



Result of a Damage/Recovery Study for PWO Samples from BTCP and SIC

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Introduction



- Following the December DPG meeting, an investigation on SIC RIAC measurement was carried out by Dr. Liyuan Zhang in January, 2005.
- 4 endcap size PWO samples, 2 from the BPCP 2003 batch (2482 & 2531) and 2 from the SIC 2004 January batch (2570 & 2572), went through a thermal annealing at 200°C, followed by a series of irradiation and recovery cycles: 2 @ 15 rad/h, 3 @ 400 rad/h, and 2 @ 9 krad/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.



Investigation on RIAC at SIC



- Following Felicitas' suggestion, Dr. Liyuan Zhang visited SIC on January 3-7, 2005.
- Two CEBAF size SIC 2002 PWO samples were irradiated under a dose rate of 32* Gy/h for 24h at the ^{60}Co facility used by SIC. Their transmittance before and after irradiation was measured. The calculated RIAC @ 420 nm result consists with what measured at Caltech under 90 Gy/h irradiation, indicating no fundamental problem in the measurement.
- The dose rate quoted by SIC in previous irradiations, however, seems having a large uncertainty.

Sample	@32* Gy/h	RIAC (1/m)	@90 Gy/h	RIAC (1/m)
T12	24 h	1.7	24 h	1.4
T13	24 h	2.0	32 h	1.9

* The 32 Gy/h seems underestimated because of the dosimeter used.

EWRIAC Measured at Caltech

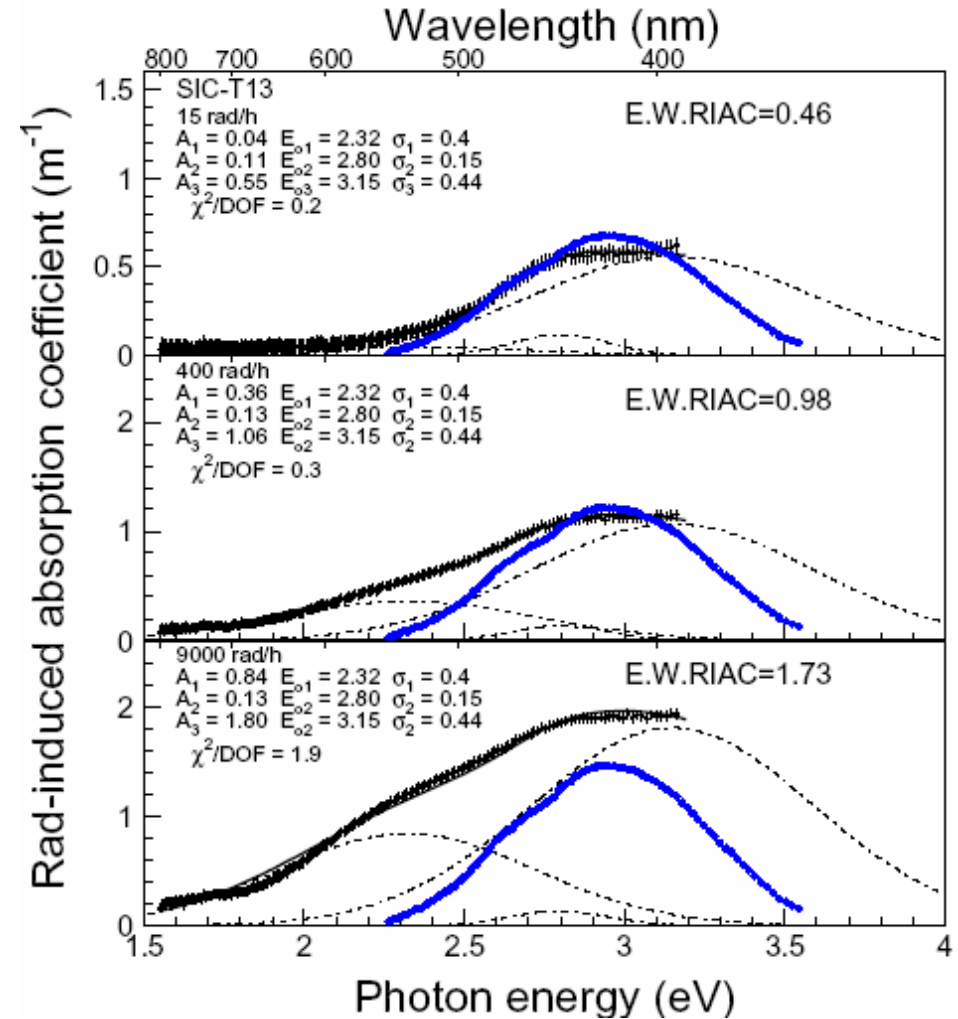
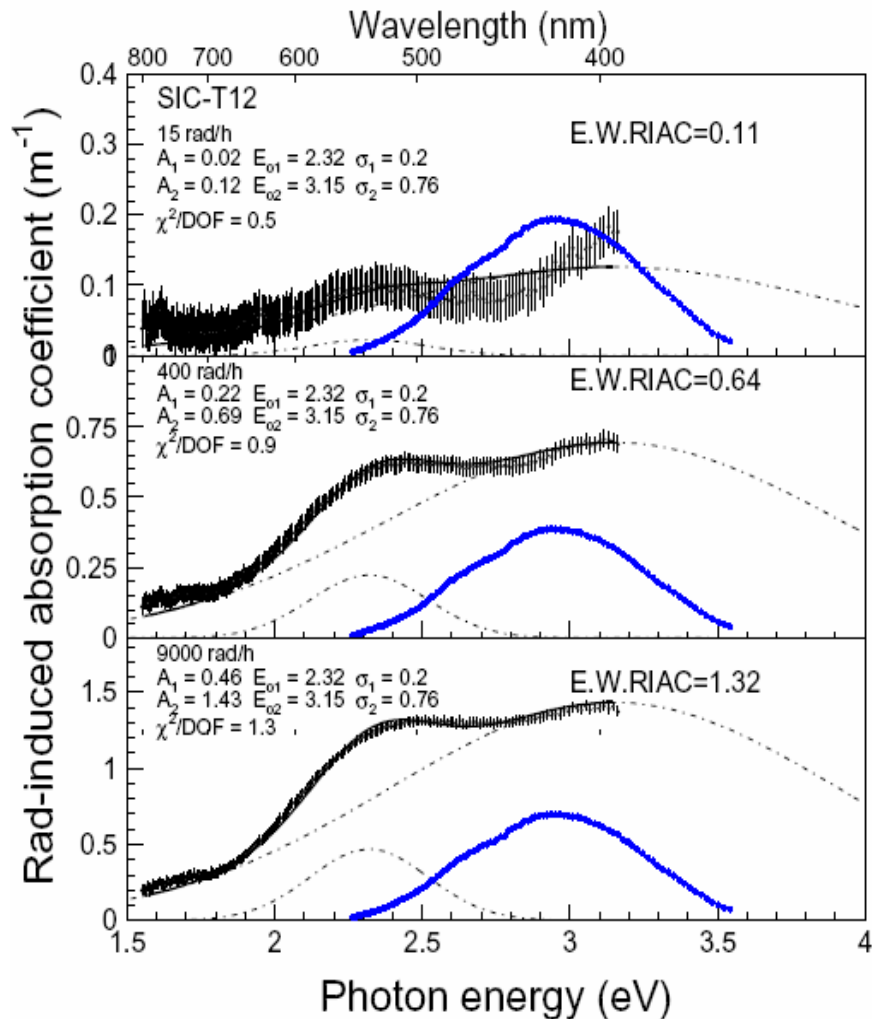
Note: emission weighted and multiple bounces

$$R_{iac} = 1/LAL_{equilibrium} - 1/LAL_{before}$$

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

$$T_s = (1 - R)^2 + R^2(1 - R)^2 + \dots = (1 - R)/(1 + R)$$

$$R = \frac{(n_{crystal} - n_{air})^2}{(n_{crystal} + n_{air})^2}$$



220k Curie ^{60}Co Source used by SIC

Photos by courtesy of Dr. Hui Yuan



View @ Facility Entrance



2 x 110k Curie ^{60}Co Boards



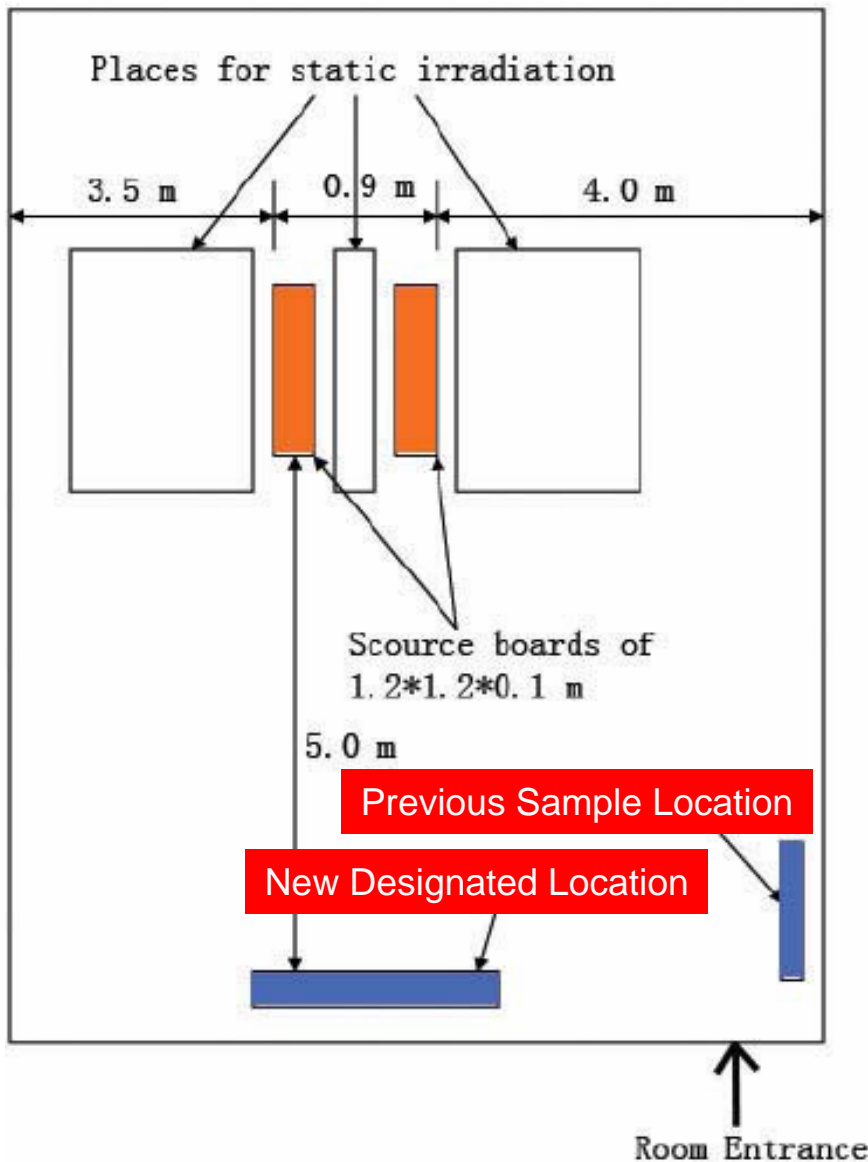
Previous Sample Location



New Designated Location

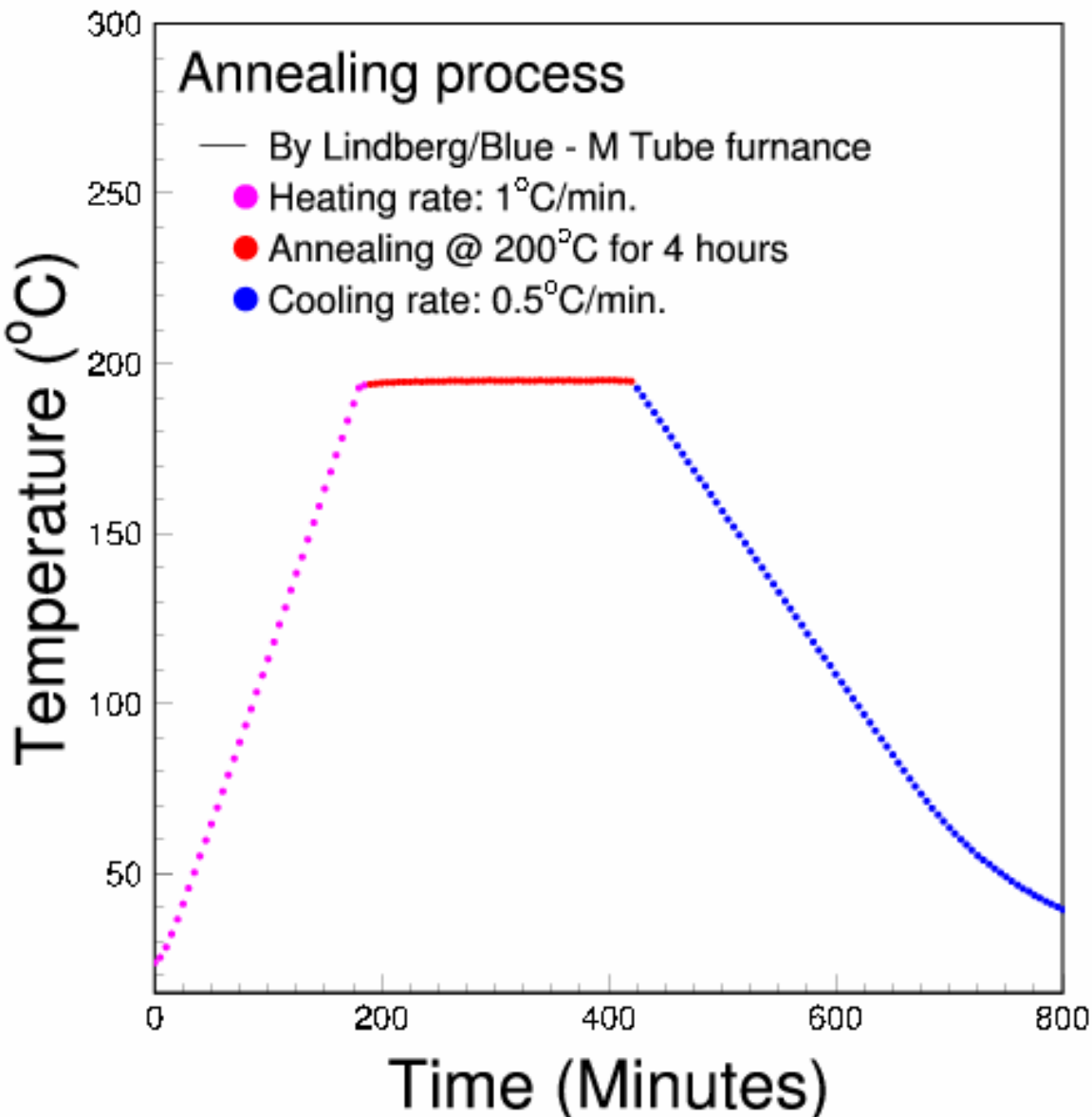
220k Curie ^{60}Co Source used by SIC

Plot by courtesy of Dr. Hui Yuan



- The dose rate at previous sample location was affected by commercial goods being irradiated at the same time.
- Better stability of the dose rate is expected when samples are placed on a rack at the designated location.
- **SIC must pay an attention to avoid commercial goods, including moving goods, between samples and the source during irradiations.**
- Dose rate: ~ 80 Gy/h.

200°C Thermal Annealing



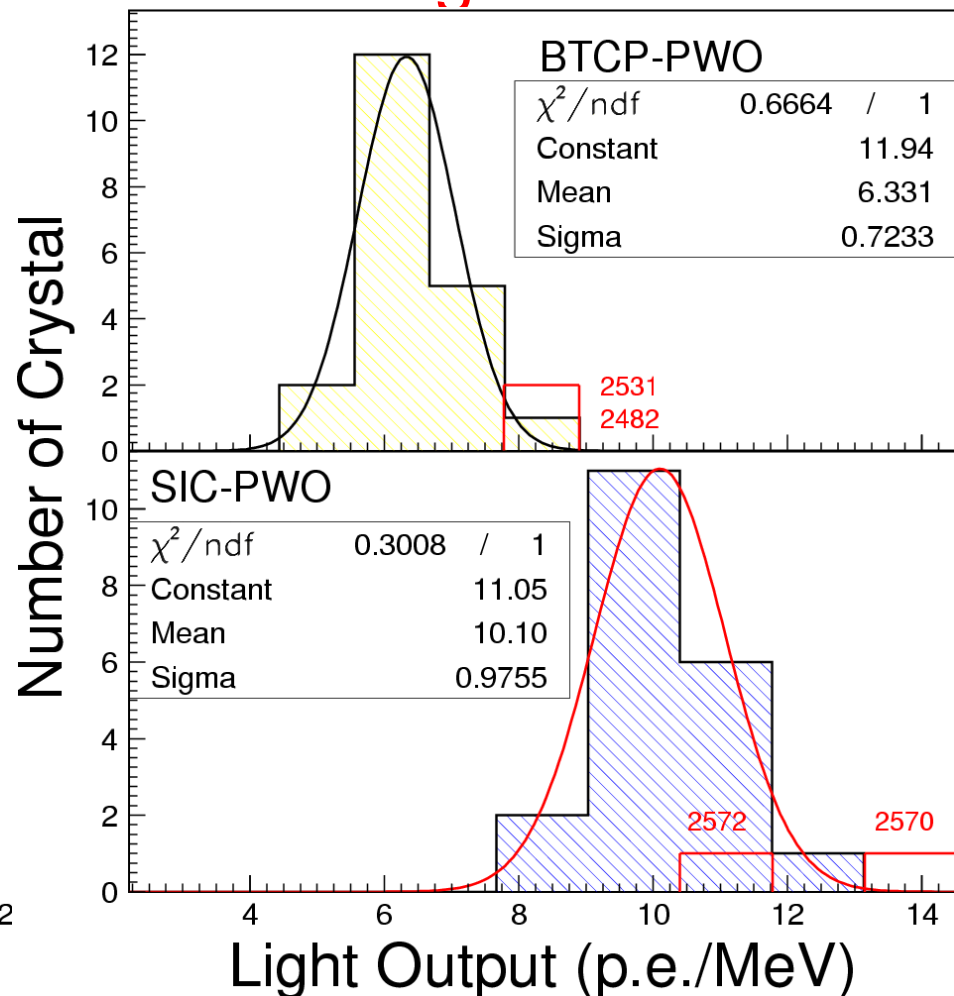
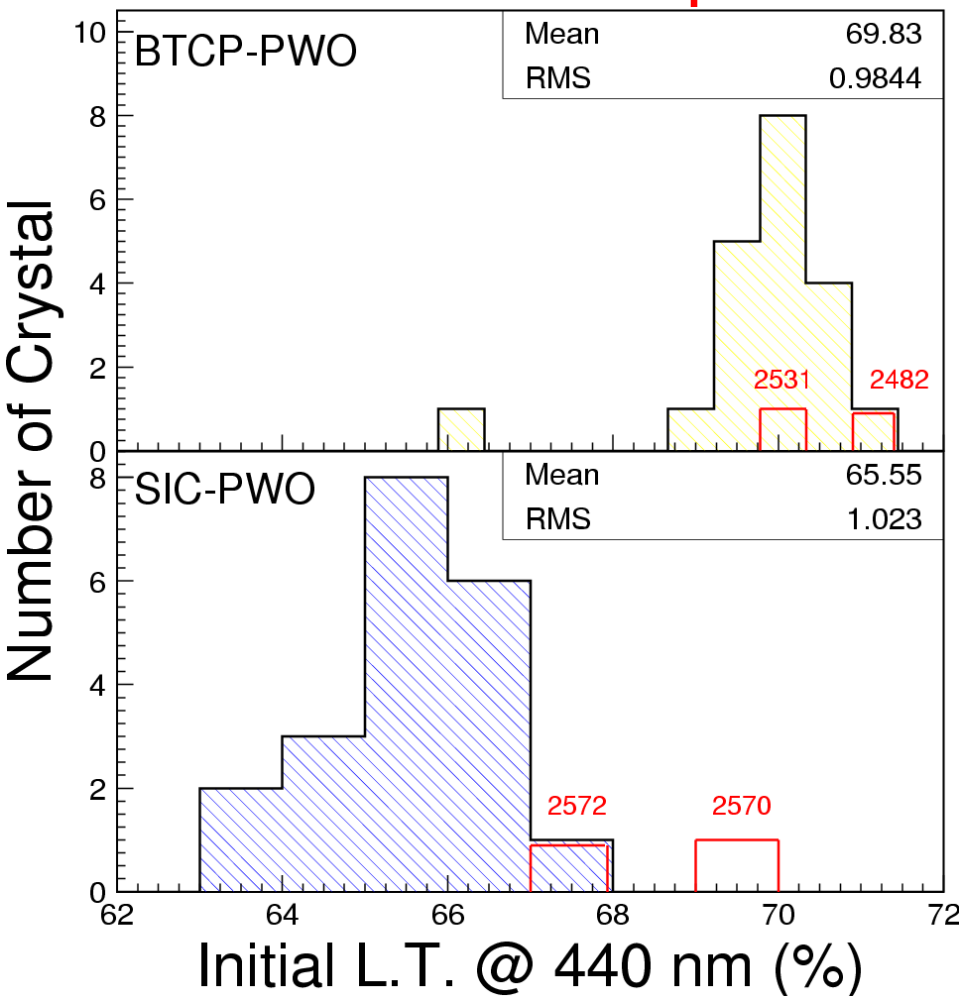
- Carried out in a Lindberg Blue-M tube furnace with automatic control.
- Removed residual absorption and restored the sample to a defined state.



Comparison of Initial LO and LT

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

SIC samples has 50% more light

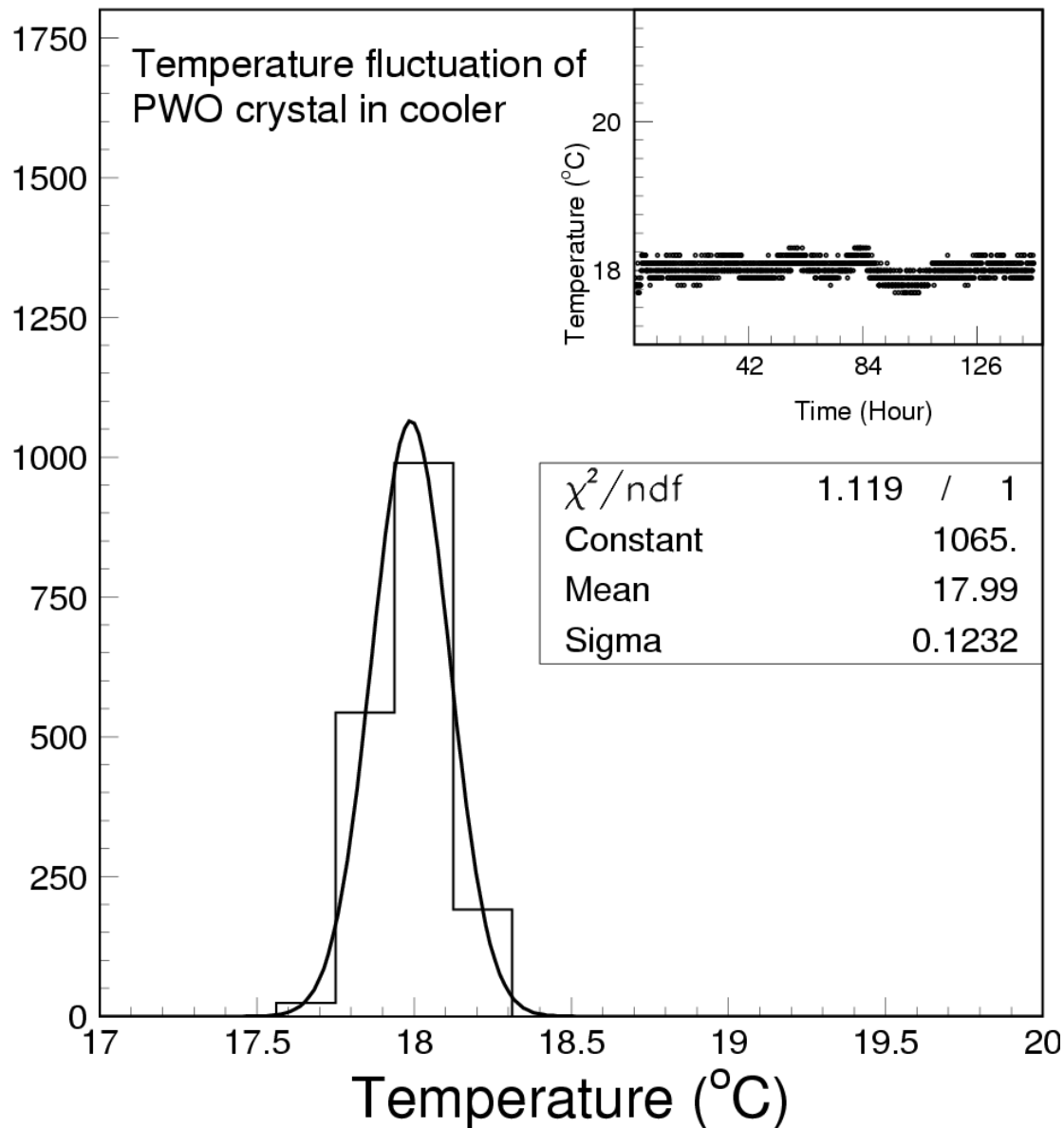


Open 50 curie Co-60:
15 and 400 rad/h

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



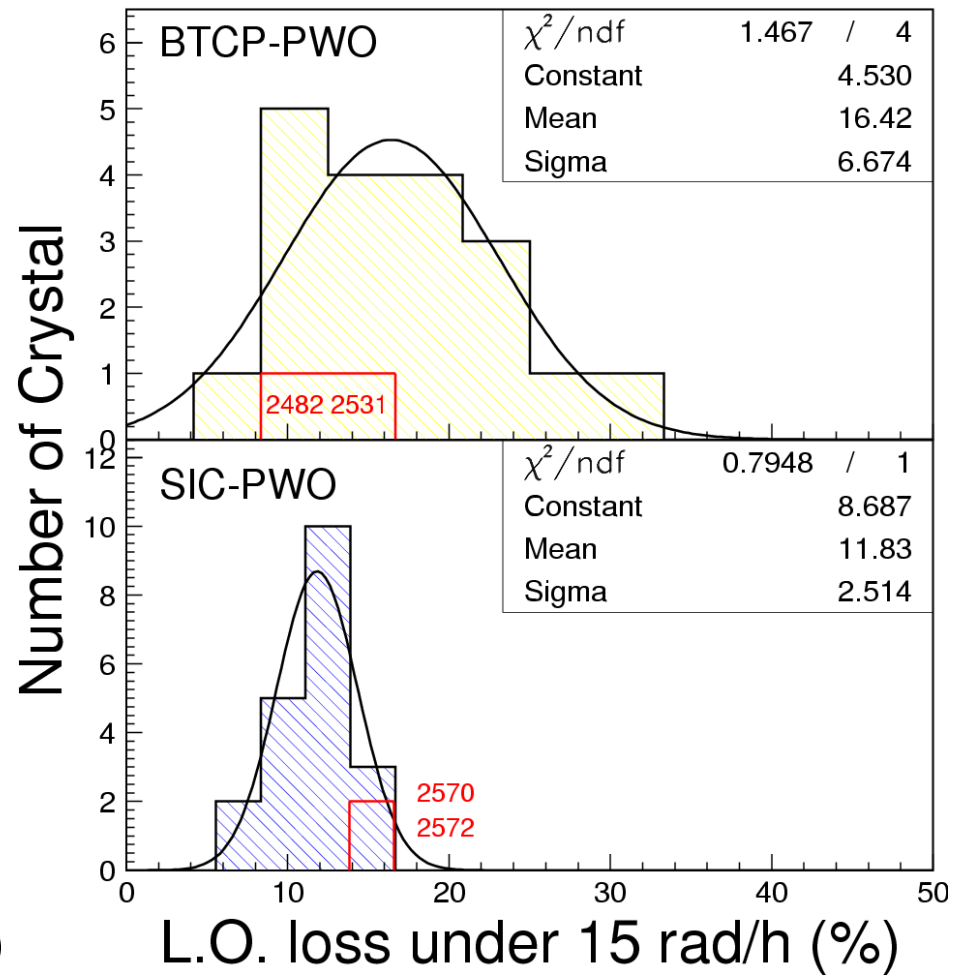
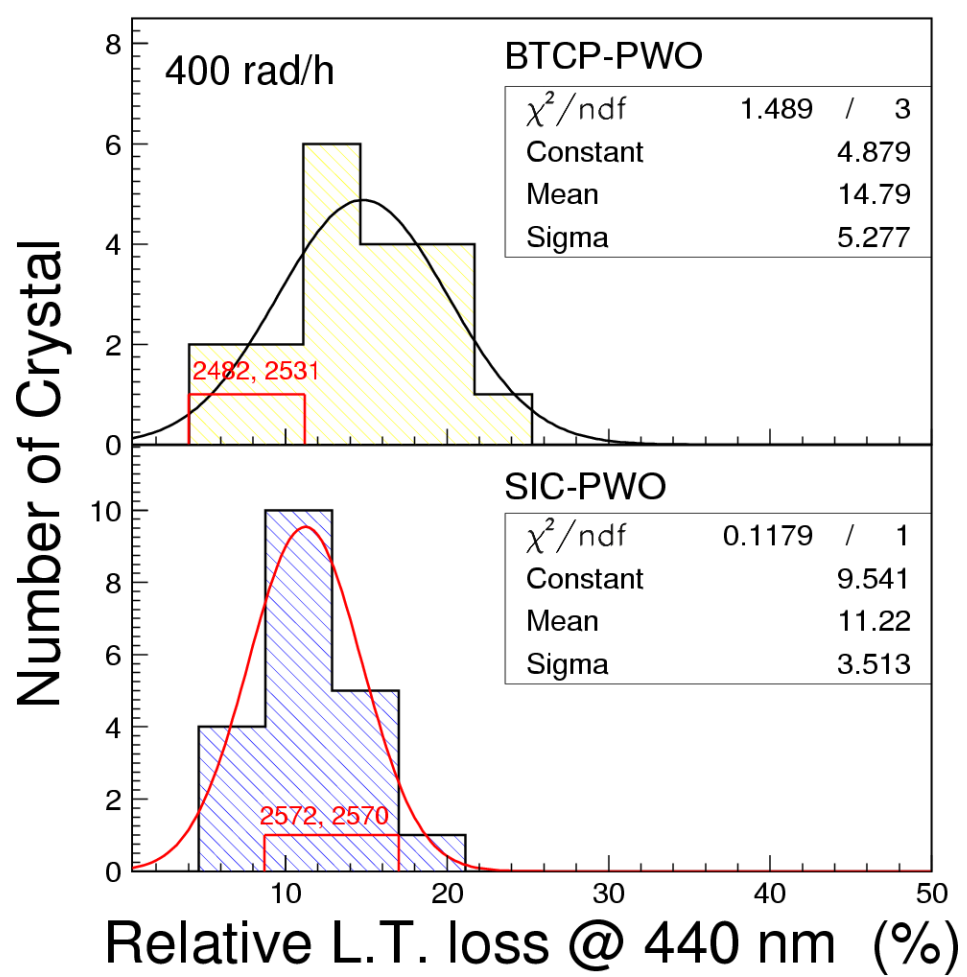
Recovery under 18°C



After irradiation recovery was measured when samples were kept in a cooler at 18°C with 0.12°C variation.

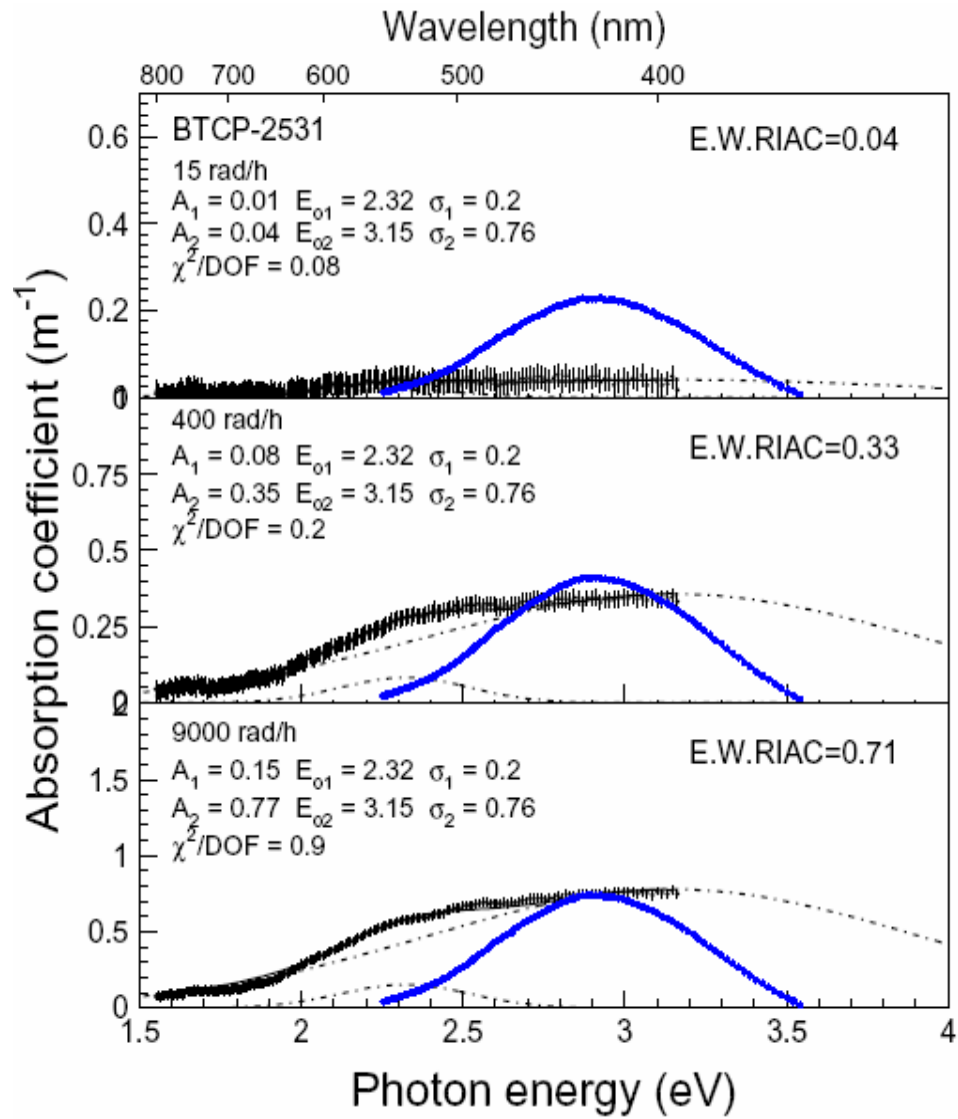
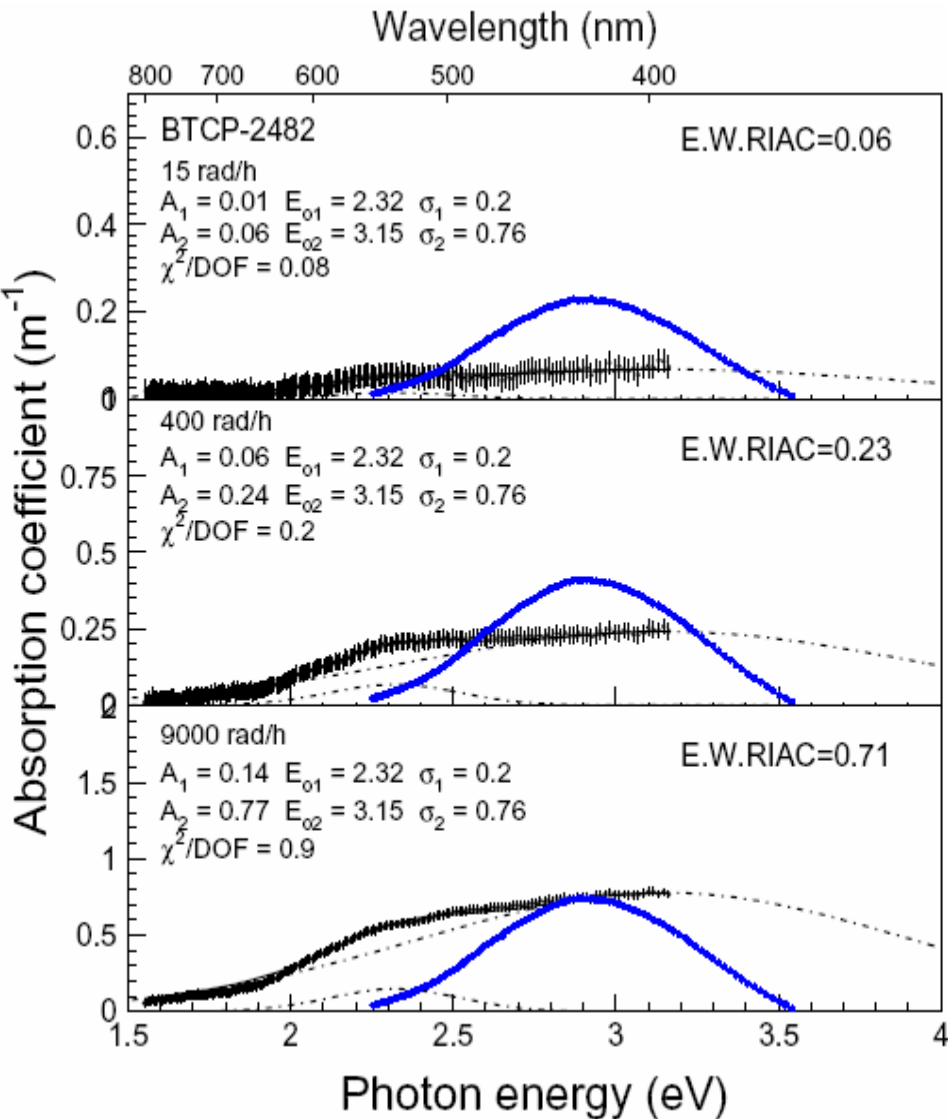
Comparison of Radiation Damage

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



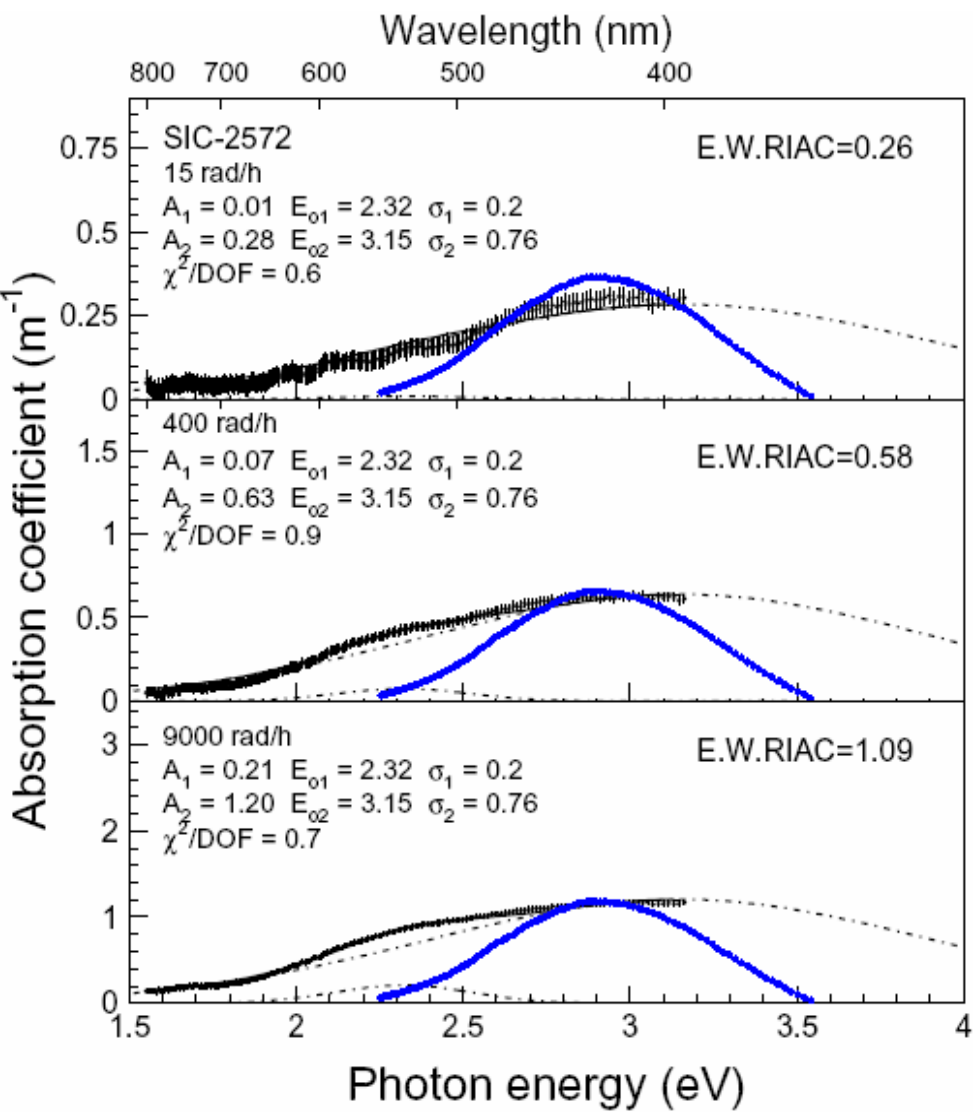
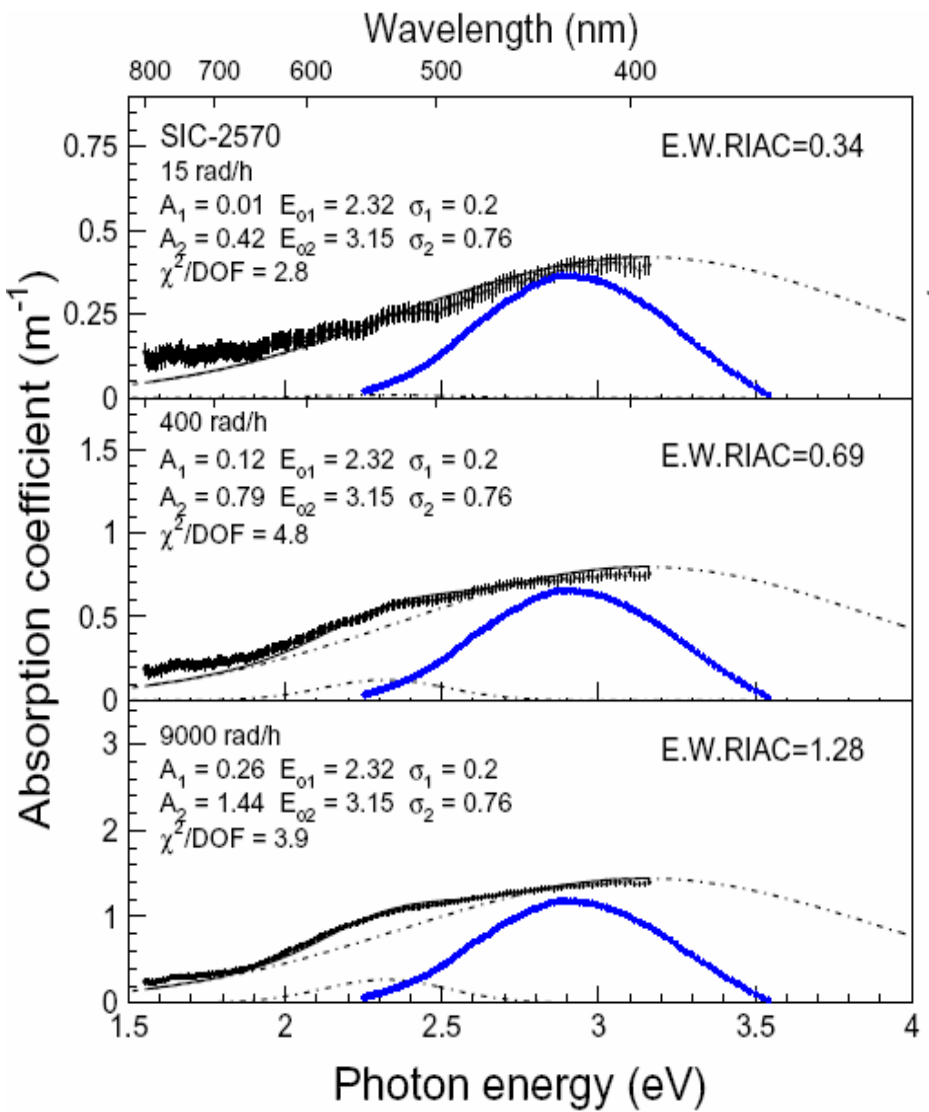
EWRIAC of BTCP Samples

BTCP samples show a small damage in LT



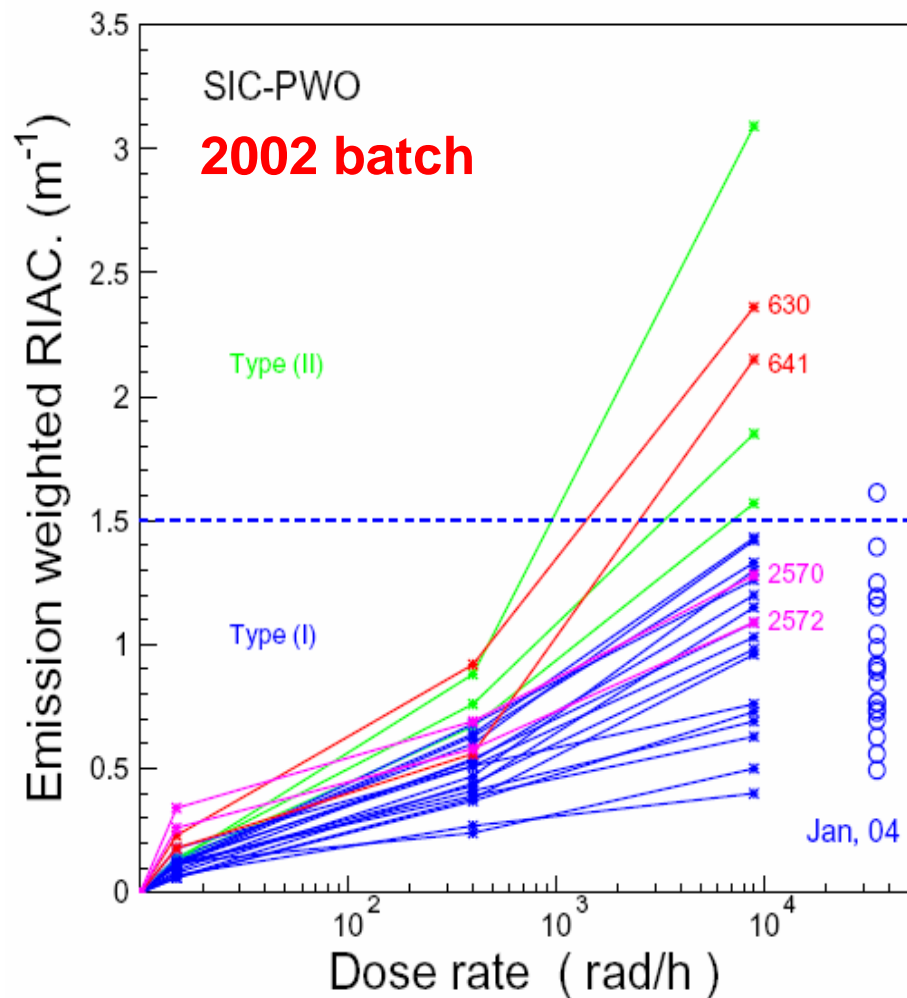
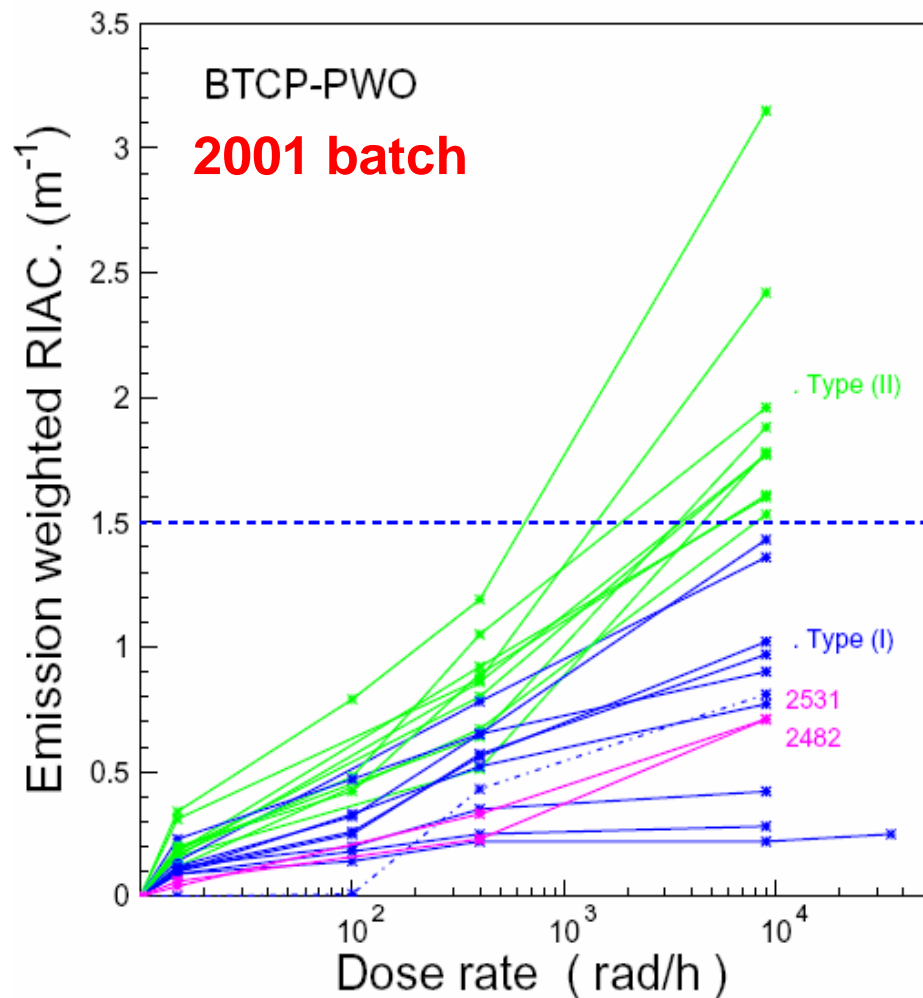
EWRIAC of SIC Samples

SIC samples show a LT damage larger than BTCP



Emission Weighted RIAC

BTCP samples are better than the 2001 batch
 SIC samples are compatible with the 2002 batch
 All four samples have EWRIAC < 1.5 m⁻¹ @ 9 krad/h

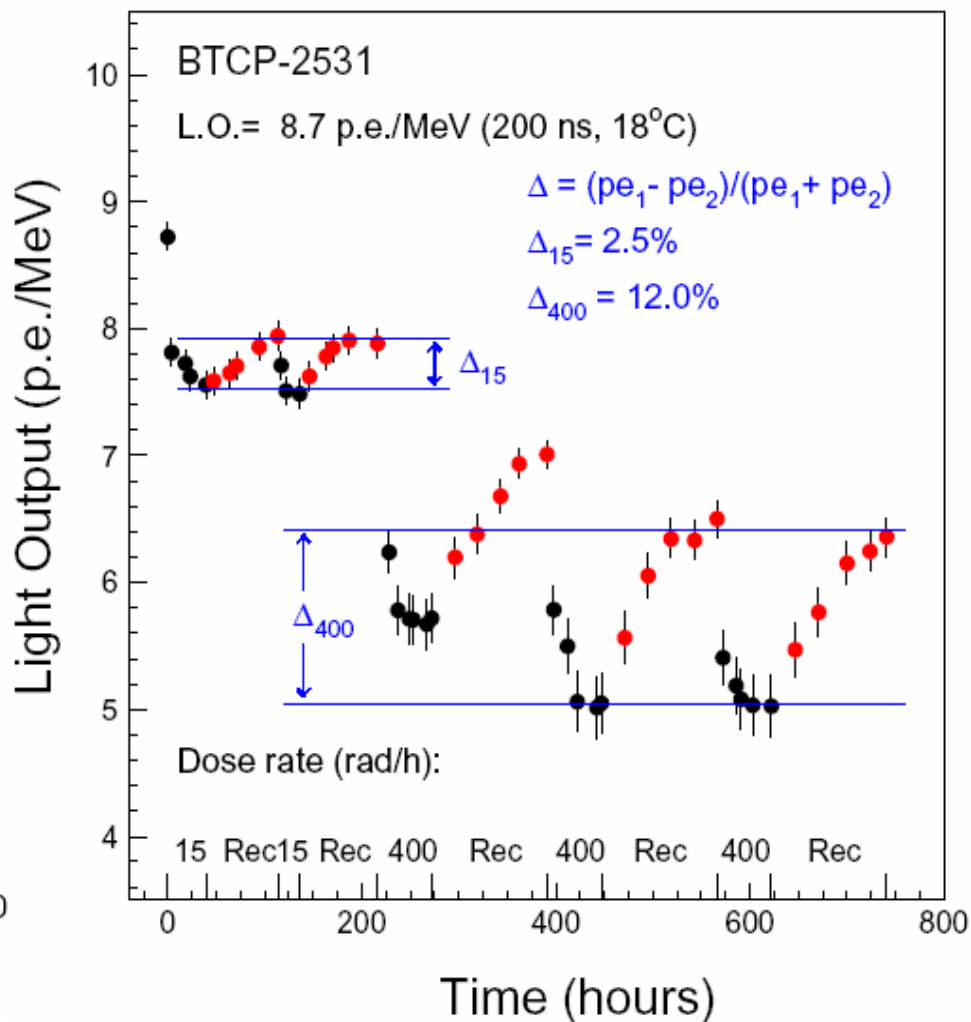
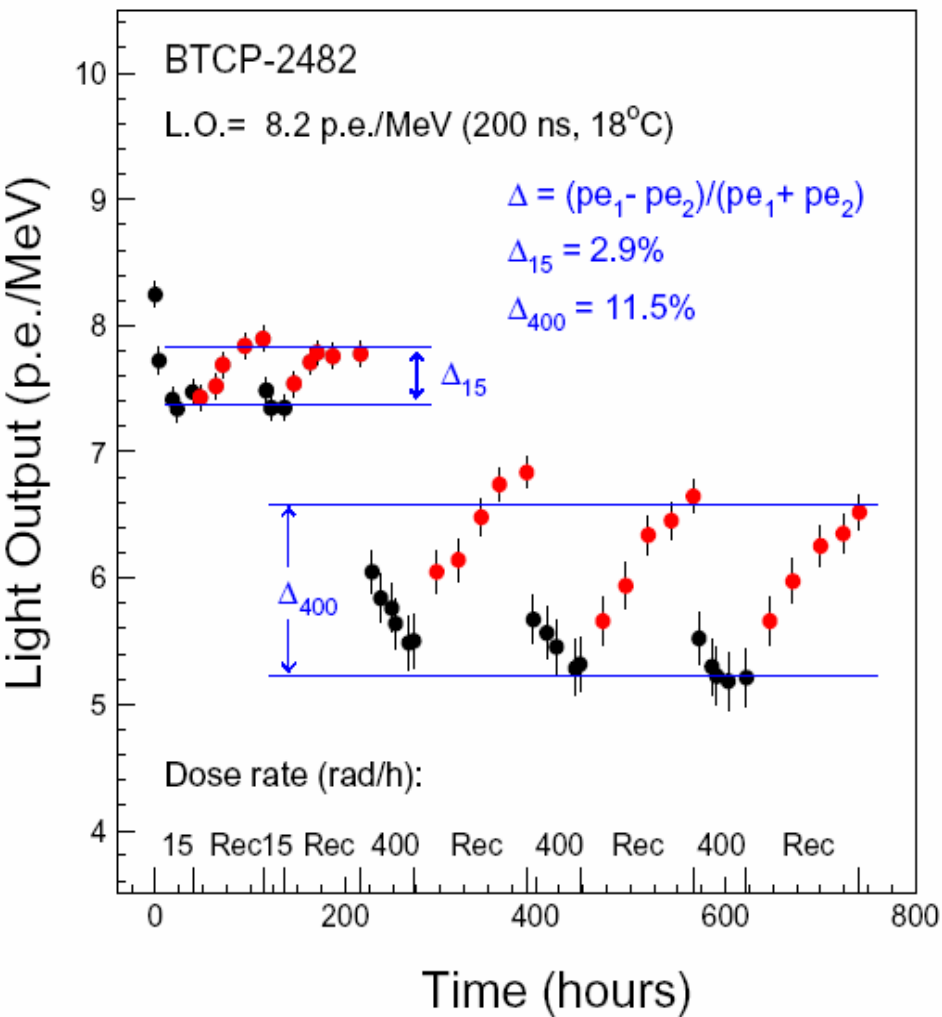




History of BTCP Light Output



Variations: 2.7% @ 15 rad/h, 11.8% @ 400 rad/h

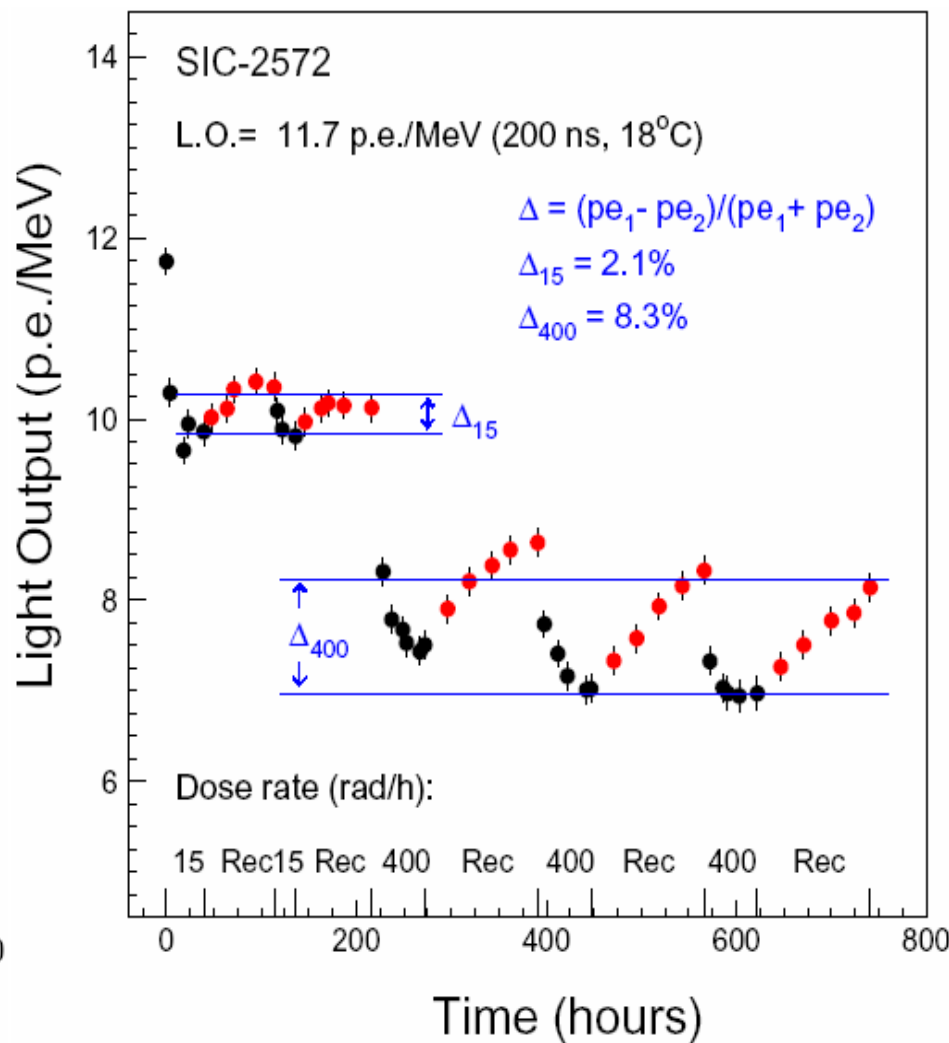
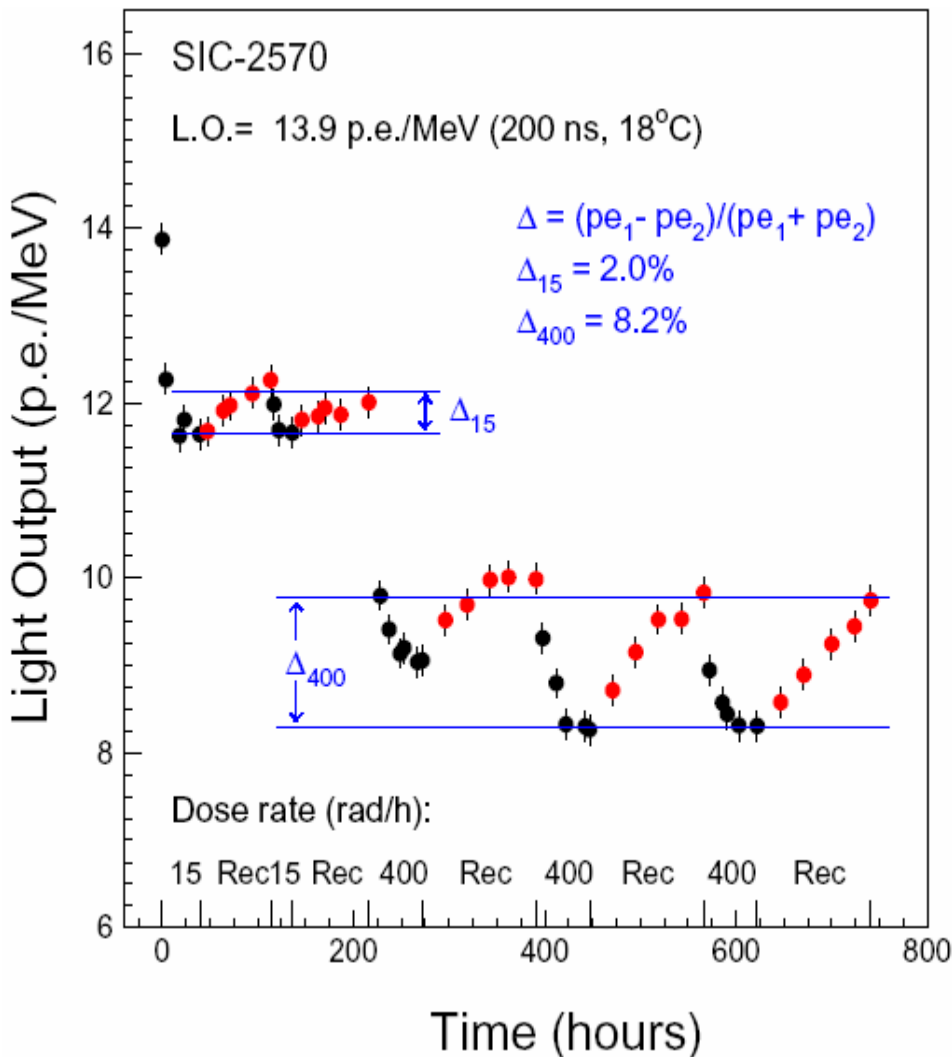




History of SIC Light Output

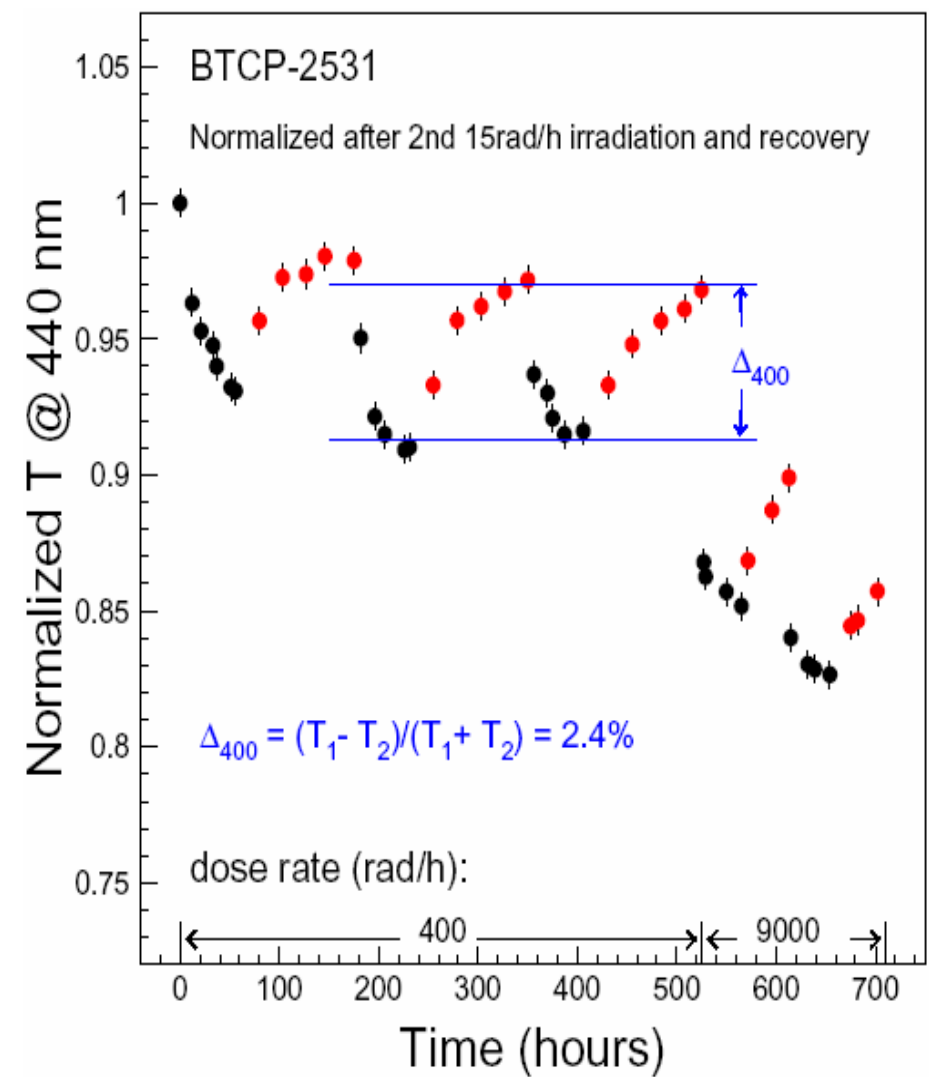
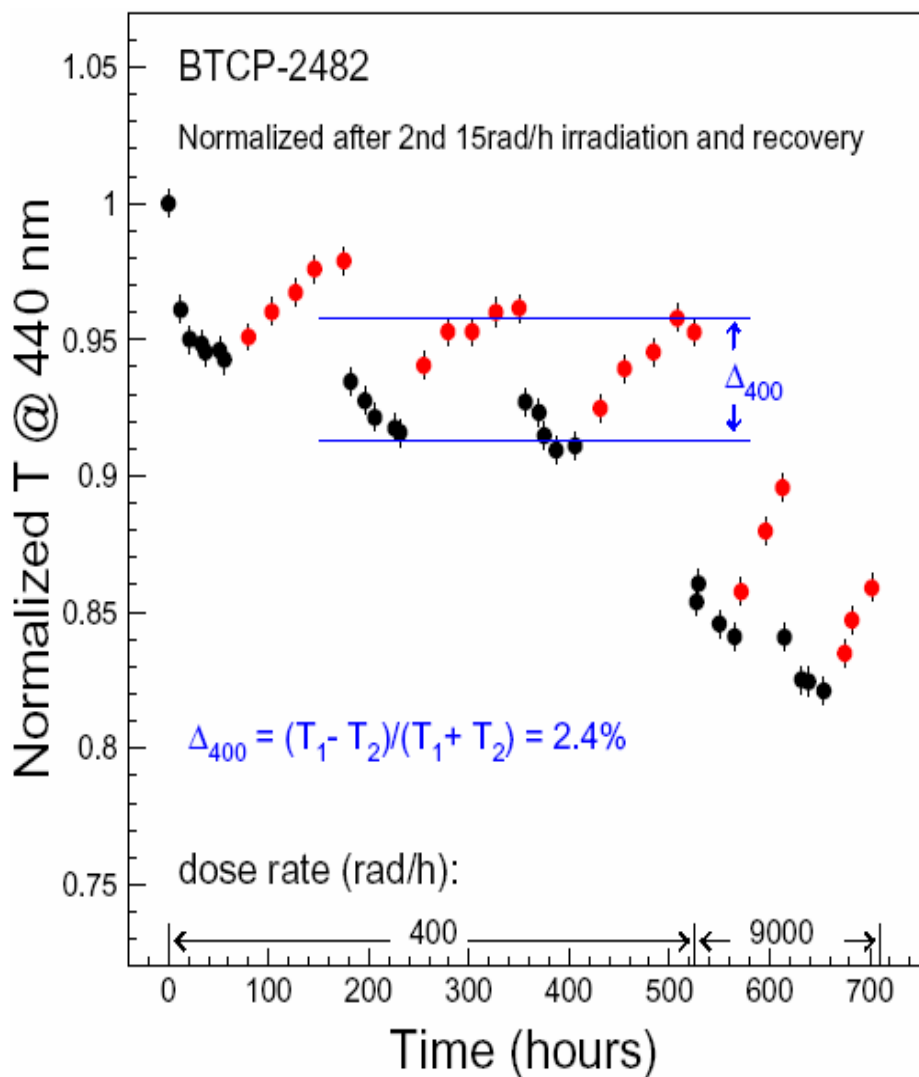


Variations: 2.1% @ 15 rad/h, 8.3% @ 400 rad/h
Smaller than BTCP



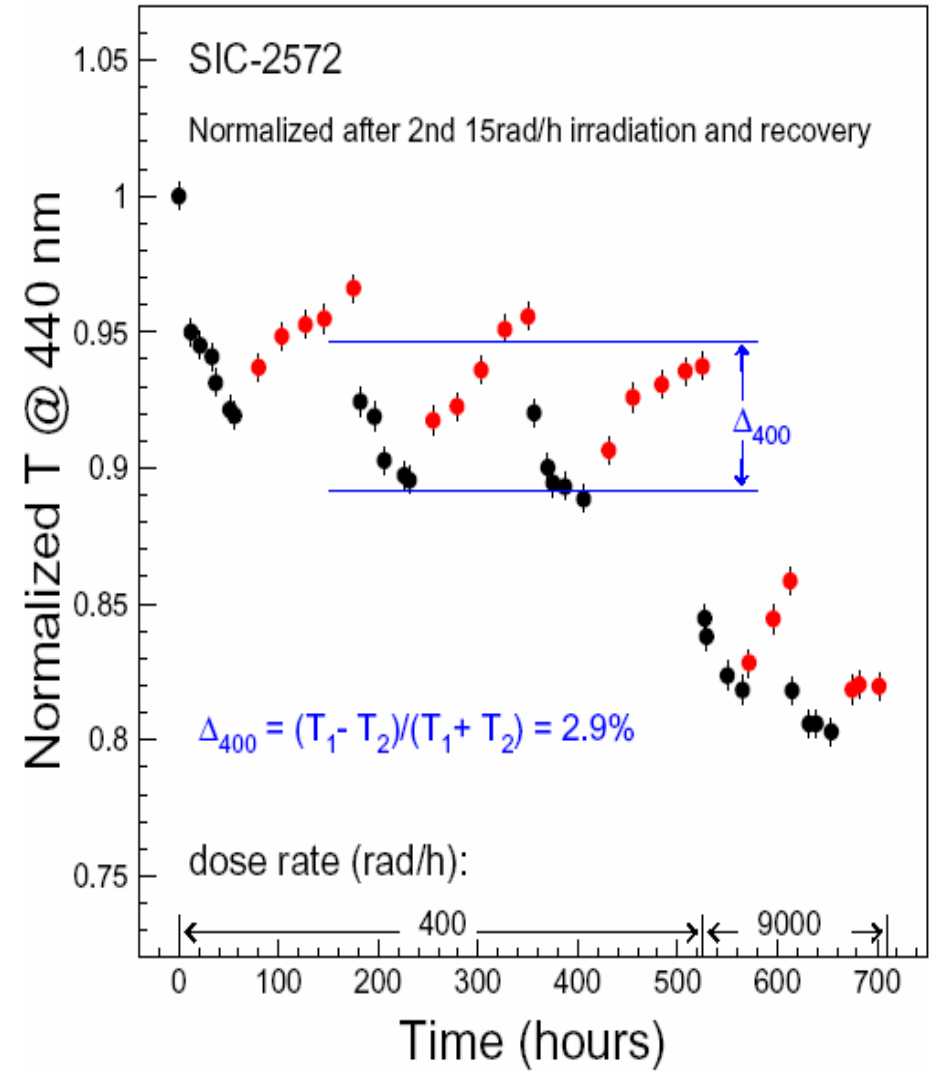
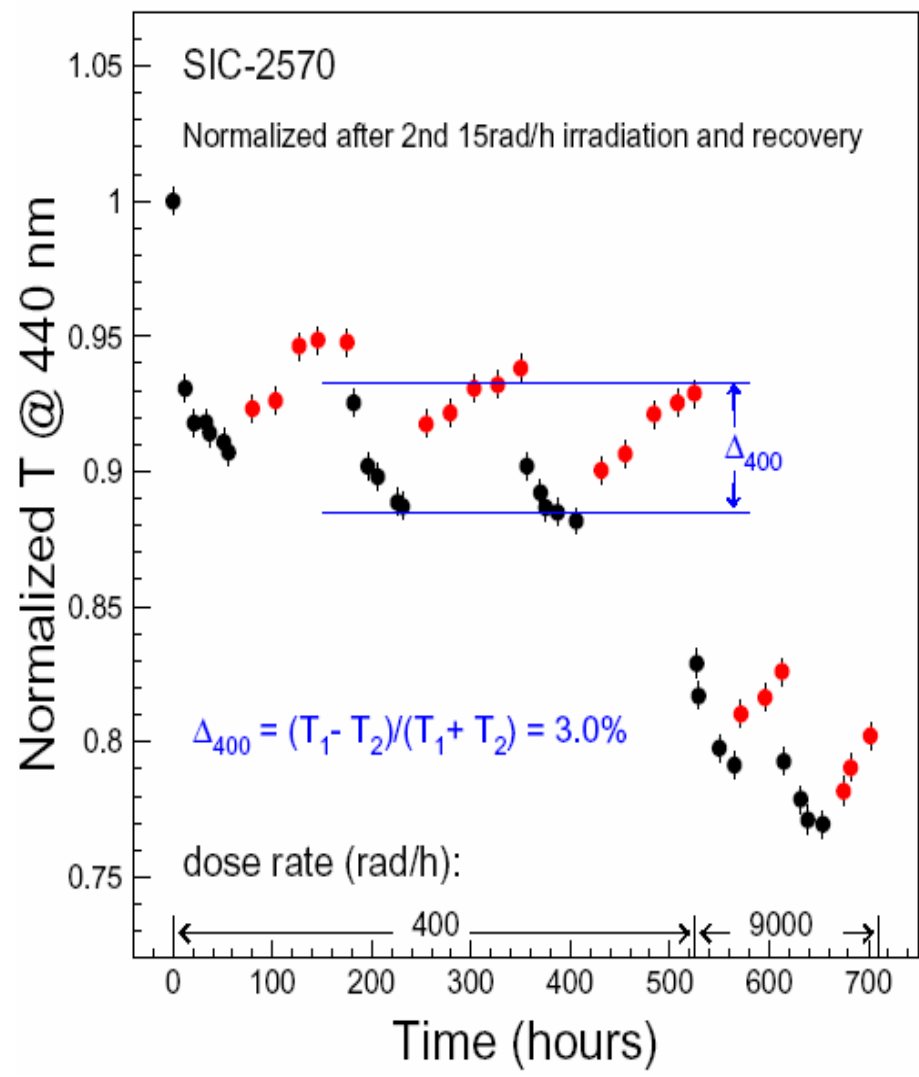
History of BTCP LT

Variation @ 400 rad/h: 2.4%



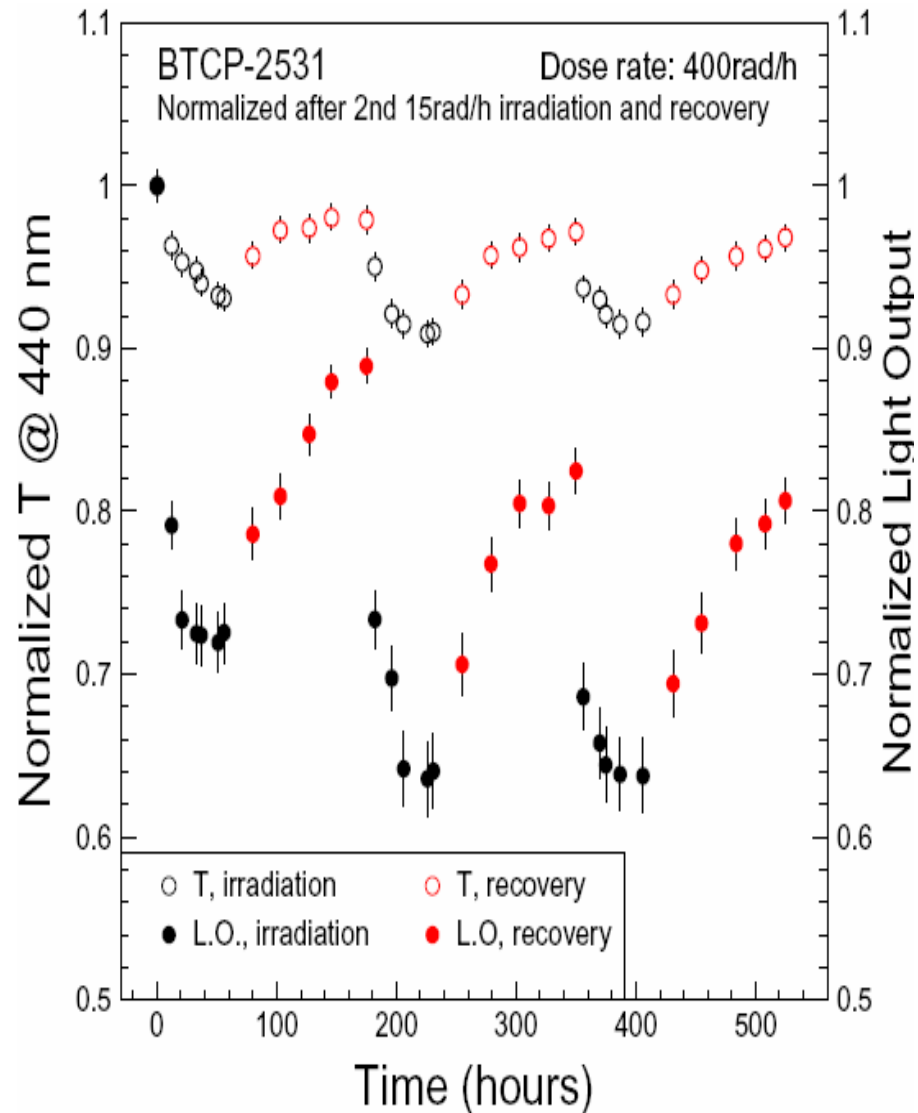
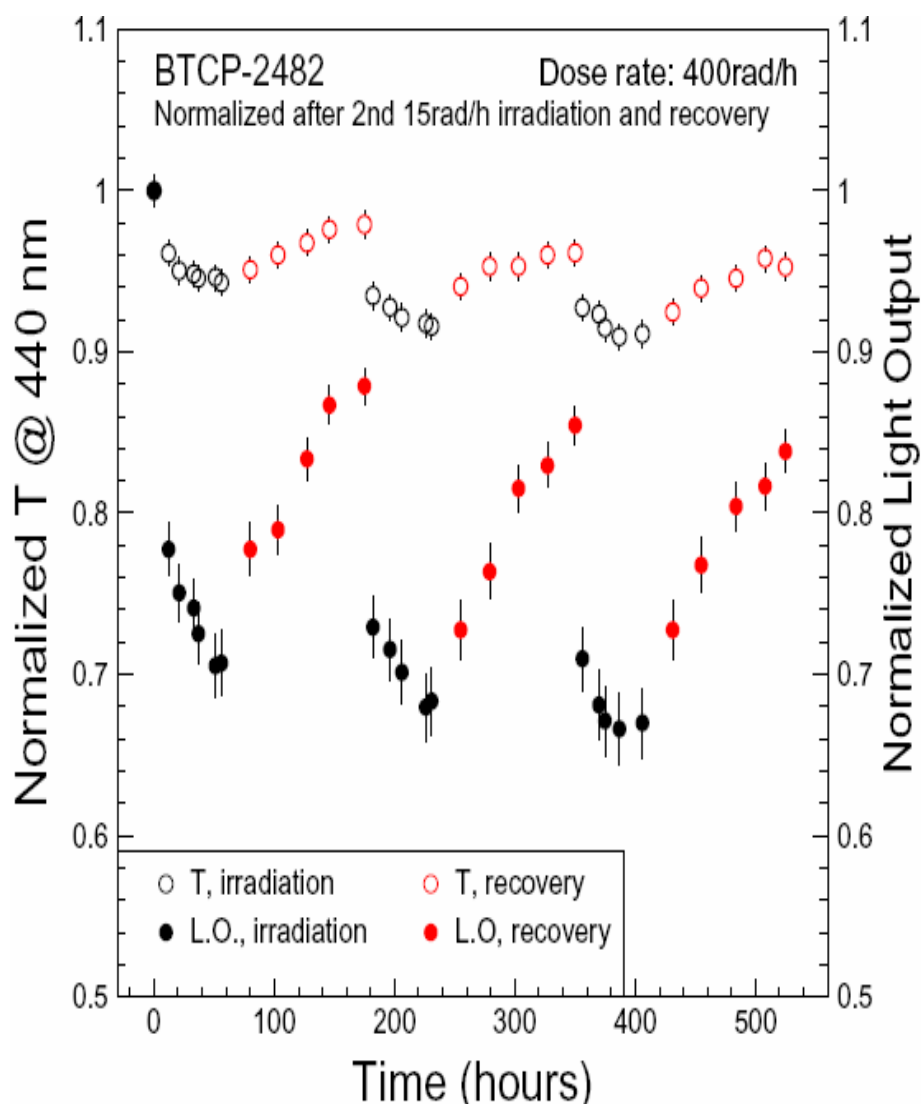
History of SIC LT

Variation @ 400 rad/h: 3.0%, larger than BTCP



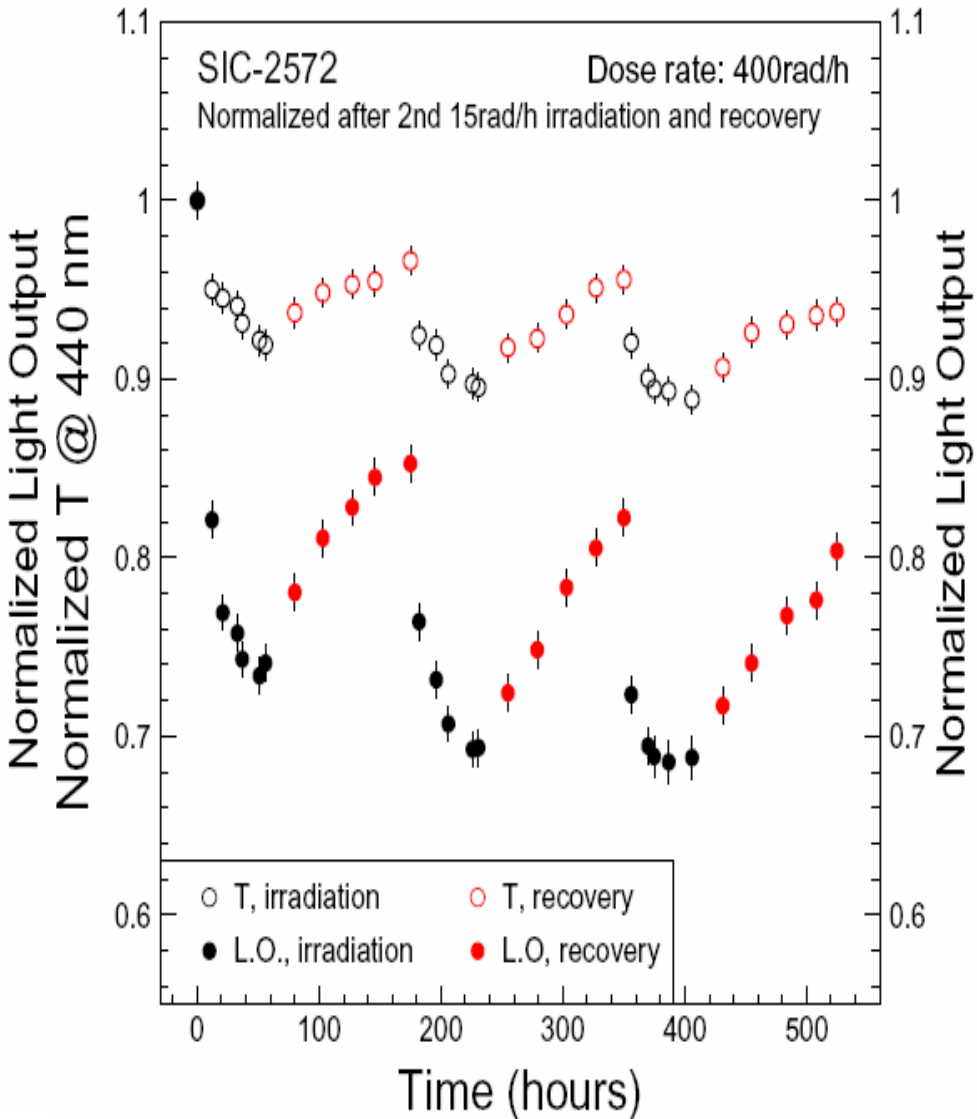
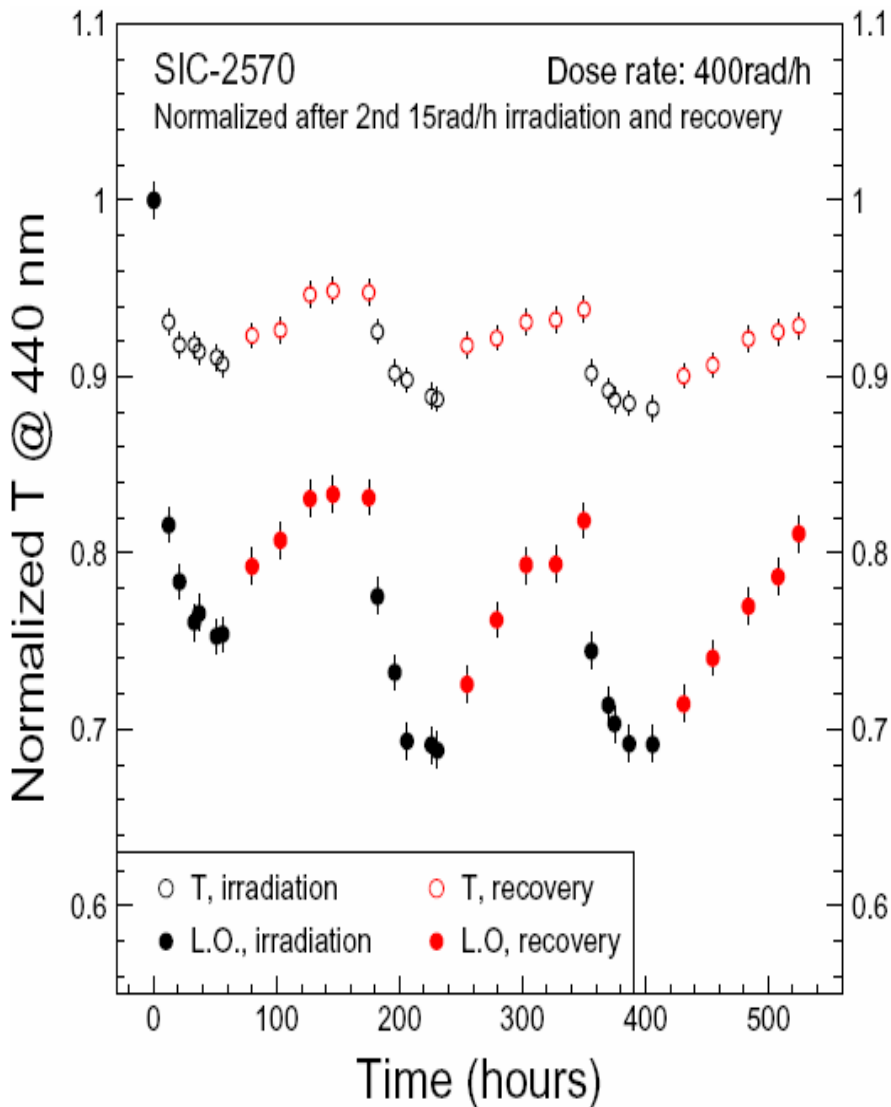
History of BTCP LT & LO @ 400 rad/h

Normalized to after 2 cycles of damage & recovery @ 15 rad/h



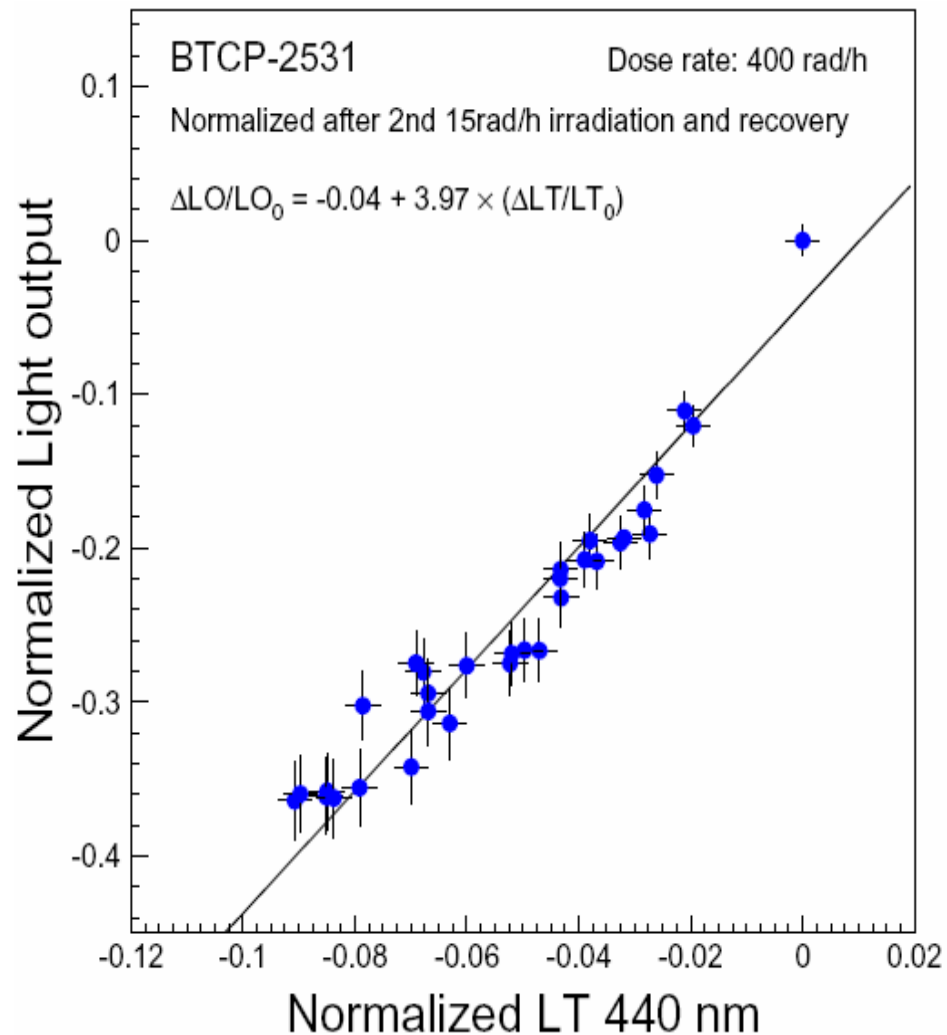
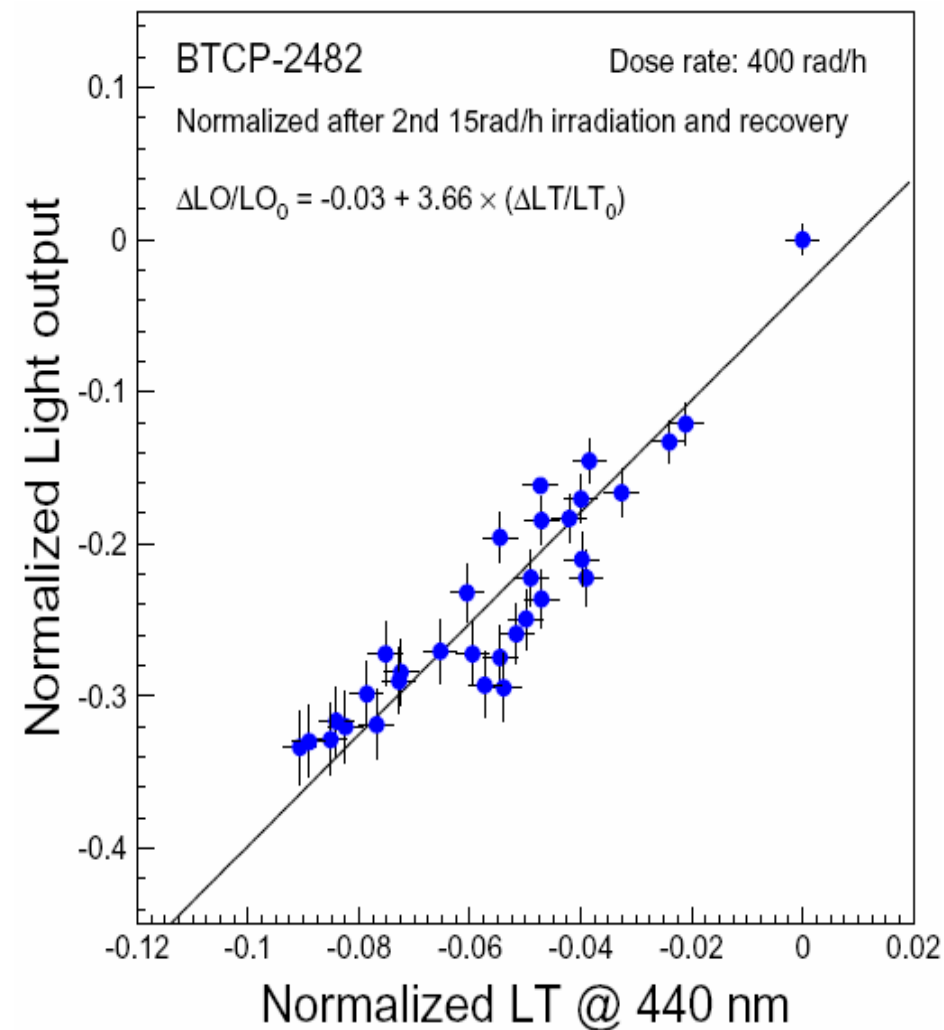
History of SIC LT & LO @ 400 rad/h

Normalized to after 2 cycles of damage & recovery @ 15 rad/h



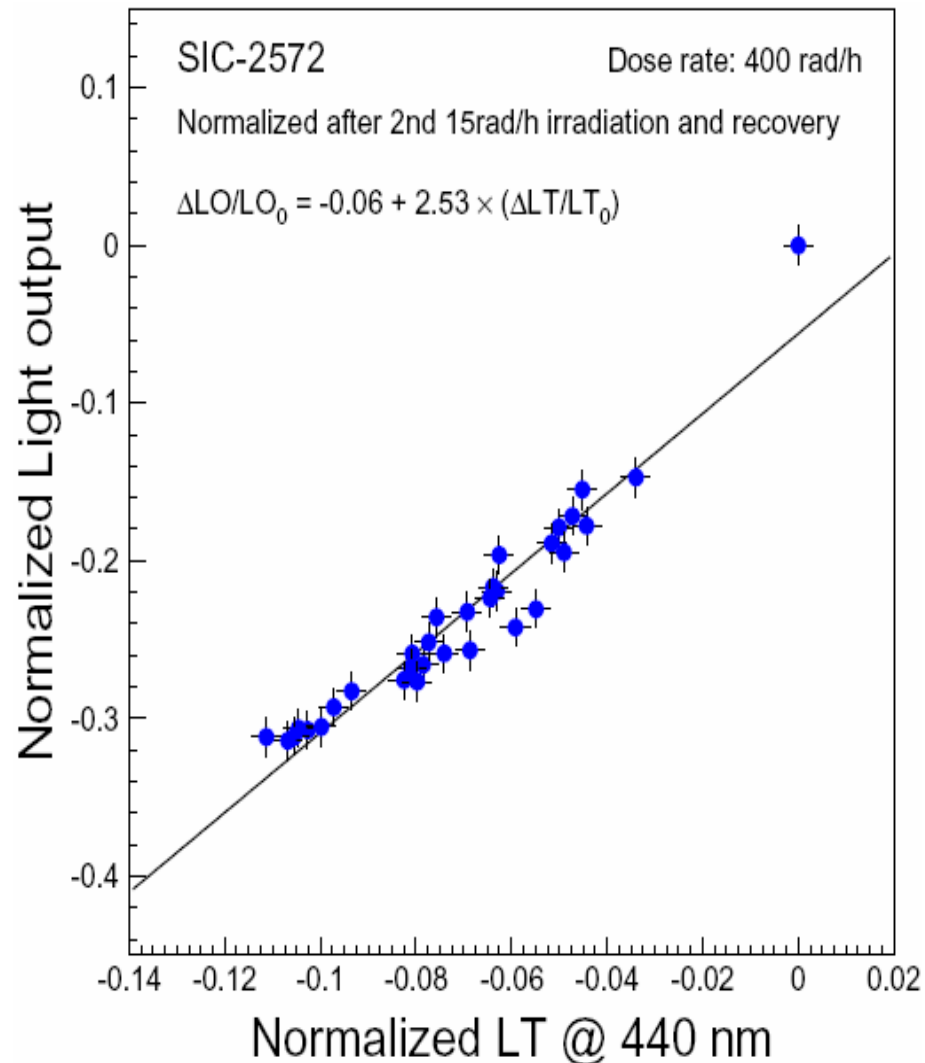
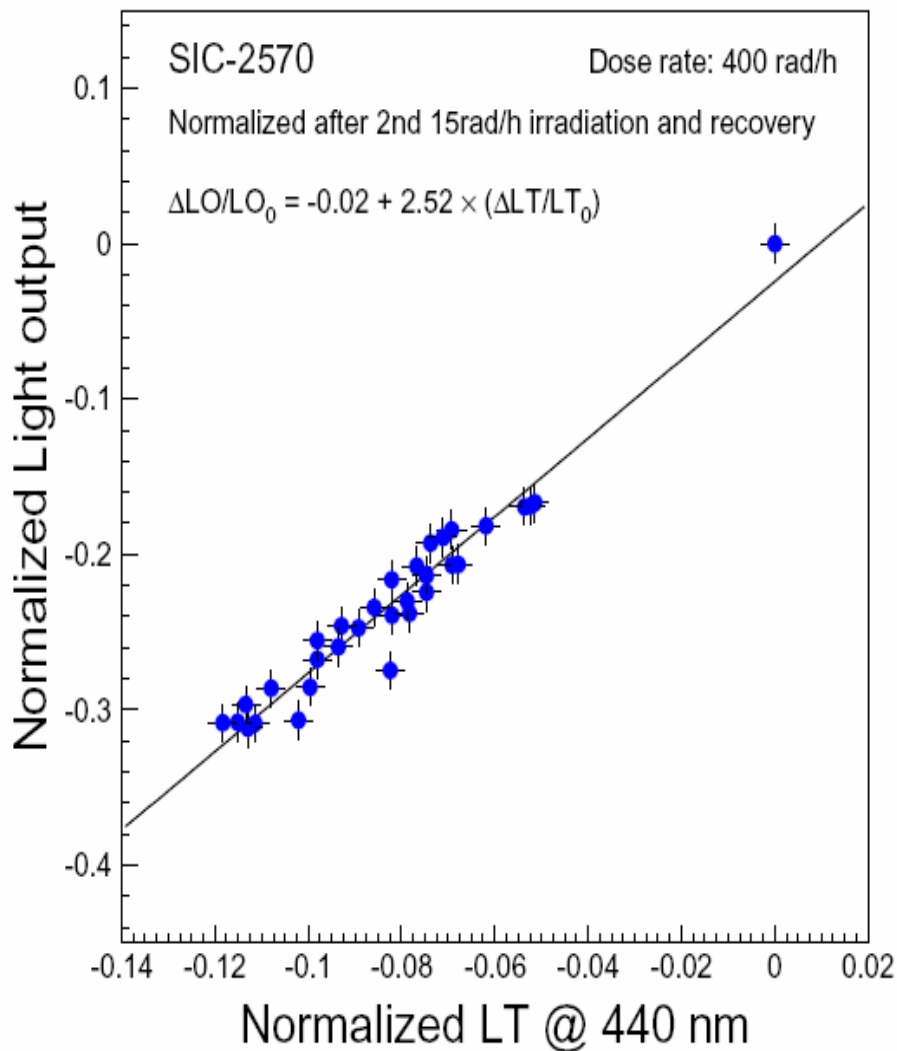
BTCP Monitoring @ 400 rad/h

Average Slope_{BTCP} = 3.82



SIC Monitoring @ 400 rad/h

Average Slope_{SIC} = 2.53 = Slope_{BTCP}/1.5





Summary

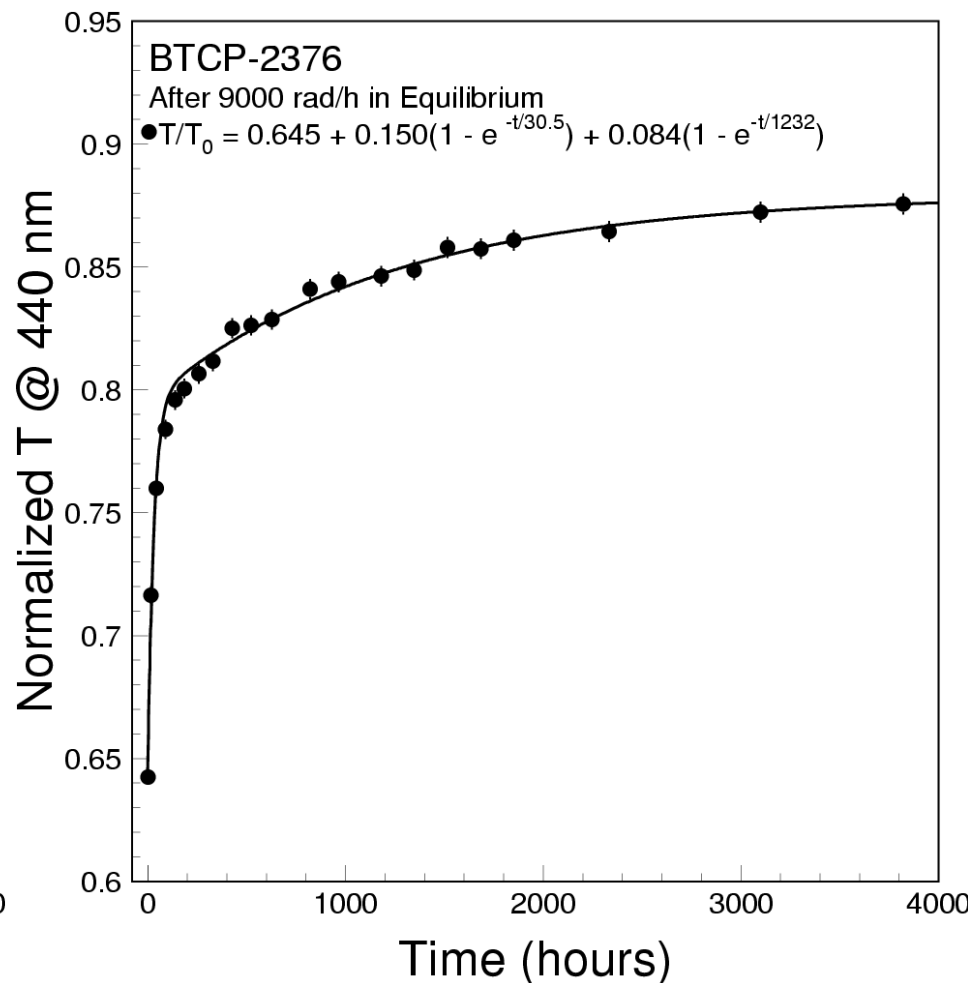
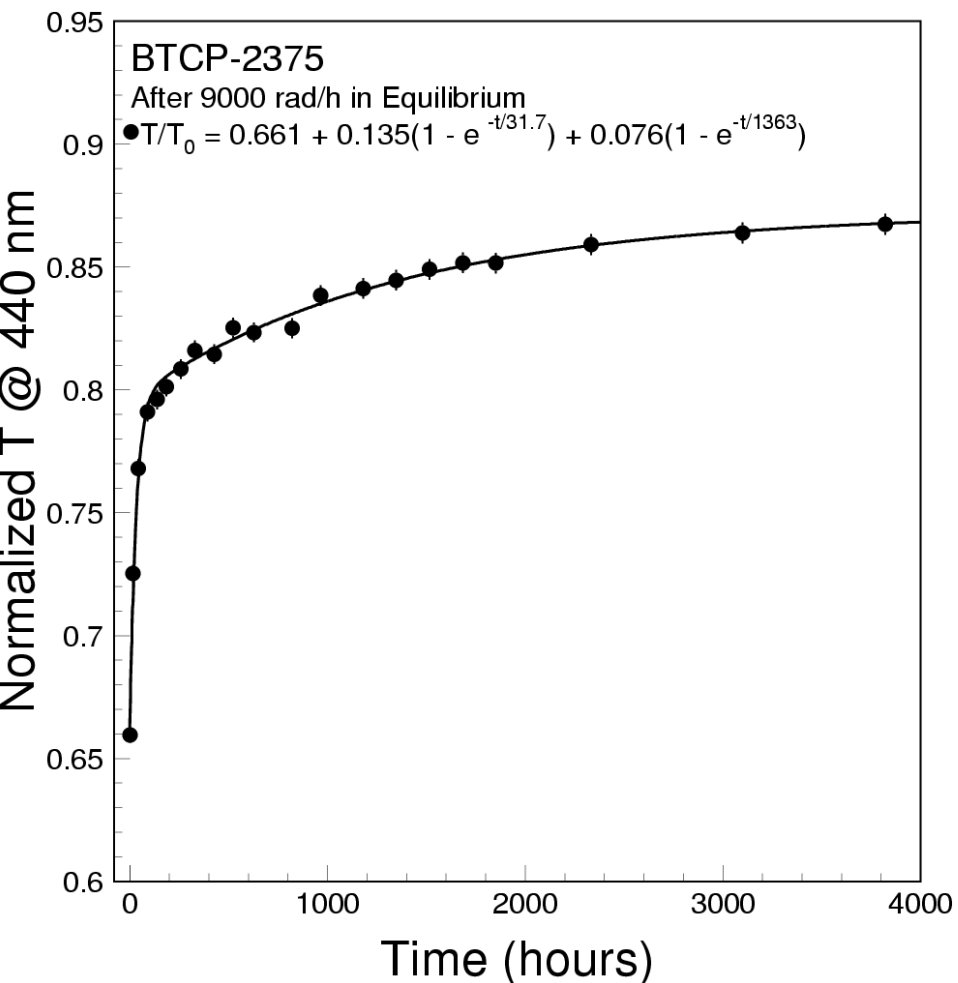


- There was a large uncertainty in dose rate in SIC's RIAC data, which seems the origin of the discrepancy discussed in the December DPG meeting. Current sample location has a dose rate of about 80 Gy/h with uncertainty reduced.
- SIC samples produce 50% more light than BTCP samples.
- BTCP samples are more radiation hard than 2001 batch. SIC samples are compatible with the 2002 batch. All four samples satisfy the CMS RIAC requirement.
- BTCP samples have a smaller variation in LT: **2.4% @ 400 rad/h** versus **3%** of SIC, but have a larger variation in LO: **2.7%** and **11.8%** @ 15 and 400 rad/h respectively versus **2.1%** and **8.3%** of SIC, caused by slower recovery of SIC.
- The variation of LO is proportional to the variation of LT. The slope between these two variations are **3.82** and **2.53** for BTCP and SIC samples respectively. The observed ratio of these slopes consists with the 2004 beam test result.
- **To be studied: the nature of the differences observed.**



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

