Evaluation of Mass Produced PWO Crystals

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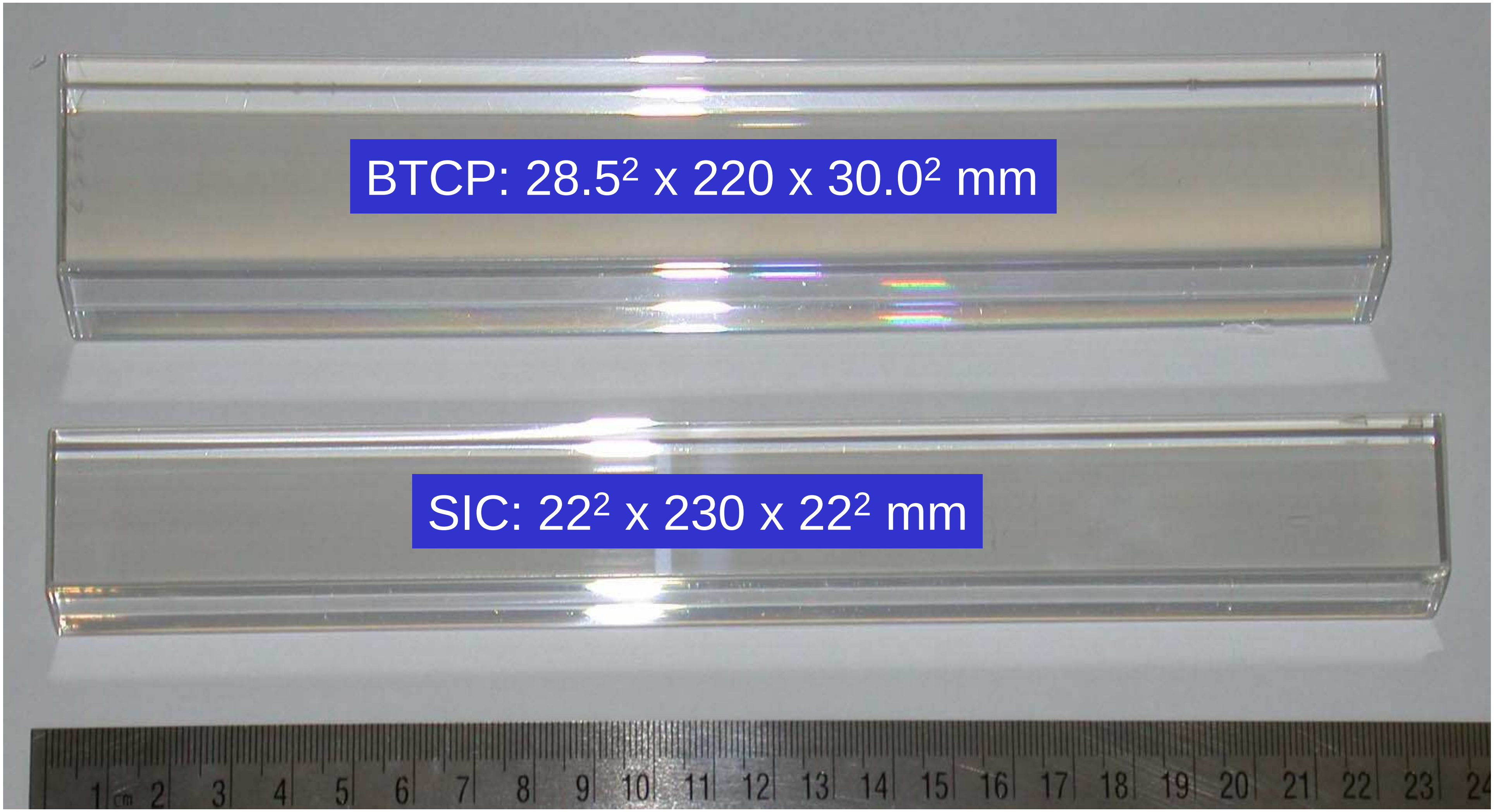
Randomly Selected PWO Samples

BTCP: 20 from 1st batch (100) for CMS endcaps
SIC: 20 from production batch for PrimEx

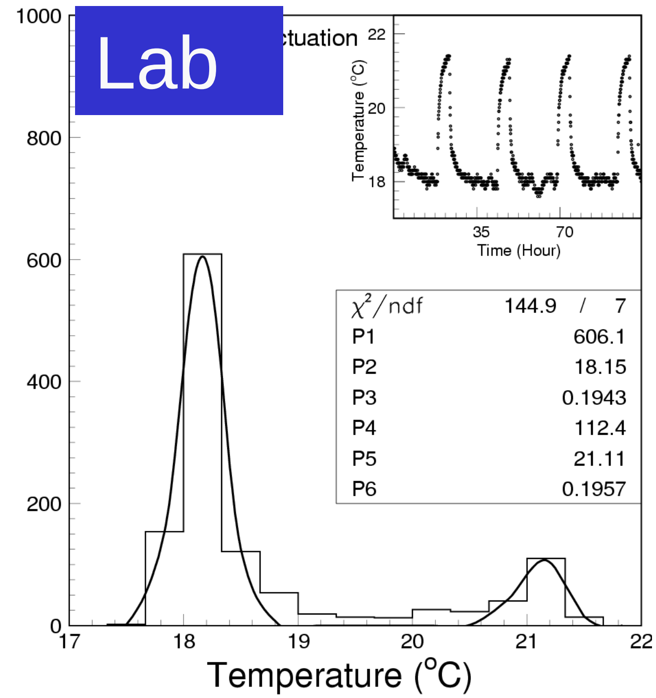


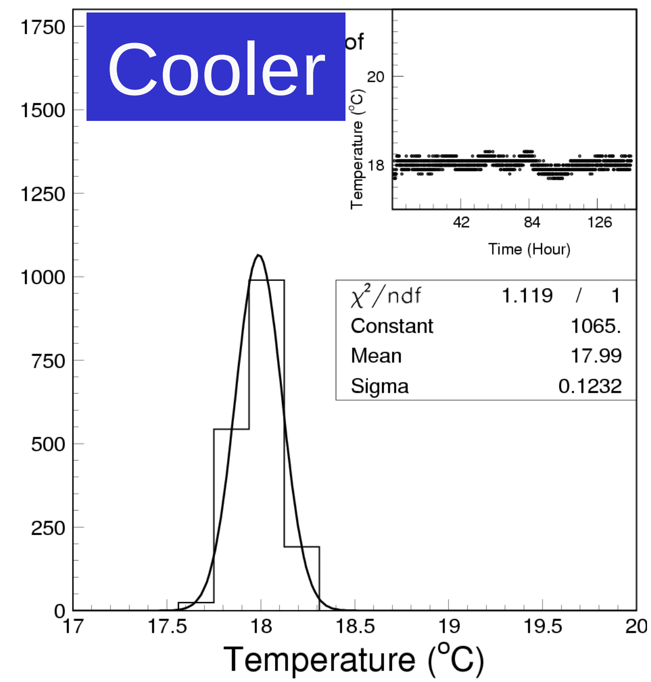
Experiment

- All crystals went through (1) thermal annealing at 200^{o}C, (2) irradiations by γ–ray at 15, 400 and 9k rad/h until equilibrium and (3) recovery.
- Properties measured: Transmittance, emission and excitation spectrum, light output, decay kinetics and light response uniformity, as well as their degradation, radiation induced color center and emission weighted radiation induced absorption coefficients.
- Light output degradation was only measured at 15 rad/h because of limited light output: less than 8 p.e./MeV for BTCP samples.

Thermal Annealing

- Rigorous temperature control both in amplitude and slope:
  - From RT to 200ºC: 200 minutes;
  - Maintain at 200ºC: 240 minutes;
  - From 200ºC to 25ºC: 400 minutes.
- Crystals are kept in dark at RT (18ºC) after annealing. The minimum time between annealing and the 1st measurement is 48 hours.

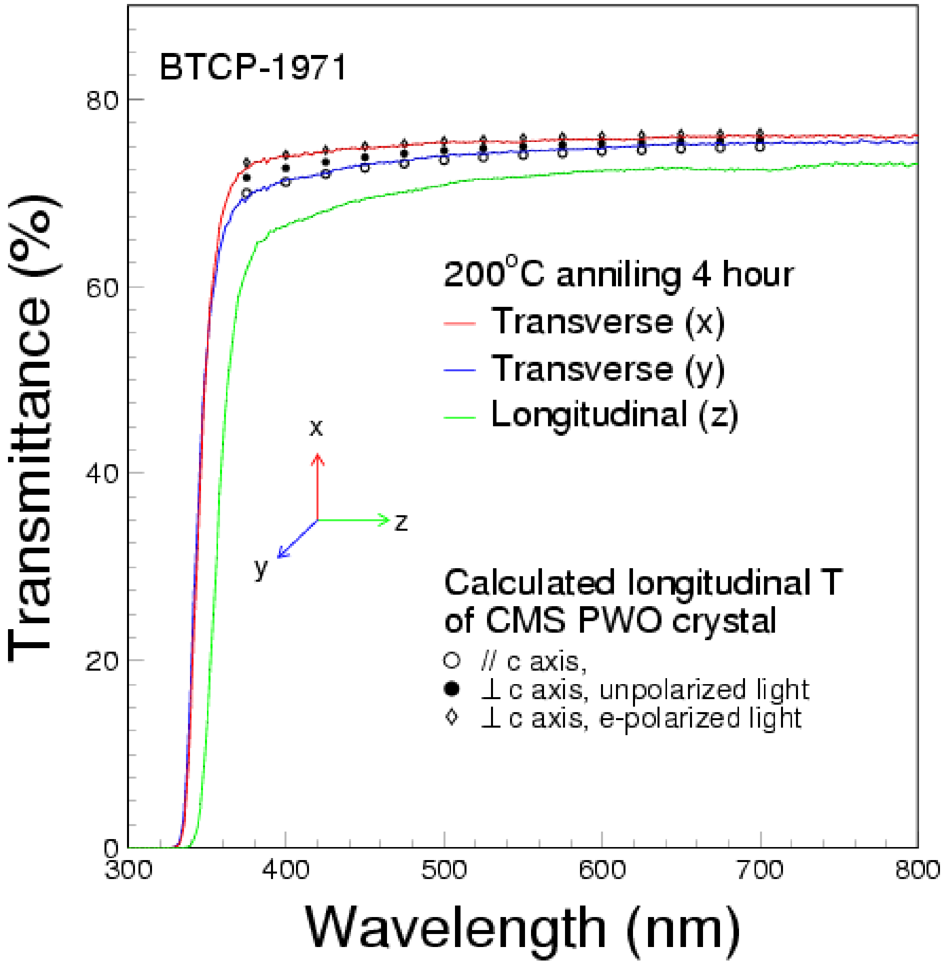




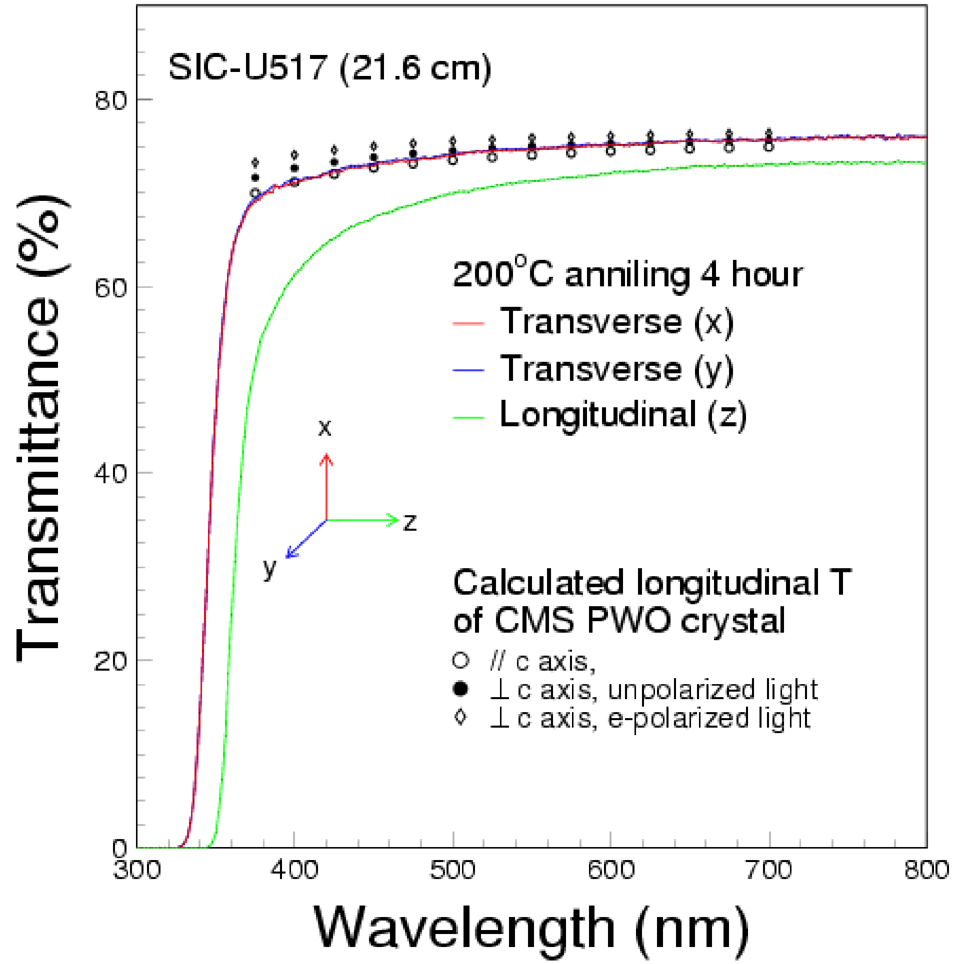
Transmittance and Birefringence

a axis: better longitudinal T., but non-isotropic transverse T.
Both approaching theoretical limit

Czochralski: grown along the ***a axis***

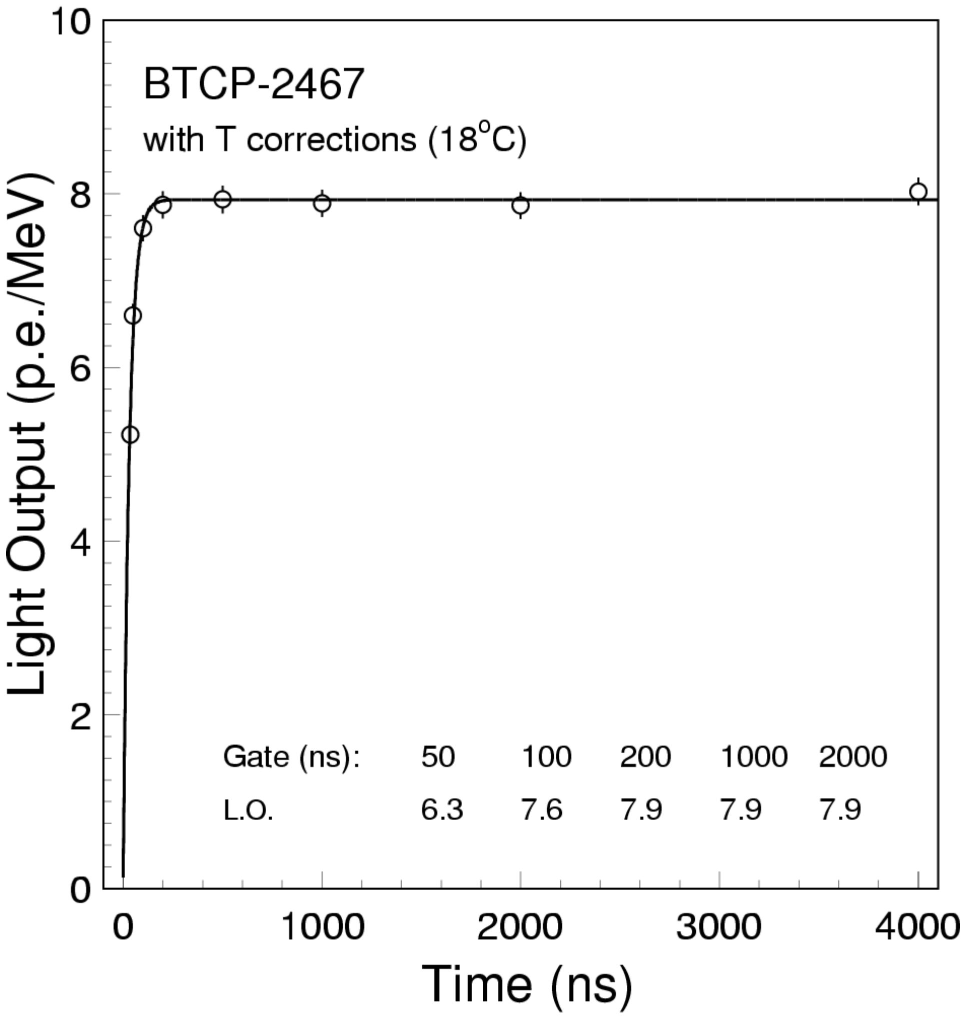


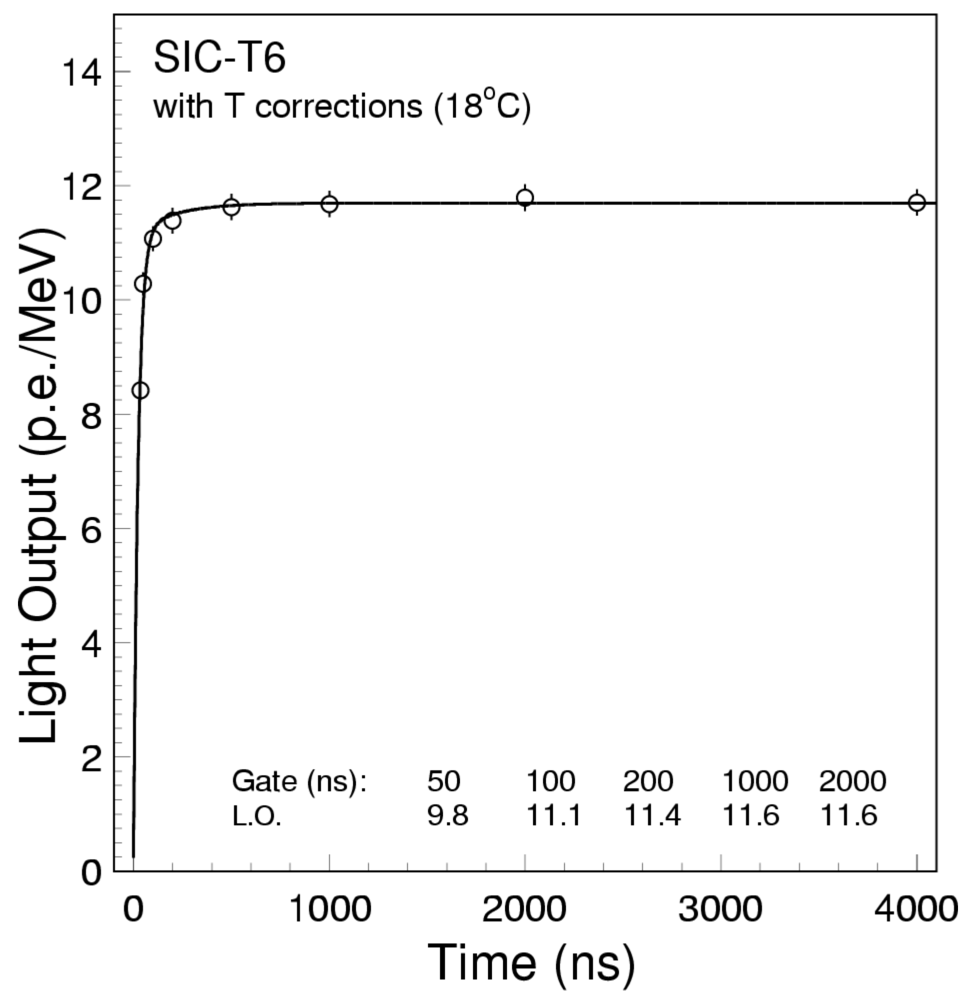
Bridgman: grown along the ***c axis***



Light Output and Decay Kinetics

SIC samples have higher light output
Both are fast: 84 and 96% of light in 50 and 100 ns

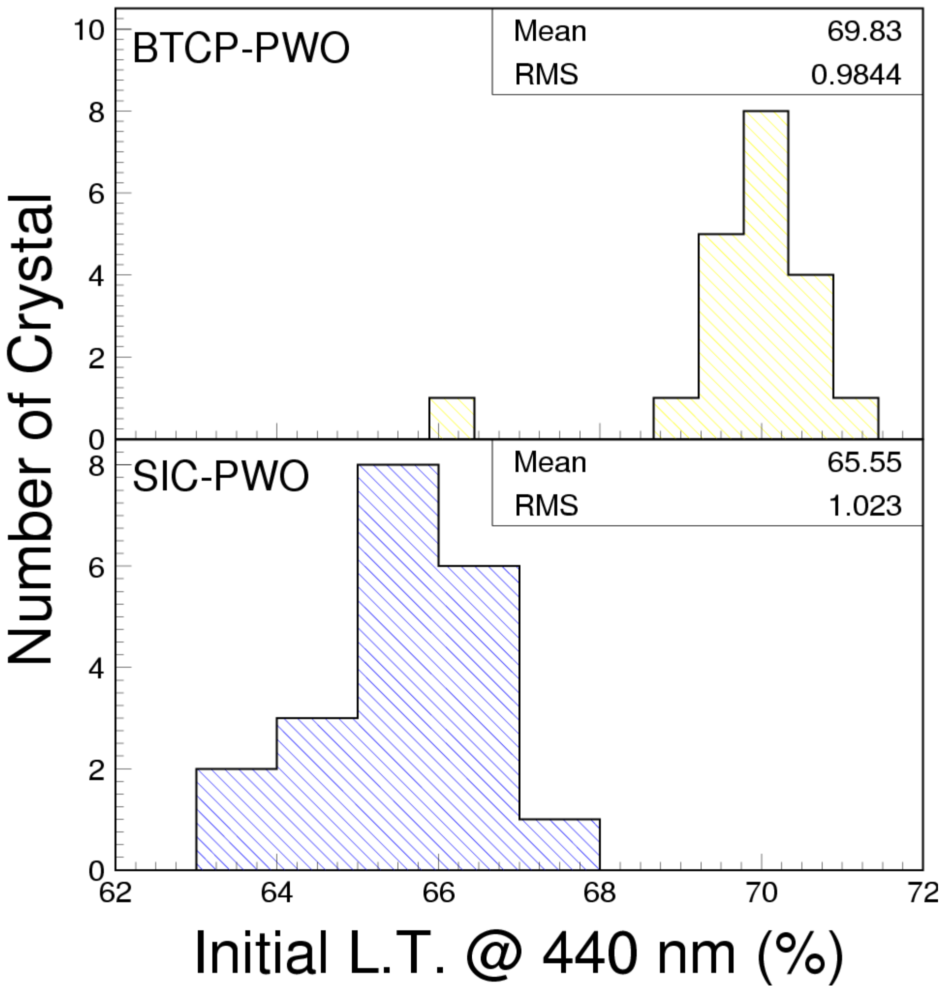


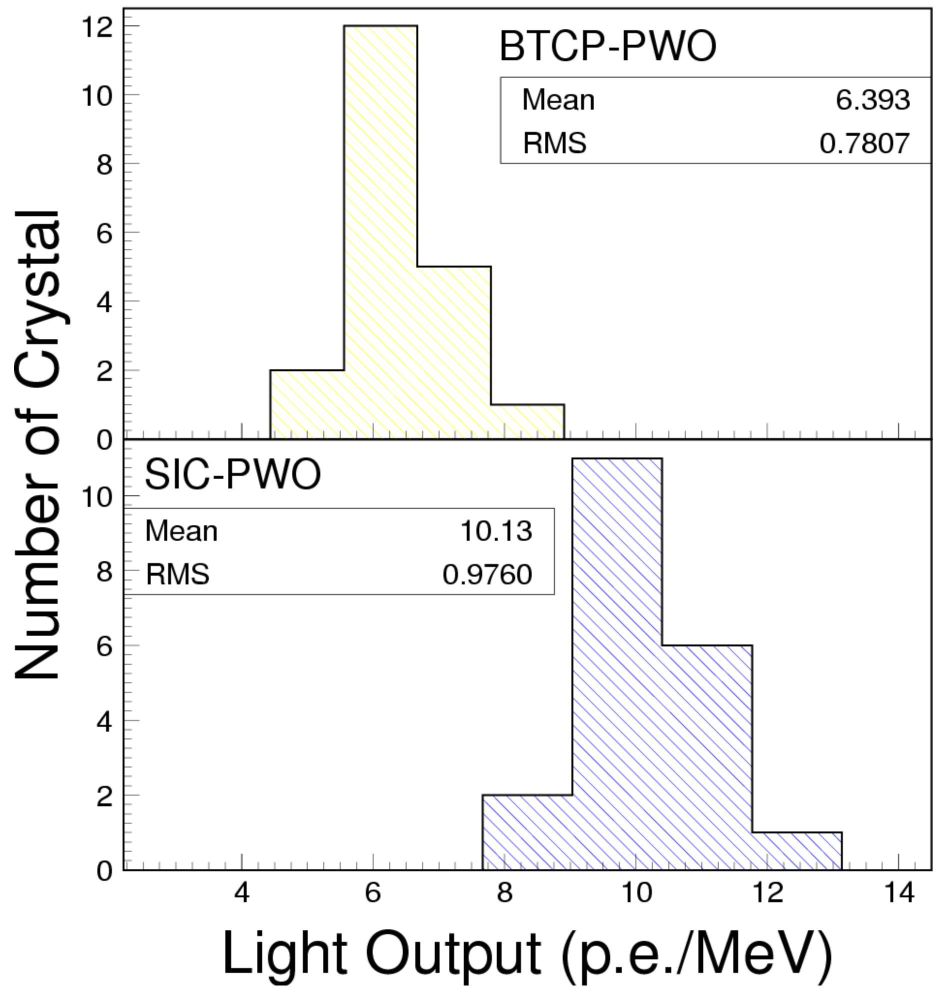


Comparison of L.T. and Light Yield

BTCP:higher l. transmittance, partly due to birefringence

SIC: higher light yield, the reason is unknown

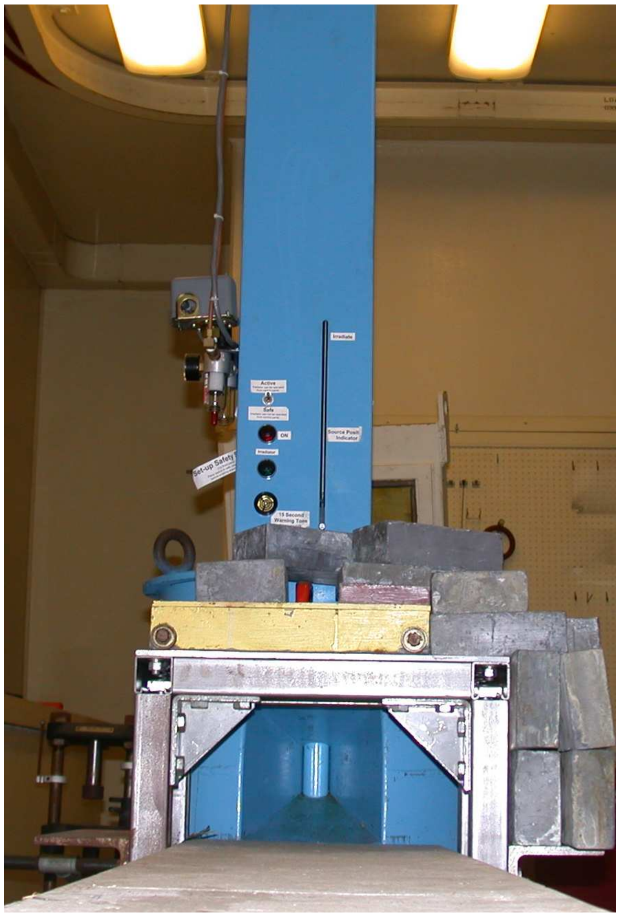




Caltech γ–ray Irradiation Facilities

Open 50 curie Co-60:
15, 100 and 400 rad/h

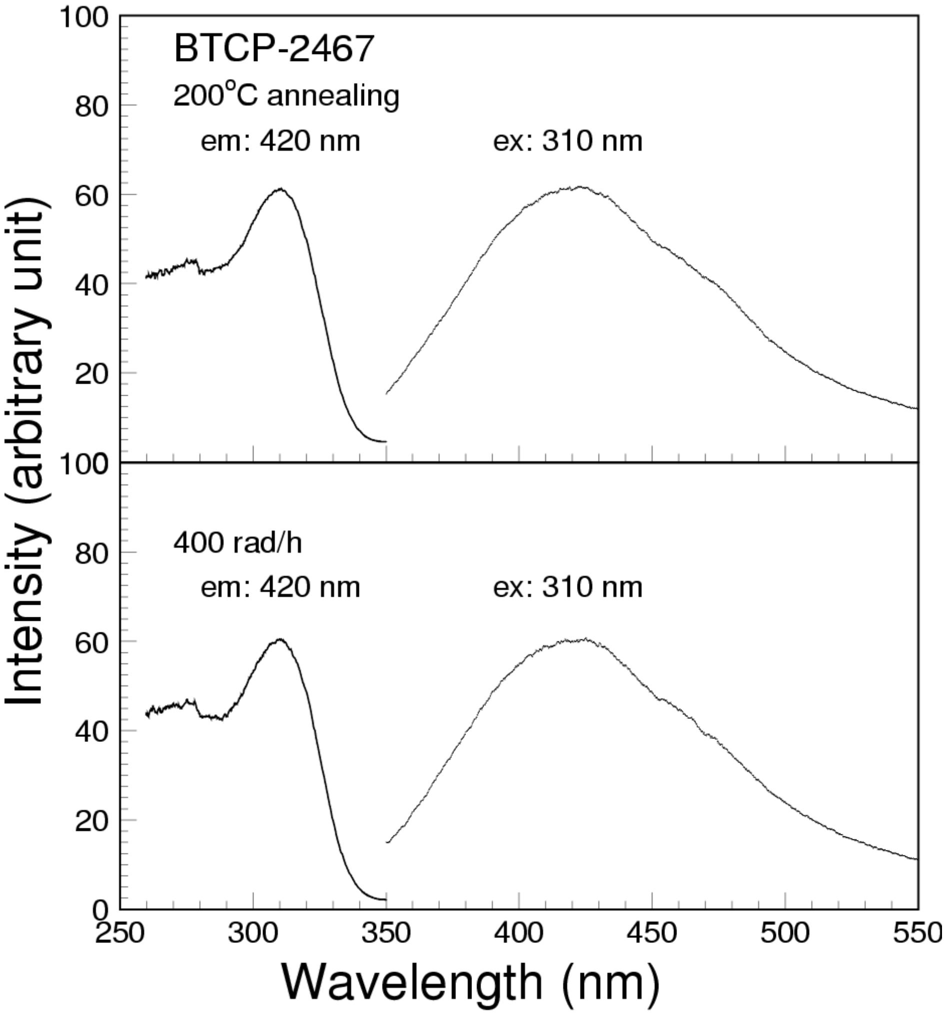
Closed 2,000 curie Cs-137:
9k rad/h at center, up to 36k rad/h

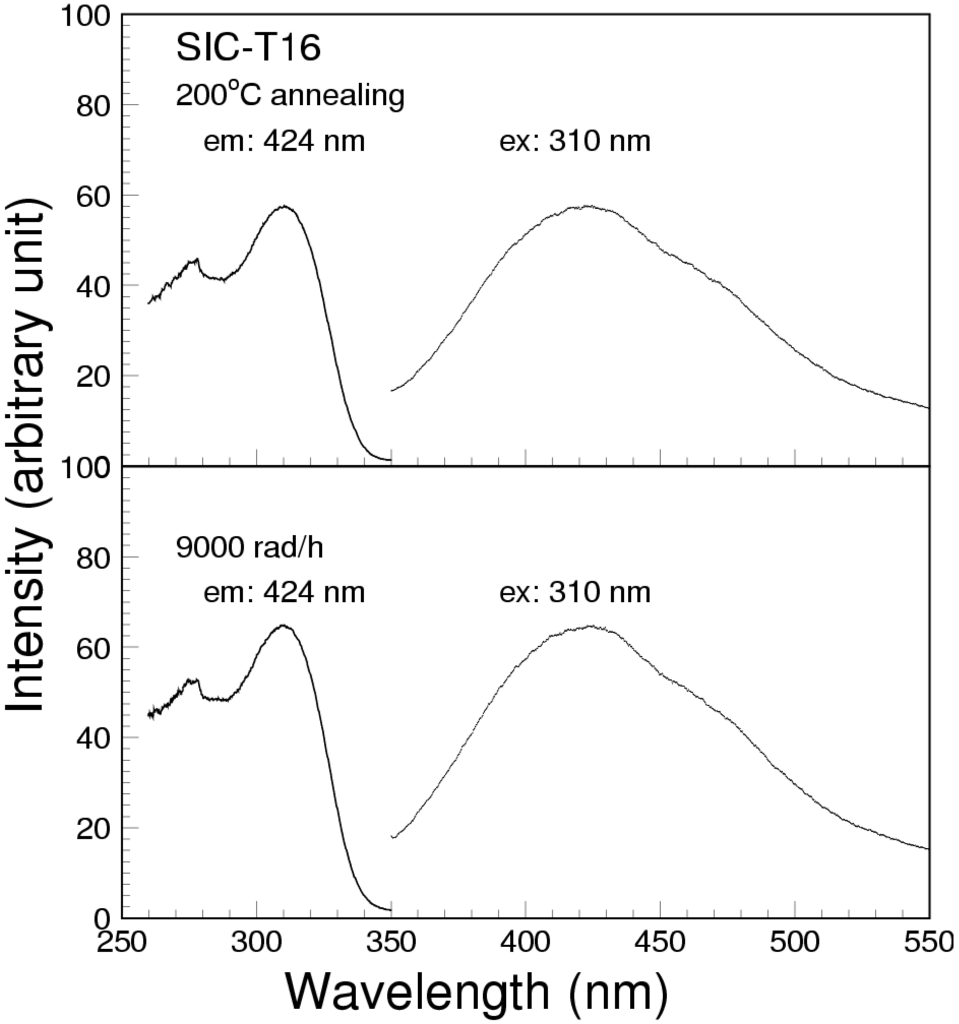


Photoluminescence

No variation in either excitation or emission spectrum

No damage in scintillation mechanism

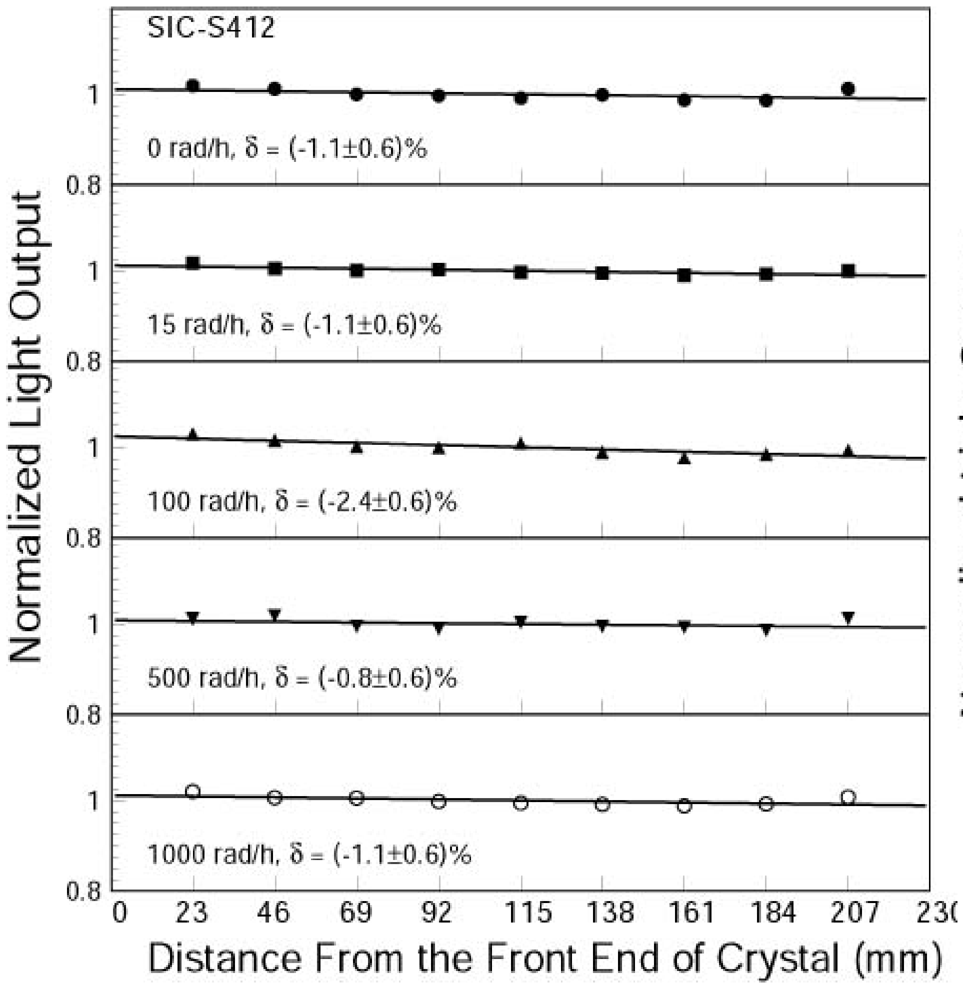


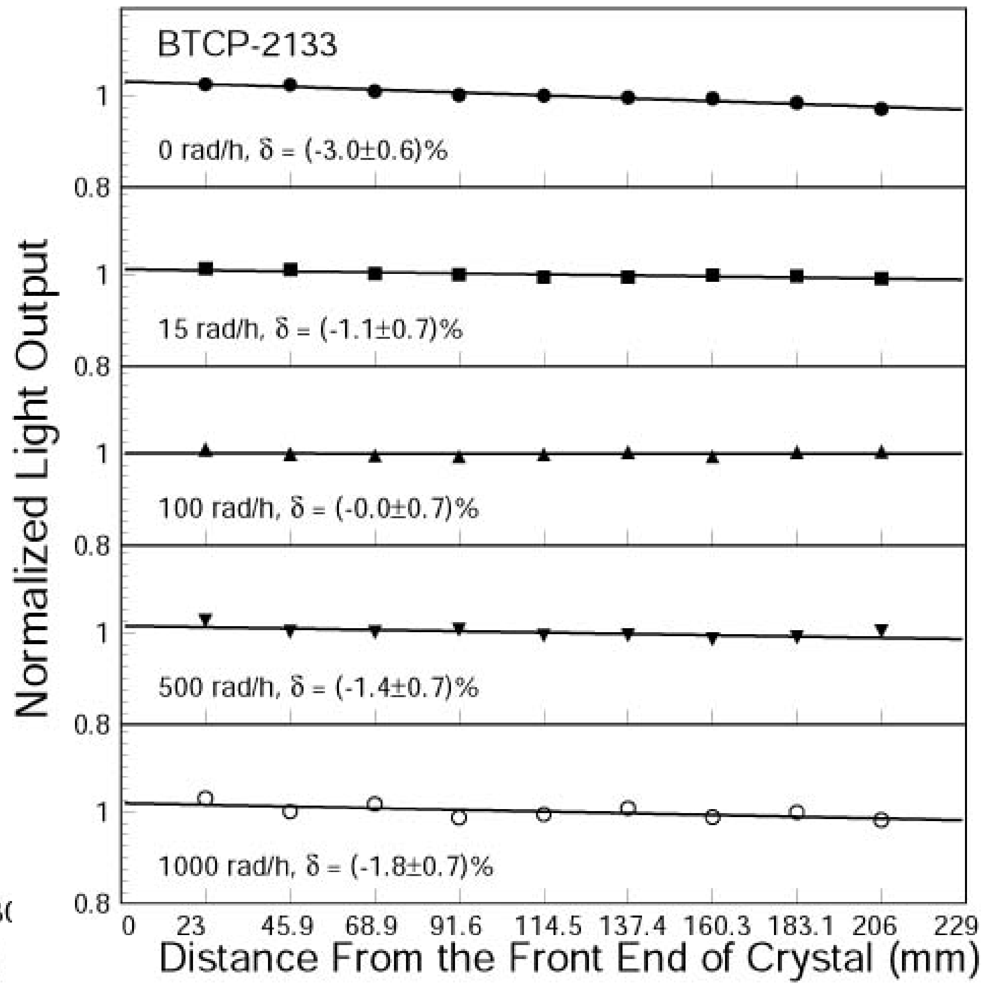


No Variation in Light Response Uniformity

The response (*y*) along the axis was fit to a linear function

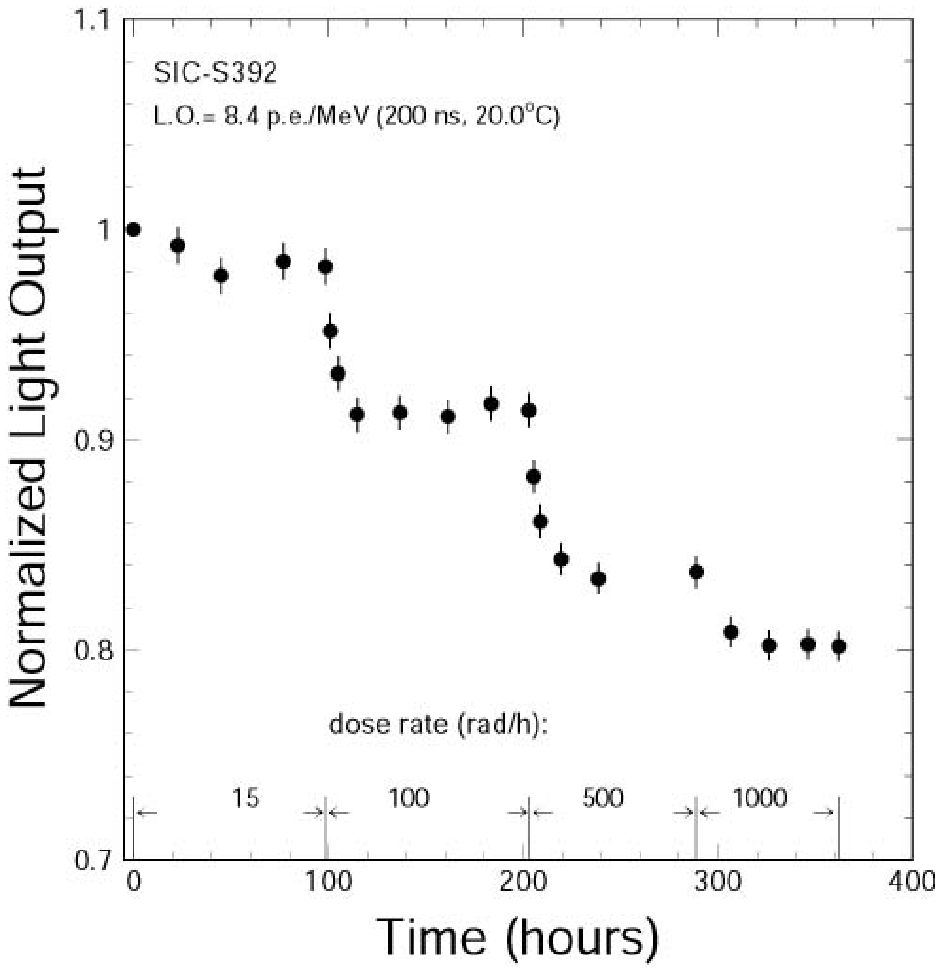
$$\frac{y}{y_{mid}} = 1 + \delta(x / x_{mid} - 1)$$

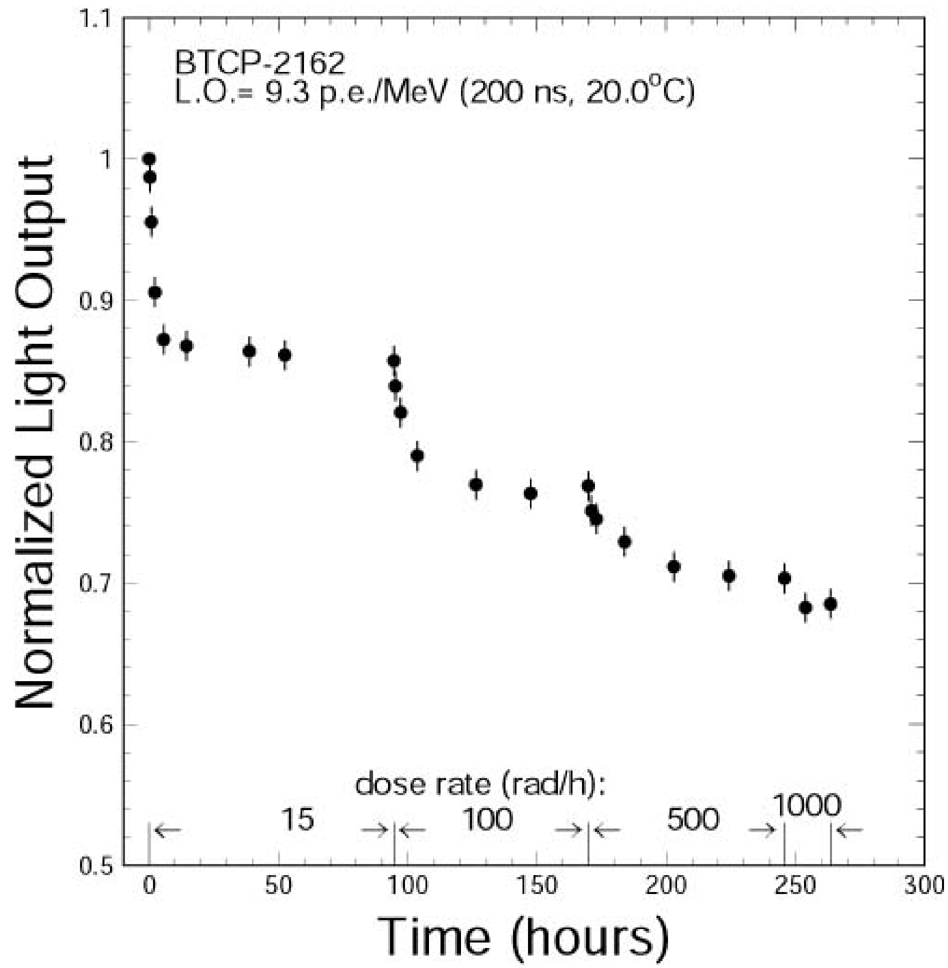




Light Output Degradation

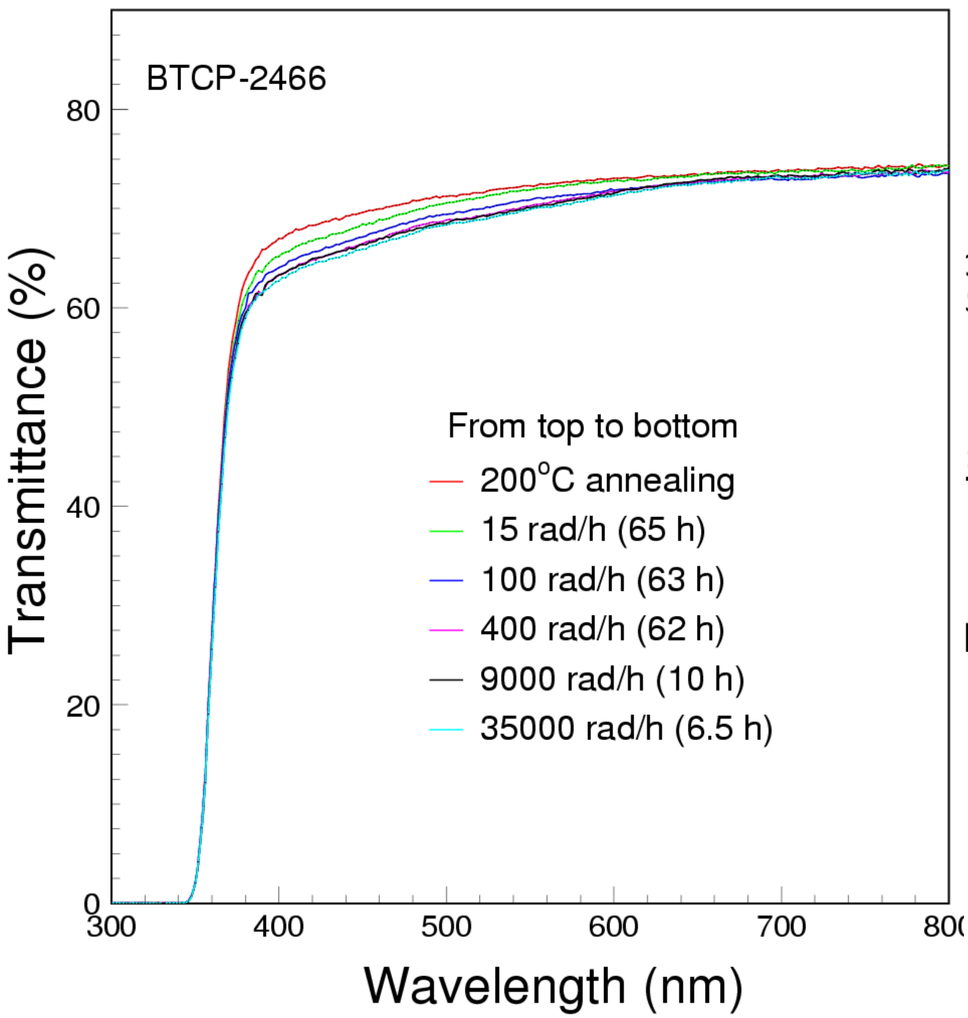
5-15% and 15-30% light output loss under 15 and 500 rad/h
Damage is dose rate dependent

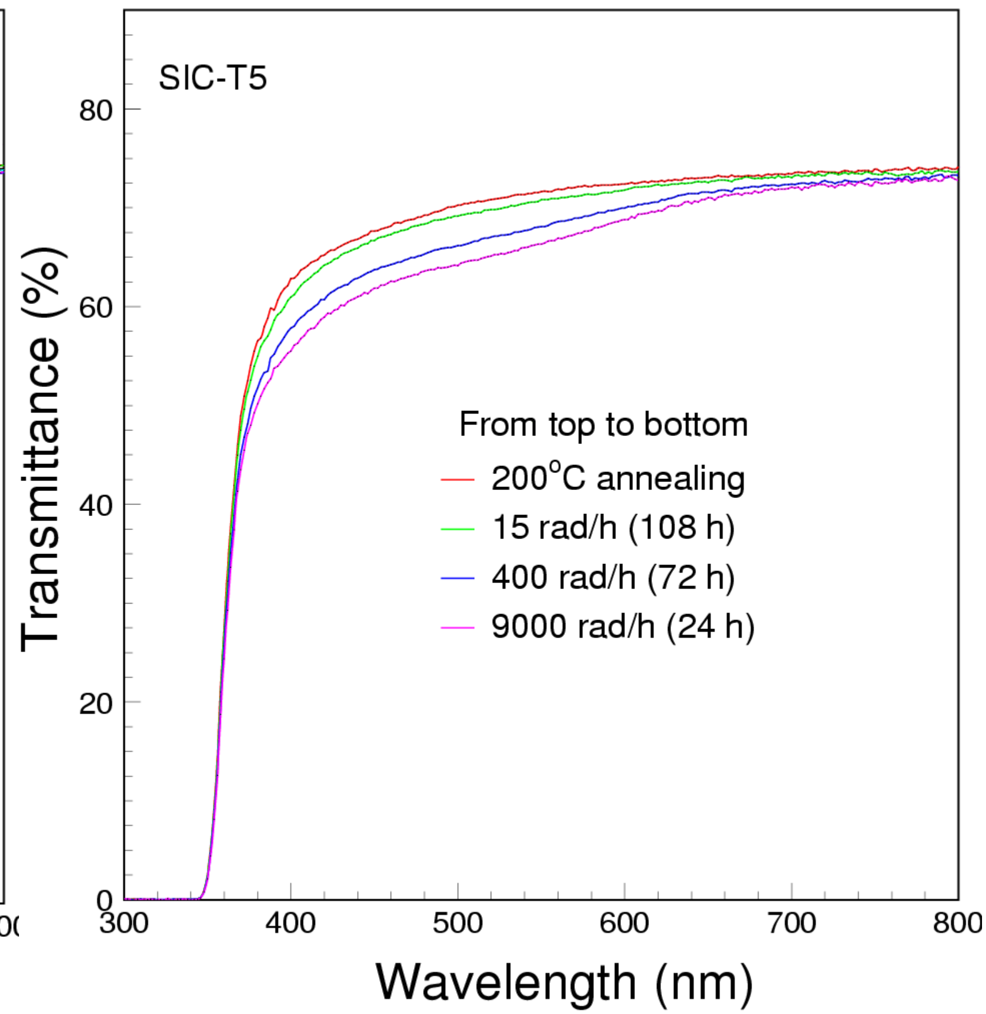




Damage in Longitudinal Transmittance

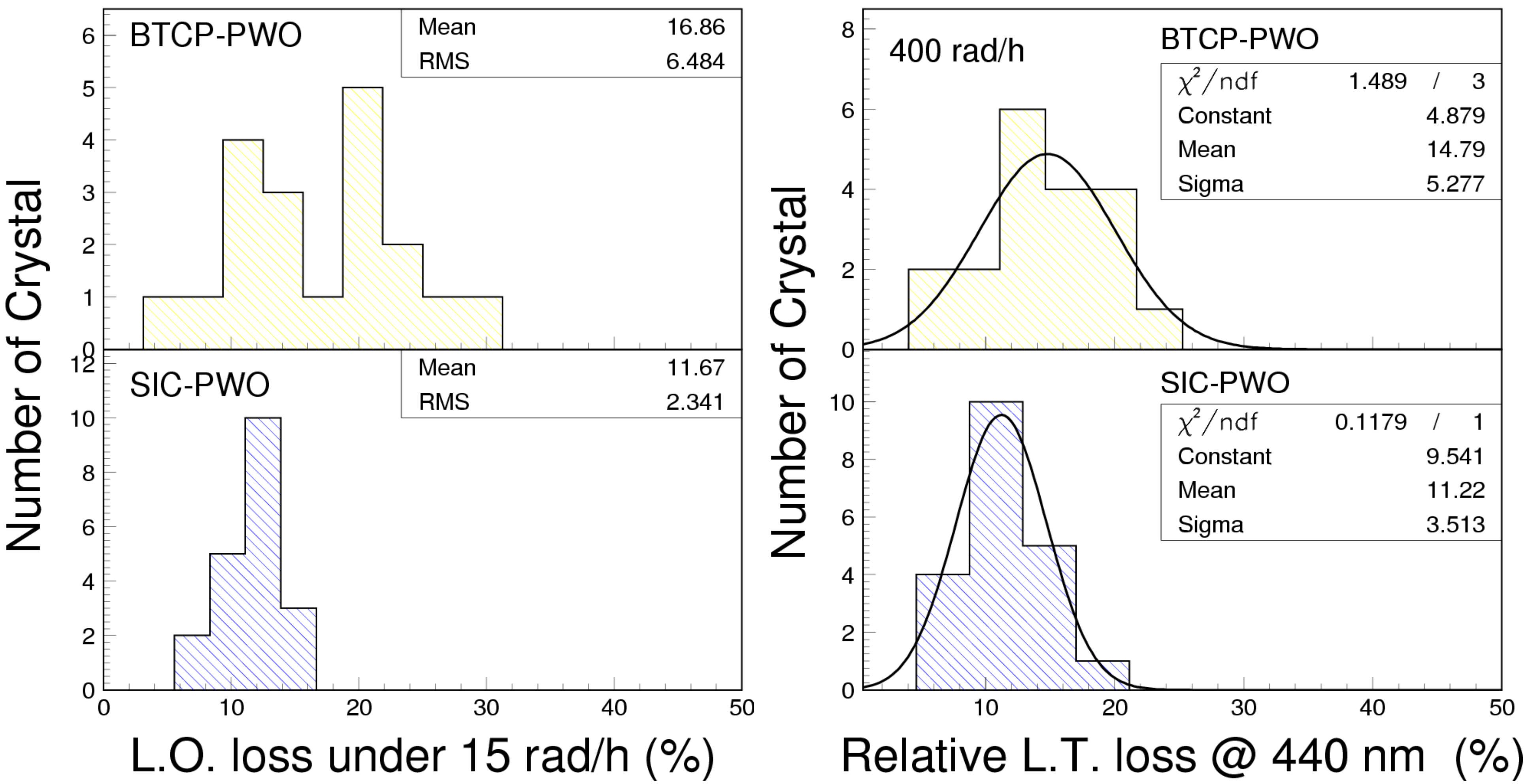
Radiation induced absorption caused by CC formation





Comparison of Radiation Damage

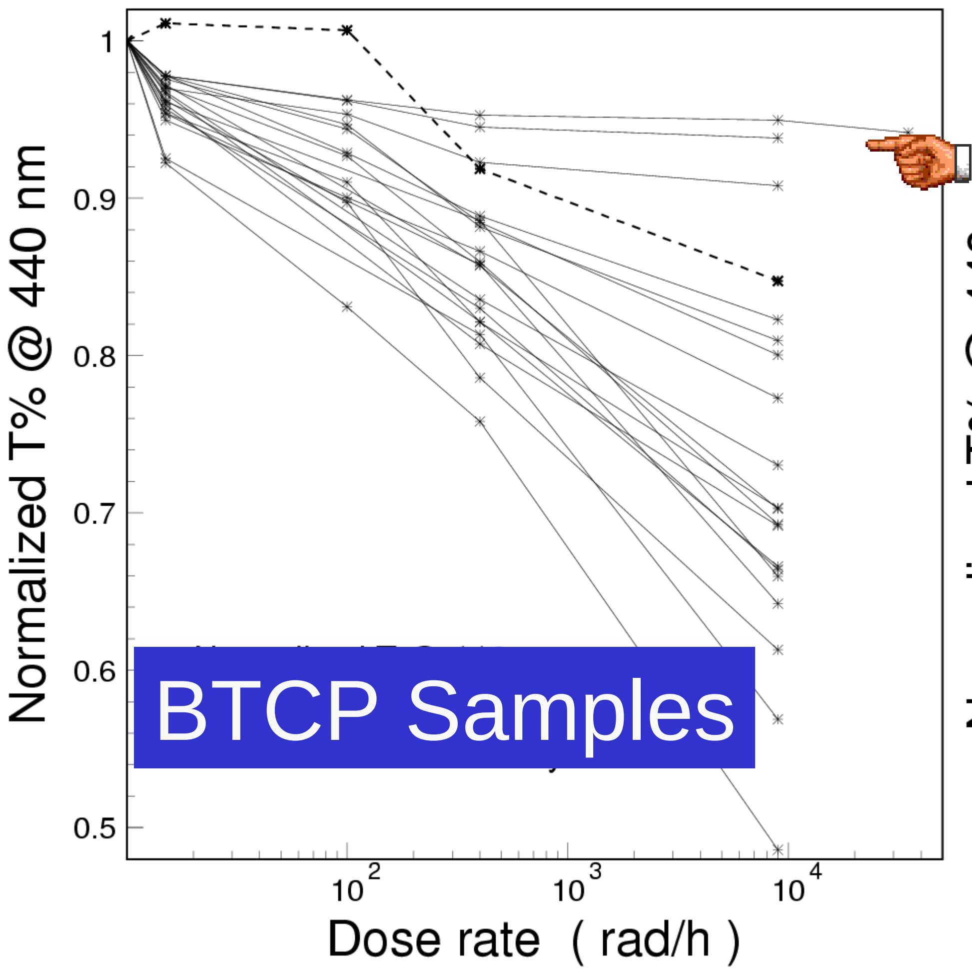
SIC samples seem more radiation hard

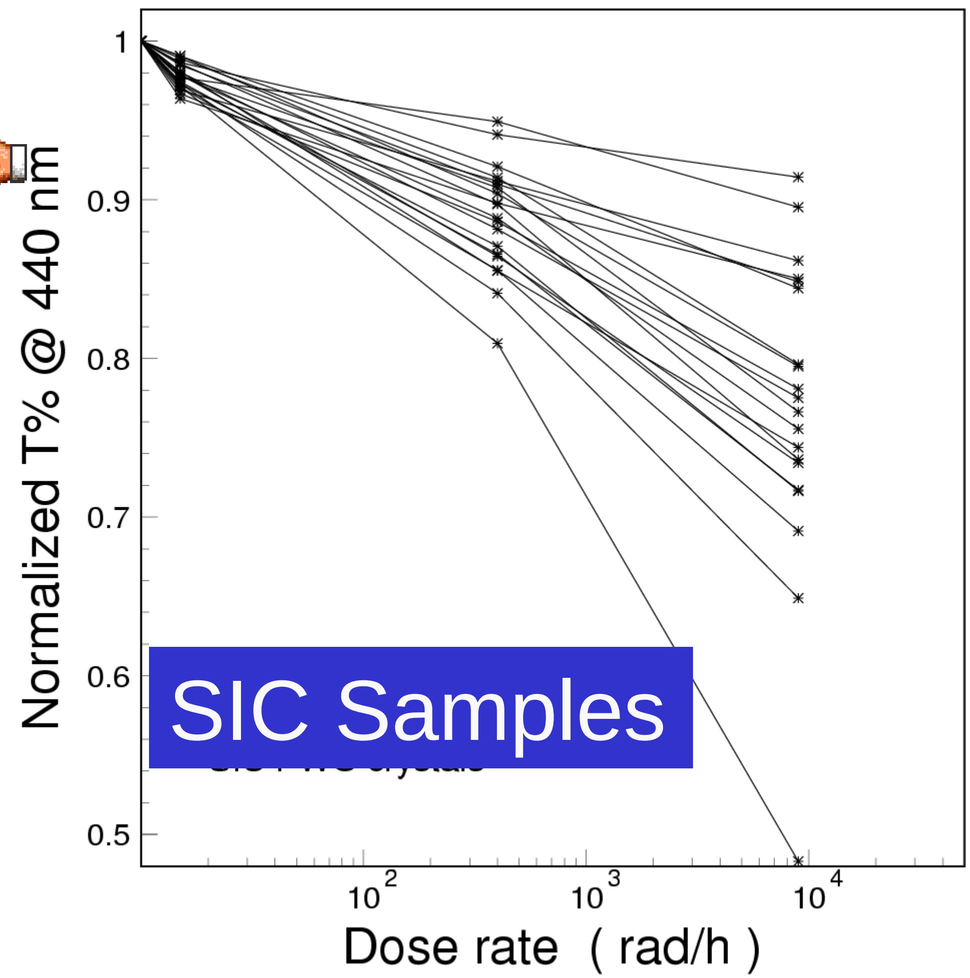


Comparison of Transmittance Loss

SIC samples less diverse: Bridgman technology

Some BTCP samples are very rad hard at high doses





Radiation Induced Color Center Density

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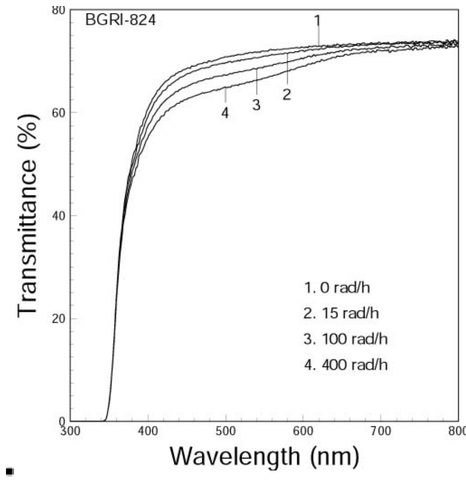
RIAC or radiation induced color center density can be calculated precisely by using longitudinal transmittance (0.2%)



$$RIAC \ or \ D_{Color-Center} = 1/LAL;$$

$$LAL = \frac{\ell}{\ln\{[T(1-T_s)^2]/[\sqrt{4T_s^4 + T^2(1-T_s^2)^2} - 2T_s^2]\}}$$

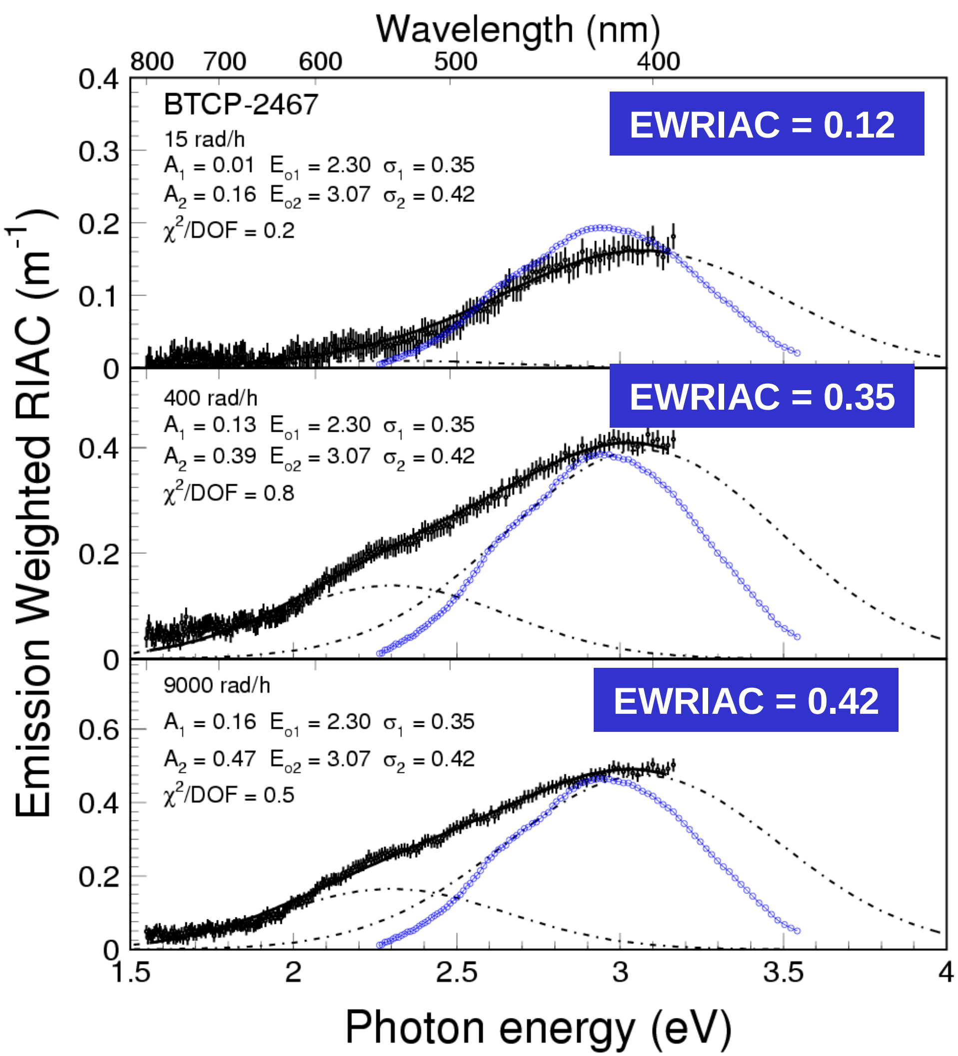
where T is transmittance measured along crystal length ℓ and T_s is the theoritical transmittance without internal absorption:

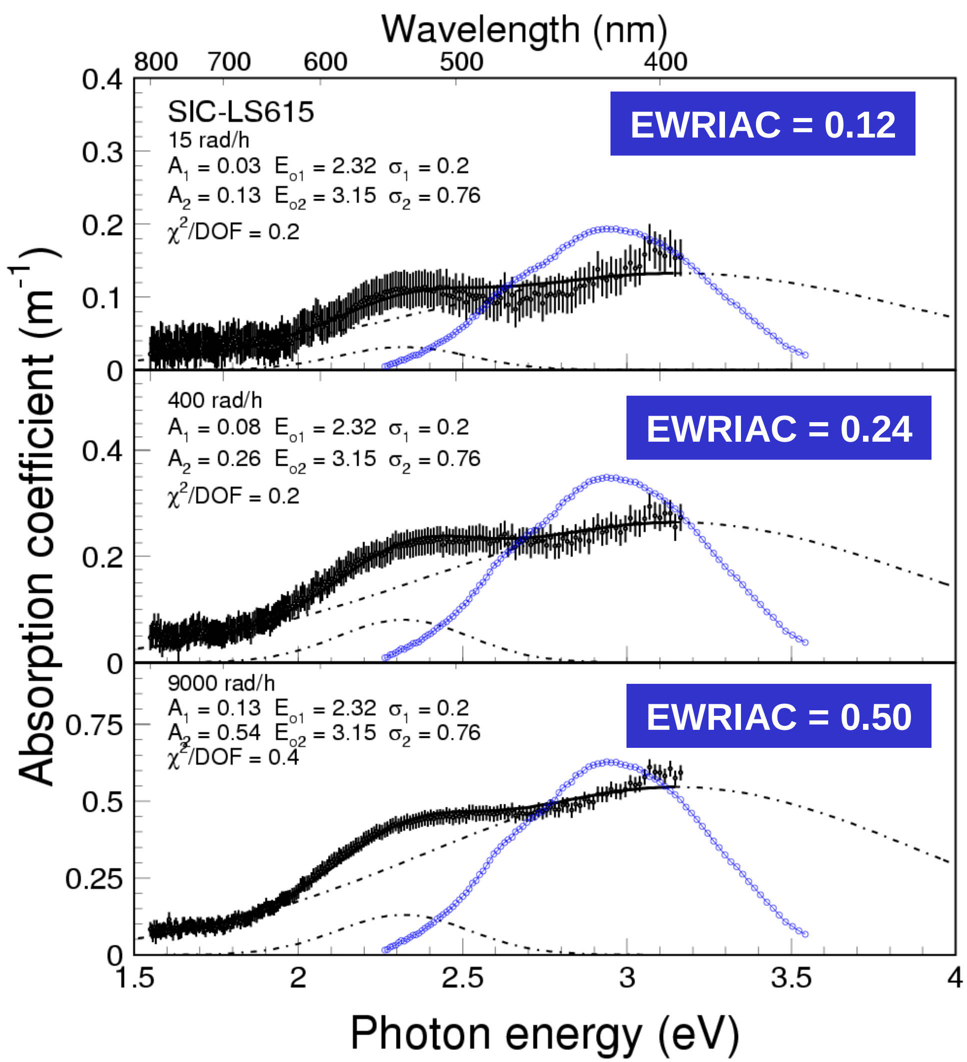
$T_s = (1-R)^2 + R^2(1-R)^2 + ... = (1-R)/(1+R)$, with $R = \frac{(n_{crystal} - n_{air})^2}{(n_{crystal} + n_{air})^2}$.

Emission Weighted RIAC

$$EWRIAC = \frac{\int Riac(\lambda)Em(\lambda)d\lambda}{\int Em(\lambda)d\lambda}$$

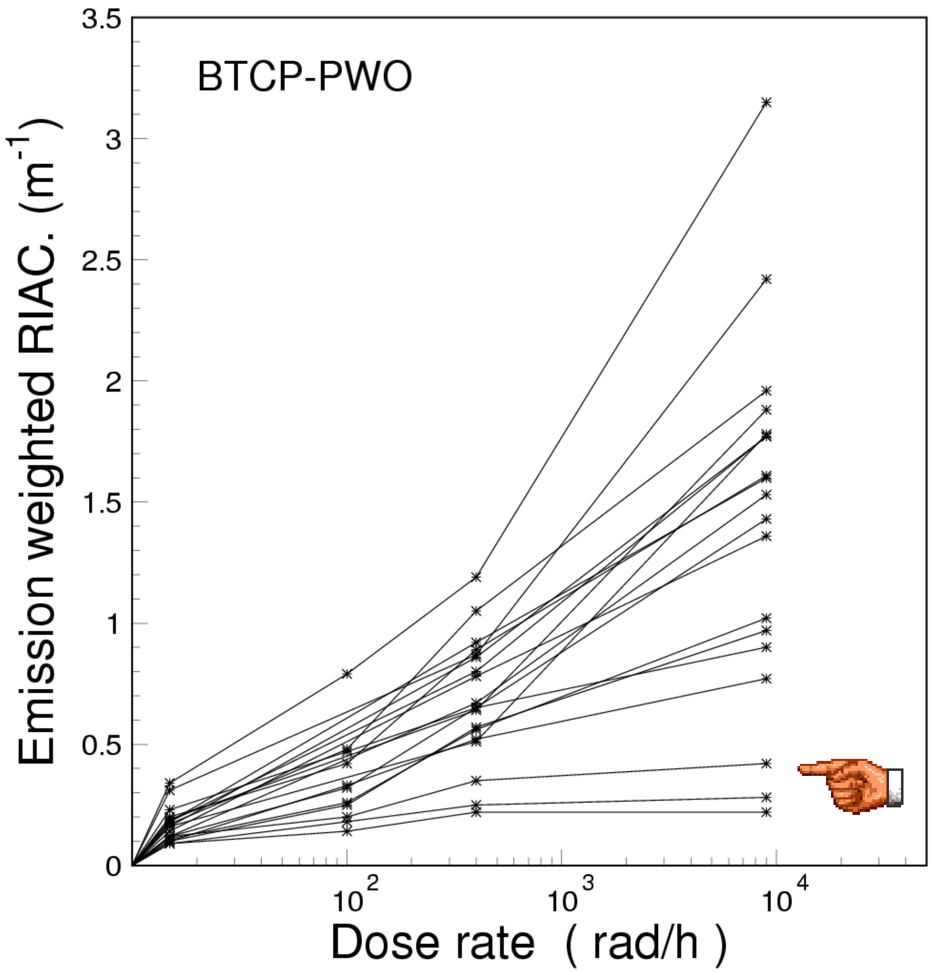
a good measure of rad. damage

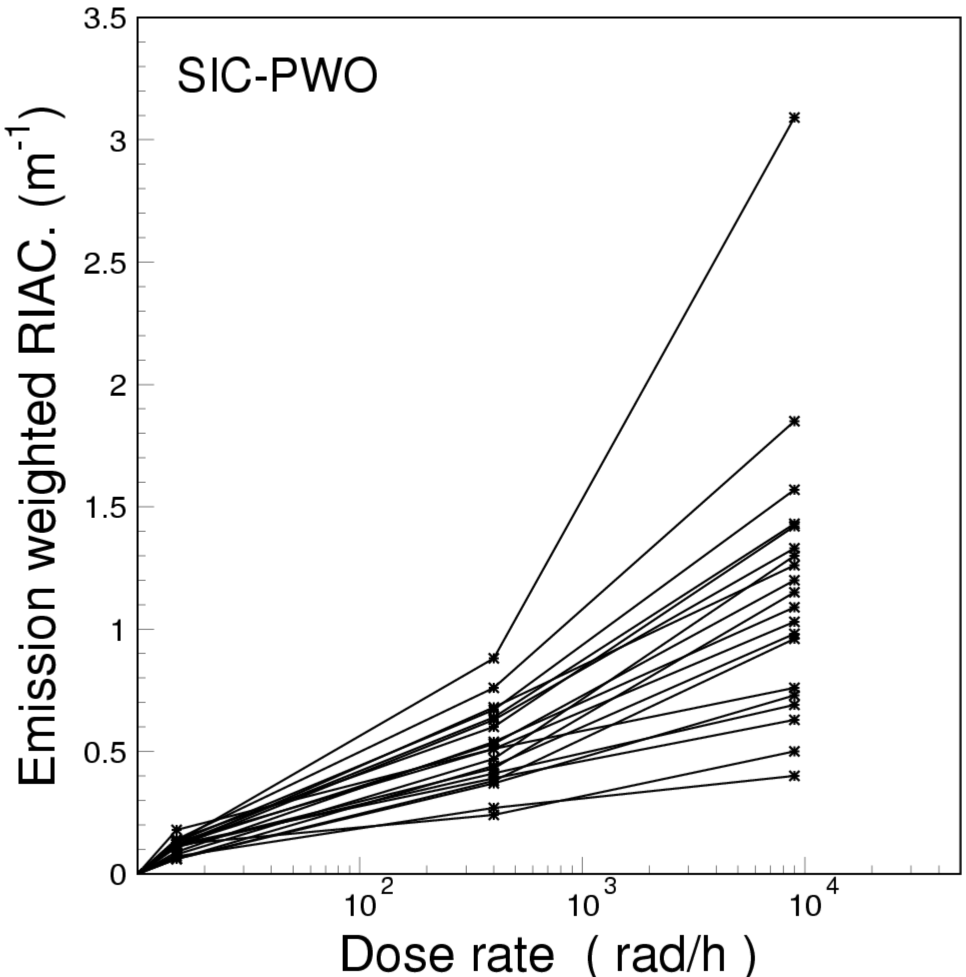




EWRIAC (1/m) and Normalized r.m.s

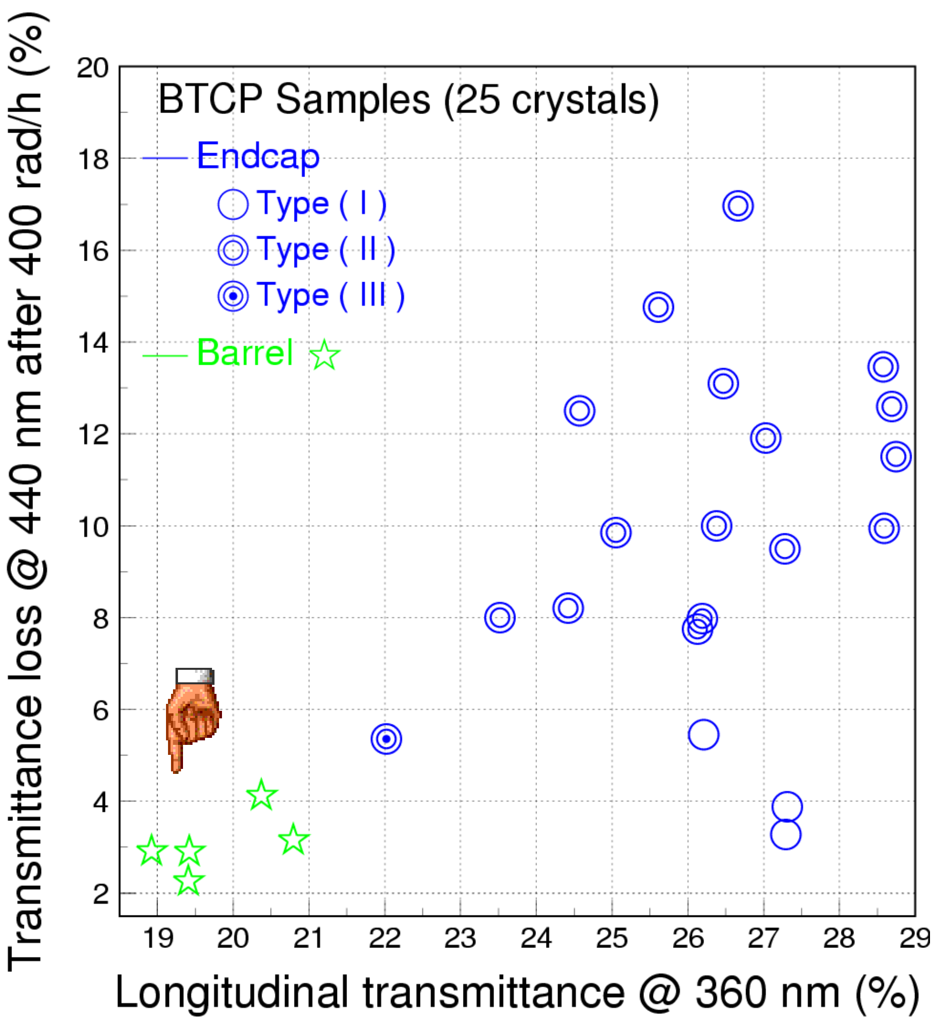
Vendor	15 rad/h	400 rad/h	9.000 rad/h
BTCP	0.16 (45%)	0.69 (37%)	1.43 (50%)
SIC	0.10 (33%)	0.51 (32%)	1.16 (48%)

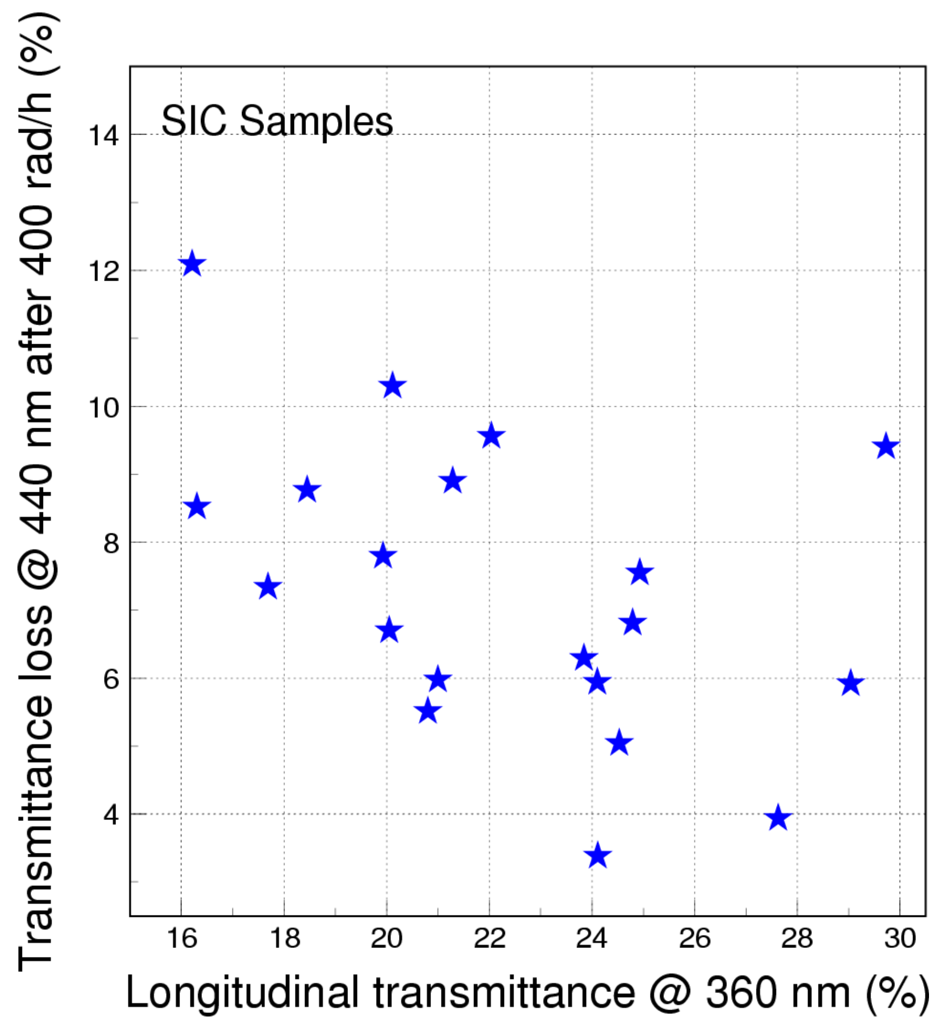




L. T. Loss versus Initial L.T. @ 360 nm

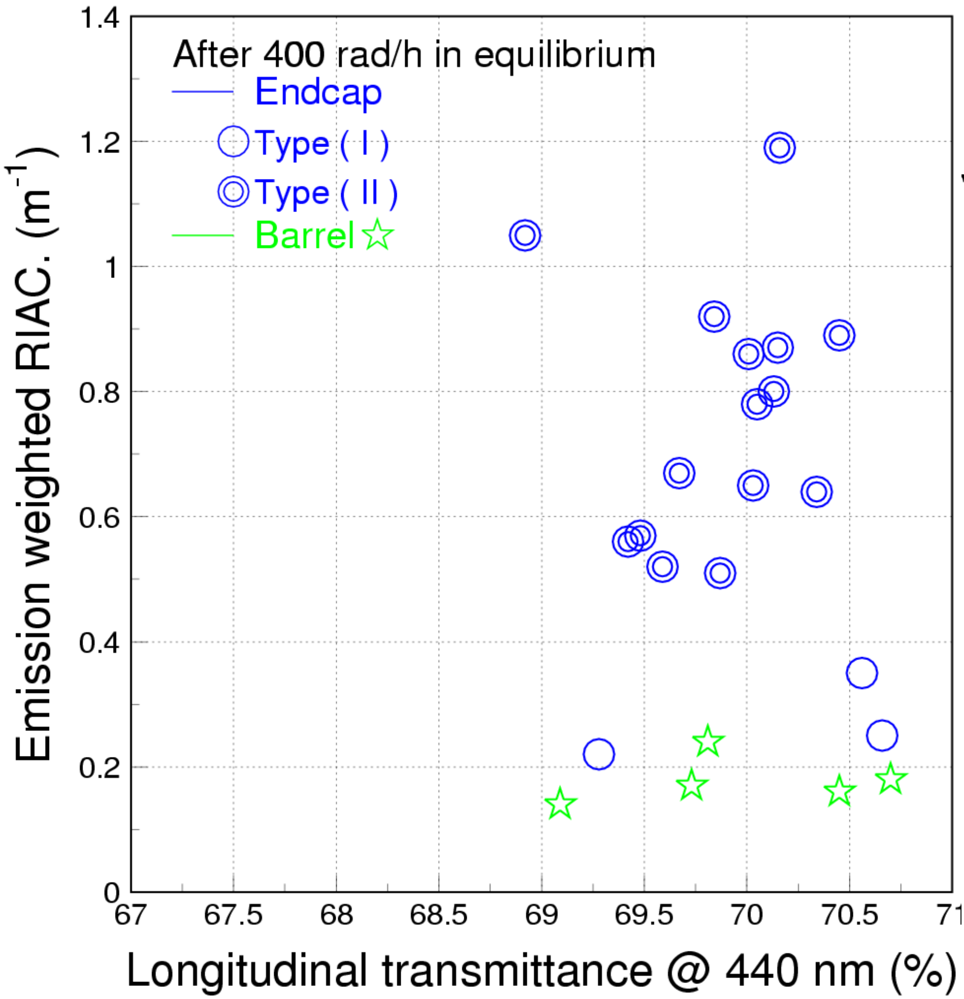
No correlation

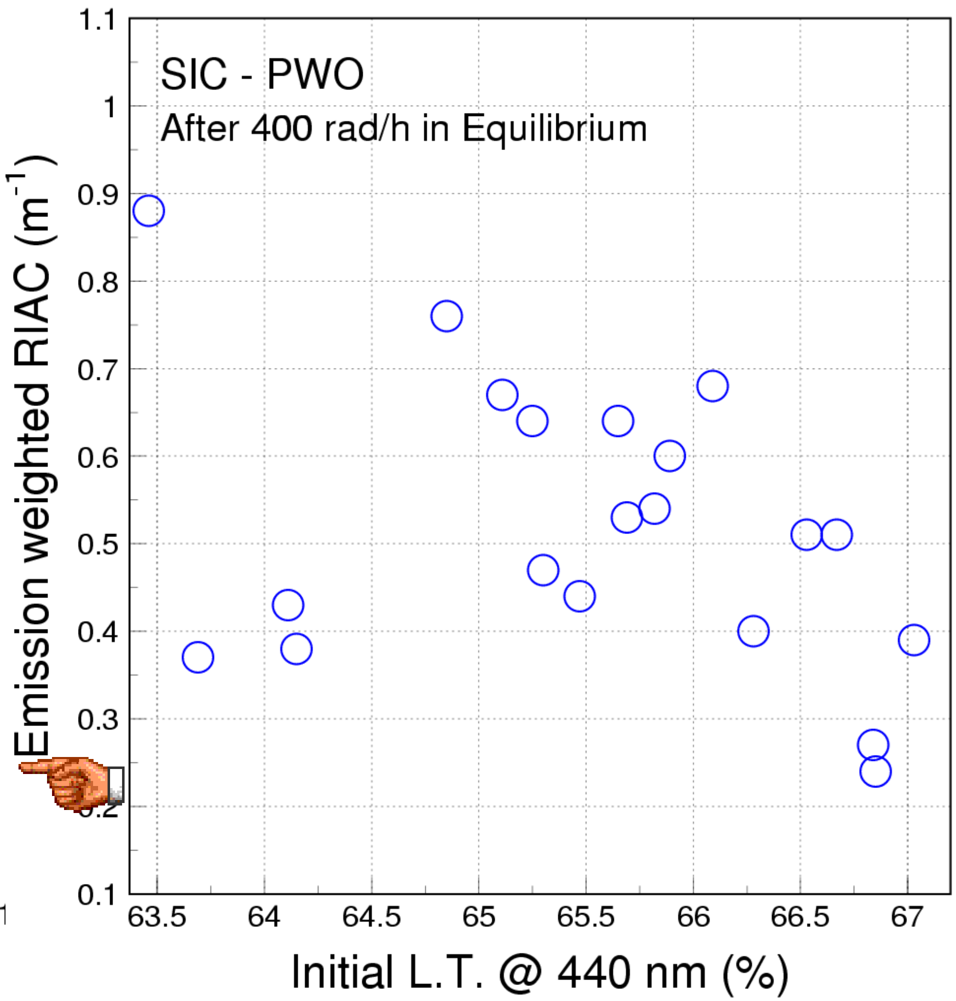




EWRIAC versus Initial L.T. @ 440 nm

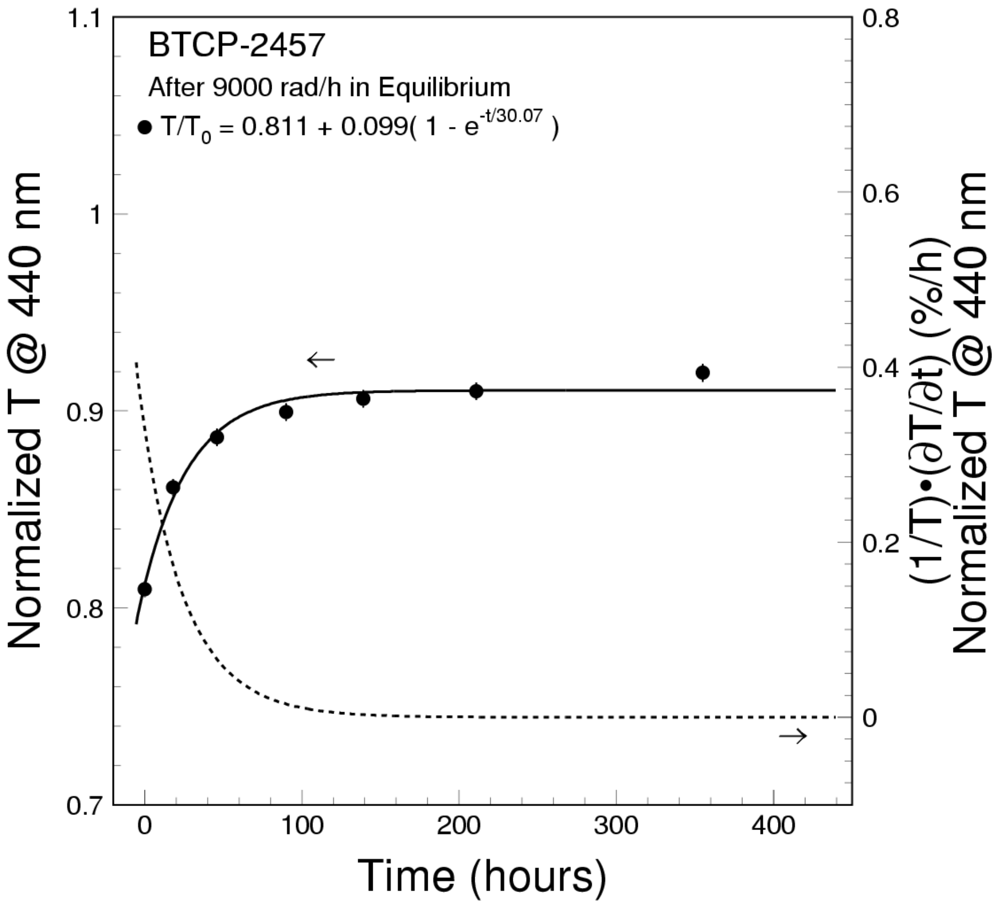
No correlation

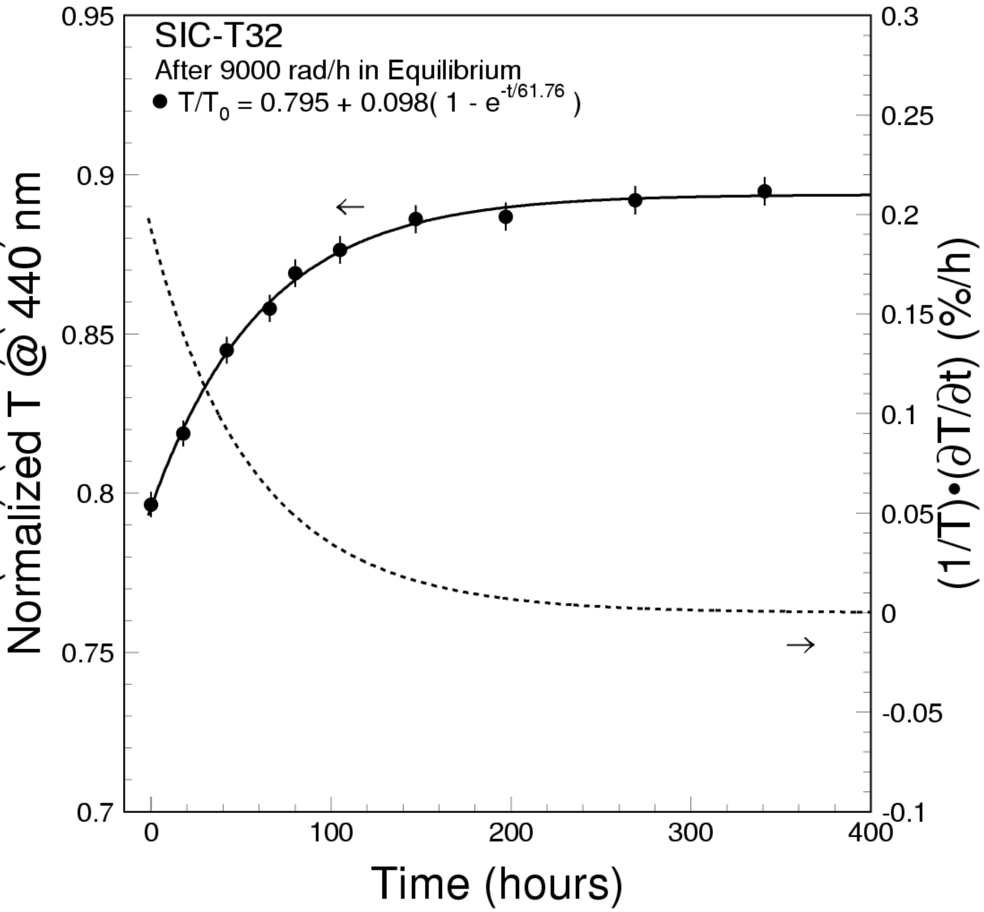




Recovery Speed and Time Constant

Recovery at 18ºC in 160 days can be described by two time constants: few tens hours and few thousands hours



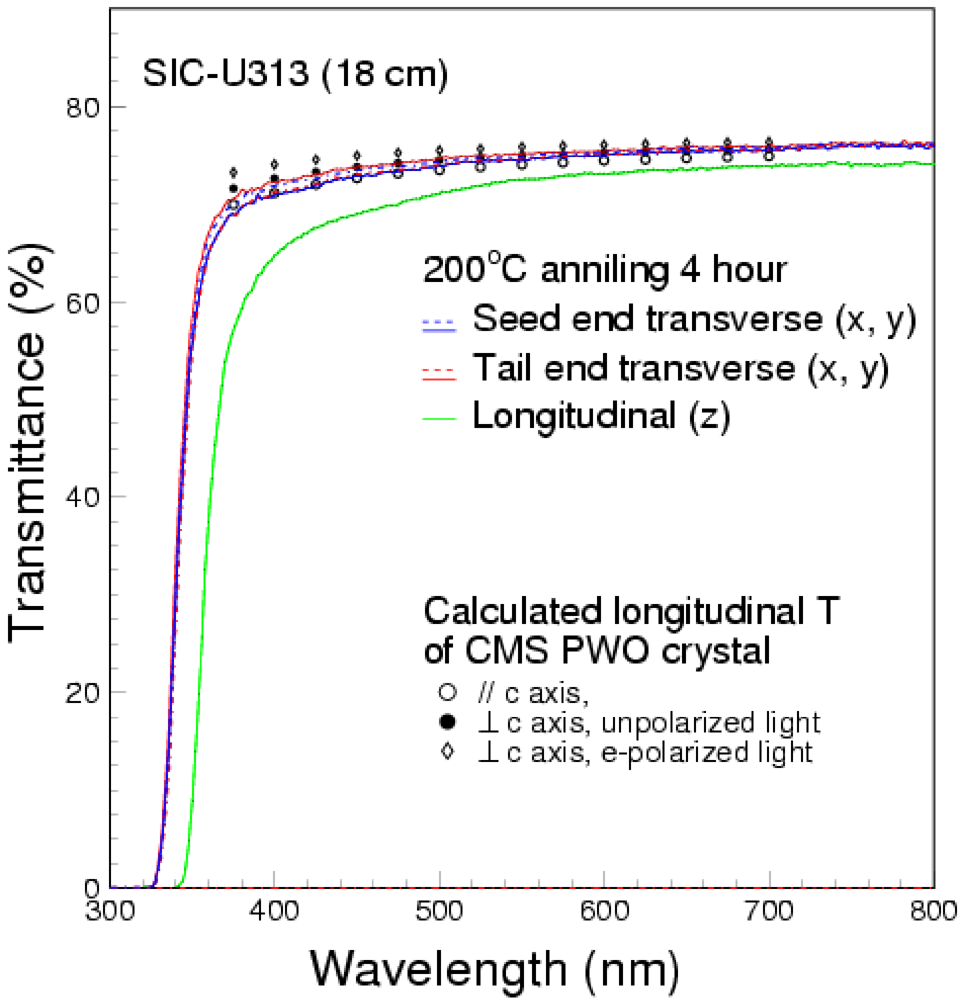


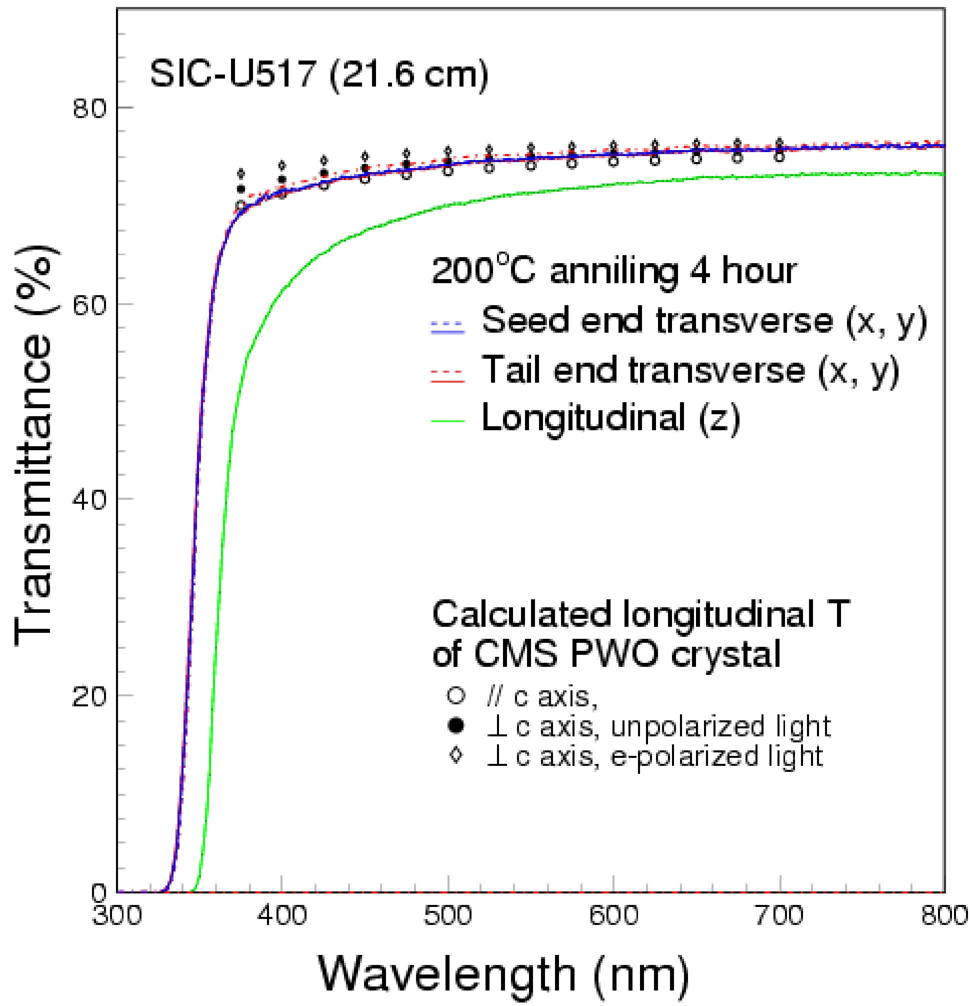
Summary

- Investigation on 20 crystals each from two vendors shows that SIC samples are more consistent (Bridgman).
- Samples from both vendors have very good transmittance and fast light output. It is not clear why SIC samples produce more (58%) light.
- No correlations between radiation hardness and initial longitudinal transmittance was observed.
- Current mass-produced PWO crystals are radiation hard enough for environment of up to a few hundreds rad/h by selection. R&D is needed if thousands rad/h is expected (SLHC).
- Some samples (from BTCP) are very radiation hard (Type I), which should be further studied.

PWO Crystals Grown along ***c axis***

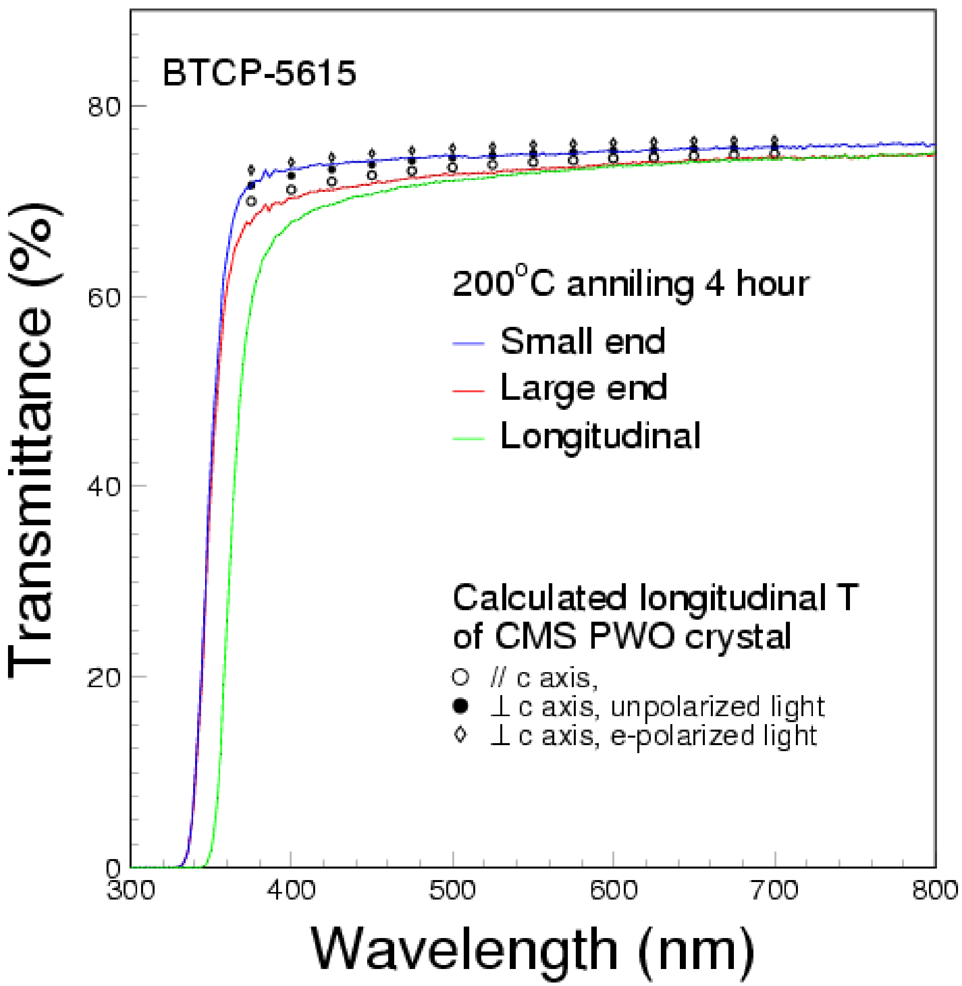
Isotropic transverse transmittance uniformity along crystal length

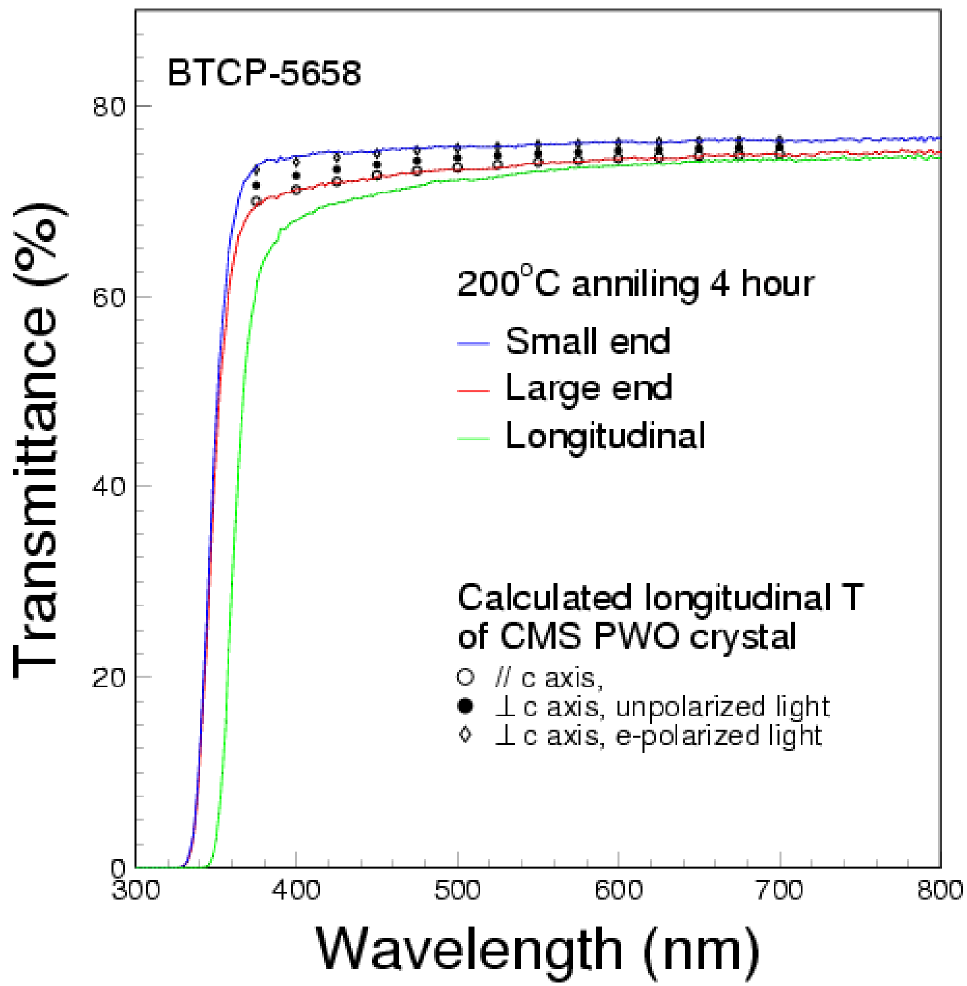




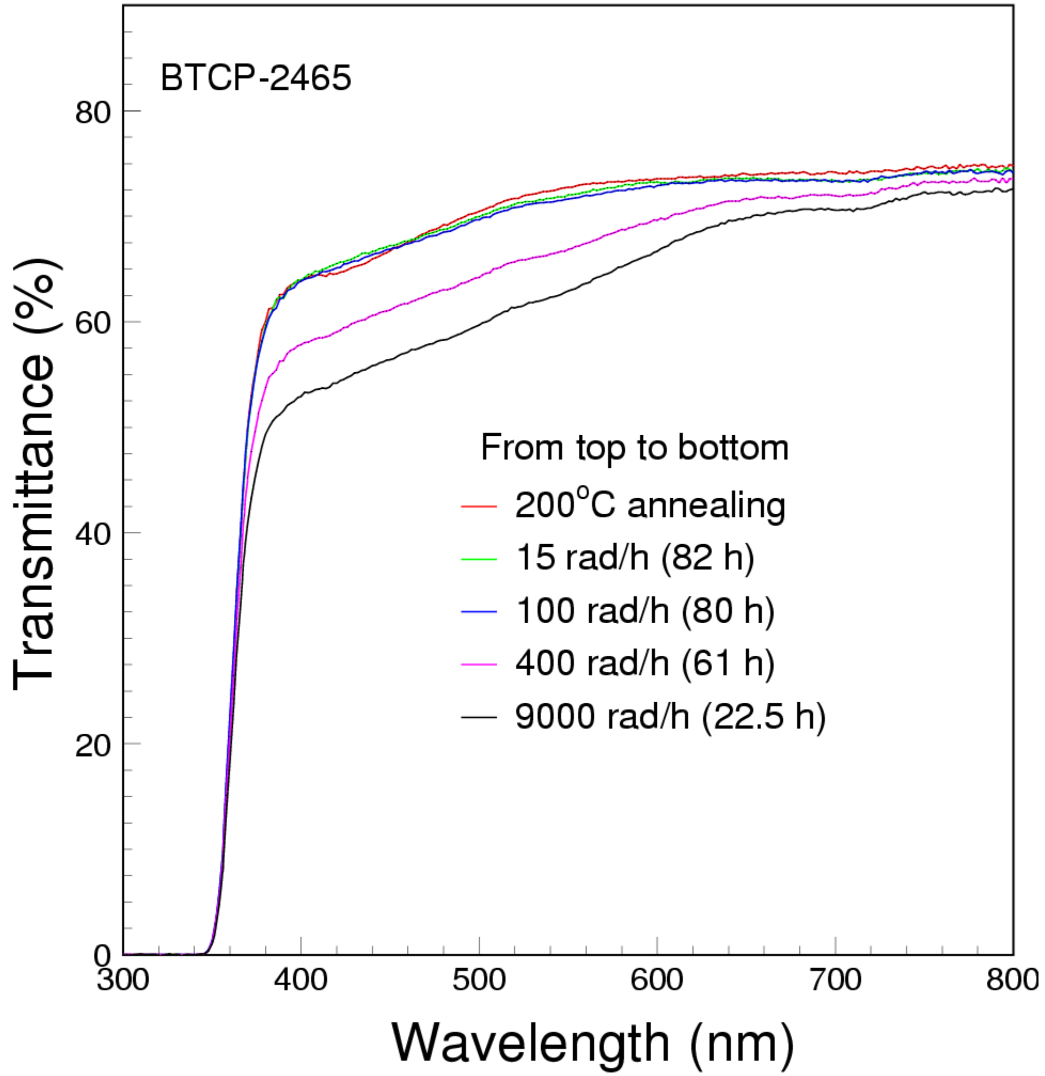
PWO Crystals Grown along ***a axis***

Not isotropic transverse transmittance
Not uniform along crystal length





Type III Sample: Transmittance Loss



Type III sample: preexisting intrinsic color center at 420 nm after 200 degree annealing, causing difficulty for monitoring with 440 nm light