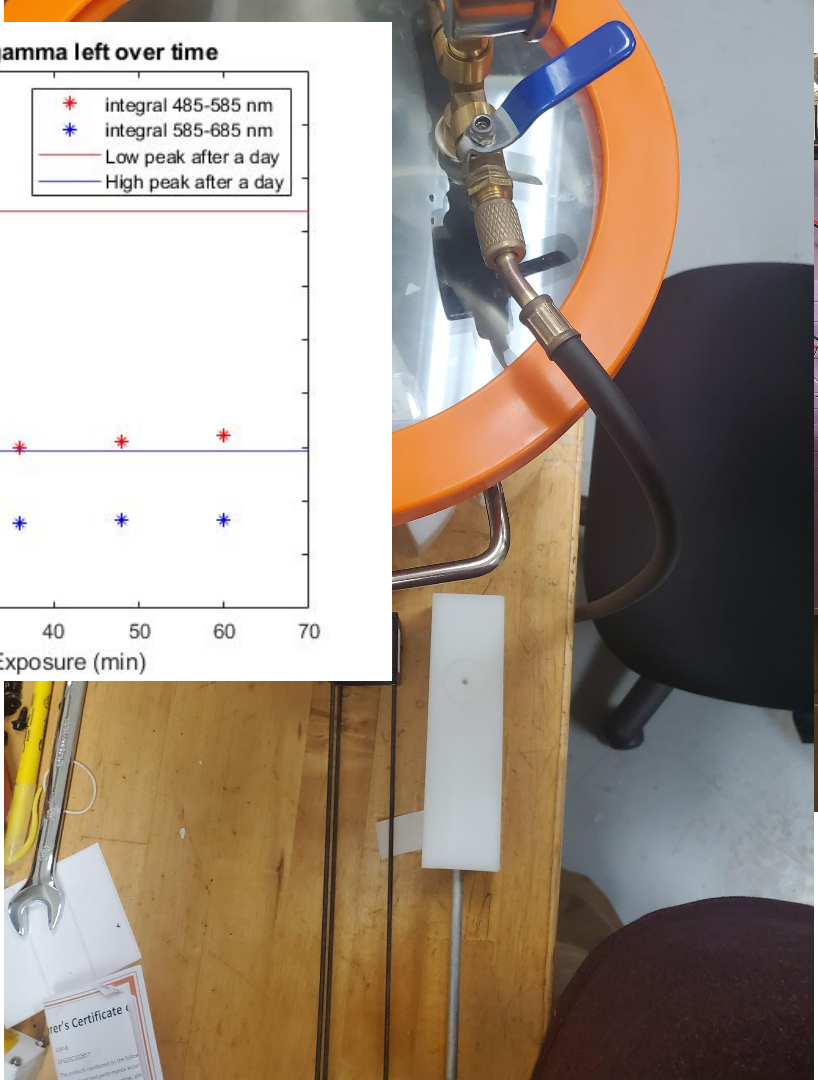
Cooking at increasing temperatures

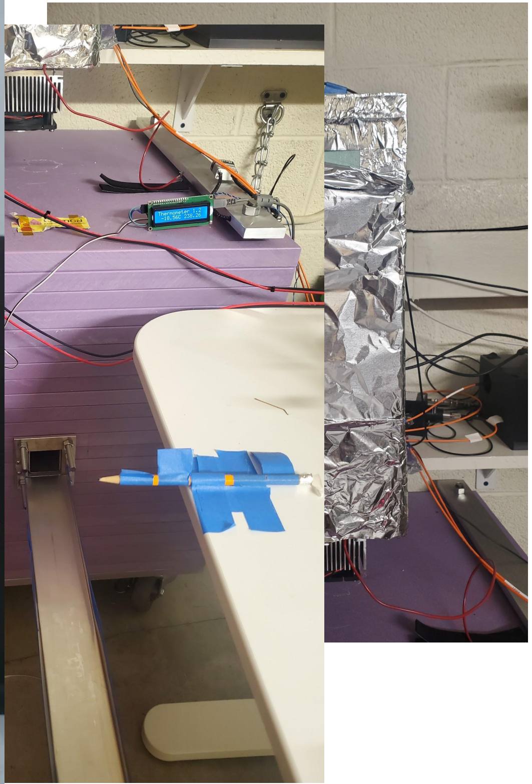




- Cooking at increasing temperatures shows a similar uptick in light intensity to the alpha exposed sample, albeit peaking at lower temperature.
- I don't know what to use for uncertainty here.
- Do we want to redo that Polish paper more precision in the uptick region and with gamma exposure or is it sufficient to show that baking let's us re-use crystals?


Sample 7-05 exposed to gamma left over time
integral 485-585 nm
integral 585-685 nm
Low peak after a day
High peak after a day
Integral of Intensity (A.U.)
Time from Gamma Exposure (min)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-10
0
10
20
30
40
50
60
70





Bleaching (LED)

- Gamma exposed sample was bleached using LED light.
- When resting on the wooden block, the sample holder got very hot, eventually melting.
- I moved the sample off of the block, but with 1 hour exposure I measured 56C° with the laser thermometer.
- I can't tell if effects are from bleaching or heating the sample.