Damage and Recovery Study for BTCP and SIC samples

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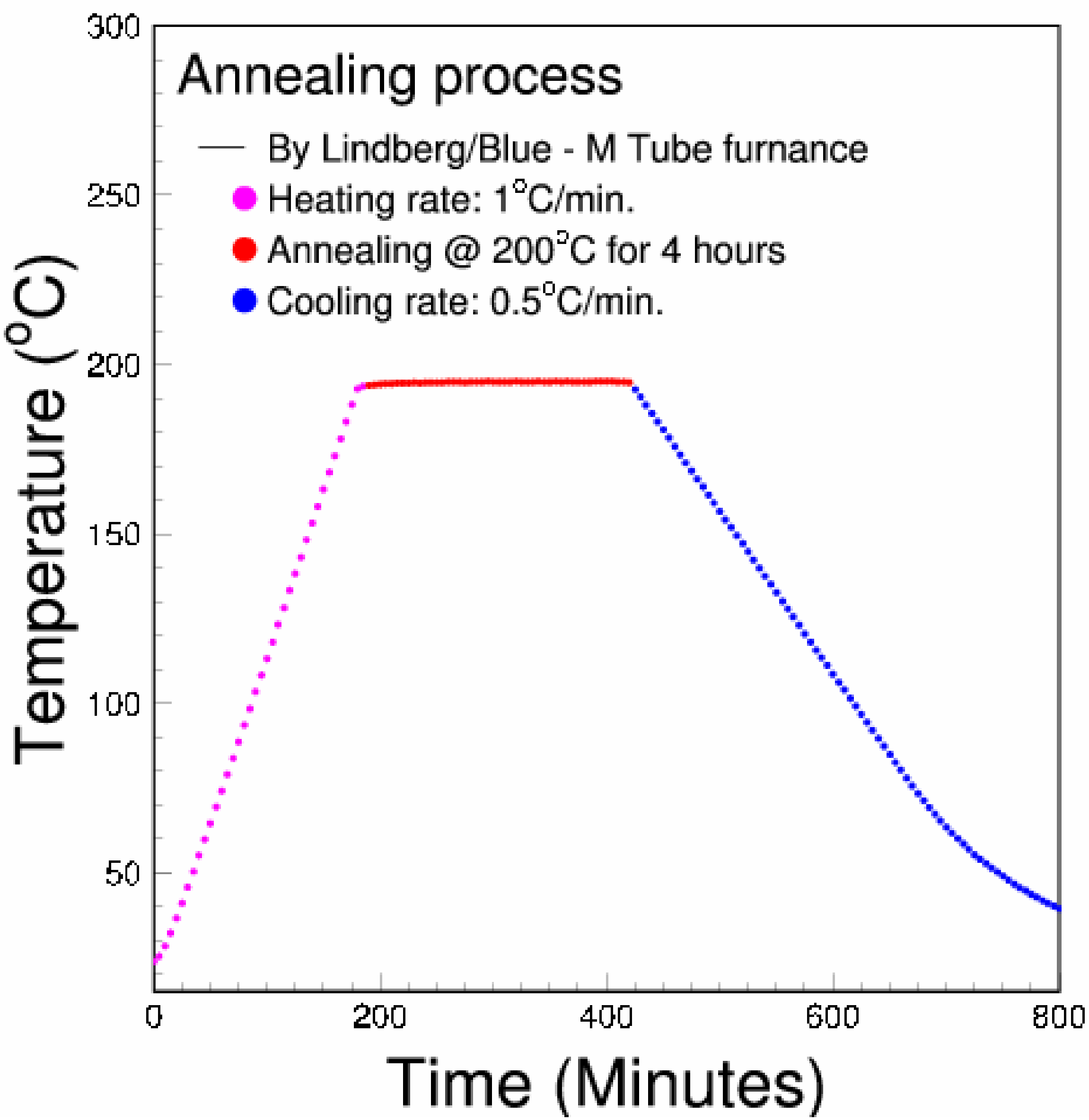
Introduction

- Four endcap size PWO samples: 2 from BPCP 2003(?) batch (2482 & 2531) and 2 from the SIC 2004 January batch (2570 & 2572) were received on November 9. Since then they went through a thermal annealing at 200^{o}C, and a series of two irradiations followed by recovery at 15 and 400 rad/h.
- Properties measured: transmittance, emission and excitation spectra, light output, decay kinetics and their degradation
- Results are compared to 20 samples each from the BTCP 2001 batch of the endcap size and the SIC 2002 batch of the CEBAF size, as well as two endcap size samples from the SIC 2004 May batch.
- An update of long term recovery for two SIC samples from the 2004 May batch (2630 & 2641).

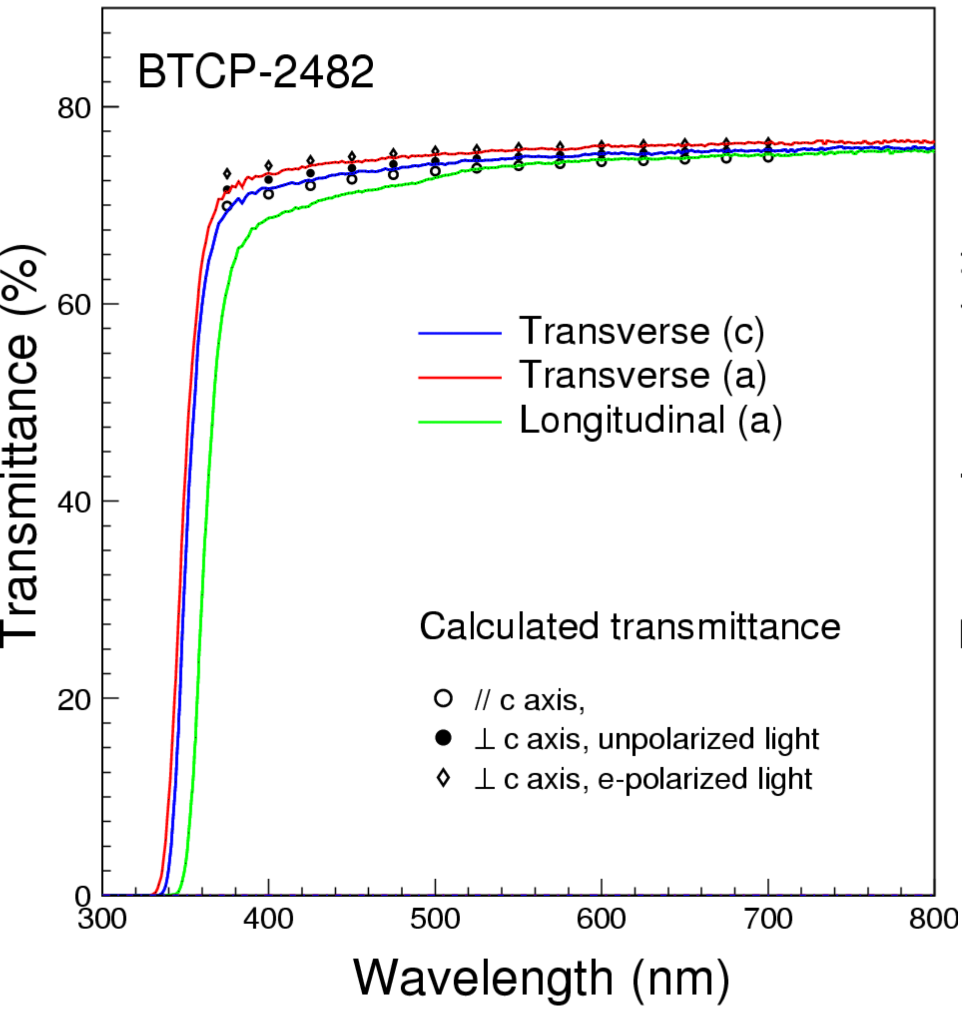
Thermal Annealing

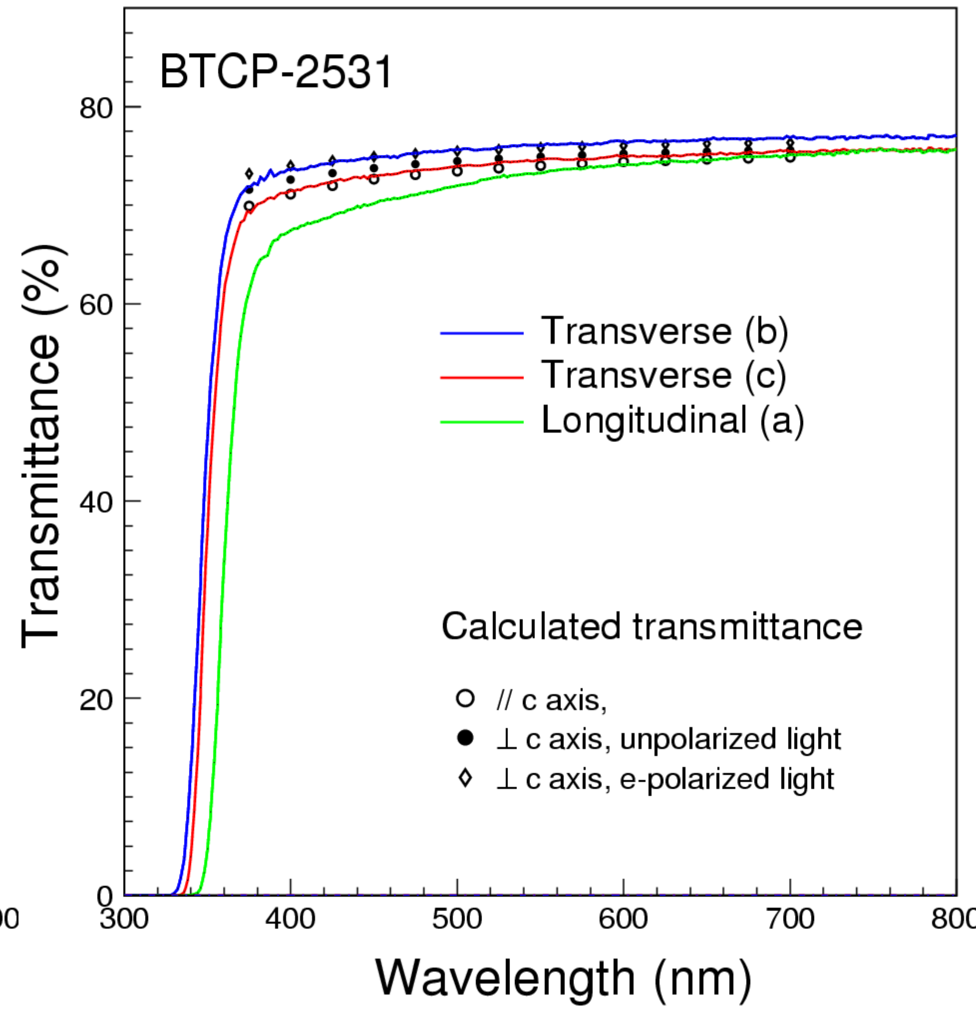


- Carried out in a Lindberg Blue-M tube furnace with automatic control.
- Removed residual absorption from previous irradiations; Restored the sample to its **initial?** state.

BTCP Initial Transmittances

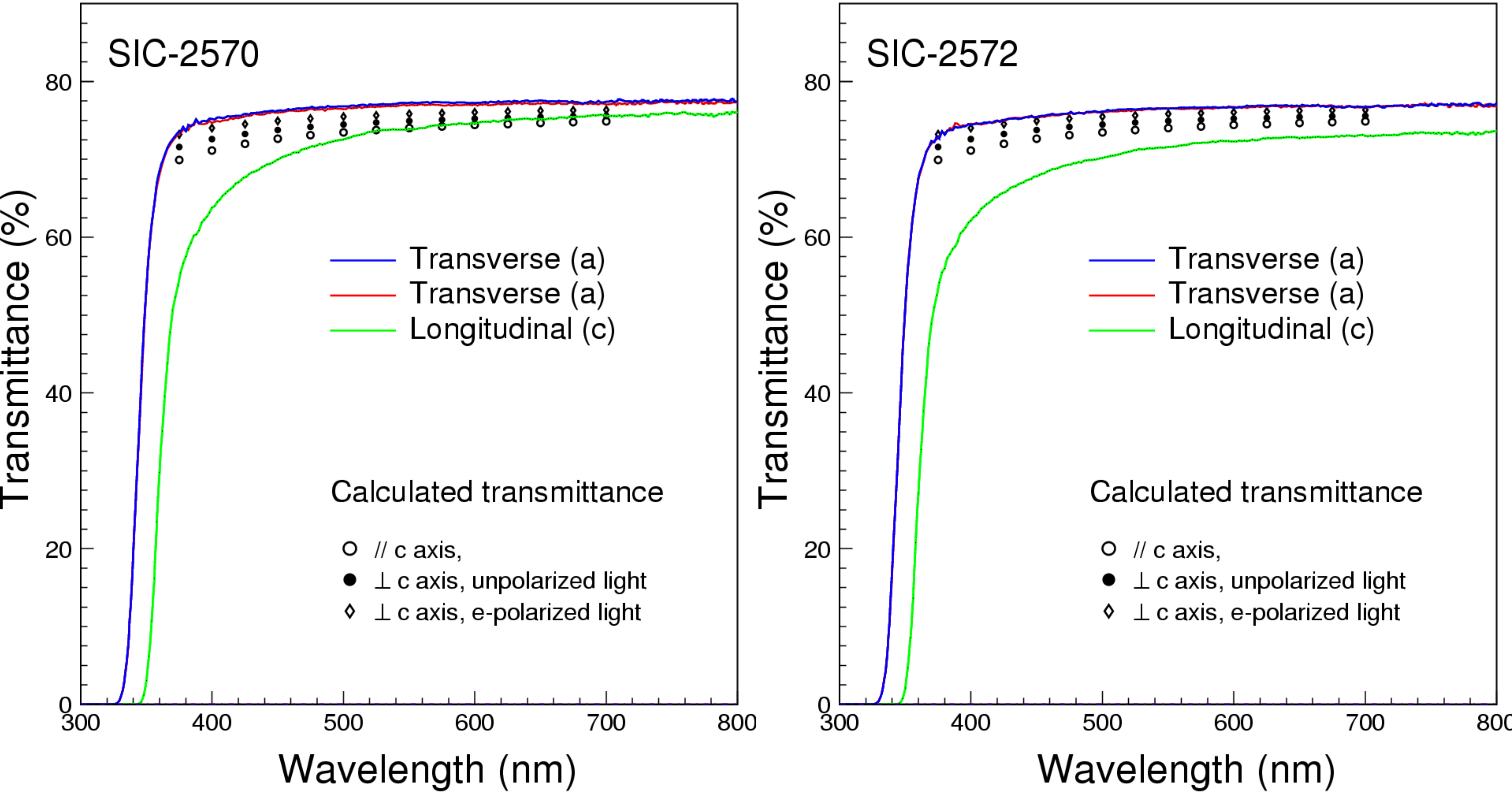
Longitudinal transmittance along the "a" axis
Transverse transmittance approaches theoretical limit





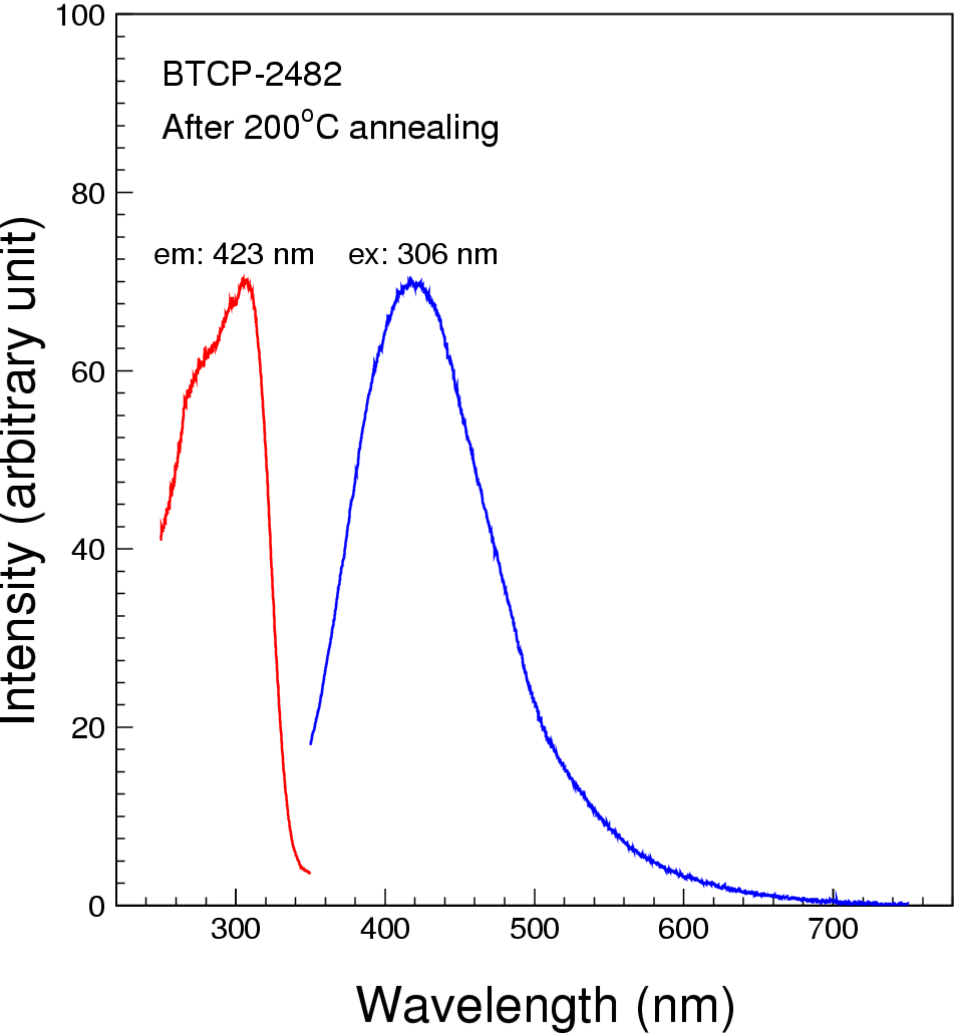
SIC Initial Transmittances

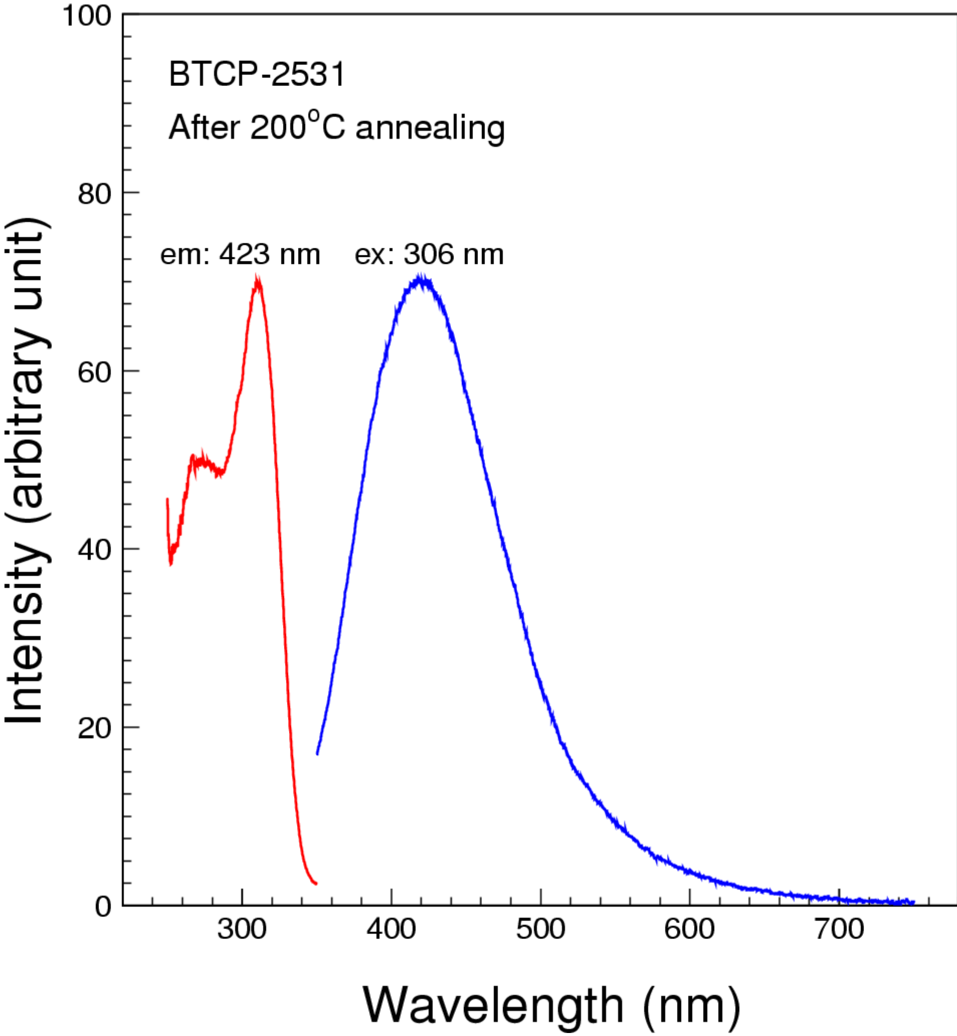
Longitudinal transmittance along the "c" axis
Transverse transmittance approaches theoretical limit



BTCP Initial Photo-luminescence

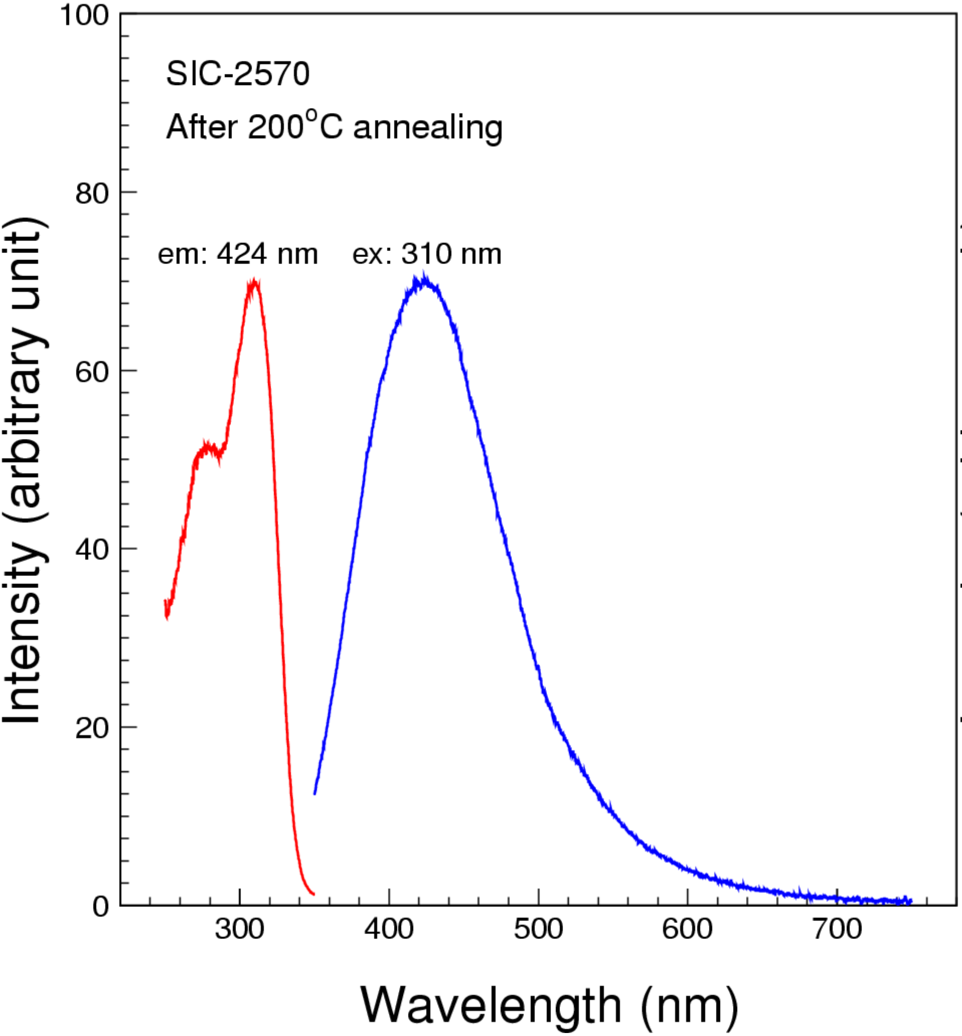
No red emission

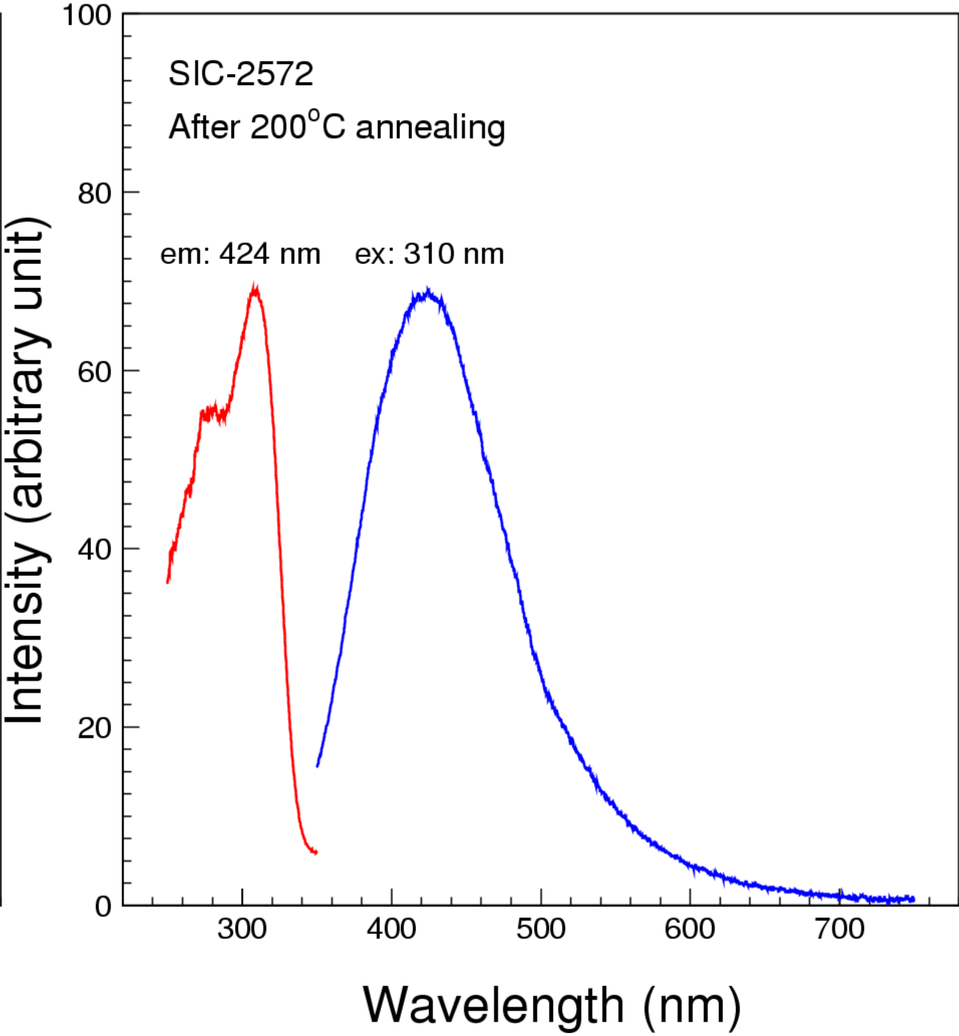




SIC Initial Photo-luminescence

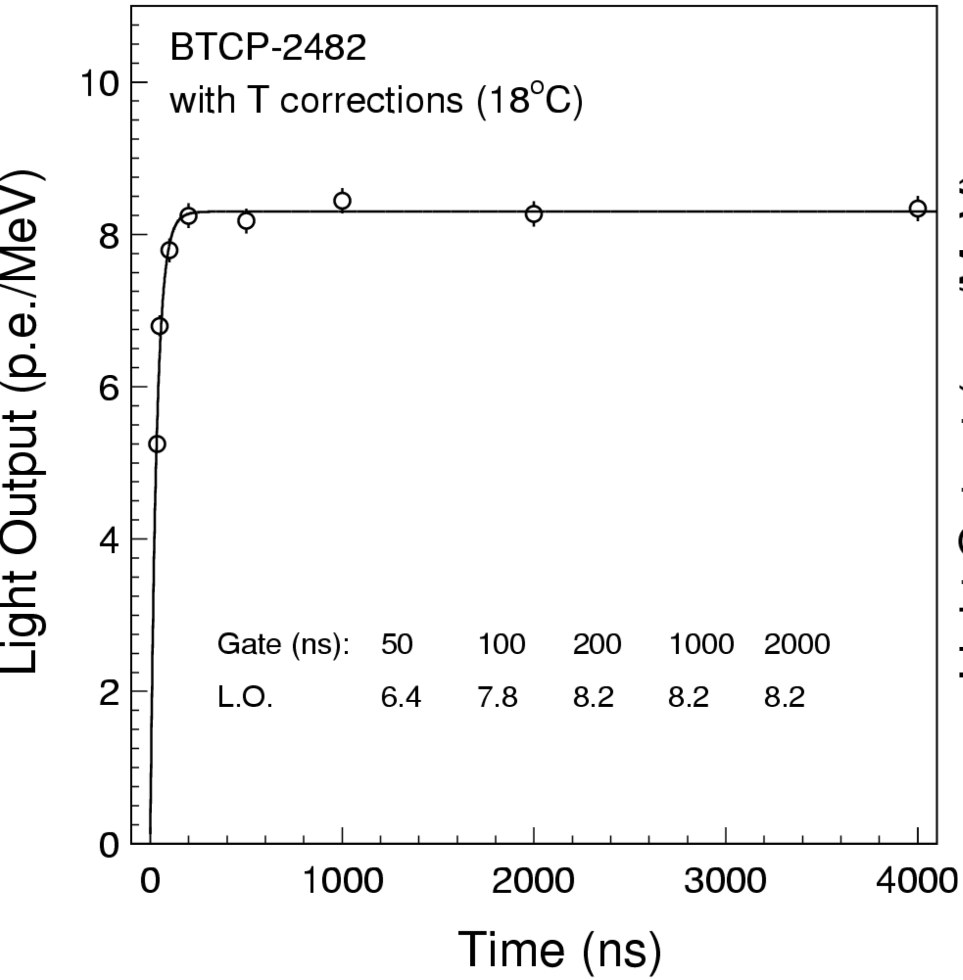
No red emission

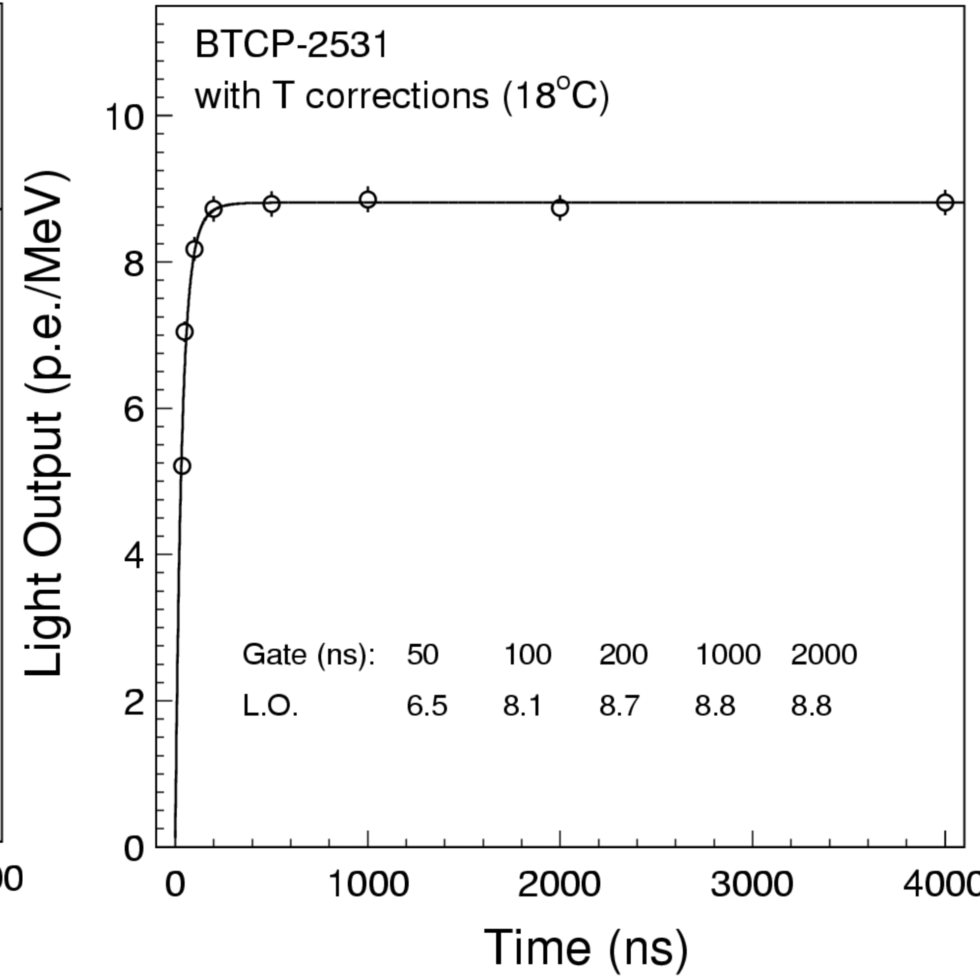




BTCP Light Yield and Decay Kinetics

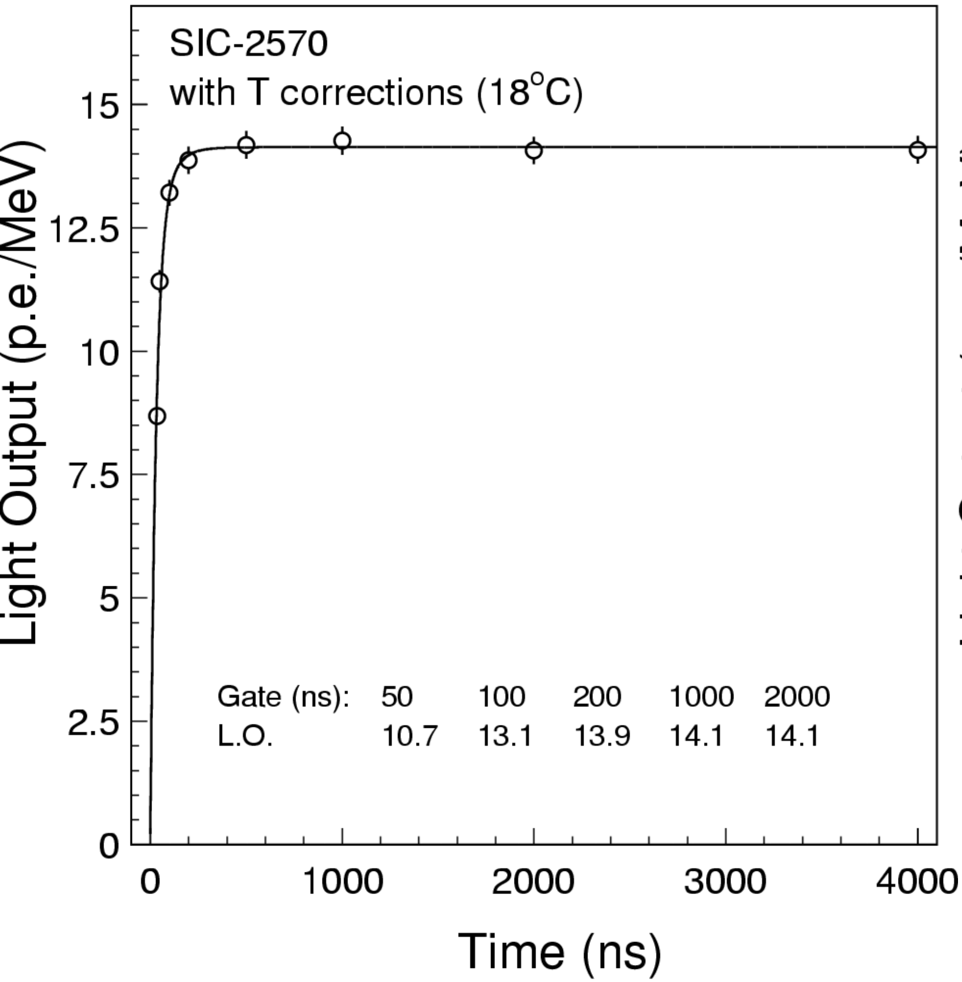
Average initial light output: 8.5 p.e./MeV

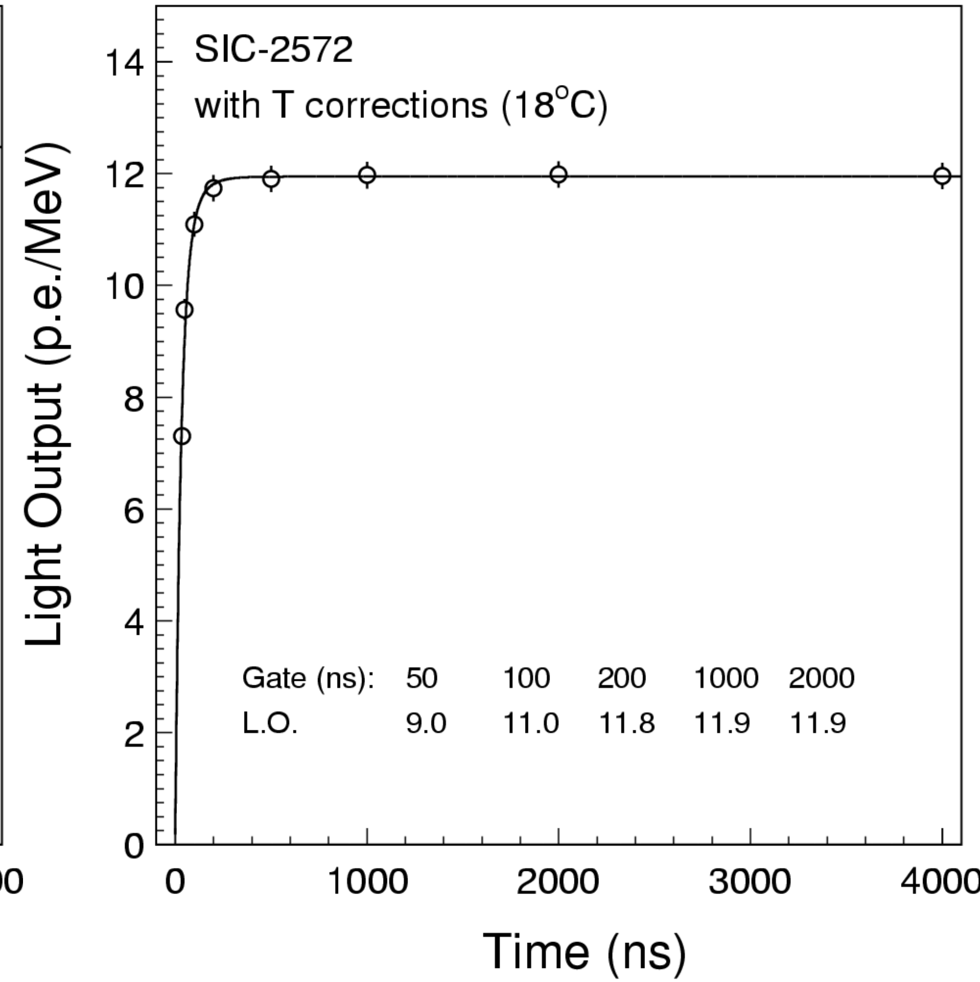




SIC Light Yield and Decay Kinetics

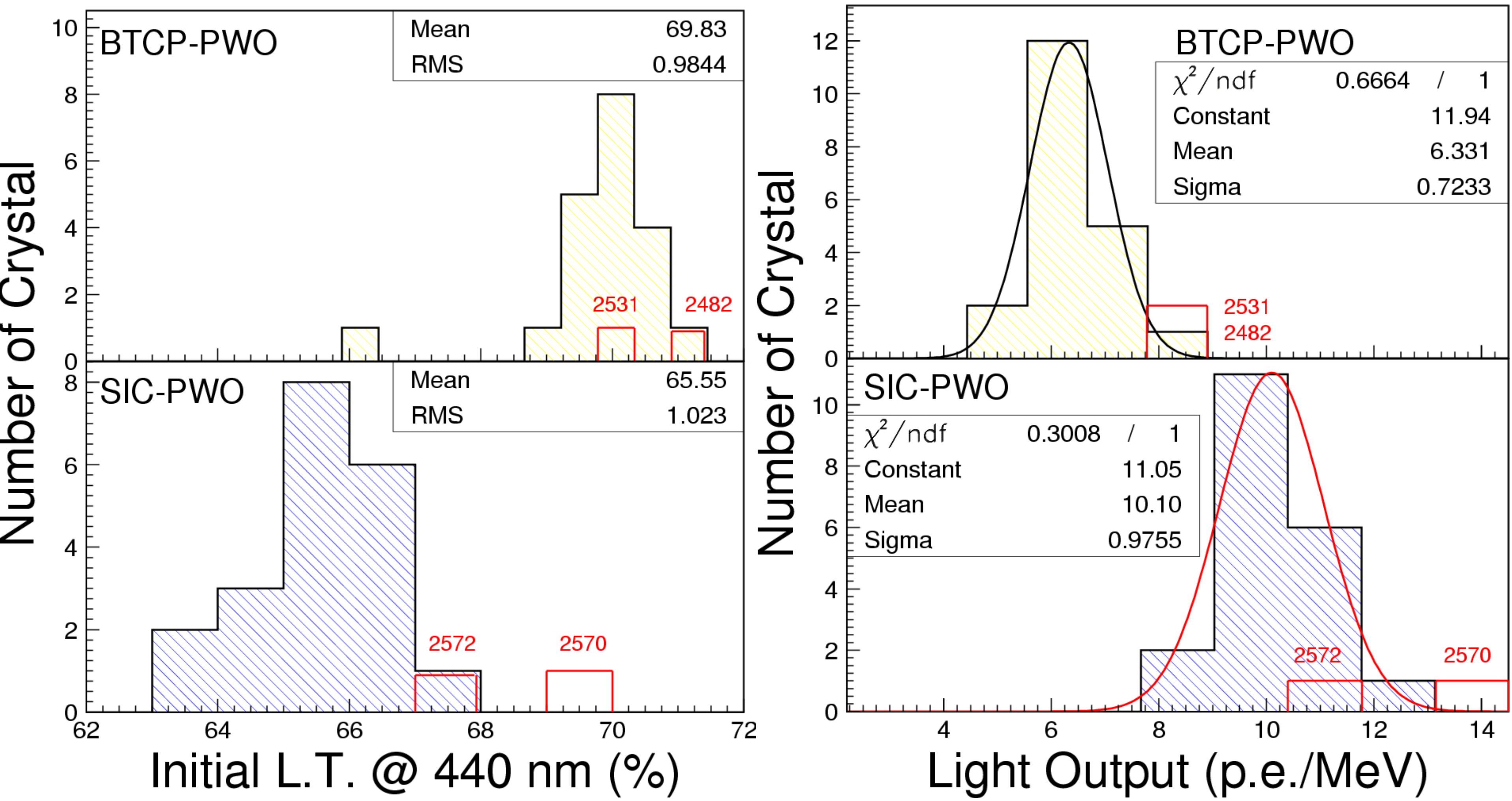
Average initial light output: 12.8 p.e./MeV





Comparison with Previous 20 Crystals

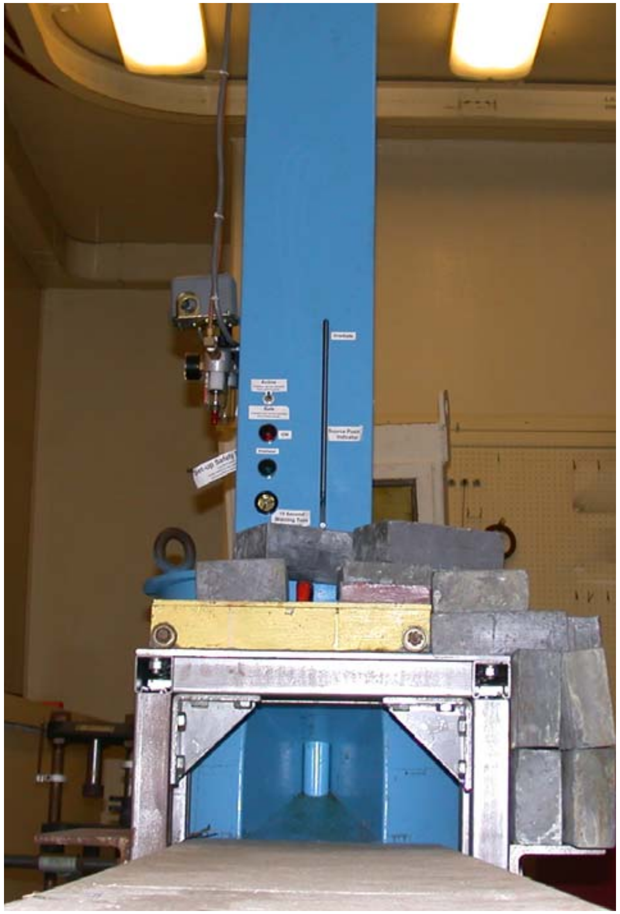
New BTCP and SIC samples are better than corresponding 2001 and 2002 batches respectively

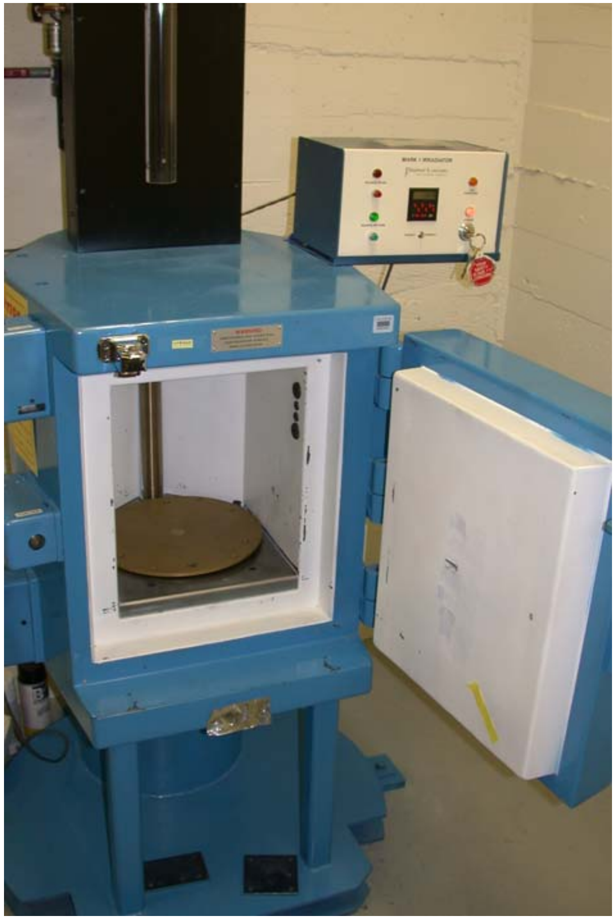


Caltech γ–ray Irradiation Facilities

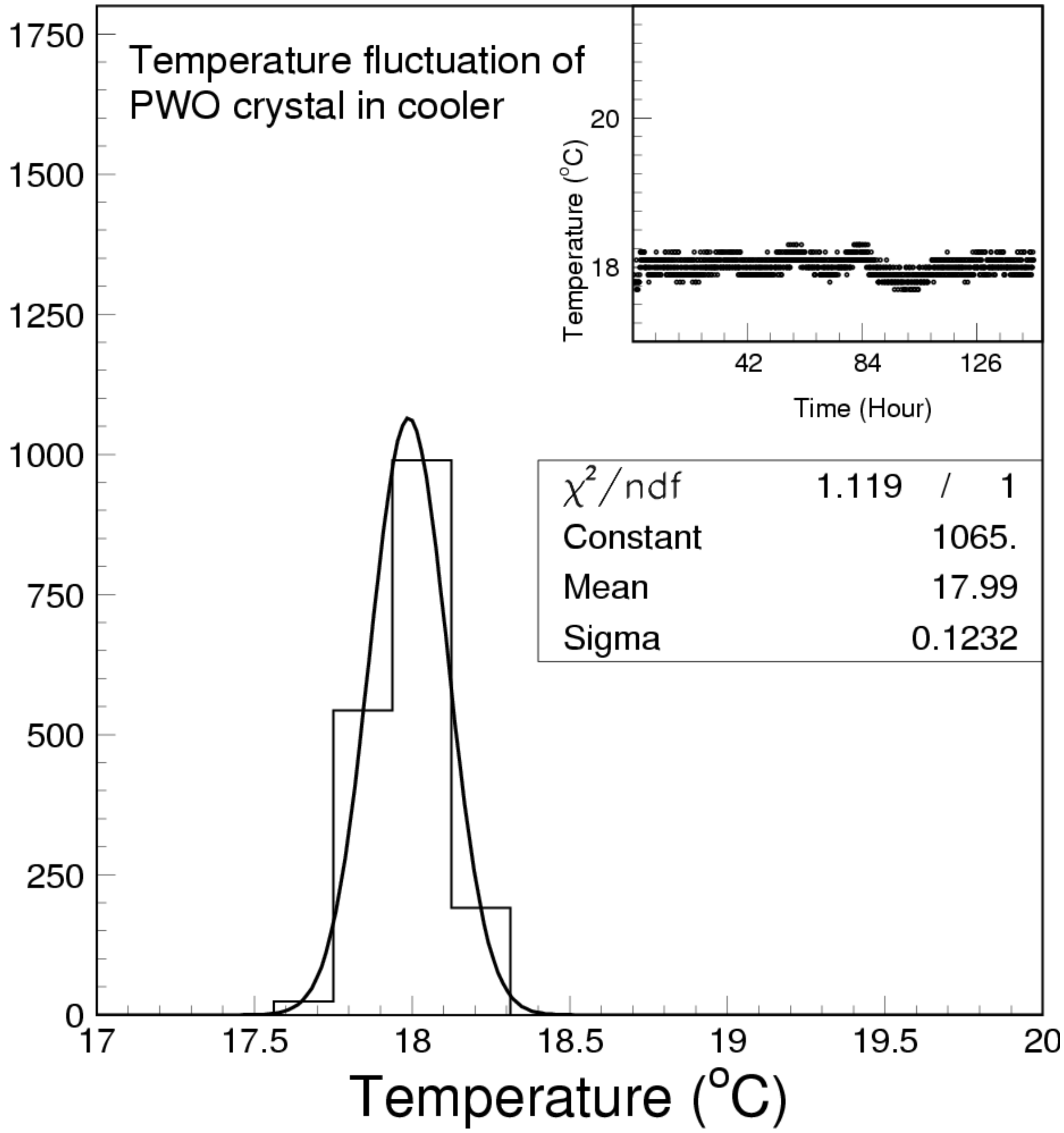
Open 50 curie Co-60:
15 and 400 rad/h

Closed 2,000 curie Cs-137:
9k rad/h at center (10% uniformity)





Long Term Recovery under 18^{o}C



After irradiation recovery was measured when samples were kept in a cooler at 18^{o}C with 0.12^{o}C variation.

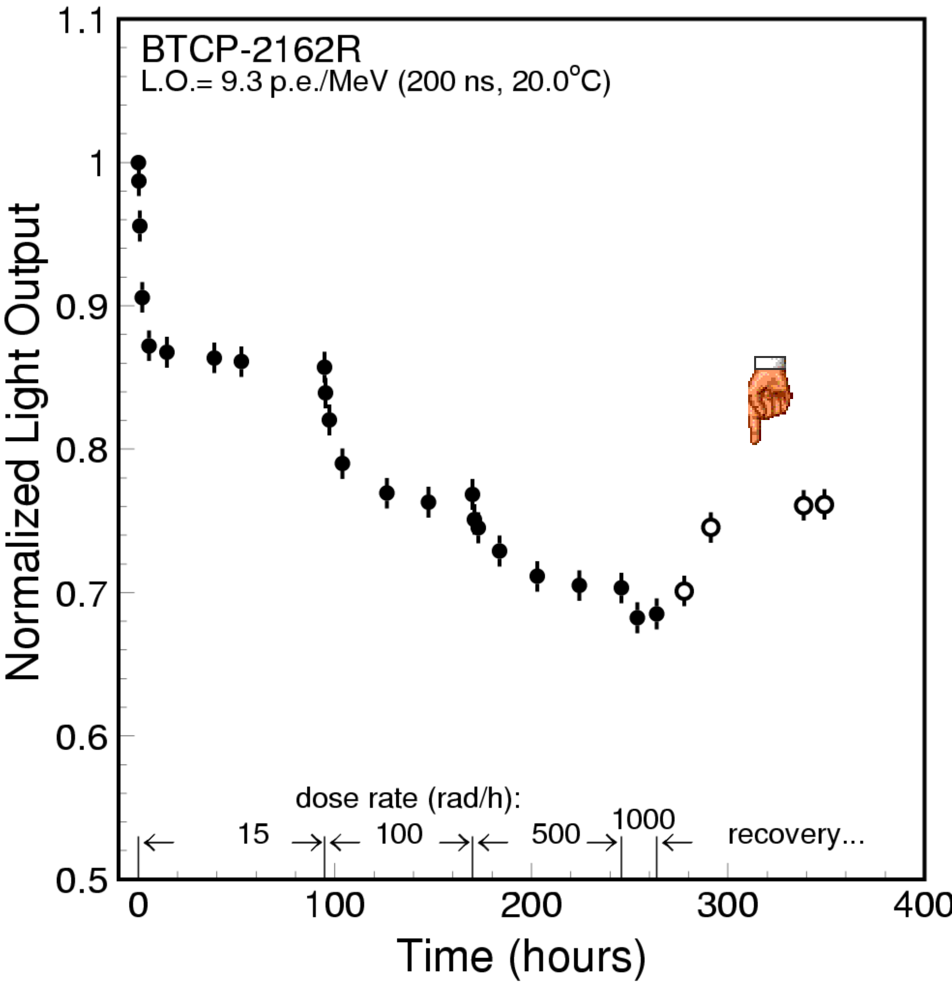
Dose Rate Dependence

IEEE Trans. Nucl. Sci., Vol. 44 (1997) 468-476

$$dD = \sum_{i=1}^{n} \{-a_i D_i dt + (D_i^{all} - D_i)\, b_i R dt\}$$

$$D = \sum_{i=1}^{n} \{\frac{b_i R D_i^{all}}{a_i + b_i R}\,[1 - e^{-(a_i+b_iR)t}] + D_i^0 e^{-(a_i+b_iR)t}\}$$

- D_i: color center density in units of m^{-1};
- D_i^0: initial color center density;
- D_i^{all} is the total density of trap related to the color center in the crystal;
- a_i: recovery costant in units of hr^{-1};
- b_i: damage contant in units of kRad^{-1};
- R: the radiation dose rate in units of kRad/hr.



$$D_{eq} = \sum_{i=1}^{n} \frac{b_i R D_i^{all}}{a_i + b_i R}$$

Two issues: LAL and monitor-ability

Light Attenuation Length Affects LRU

Nucl. Instr. And Meth. A413 (1998) 297

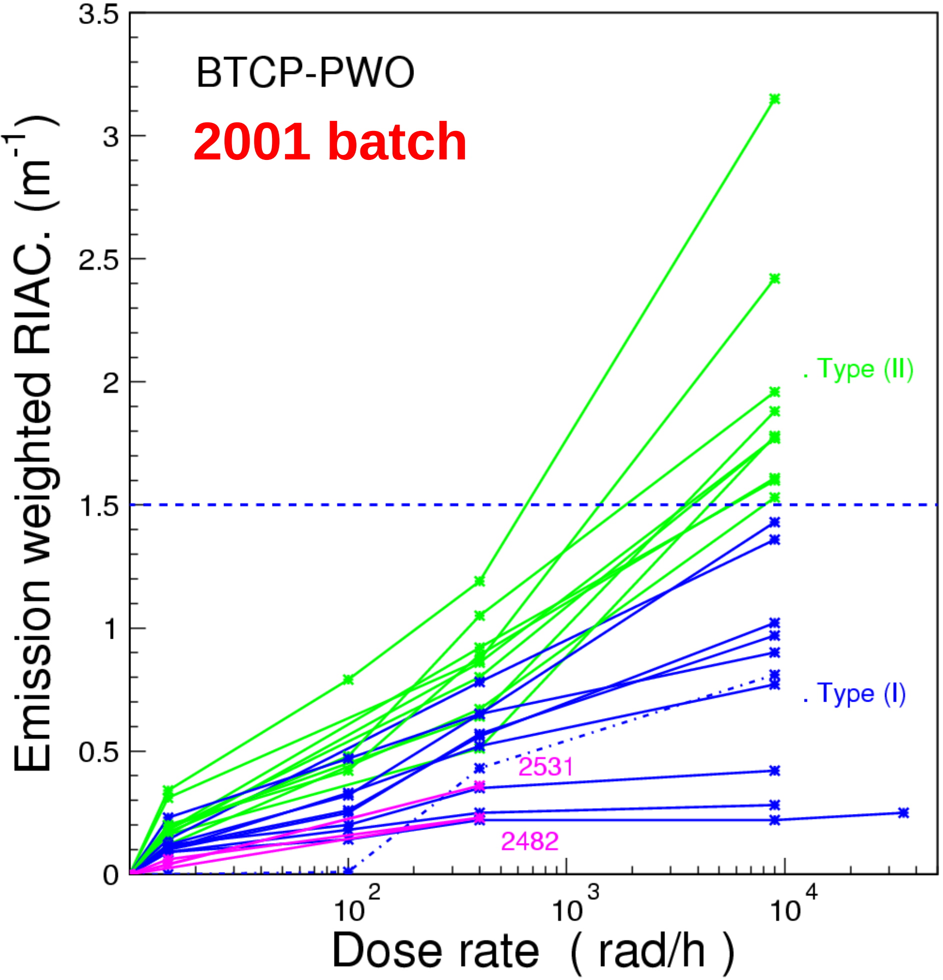
Ray-Tracing simulation for CMS PWO crystals shows no change in LRU if LAL is longer than 3.5 crystal length

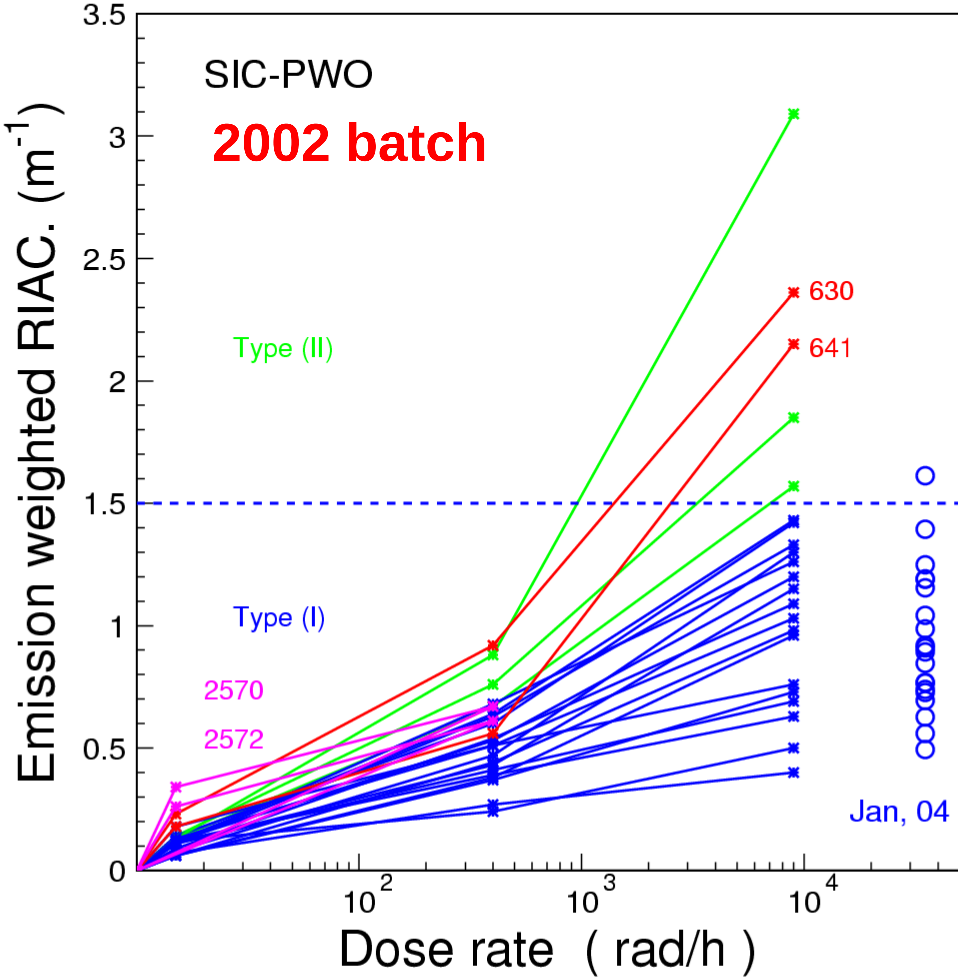
Light collection efficiency, fit to a linear function of distance to the small end of the crystal, was determined with two parameters: the light collection efficiency at the middle of the crystal and the uniformity.

LAL (cm)	20	40	60	80	200
Large Area Photo Detector, covering 100% back face					
η_m (%)	9.5±.2	15.7±.4	19.2±.5	21.6±.6	26.9±.7
δ (%)	23±1	-4.6±.8	-11±1	-15±1	-15±1
ϕ5 mm Photo Detector, covering 3.7% back face					
η_m (%)	.38±.04	.74±.08	1.1±.1	1.4±.2	3.0±.3
δ (%)	23±4	–3.5±4	-12±4	-16±4	-17±3
$\frac{\eta_m(\phi 5mm)}{\eta_m(Full)}$ (%)	4.0	4.7	5.7	6.5	11

Emission Weighted RIAC

Light attenuation length longer than 67 cm, or EWRIAC < 1.5 m^{-1}, is a necessary condition





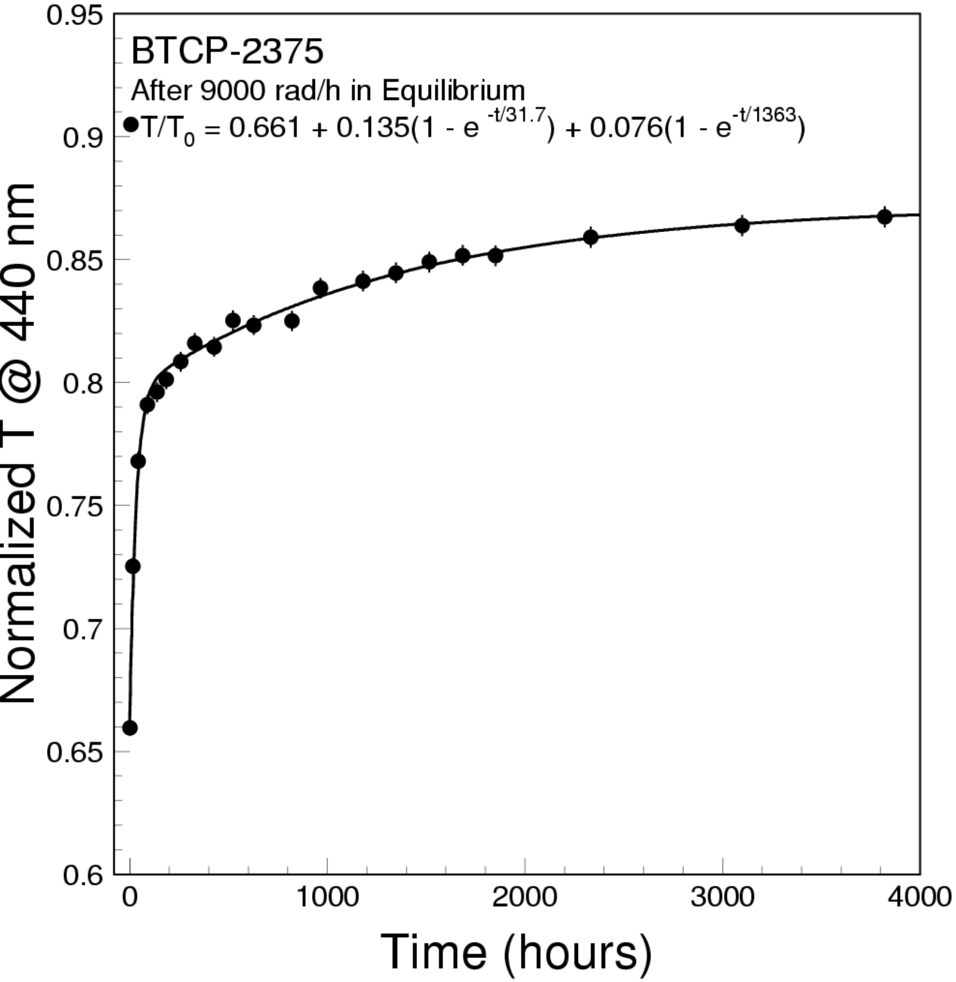
Selection required for dose rate higher than a few hundreds rad/h

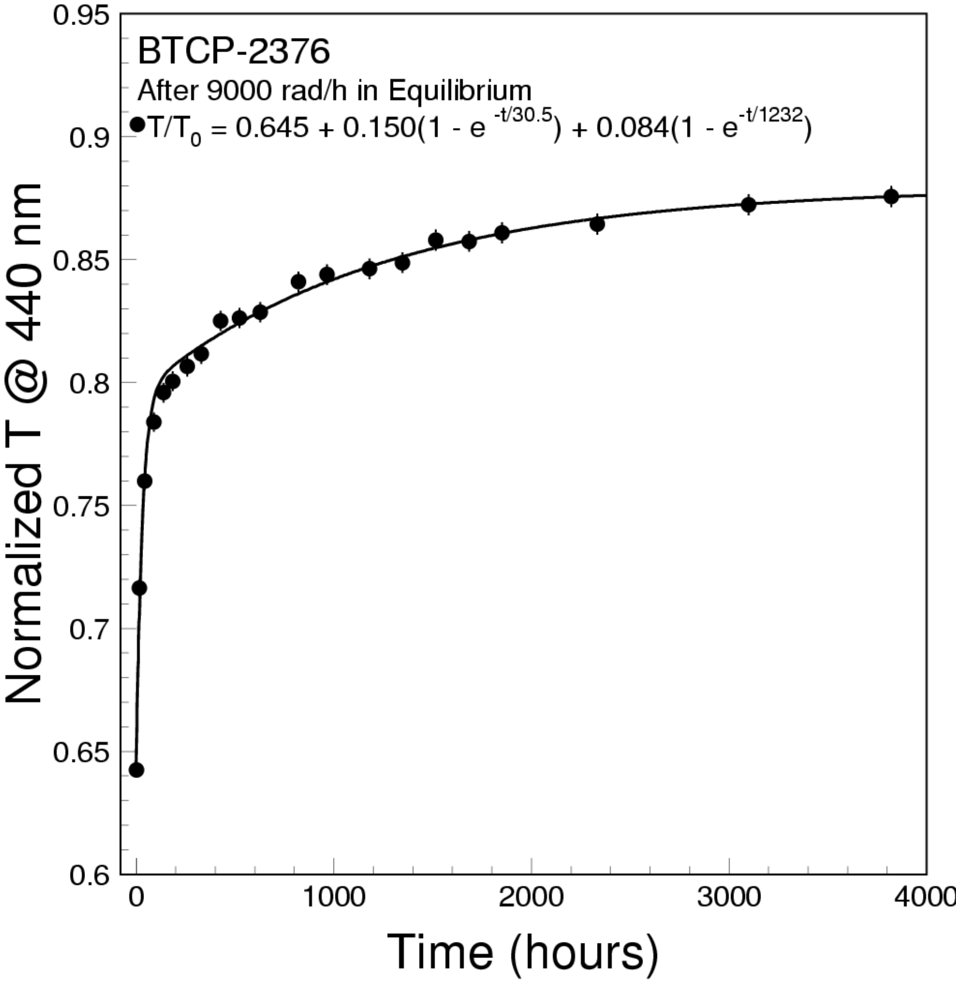
Long Term Recovery (BTCP 2001 Batch)

Fast: 40% and 42% with time constant of 31 and 31 h

Slow: 22% and 24% with time constant of 1363 and 1232 h

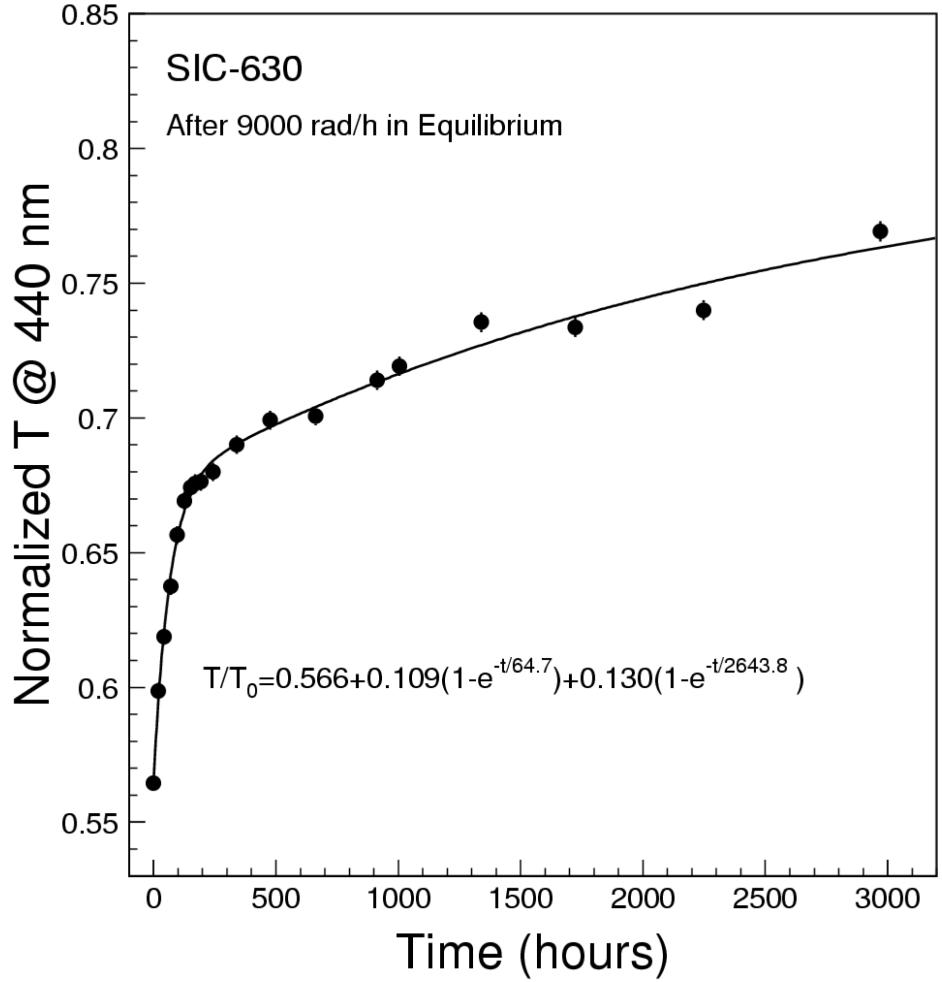
35% unrecoverable damage

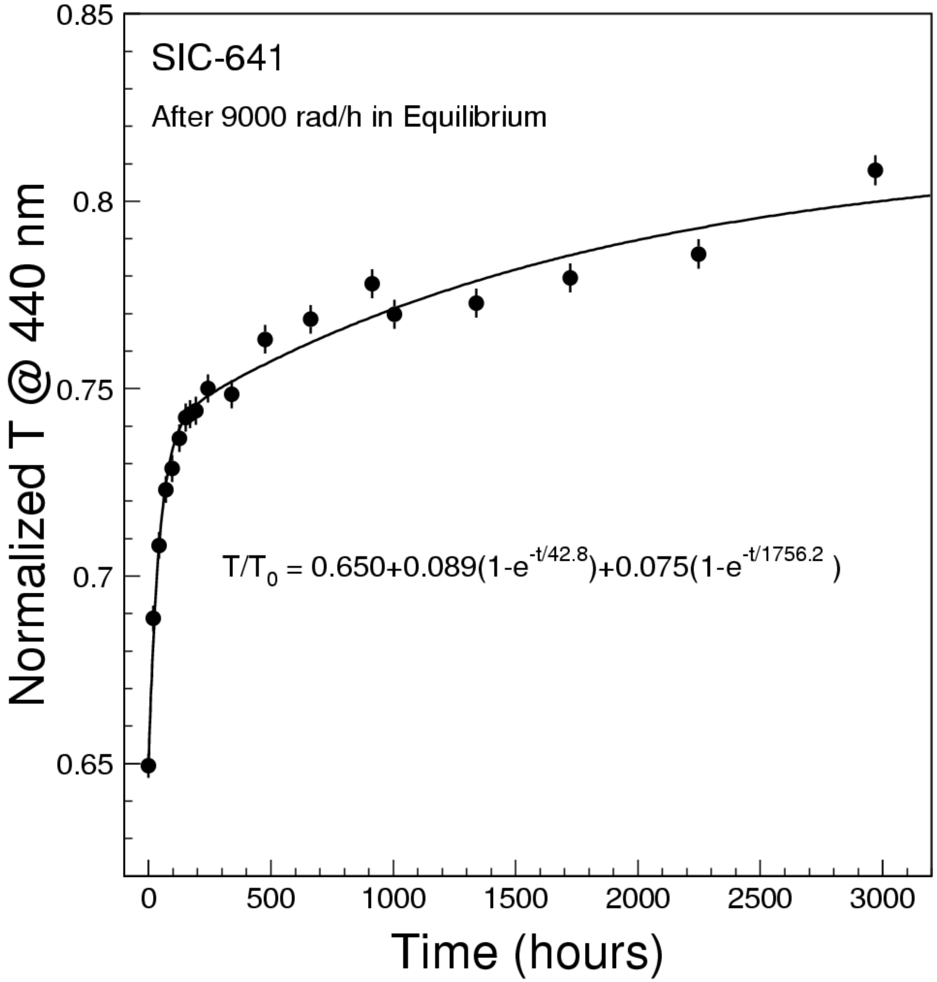




Long Term Recovery (SIC May 2004 Batch)

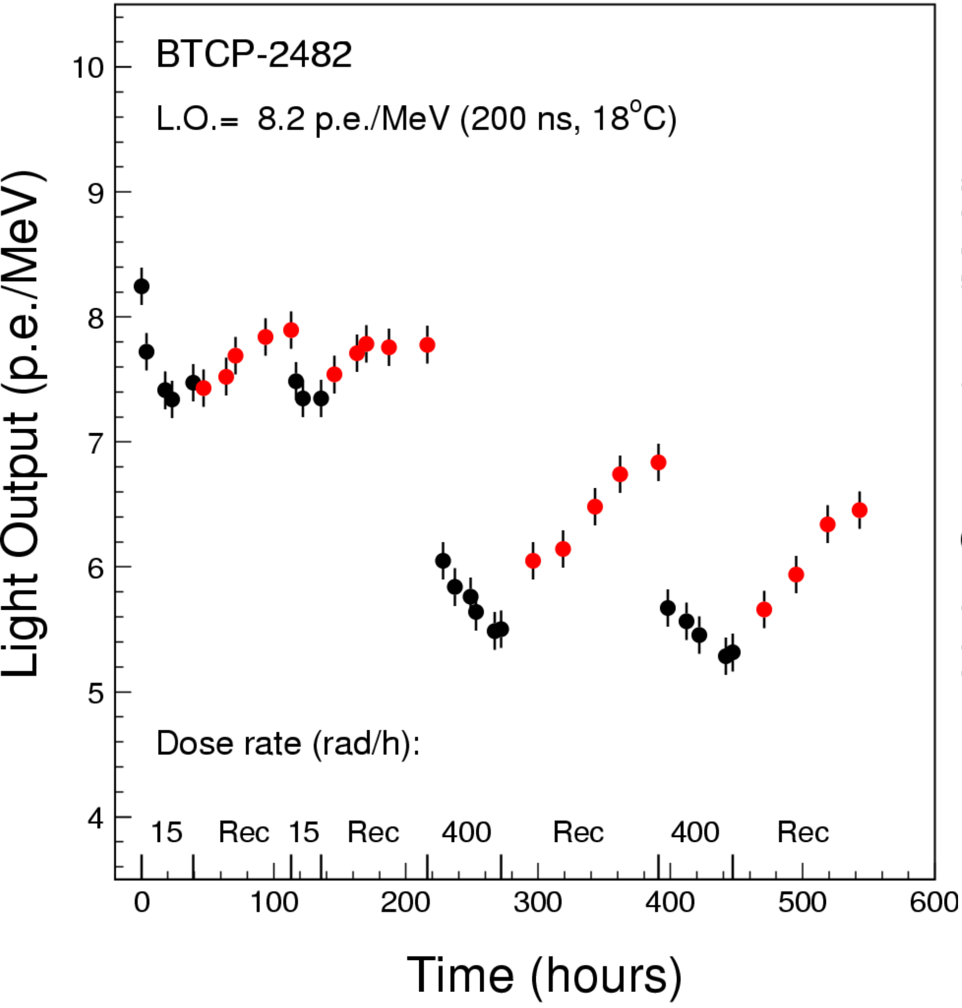
Fast: 25% and 25% with time constant of 65 and 43 h
Slow: 30% and 21% with time constant of 2644 and 1756 h
50% unrecoverable damage

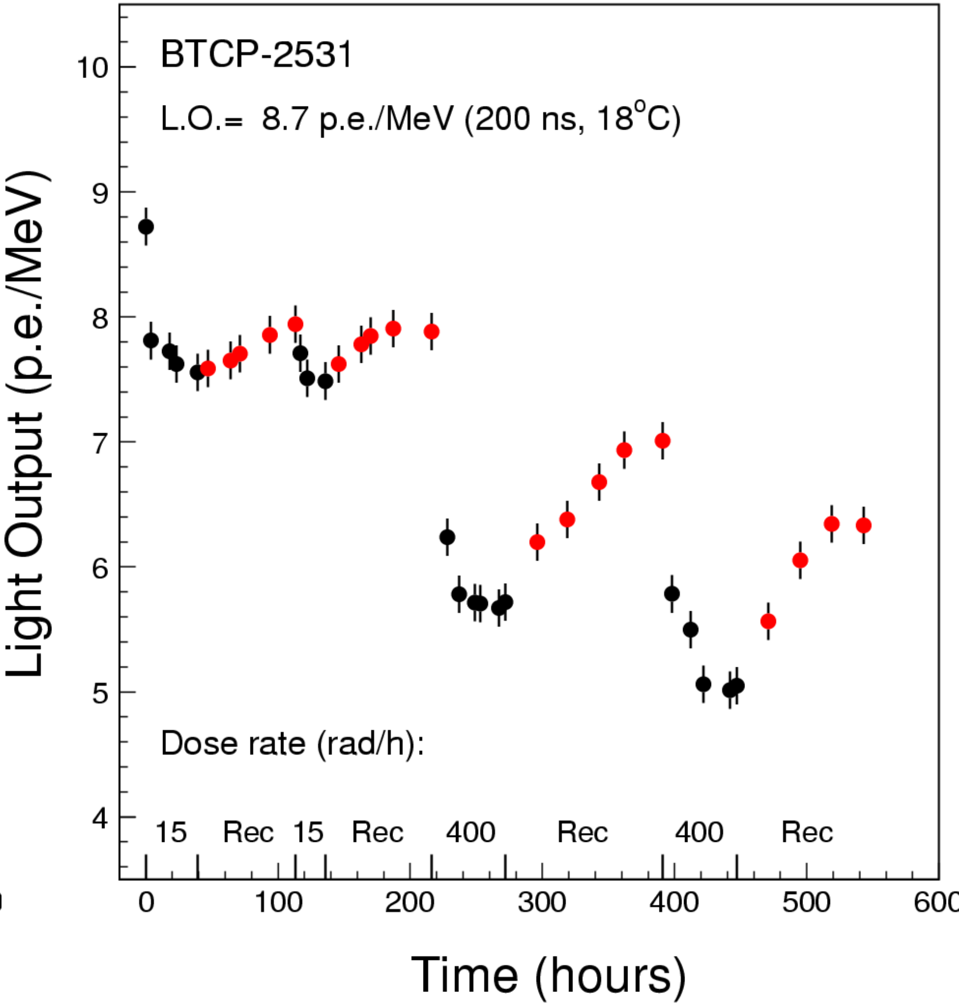




BTCP Damage & Recovery

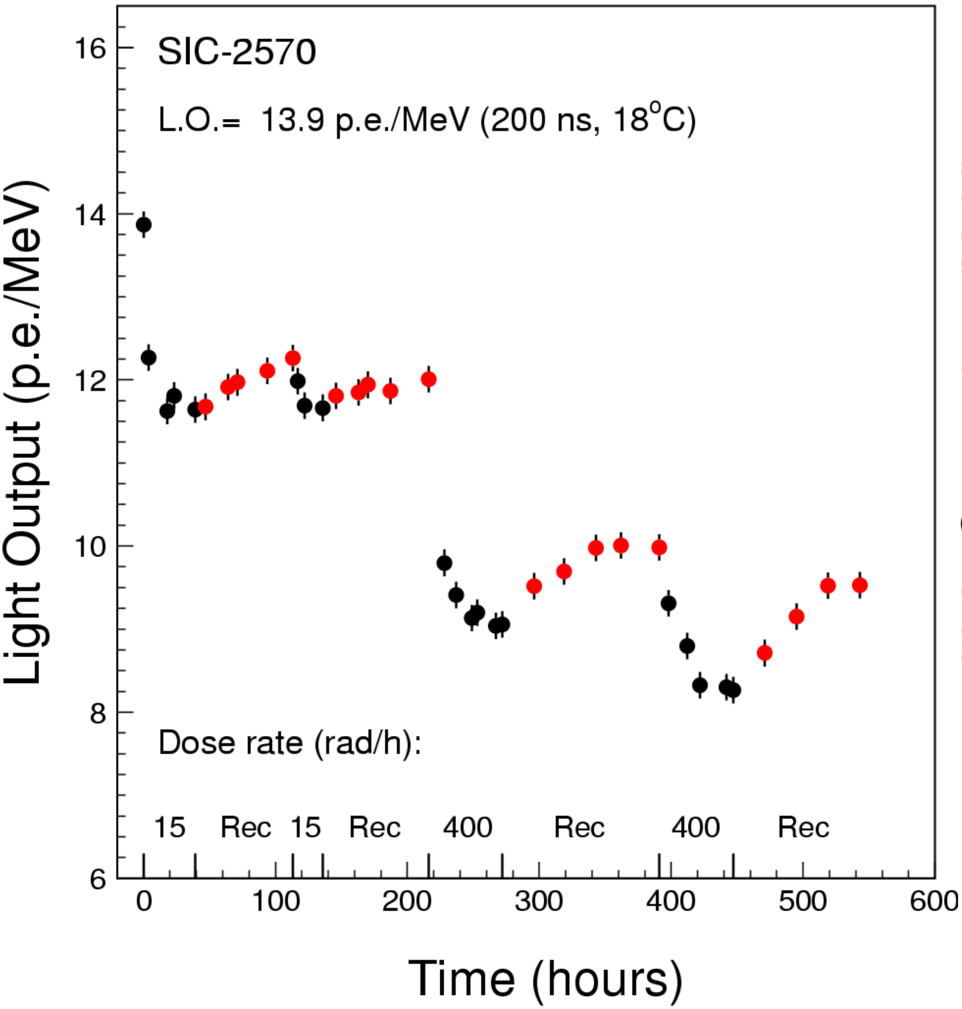
Monitor-ability: 6.6% and 5% variation at 15 rad/h
27% and 34% variation at 400 rad/h

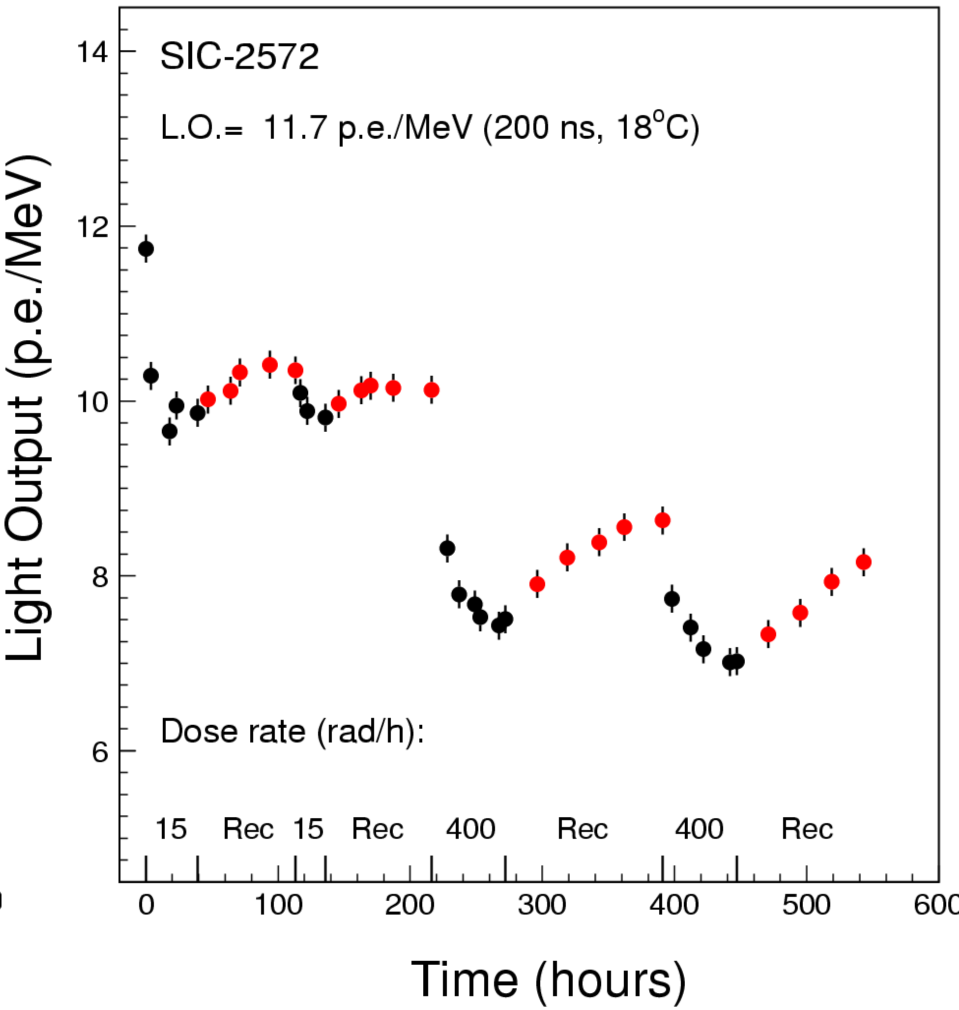




SIC Damage & Recovery

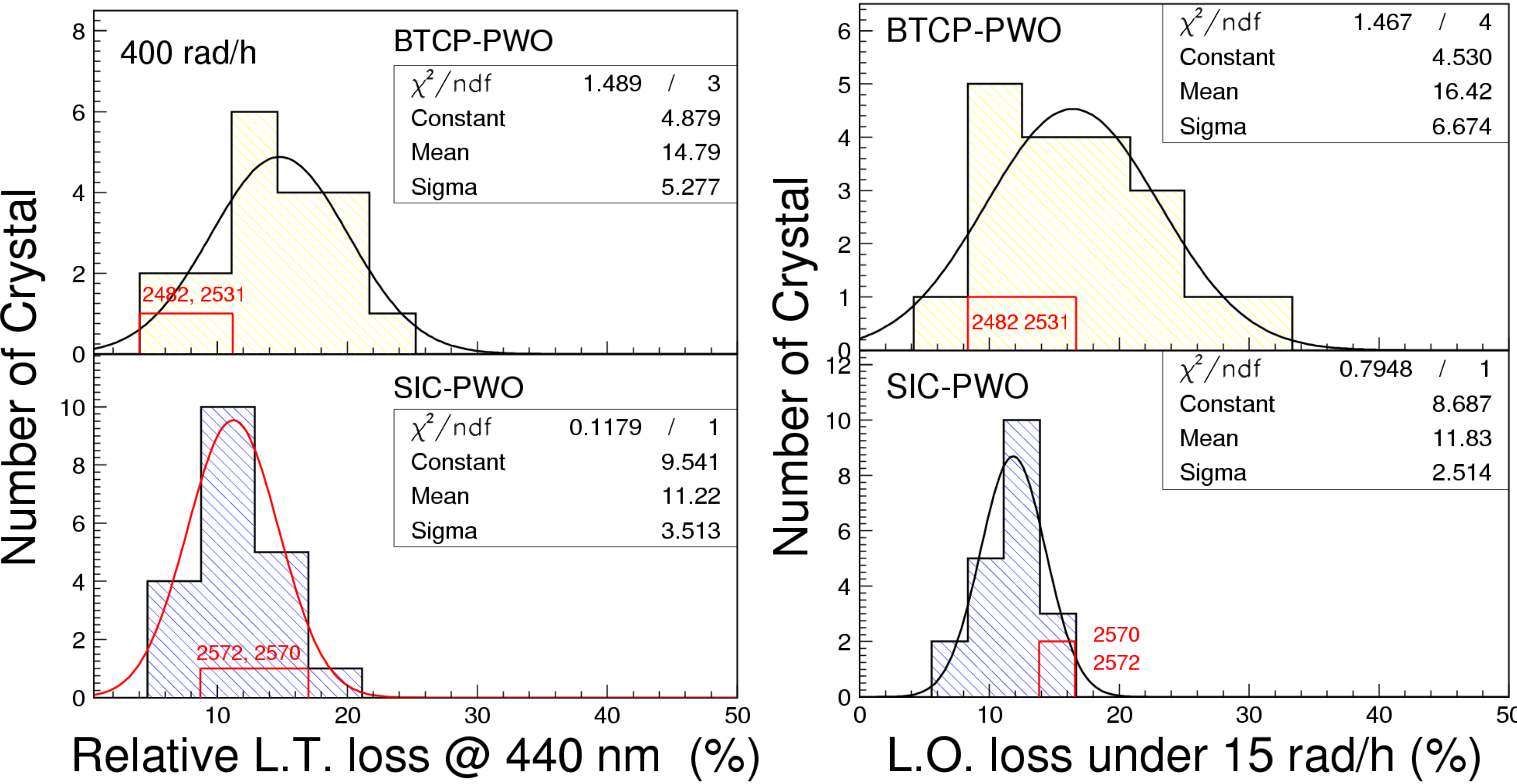
Monitor-ability:
5% and 5.5% variation at 15 rad/h
19% and 19% variation at 400 rad/h





Comparison of Radiation Damage

BTCP samples better than corresponding 2001 batch
SIC samples consistent with corresponding 2002 batch



Summary

- No significant difference was found between two new samples each from BTCP and SIC , except the initial light yield: SIC samples have 50% more light.
- A long term recovery study reveals 50% and 35% unrecoverable damage for SIC and BTCP samples respectively, which may be caused by the difference of color center densities between 200^{o}C annealing and natural recovery at 18^{o}C. This component is irrelevant to our application.
- Short term damage and recovery study shows consistent variations at 5% to 6% level in light output for samples from both vendors at 15 rad/h and 19% and 30% variation for SIC and BTCP samples at 400 rad/h respectively. The larger variation of BTCP samples under high dose rate is caused by their faster recovery.
- While two new BTCP samples are more radiation hard than the corresponding 2001 batch, two new SIC samples are consistent with the corresponding 2002 batch.