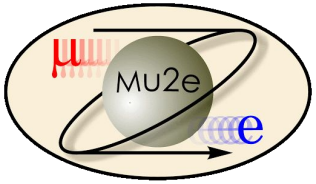

TiO_2 Coupon Reflectivity and Aging Study

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Scintillator R&D Workshop
5/19/23

MICHIGAN

Fermilab

Overview

- Aging, reflectance over time studies
  - Coupons: USPN115101
  - Standards: NOvA N-27-09-NC, GoreDRP
  - Extrusions: thin extrusions, polymer and cladding sides
  - Results
- Reflectance metric
  - Defining a metric to decouple POPOP fluorescence over time
  - Reflectance metric over time
  - Stability measurements
  - Results

Aging Study: Measuring Reflectance Over Time

Quick intro:

- I measured that the Mu2e CRV is aging at a higher overall rate than expected, around 8% per year based on the first year of preliminary cosmic ray data at Wideband
- The reason for high CRV aging rate is not understood, is one component of the CRV bars responsible for aging?
  - Components: cladding, fibers, scintillator
- If the cladding changes in reflectivity over time, could it have a significant impact on the light yield in the CRV bars?... change mean number of bounces that light has with the cladding surface?

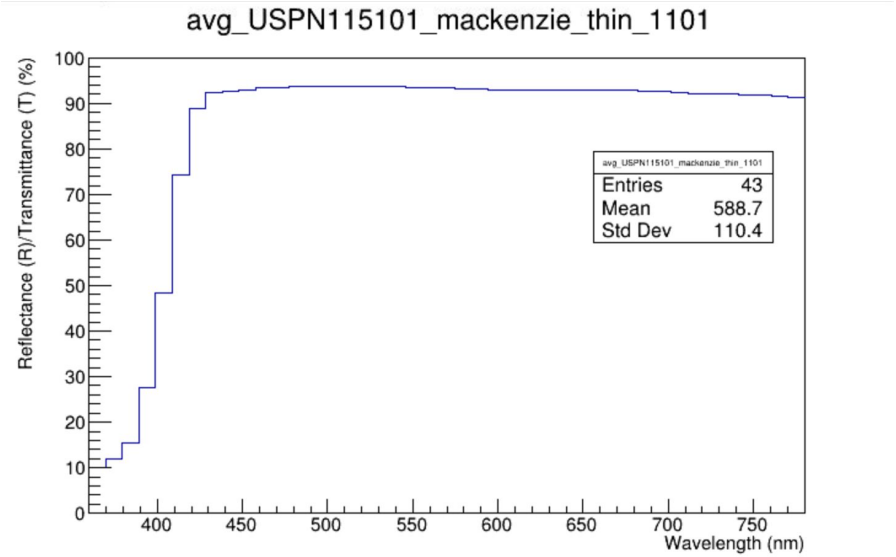
Methodology of Reflectance Over Time

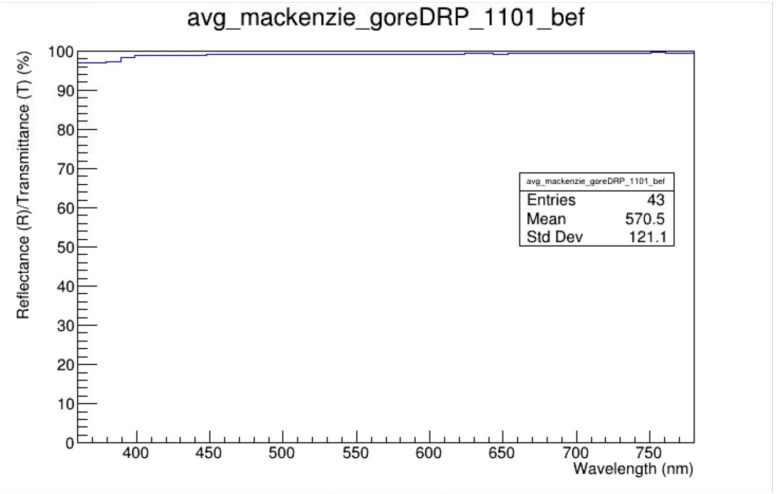
- Using the HunterLabs UltraScan VIS Reflectometer in Lab 6, the reflectivity of different samples has been measured on a ~weekly basis for some time
- If we track the reflectivity over time, do we see a trend?
- Often have multiple samples or take multiple measurements on one sample to get standard deviation errors
- Reflectometer instrument presents data as R/T%, this really just means R

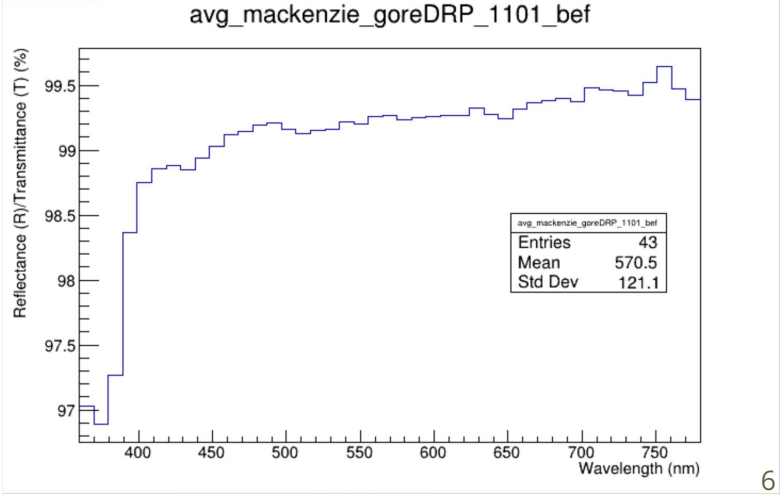
Measurement Samples and Dates

- TiO2 cladding coupon: USPN115101
  - This is the coupon batch that we received in March 2022 while I was at the lab. This sample has been regularly measured since arrival at Fermilab, beginning 3/17/22
- Standards: NOvA N-27-09-NC and GoreDRP
  - The NOvA sample has always been used to calibrate the reflectometer, it is a well-known sample that has been in use for some time
  - GoreDRP is a highly reflective material with a relatively flat spectrum on the relfectometer. Measurements on this standard began 8/31/22
- Scintillator extrusion samples
  - Machined by Alan to be thin samples, though a small amount of polymer is present on the inner side of the sample. Both sides have been measured since 9/6/22
  - 10 of these samples produced, 5 chosen at random for each measurement

Reflectometer Spectra Examples







Average Results and Interpretation

- These results are averages across all wavelengths from 1D histograms of slopes from all wavelengths, sign indicates direction of aging
- TiO2 coupons:
  - Thin side: -0.41% ± 0.12% lost per year
  - Thick side: -0.22% ± 0.10% lost per year
- Extrusion samples:
  - Polymer side: +0.87% ± 1.2% gained per year
  - Cladding side: -0.58% ± 0.99% lost per year
- Standards:
  - NoVA N-27-09-NC: +0.62% ± 0.23% gained per year
  - GoreDRP: +0.16% ± 0.14% gained per year

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Ignore these two samples:

Polymer side of extrusion samples likely have POPOP fluorescence

NOvA sample not well understood now, is old and not sure why positive slope

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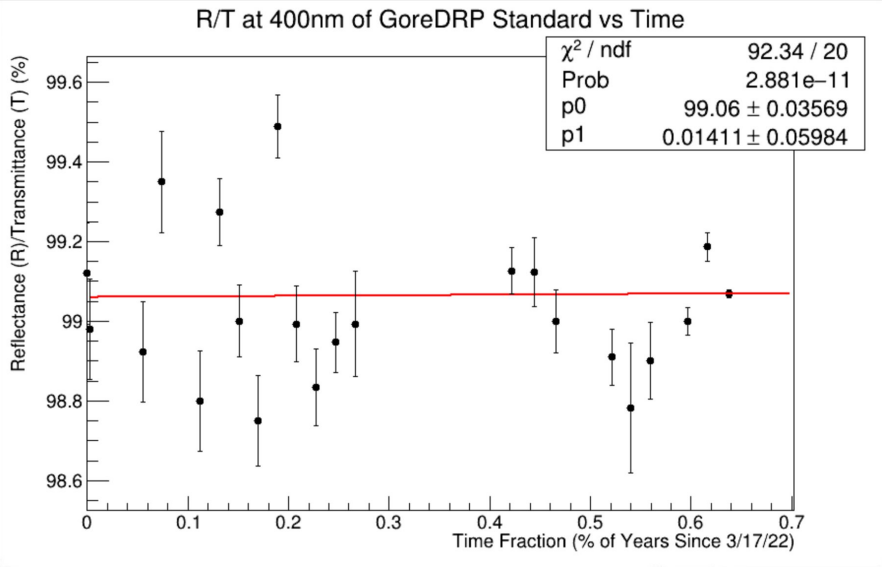
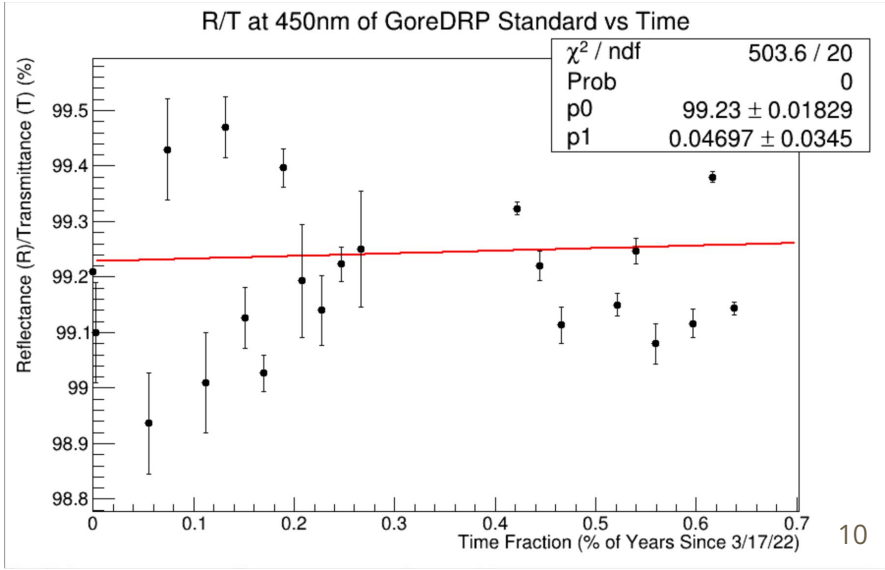
TiO2 coupon samples give reasonable slopes, as does the cladding side of the extrusions

Use GoreDRP as standard, this is very stable as expected

GoreDRP Standard Plots

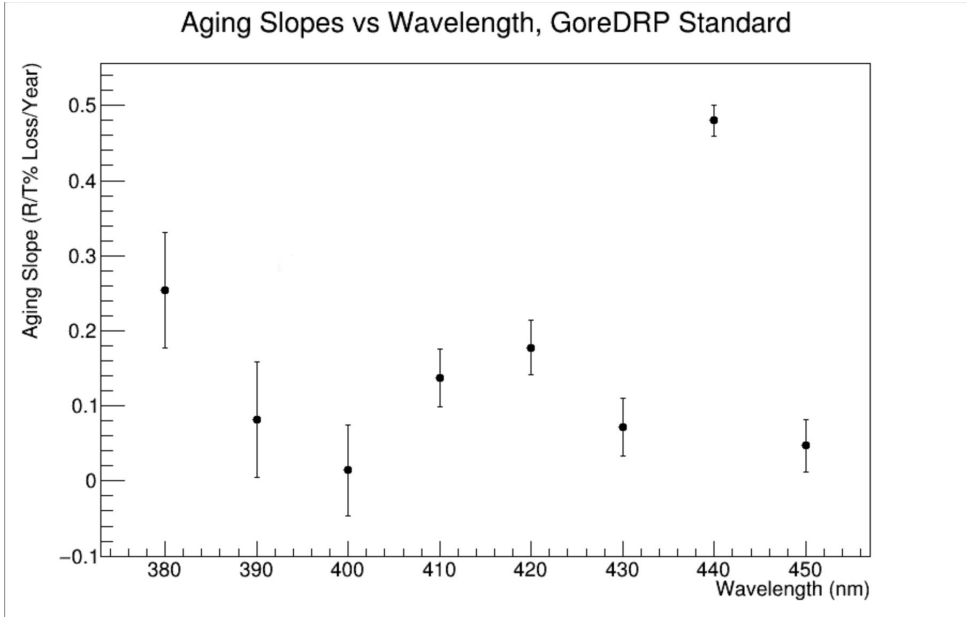
- As mentioned on previous slide, the GoreDRP standard is a very stable sample with nearly no signs of aging over the measurement period
- Error = standard deviation of repeated measurements on one sample





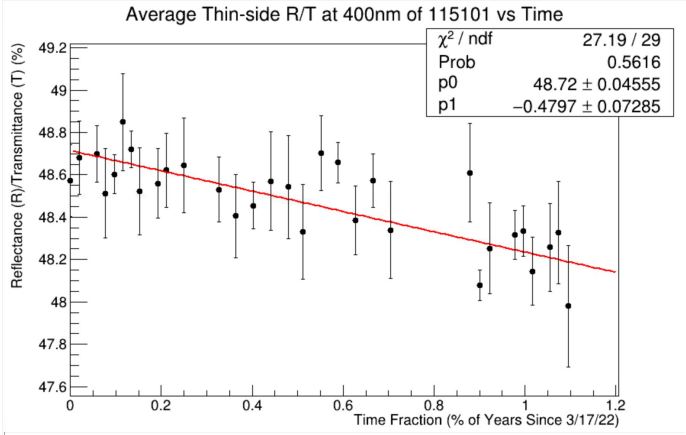
GoreDRP Summary by Wavelength

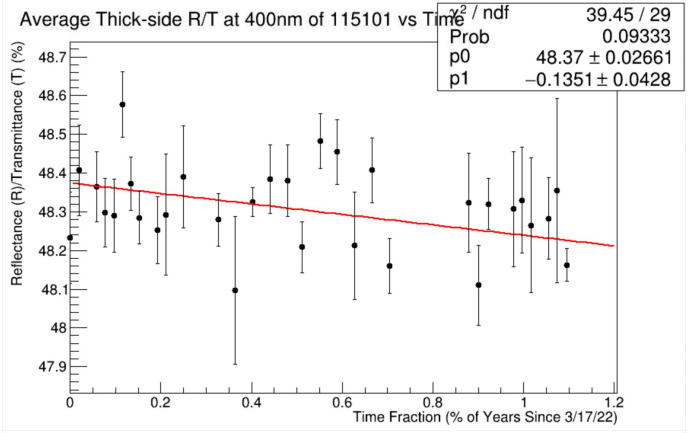
- Most wavelengths have aging slope of 0.1%
- Besides λ = 440nm, not much structure in different wavelengths
- Error here is ROOT error on the slope parameter from previous linear fits

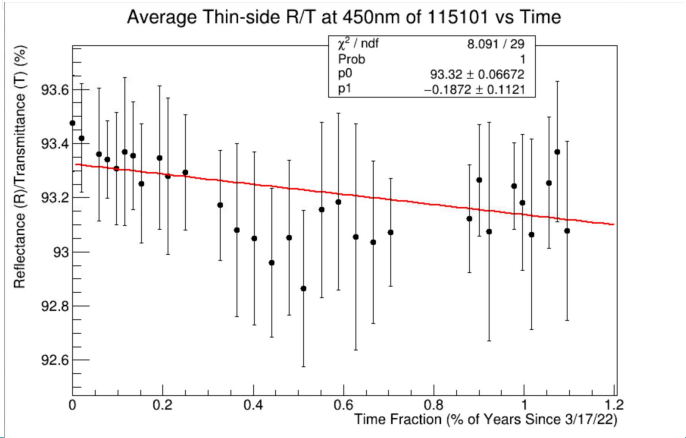


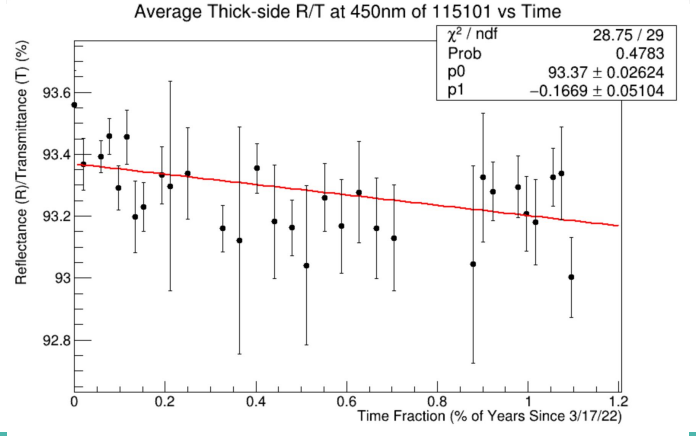
TiO2 Coupon Plots

- Error = standard deviation of measurements on the 4 different coupons



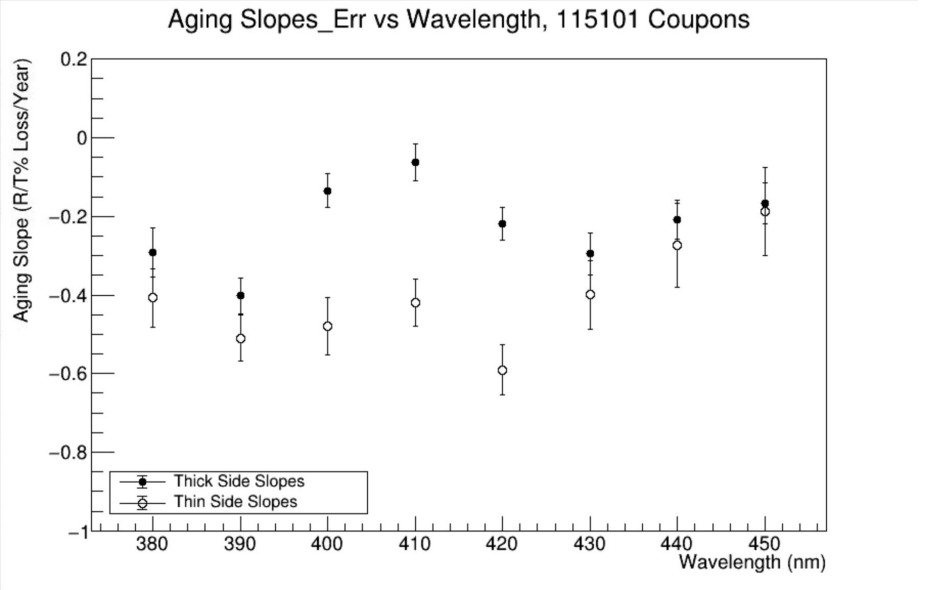






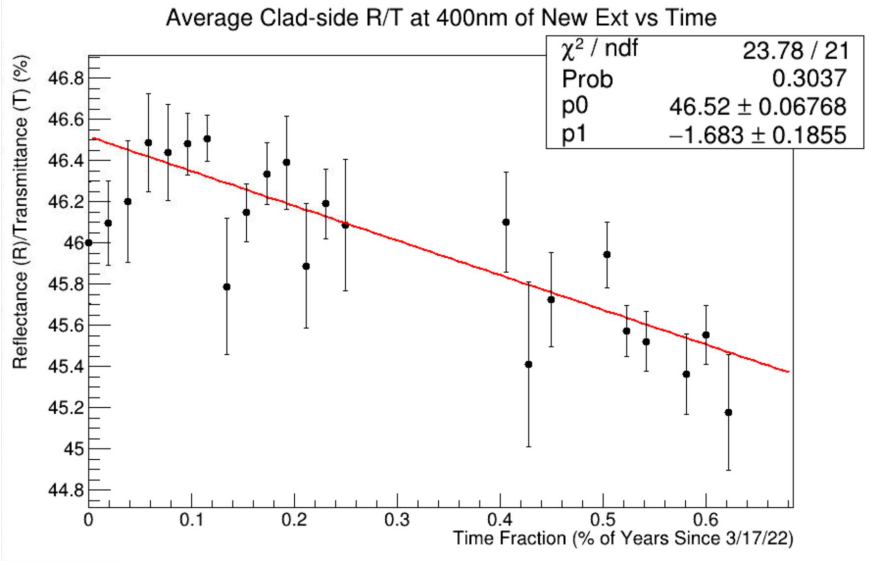
TiO2 Summary by Wavelength

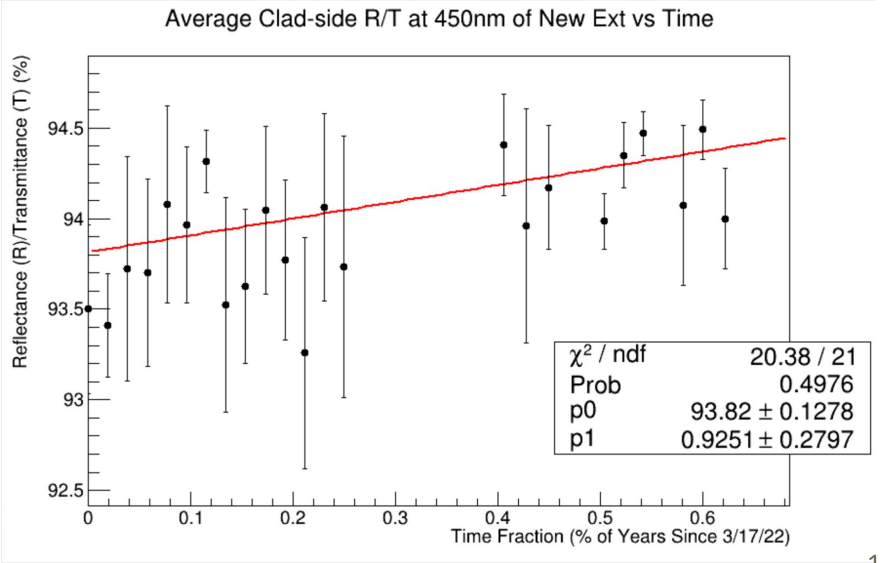
- Thin side = open circles
- Thick side = filled circles
- Some structure wrt wavelength here? Samples seem to have a peak around λ = 410nm, dip, then rise together as λ = 450nm
- Slopes do indicate reasonable direction of aging, small negative slopes



Extrusion Plots

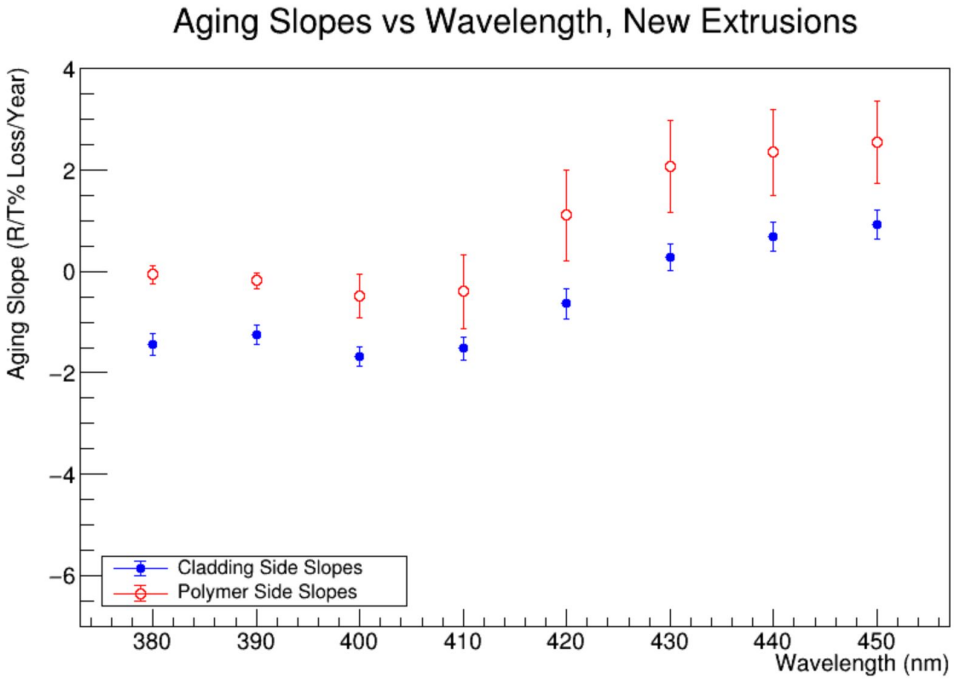
- Error = standard deviation of 5 sample measurements





Extrusion Summary by Wavelength

- Focus on blue points for the cladding side
- Similar structure wrt wavelength as the TiO2 coupon plot, increasing as wavelength increases



Stability of Reflectometer?

- While discussing the results from these aging plots, the stability of the HunterLabs reflectometer instrument has come under scrutiny
- If the instrument is truly stable, why do we see positive aging slopes?
- Solution/check:
  - Measure reflectivity once an hour for an entire day, take standard deviation
  - Measure reflectivity once a day for an entire week, take standard deviation

Brian: Stability of Reflectometer

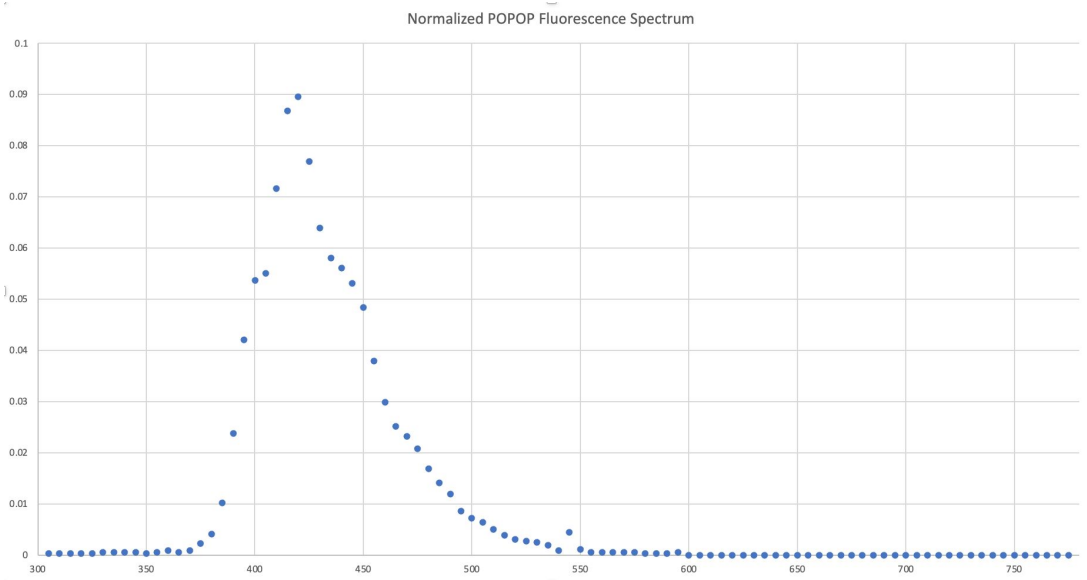
- Results after repeated GoreDRP measurements:
- Standard deviation of repeated daily measurements: ± 0.21%
- Standard deviation of repeated weekly measurements: ± 0.07%
- As a result, I added a constant error of 0.1% onto the next set of plots...

Can we define a metric to decouple wavelength-dependent effects?

- A big unknown in the coupon/extrusion cladding aging problem is whether or not aging is constant among different wavelengths
- My data points to no, I see structure in the wavelength domain
- If we define a metric with respect to POPOP fluorescence at each wavelength, can we effectively ‘weight’ different wavelengths to minimize this effect?

POPOP Fluorescence

- Data from Alan
- Measured wrt wavelength using a fluorimeter
- Normalized so area under the curve = 1, previously in arbitrary units

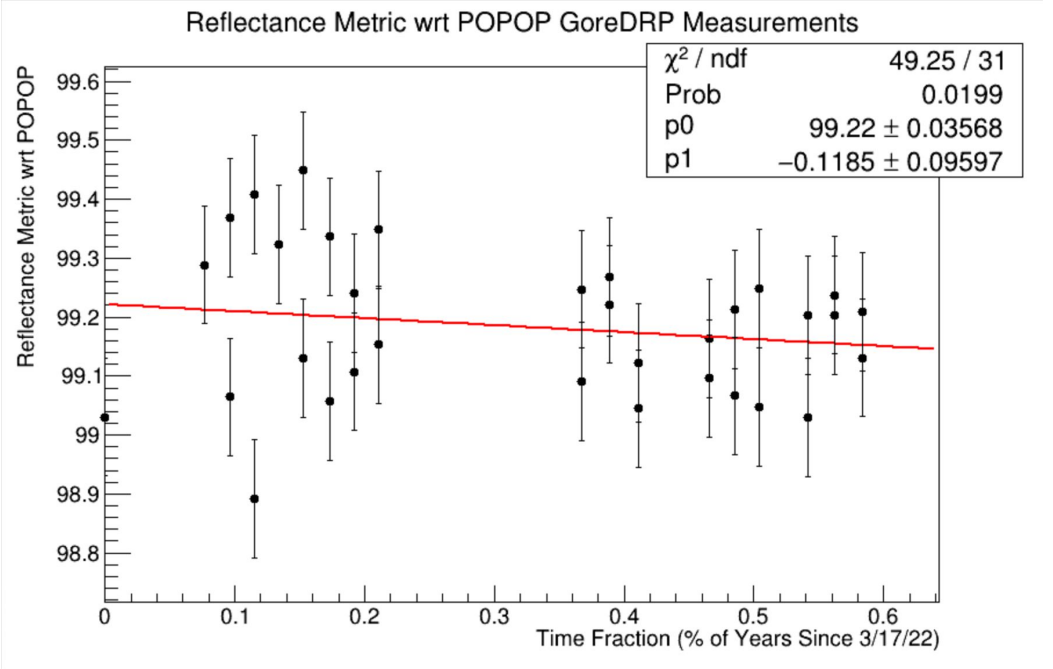


Reflectance Metric Definition

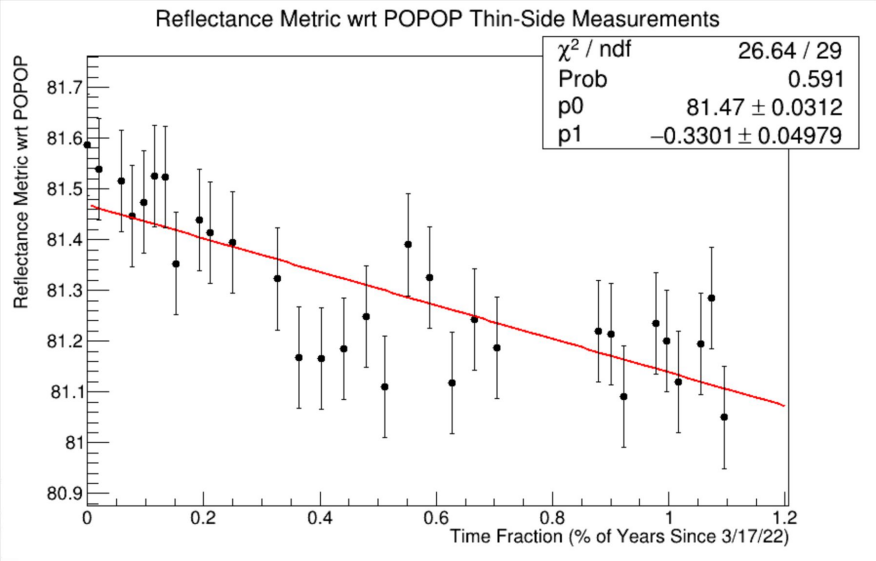
- R_metric = Σ(over λ)(R_average(λ)*POPOP_norm(λ))
- R_metric is then some number between 0 and 100…. If R_average was always 100%, then R_metric = 100%
- In this way, λs with no POPOP fluorescence are not weighted into sum

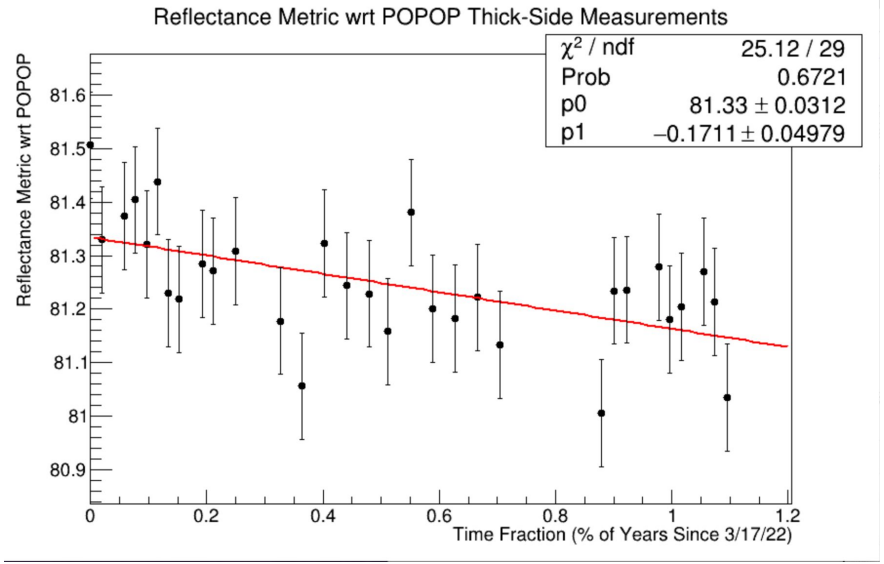
Reflectance Metric Plot - GoreDRP Standard

- Time actually starts 9/20/22
- I tried applying both the daily error and weekly error separately, 0.07% or 0.2%, but since both are constant error, it made no difference on the fit slope. Used 0.1%



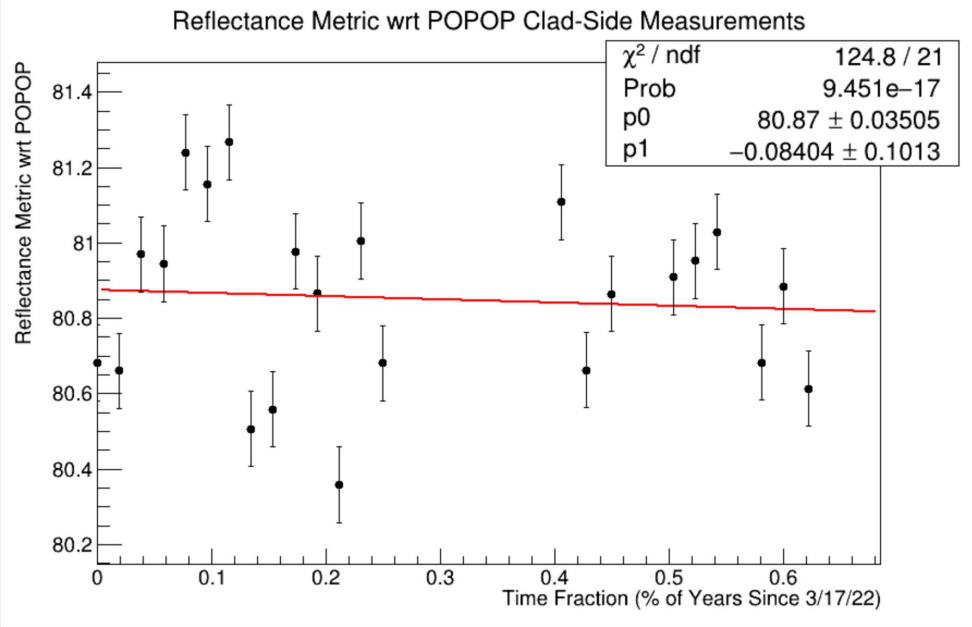
Reflectance Metric Plot - TiO2 Coupons





Reflectance Metric Plot - Extrusion Cladding Side

- Time actually starts 9/6/22



Reflectance Metric Summary and Comparison

- Do sign of R metric slopes agree with average aging rate of different samples?
- TiO_2 coupons:
  - Thin-side: aging = -0.41% ± 0.12% R = -0.33% ± 0.05%
  - Thick-side: aging = -0.22% ± 0.10% R = -0.17% ± 0.05%
- Extrusion samples:
  - Cladding side: aging = -0.58% ± 0.99% R = -0.08% ± 0.10%
- Standards:
  - GoreDRP: aging = +0.16% ± 0.14% R = -0.12% ± 0.10%

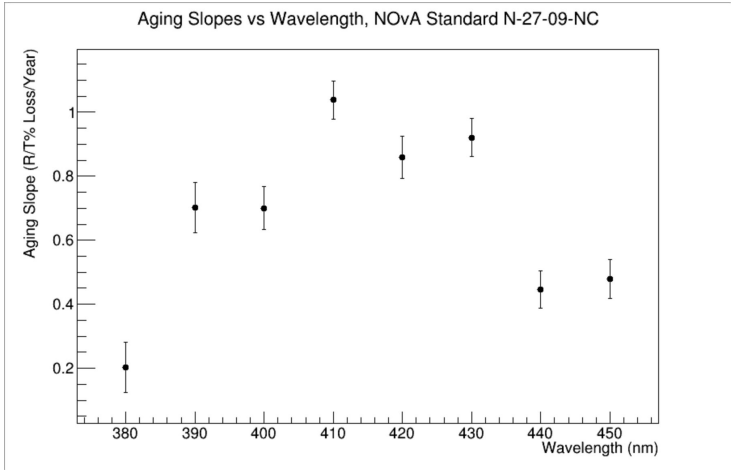
Conclusions

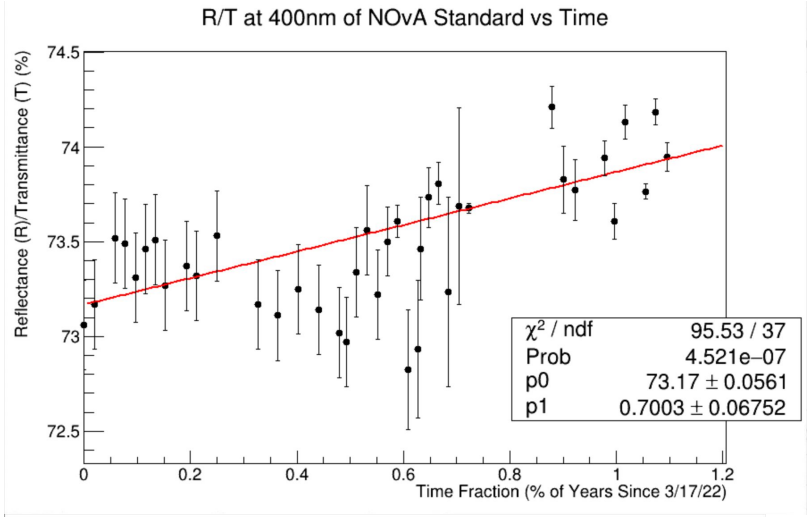
- GoreDRP is a stable standard, the stability of this sample over time proves that the HunterLabs Reflectometer instrument is reliable and has produced quality data for coupons and extrusions
- Coupons and extrusion samples both show very small aging slopes, somewhere around 0.5% or less
- If we put this small aging for cladding reflectivity into MC, does this have a significant impact on the overall light yield of the CRV?

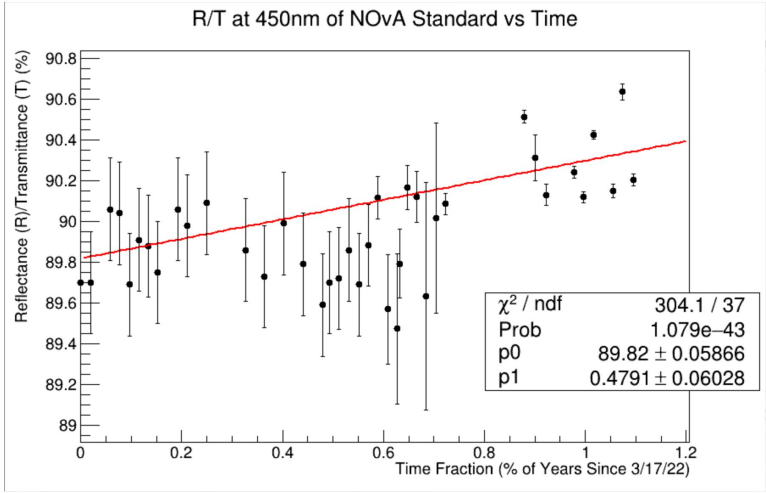
Backup

Disqualified NOvA Standard

Large variation in aging plot slopes, results pointing to unphysical “positive” aging







Disqualified Polymer-side Extrusions