Result on Two PWO Samples from the SIC May Batch

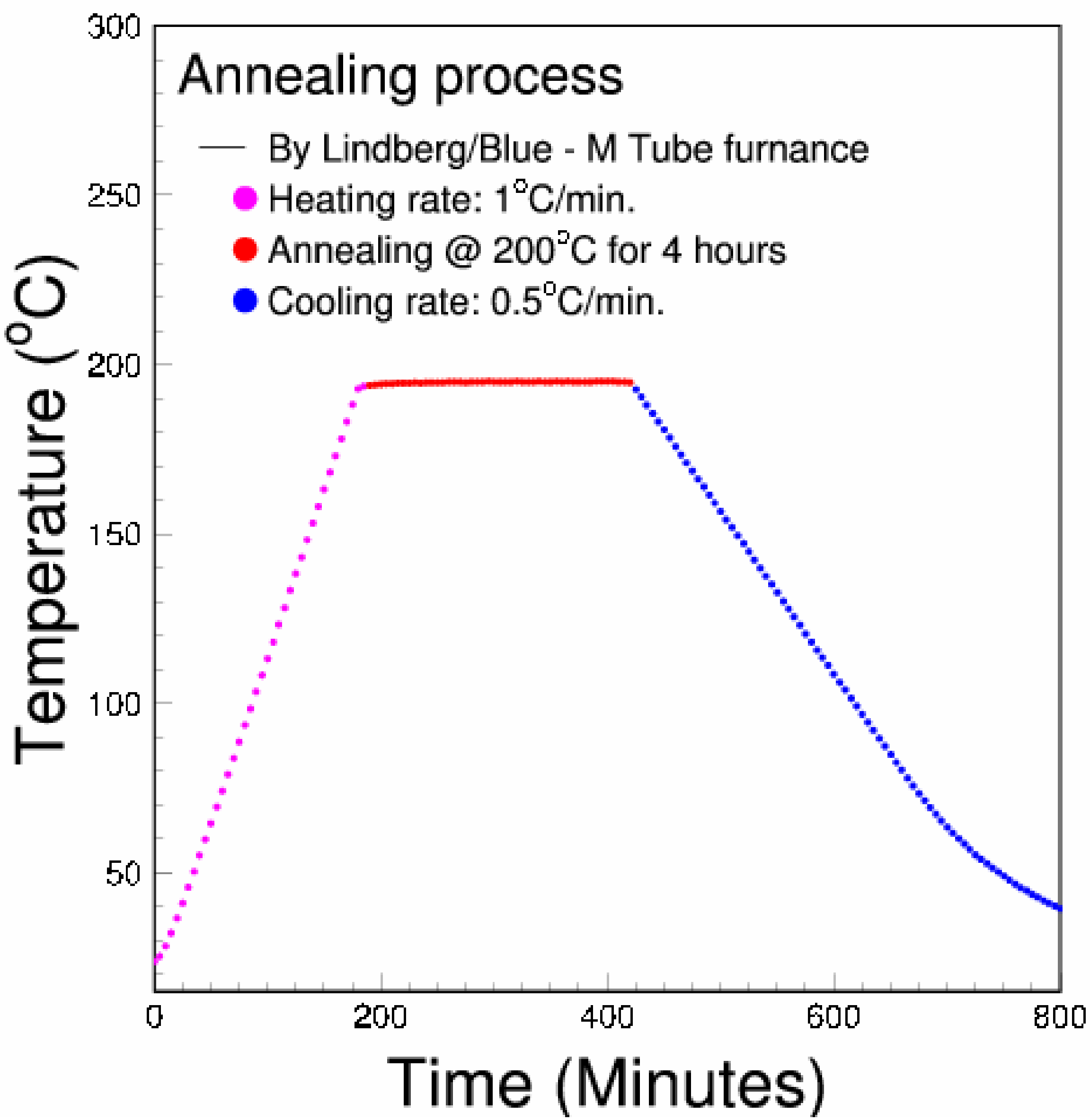
Ren-yuan Zhu

California Institute of Technology

Introduction

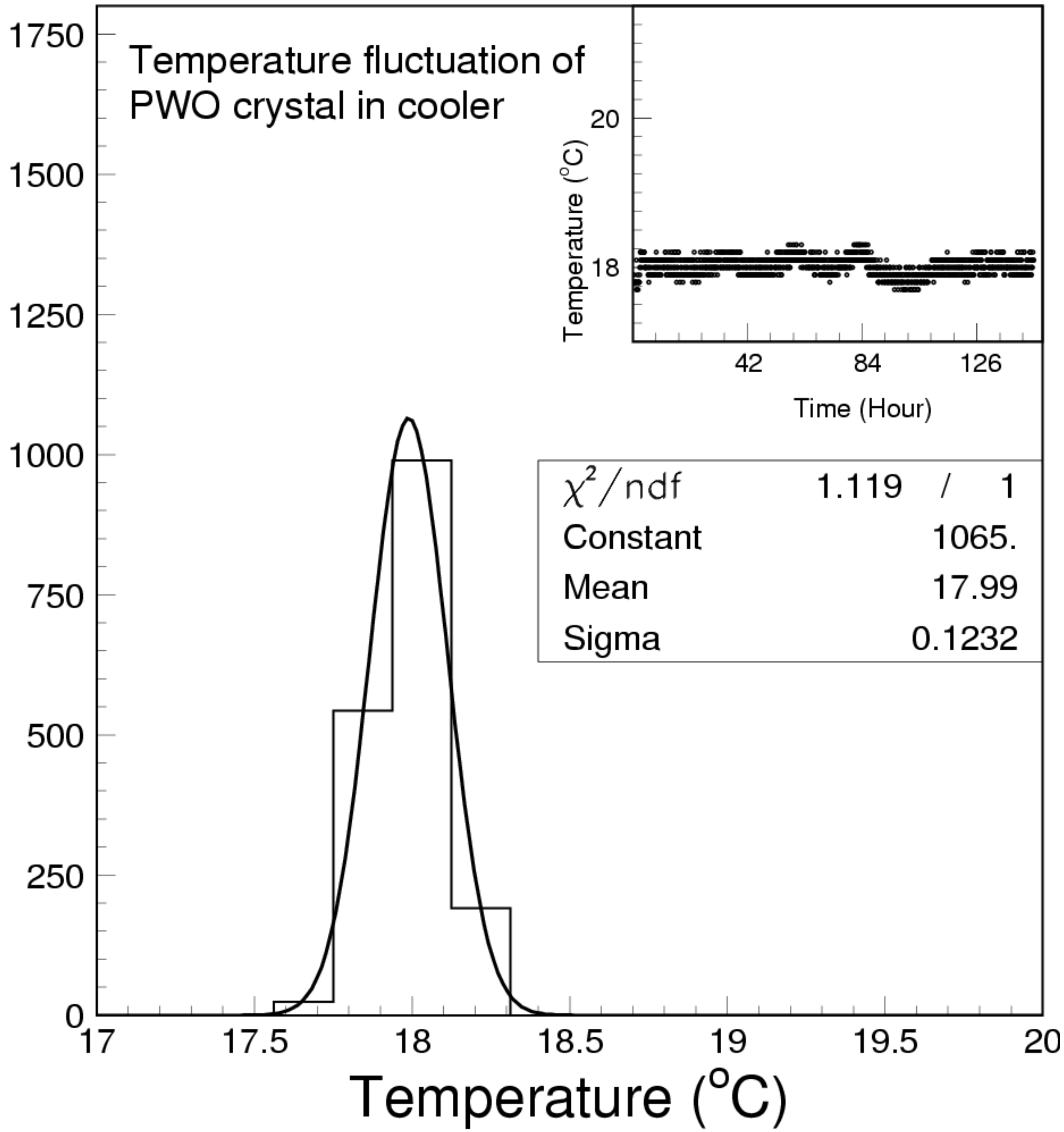
- Two endcap size PWO samples from the SIC May batch (#2630 and 2641) went through standard procedure: (1) thermal annealing at 200^{o}C, (2) irradiations by γ–ray at 15, 400 and 9k rad/h until equilibrium and (3) recovery after 9 krad/h at 18^{o}C.
- Properties measured: transmittance, emission and excitation spectra, light output, decay kinetics and light response uniformity, as well as their degradation; radiation induced color center and emission weighted radiation induced absorption coefficients (EWRIAC).
- Results are compared to 20 CEBAF size samples from the SIC 2002 batch, which was also measured at Caltech.

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.

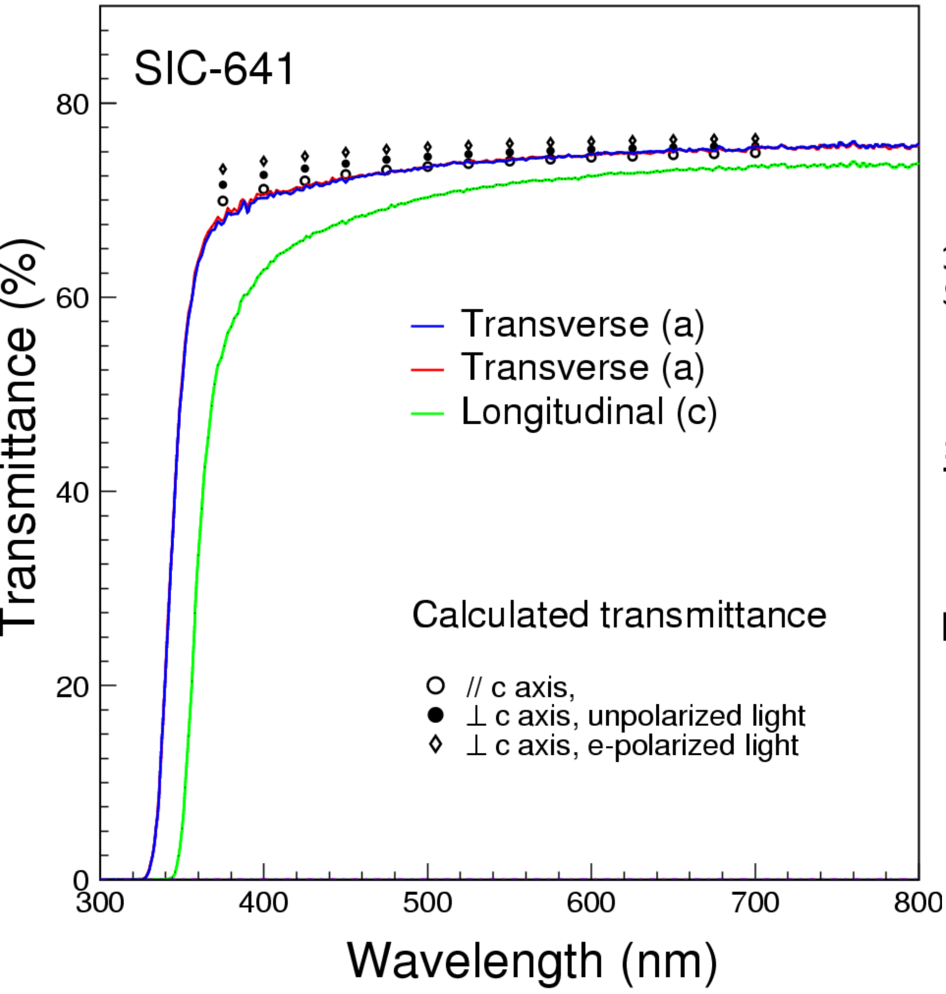
Long Term Recovery under 18°C

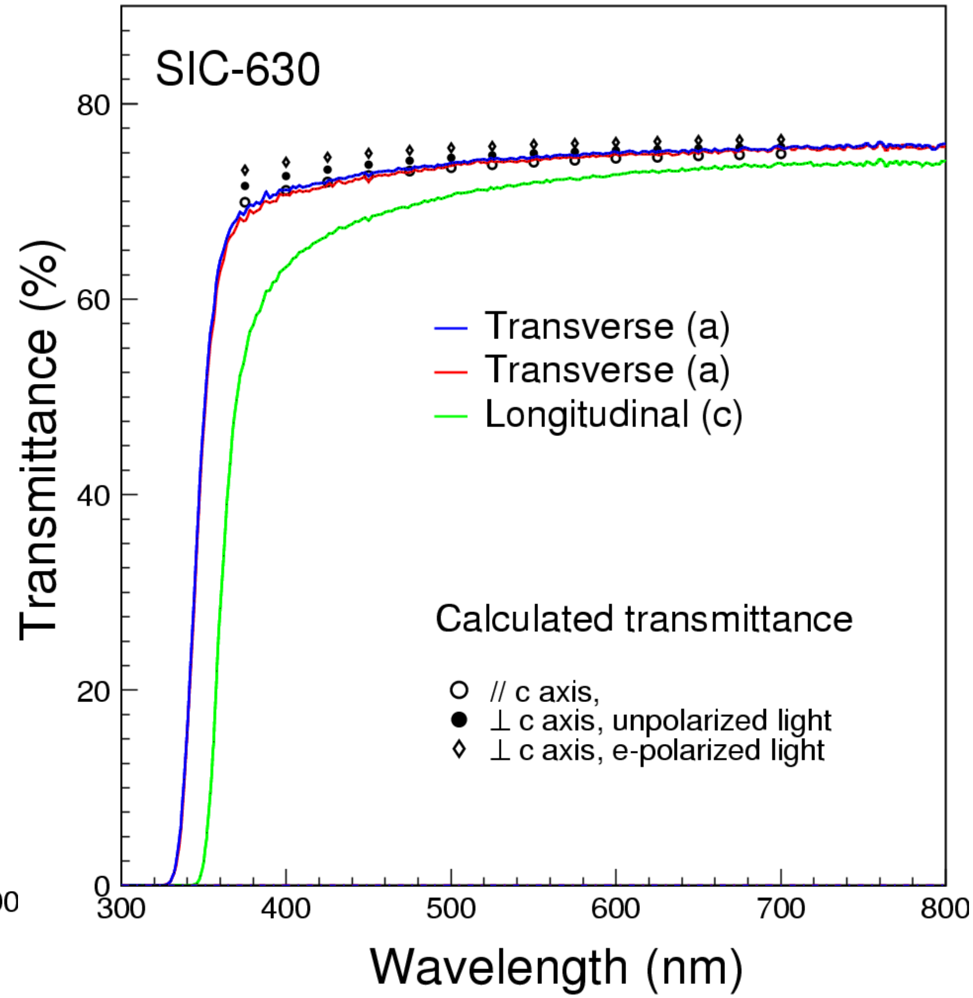


After irradiation under 9 krad/h recovery was measured when samples were kept in a cooler at 18°C with 0.12°C variation.

Initial Transmittances

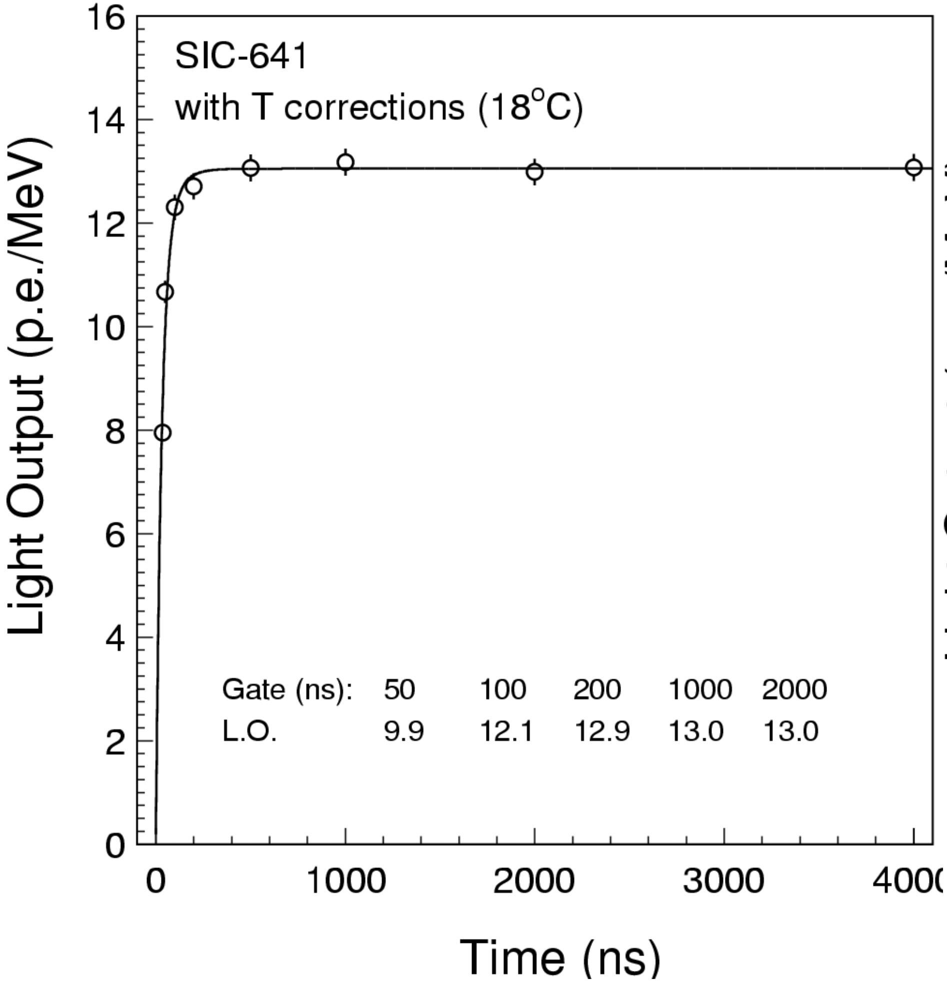
Longitudinal transmittance along the "c" axis
Transverse transmittance approaches theoretical limit

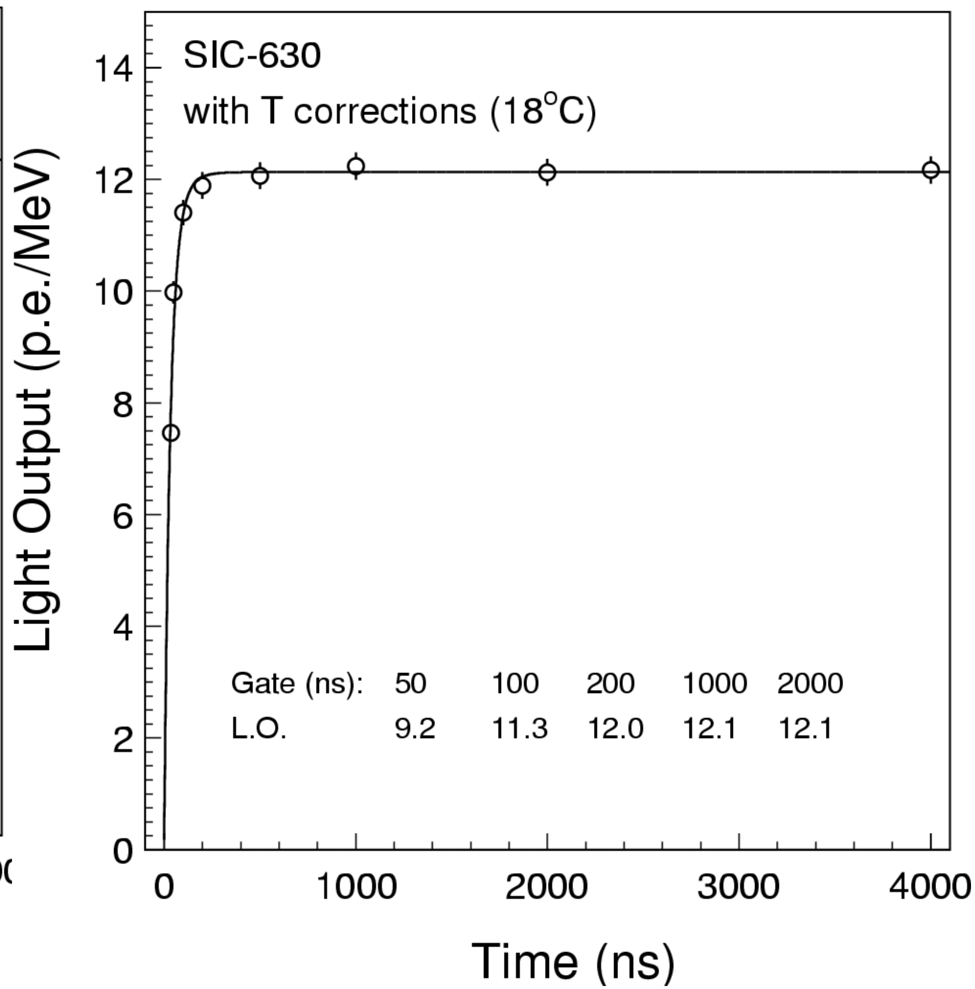




Light Yield and Decay Kinetics

Initial light output is fast and high

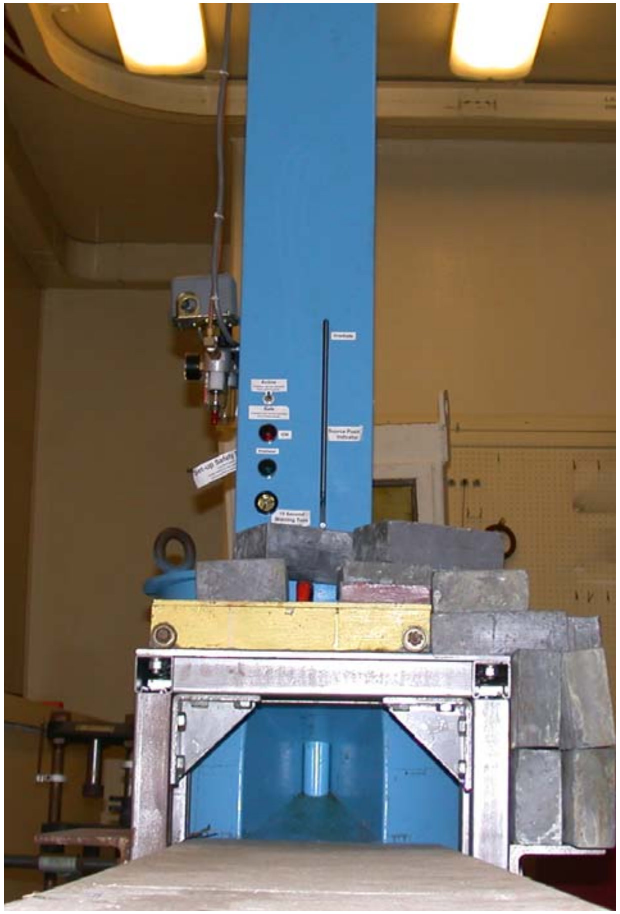




Caltech γ–ray Irradiation Facilities

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

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



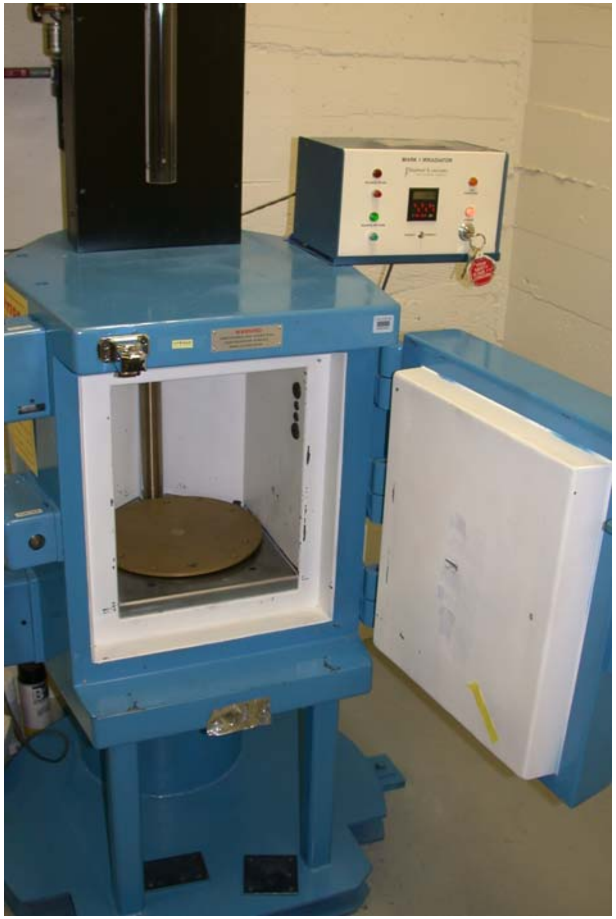
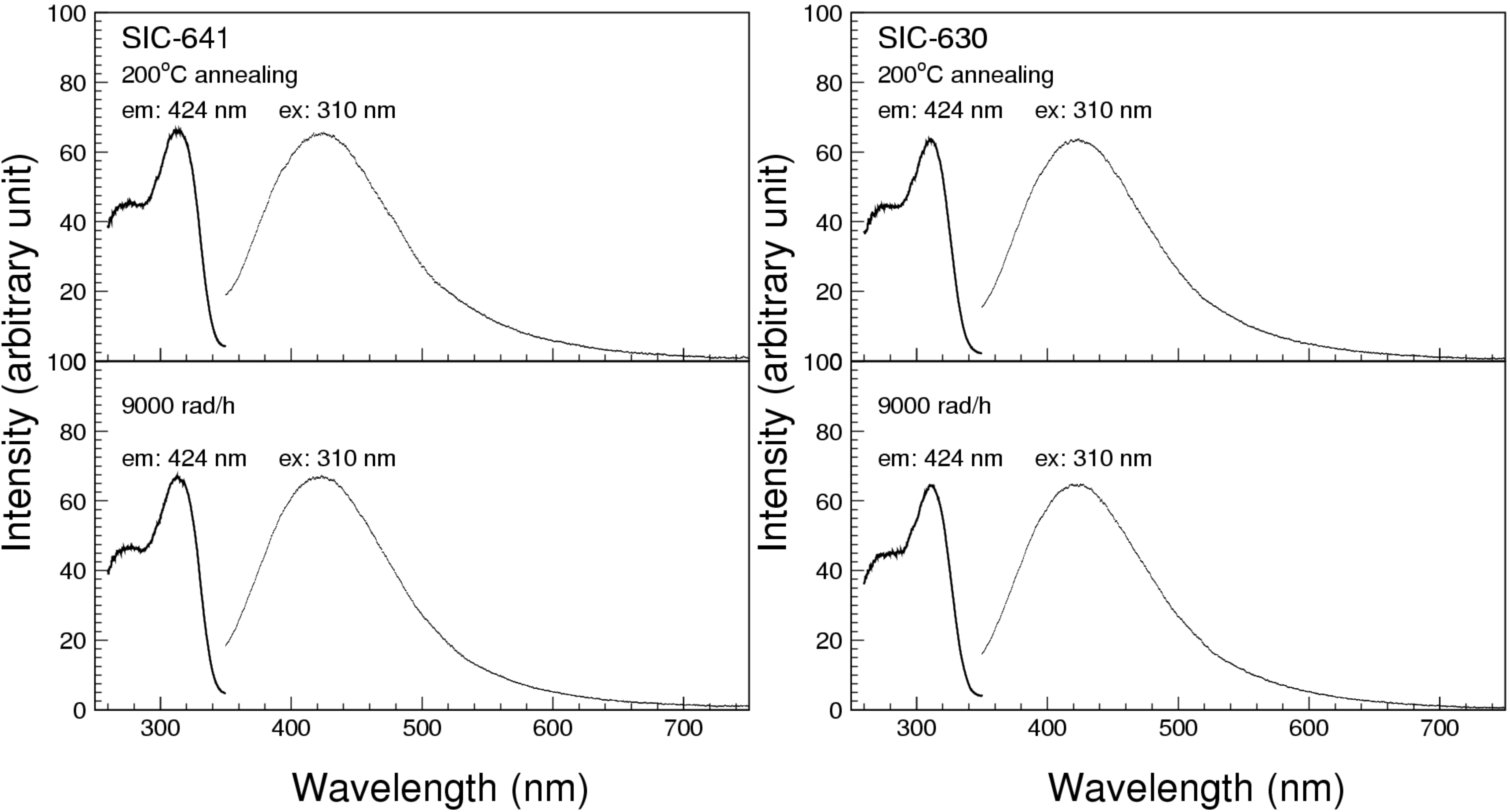


Photo-luminescence

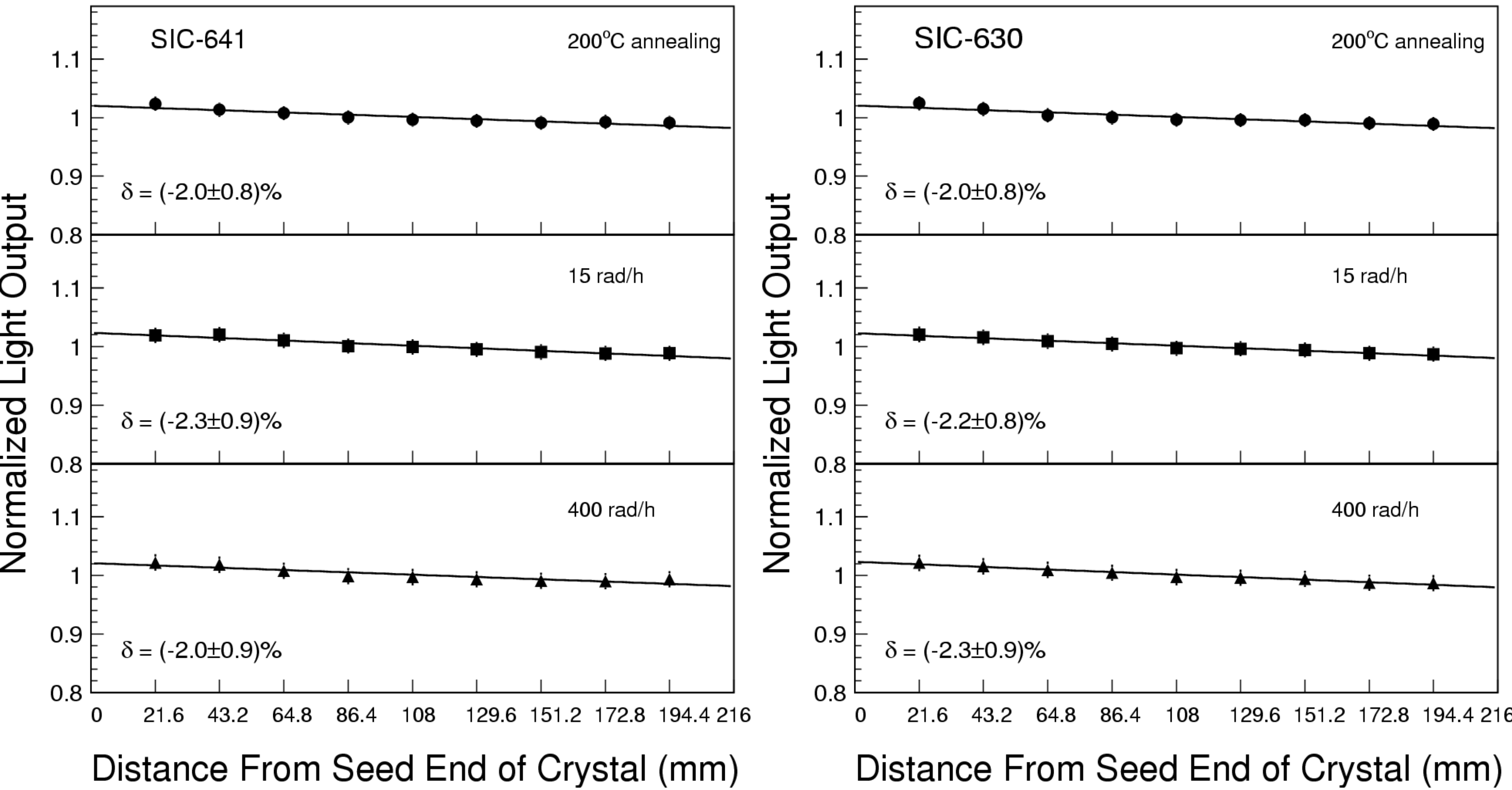
No variation in excitation or emission spectrum indicating no damage in scintillation mechanism



No Variation in Light Response Uniformity

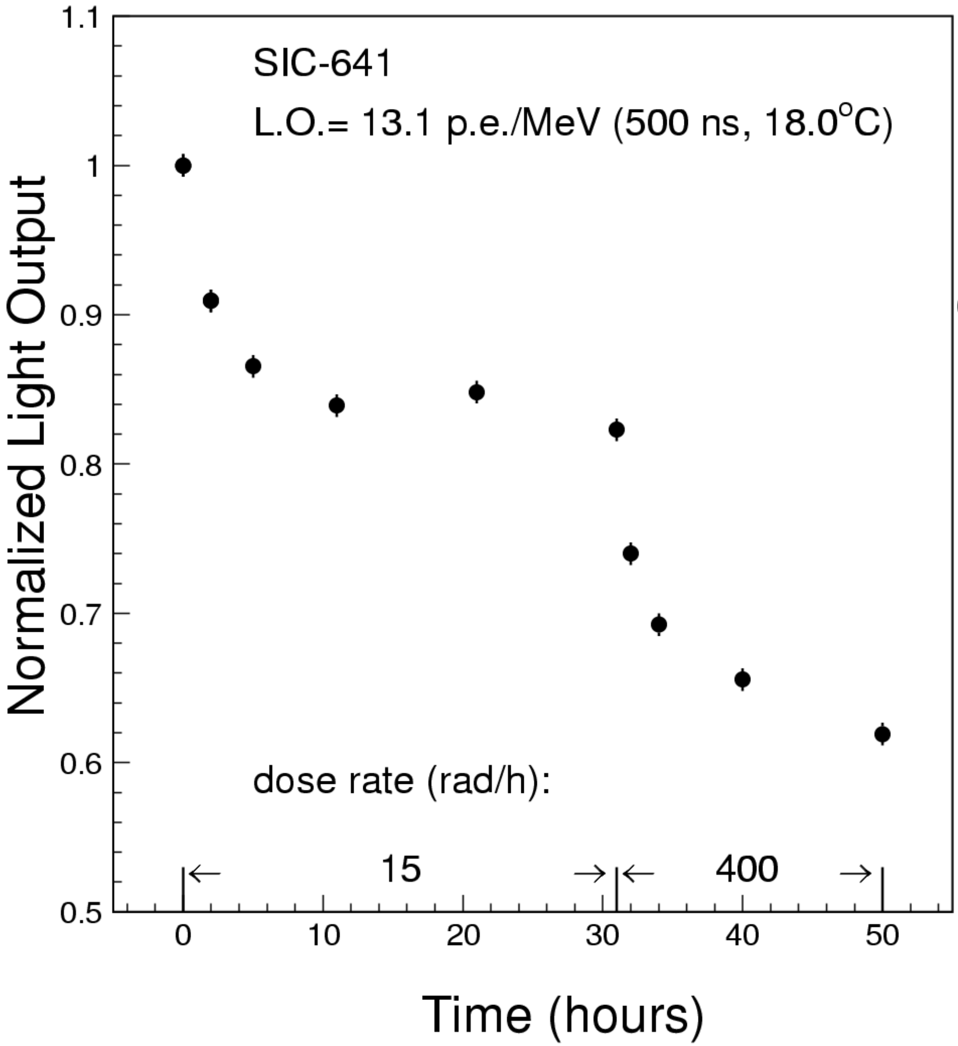
Indicating no damage in energy resolution

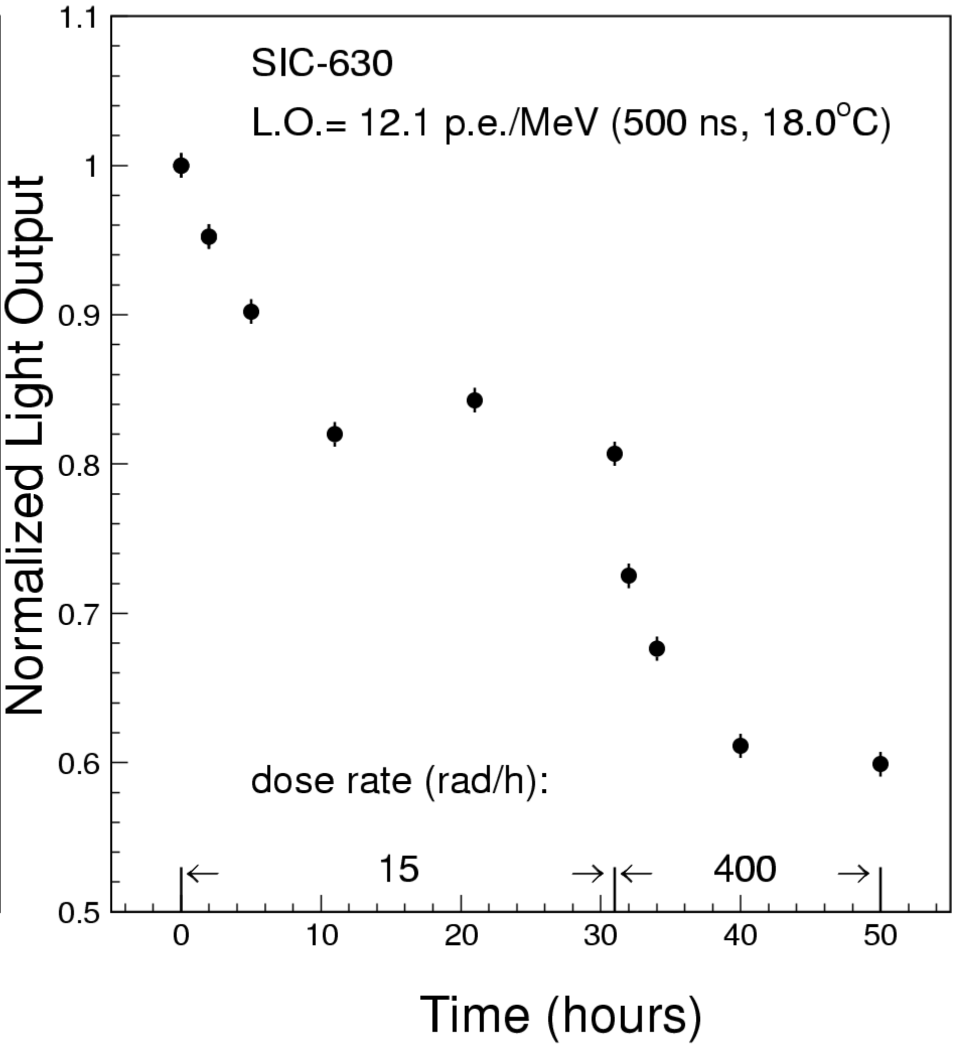
$$\frac{y}{y_{mid}} = 1 + \delta(x / x_{mid} - 1)$$



Light Output Degradation

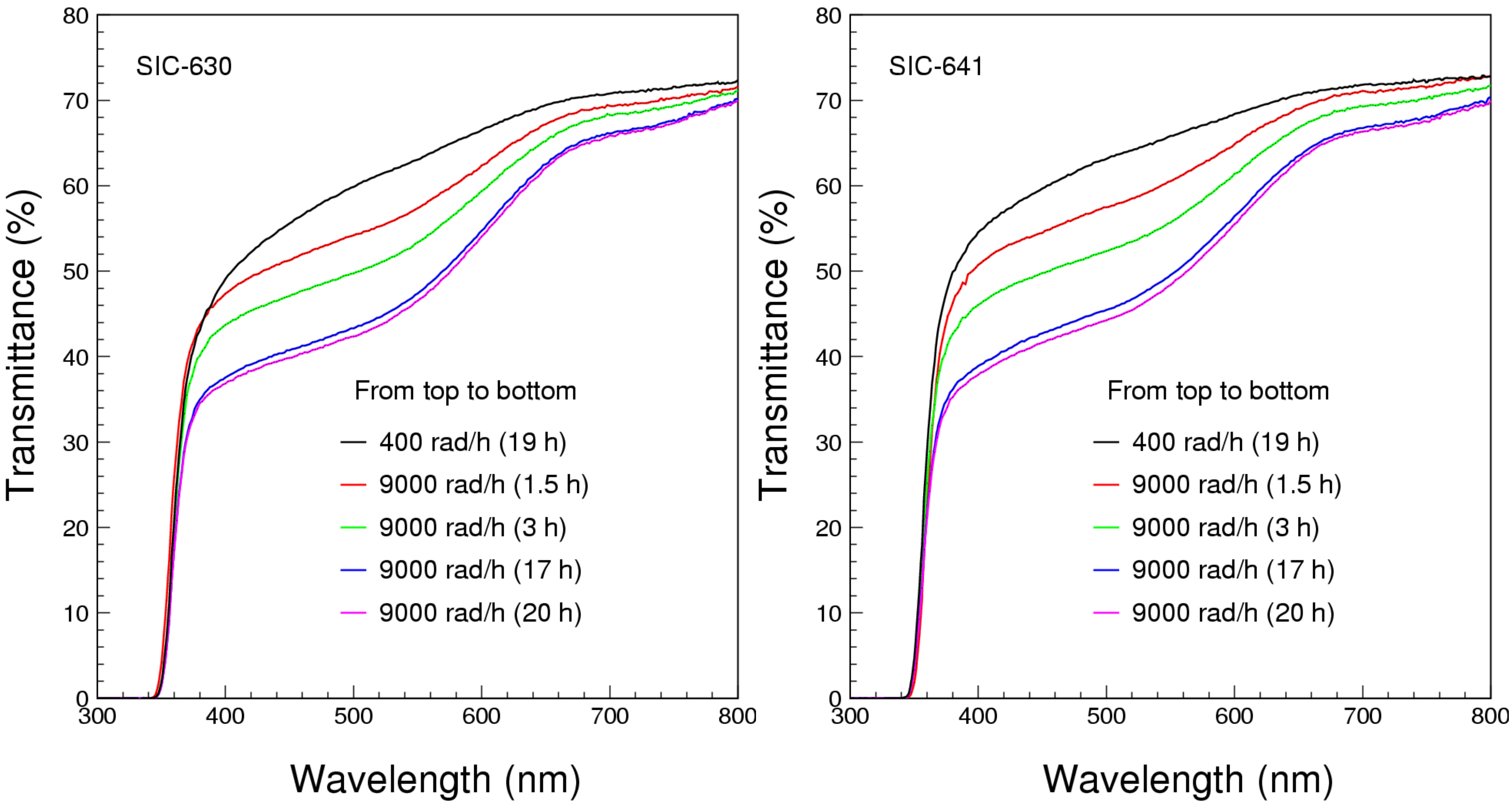
15-20% and 40% loss under 15 and 400 rad/h
Reached an equilibrium under a specific dose rate





Longitudinal Transmittance Damage

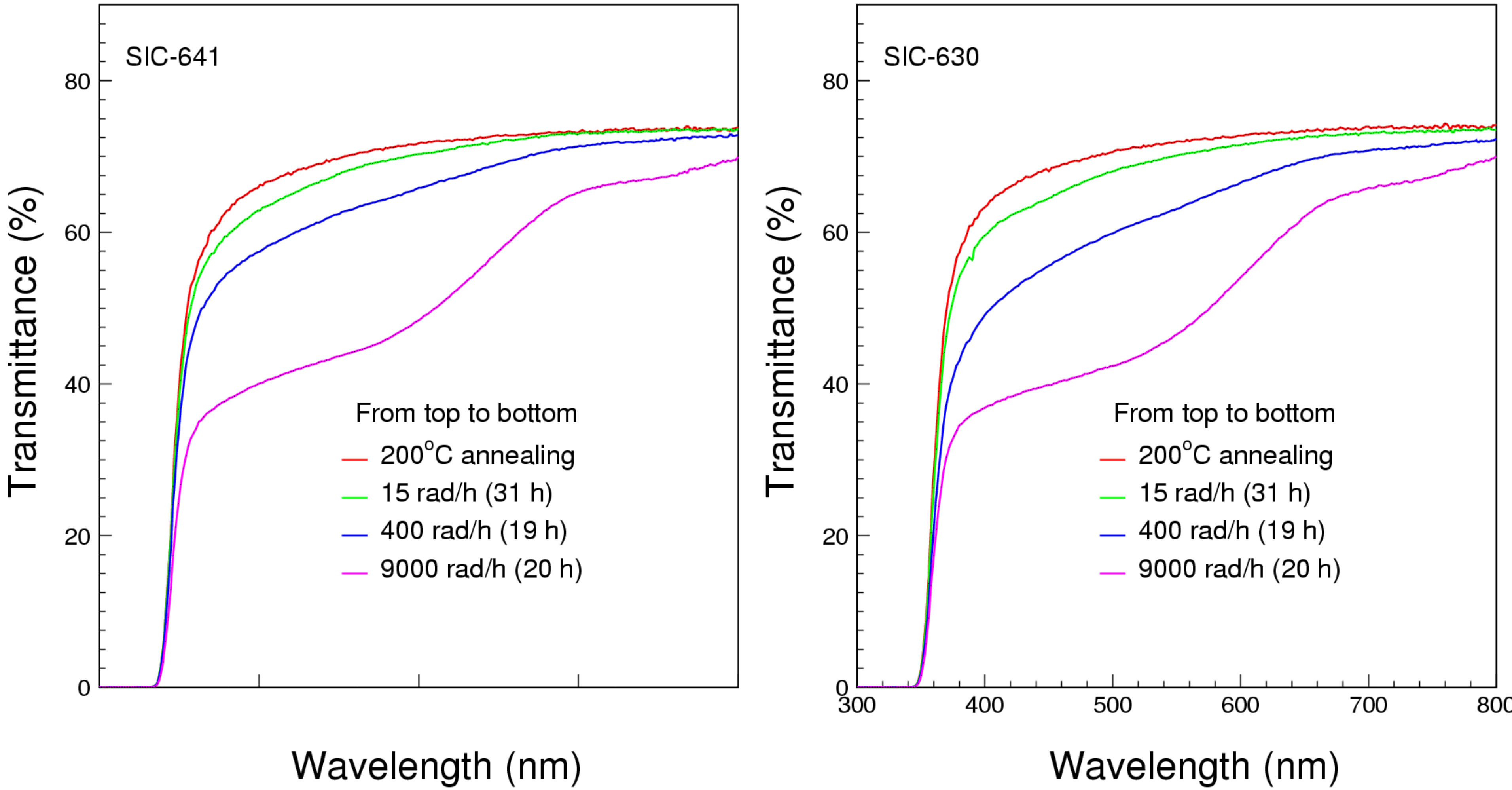
Reached an equilibrium under 9 krad/h



Longitudinal Transmittance

Radiation damage is dose rate dependent

Time spent for irradiations is not a damage time constant



Dose Rate Dependent Damage

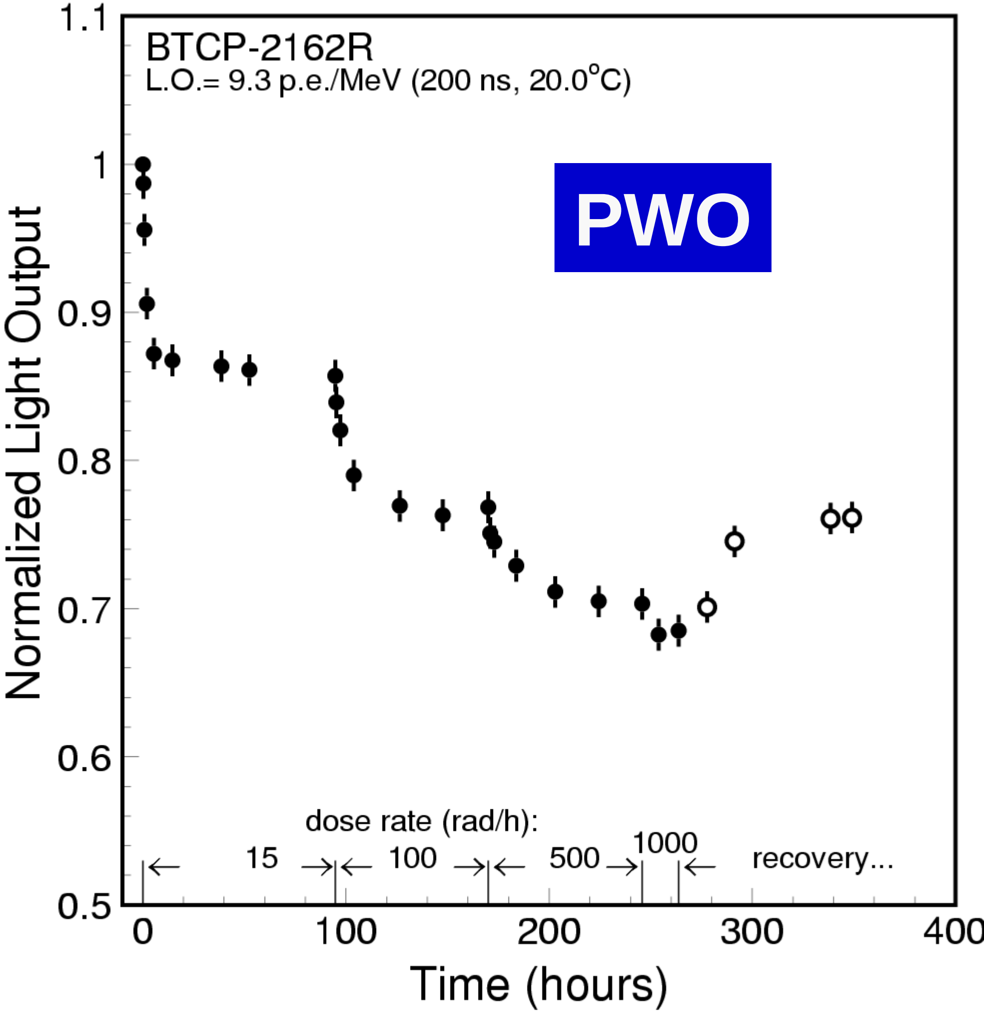
IEEE Trans. Nucl. Sci., Vol. 44 (1997) 468-476

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

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

- 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.

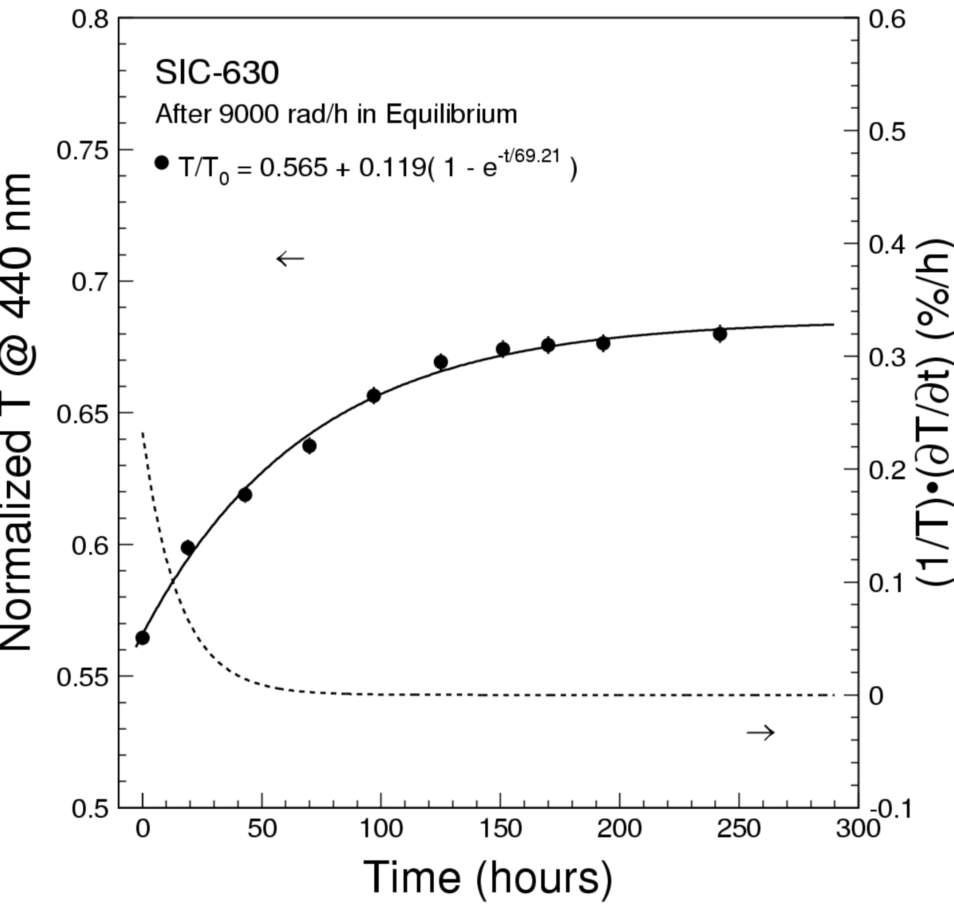
$$D_{eq} = \sum_{i=1}^{n} \frac{b_i R D_i^{all}}{a_i + b_i R}$$

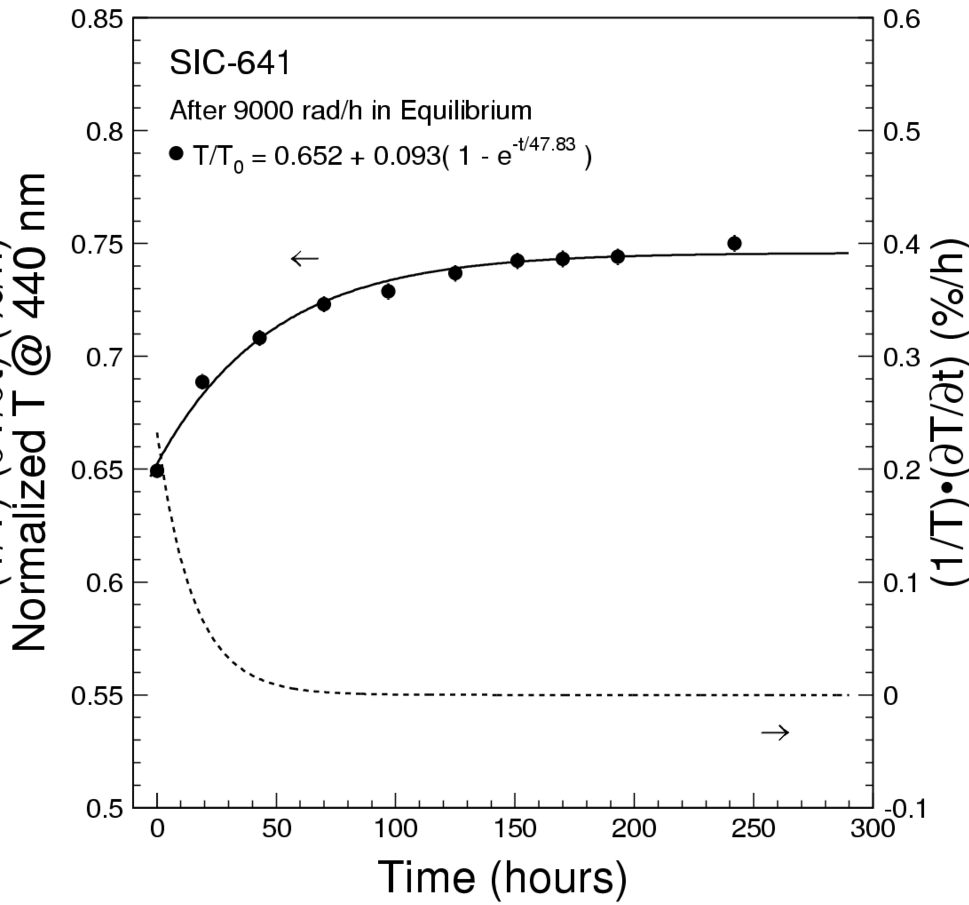


Recovery Speed and Time Constant

27% damage recovered with time constant of 69 and 48h

Significant recovery spped only in the 1st few ten hours



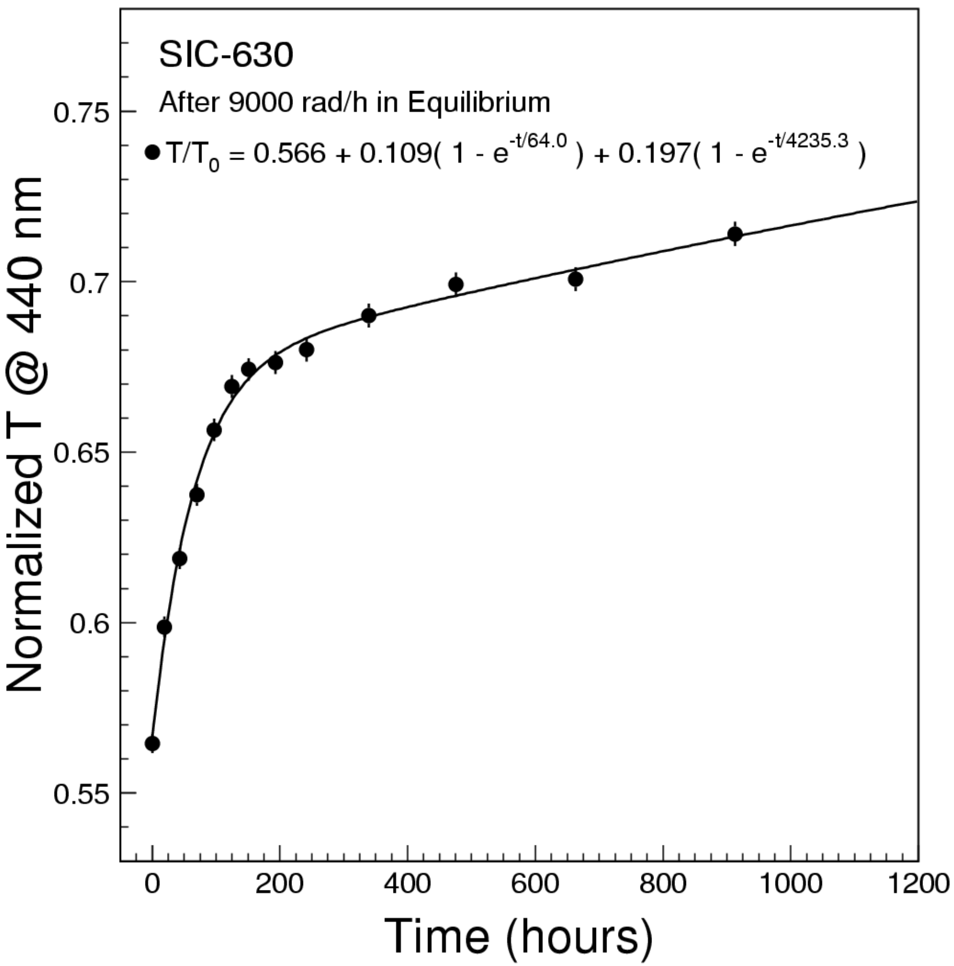


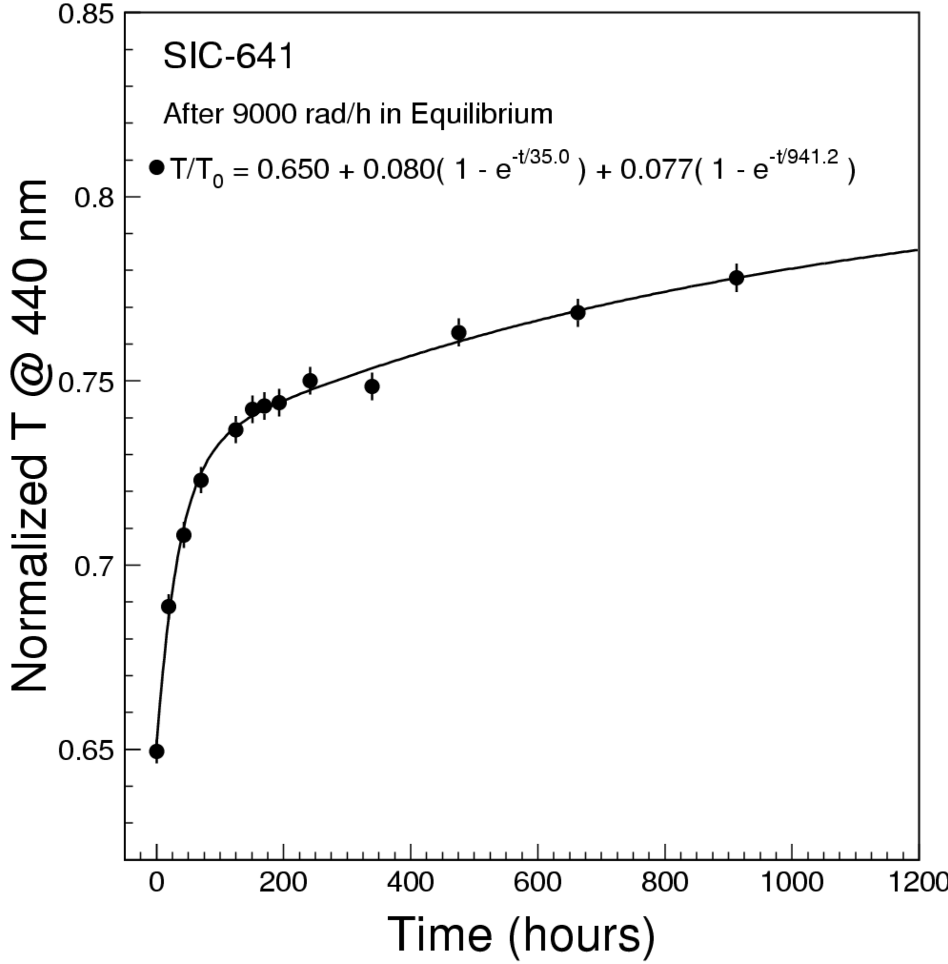
Long Term Recovery

Fast: 25 and 23% with time constant of 64 and 35 h

Slow: 45 and 22% with time constant of 4,240 and 940 h

More data points are needed to constrain time components

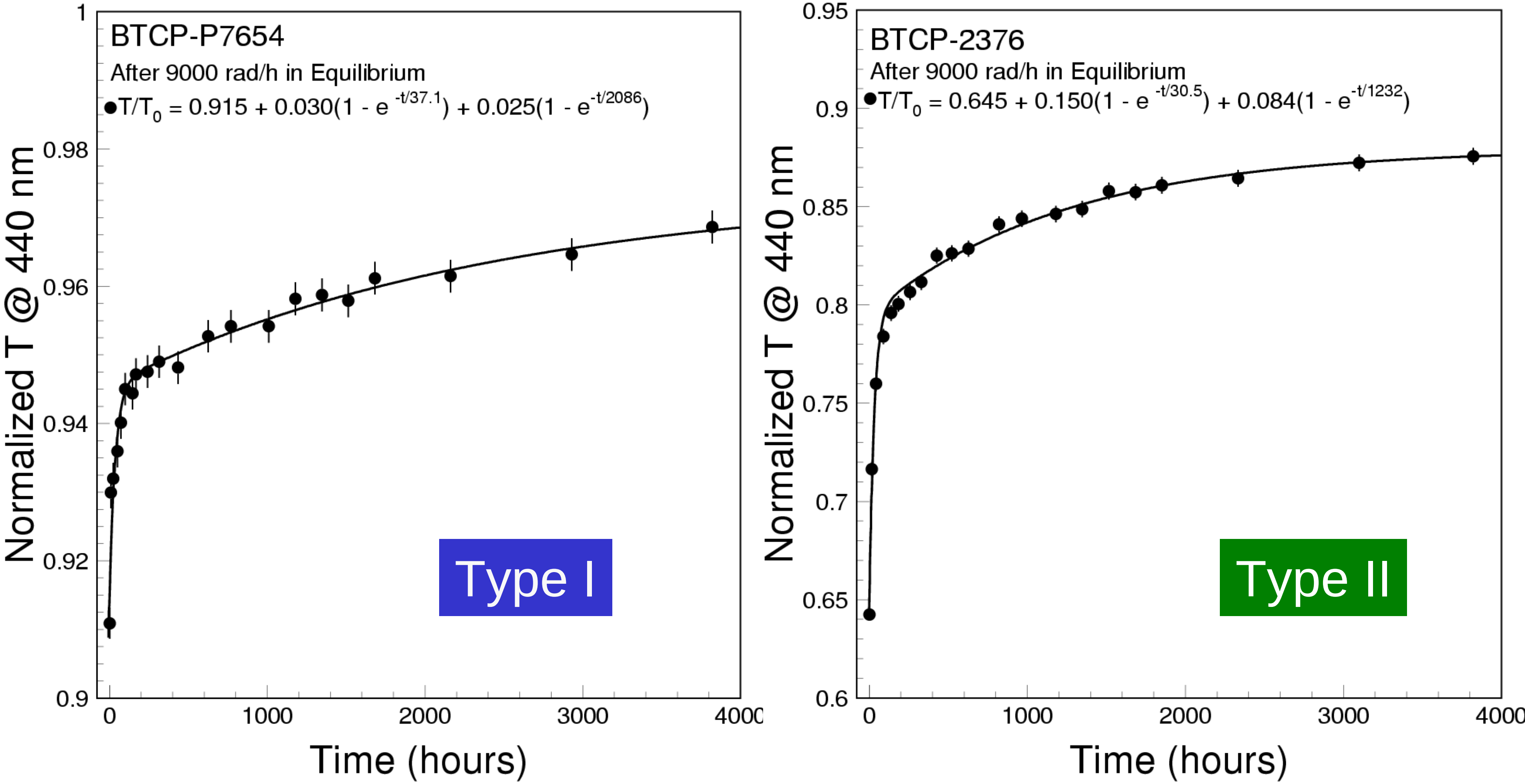




BTCP Long Term Recovery

Two Time Constants: 30-37 h and ~1,200 -2,000 h

Reported in the DPG meeting on July 8, 2003



Summary of BTCP Long Term Recovery

Reported in the DPG meeting on July 8, 2003

$$Fit: \frac{T}{T_o} = A_0 + A_1(1 - e^{-t/\tau_1}) + A_2(1 - e^{-t/\tau_2})$$

Sample ID	$1\text{-}A_0$ (%)	F_1 (%)	τ_1 (hour)	F_2 (%)	τ_2 (hour)	F_∞ (%)
Type II PWO Samples						
B2375	33.9	39.8	31.7	22.4	1,363	37.8
B2376	35.5	42.3	30.5	23.7	1,232	34.0
Average	34.7	41.1	31.1	23.1	1,298	35.9
Type I PWO Samples						
P7467	7.0	48.6	59.9	22.9	1,847	28.5
P7557	6.7	49.3	52.0	37.3	1,897	13.2
P7566	6.1	54.1	37.5	39.3	1,926	6.6
P7654	8.5	35.3	37.1	29.4	2,081	35.3
P7903	6.5	46.2	32.6	32.3	1,928	21.5
Average	7.0	46.7	43.8	32.2	1,937	21.1

F_i denotes the fraction of corresponding component.

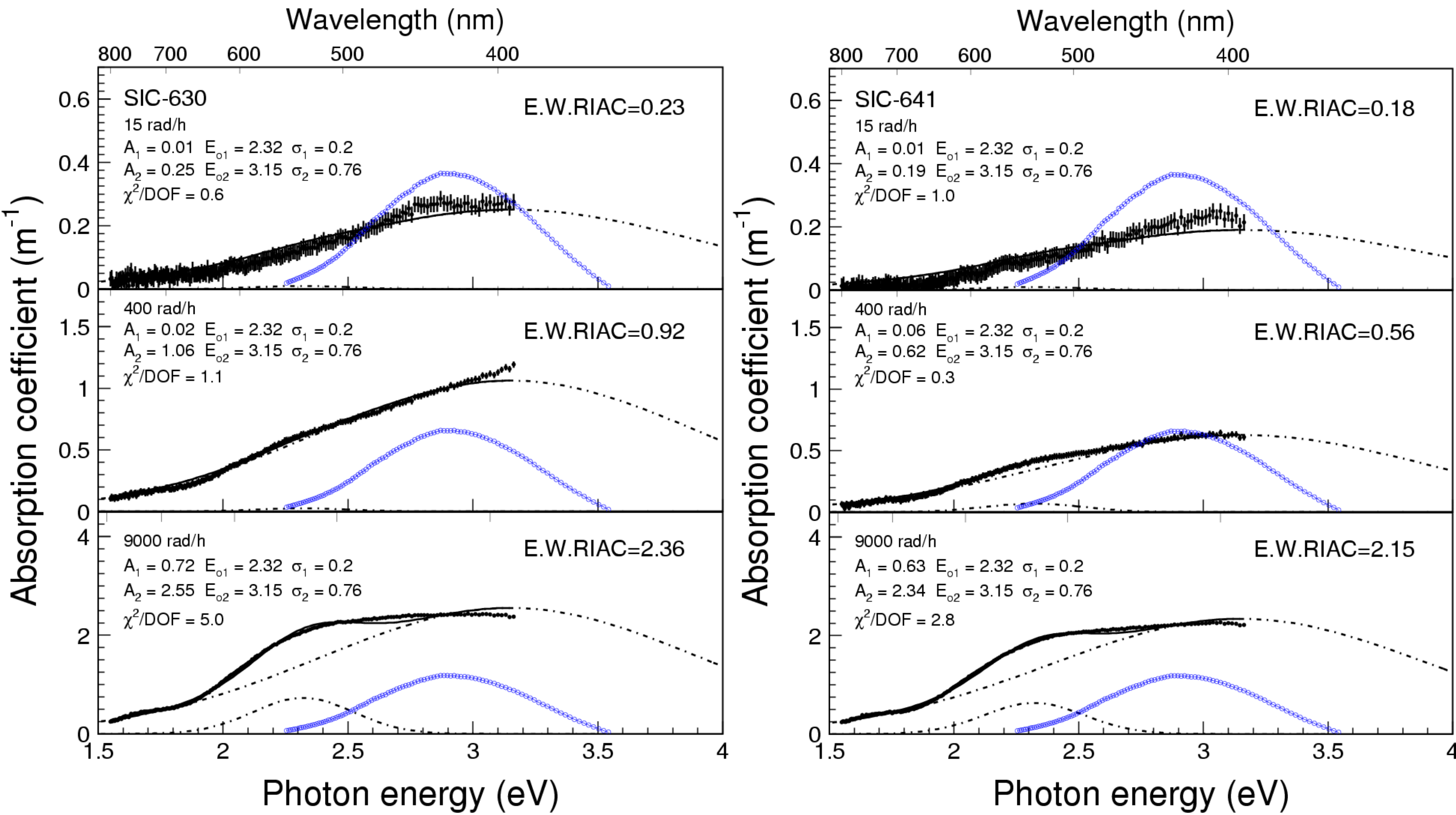
Three components in Type II or I:

- fast: 41or 47% of damage with time constant 31 or 44 h.
- slow: 23 or 32% of damage with time constant 1,300 or 1,900 h.
- residual (permanent): 36 or 21% damage not recovered after 4,000 h.

RIAC Can be fit to Two Color Centers

$$EW\,RIAC = \frac{\int Riac(\lambda)Em(\lambda)d\lambda}{\int Em(\lambda)d\lambda}$$

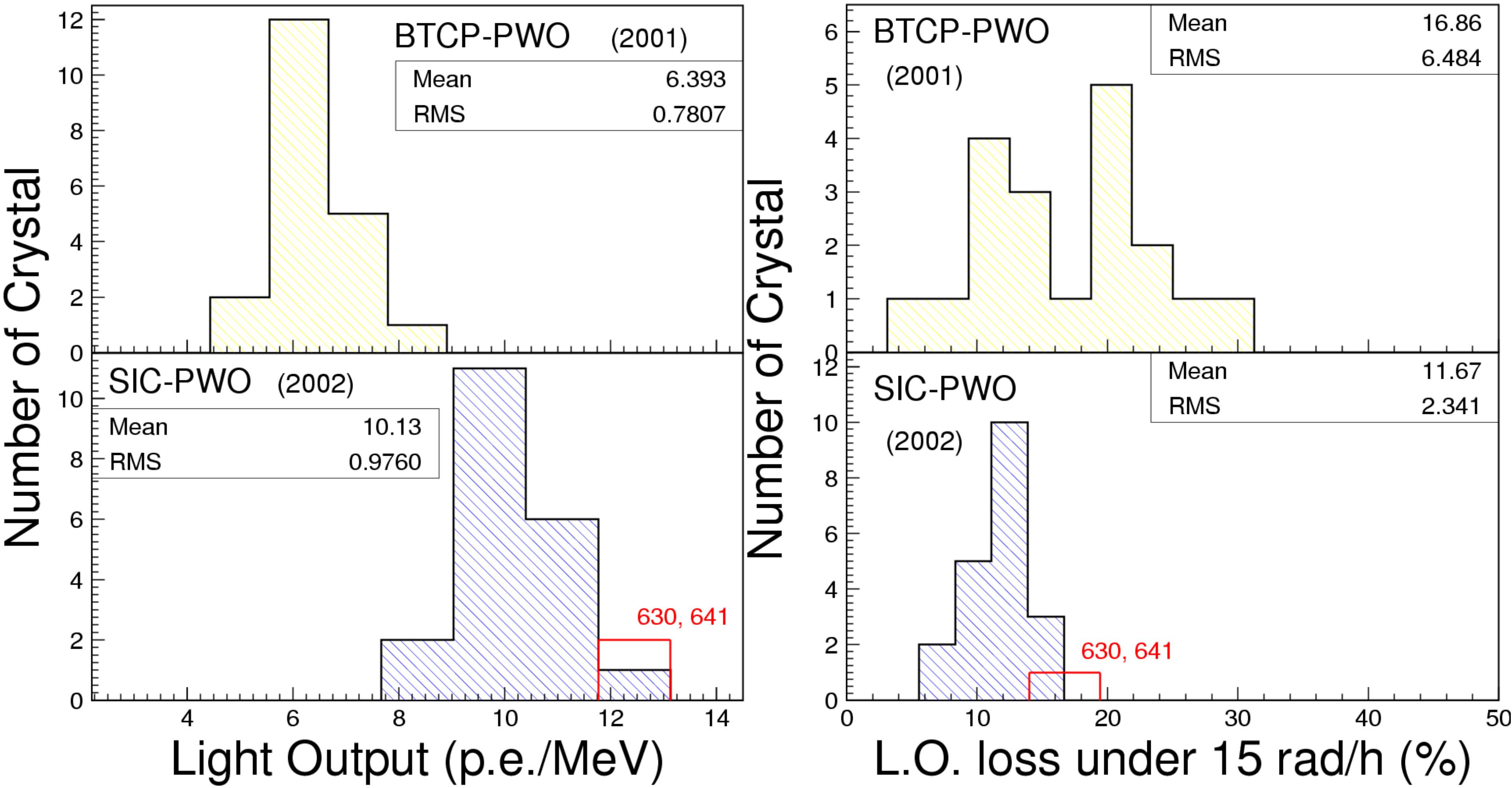
measures radiation hardness



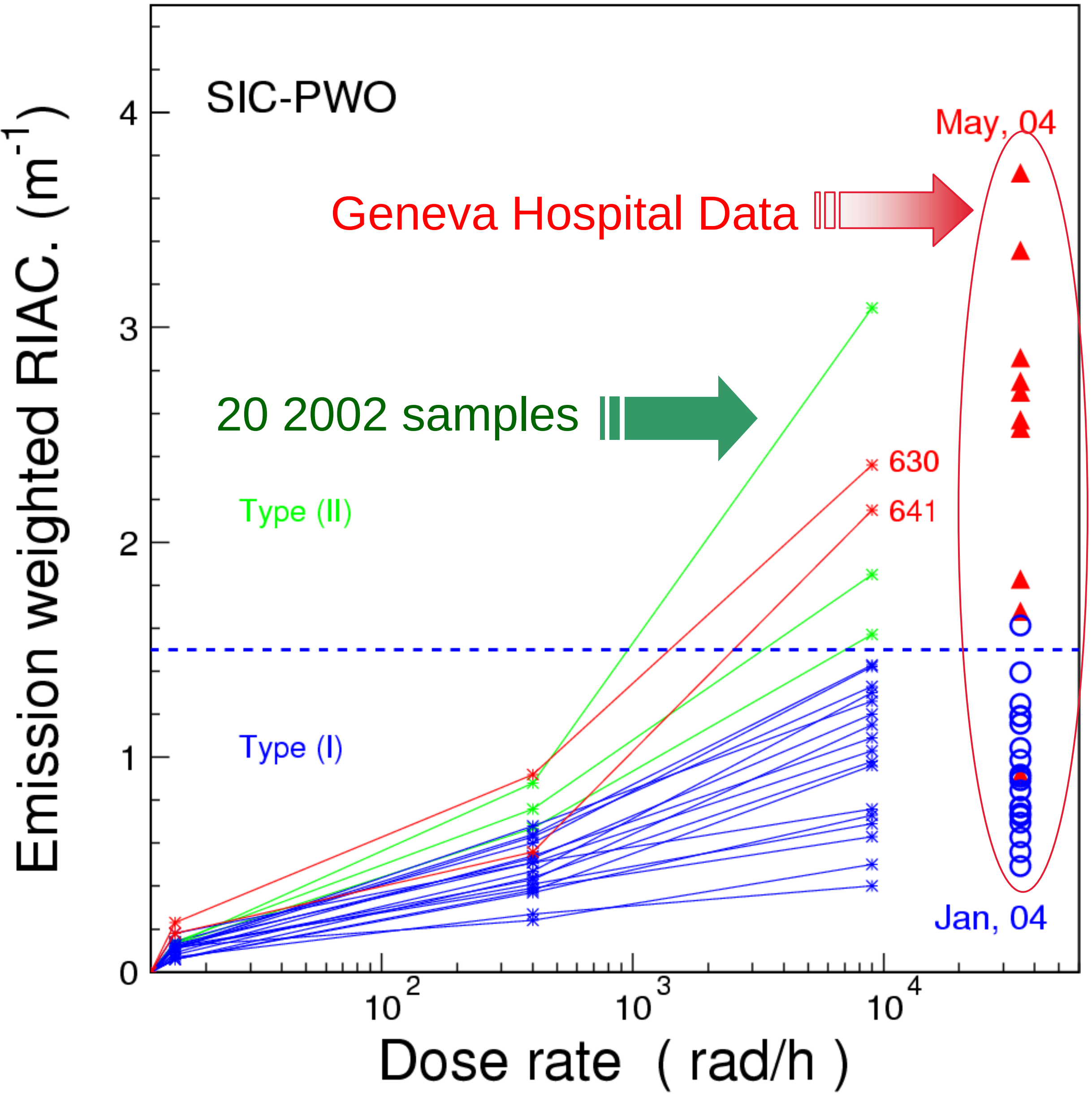
Comparison with SIC 2002 Batch

Initial light output is larger: geometry?

Relative loss in light output damage is larger: Chemistry?



Comparison with 2002 Batch (EWRIAC)

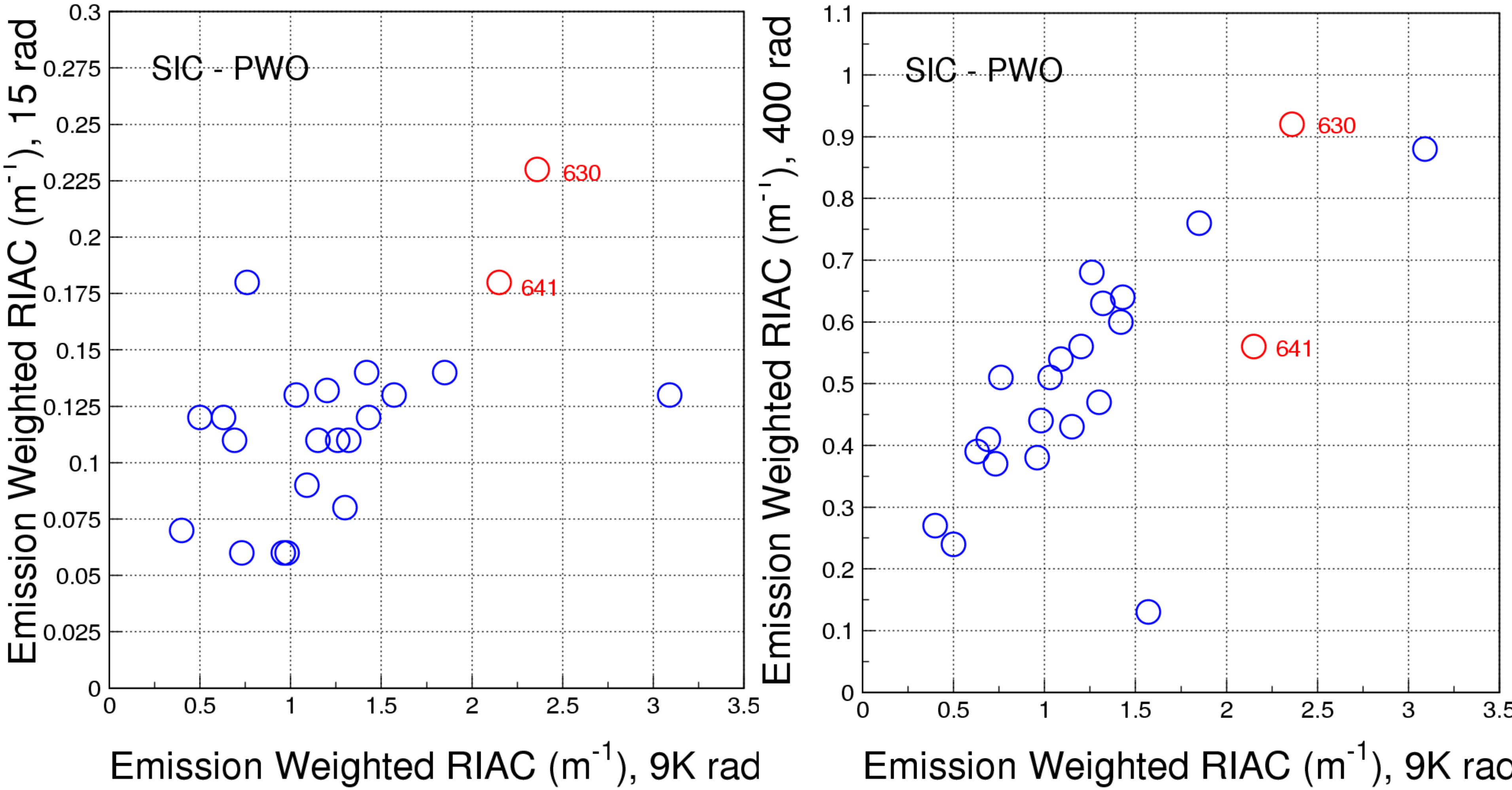


630 & 641 are soft as compared to the twenty 2002 SIC samples measured at Caltech.

CERN data from Geneva hospital indicates that the January batch is more radiation hard than the May batch.

Correlations

A weak correlation exists between damage levels under different dose rates



Conclusions

- Two endcap size PWO samples from the SIC May batch were studied at three dose rates.
- Two radiation induced color centers, two recovery time constants, dose rate dependence and a weak correlation between damage levels at different dose rates are observed.
- Compared to 20 CEBAF size samples from the SIC 2002 batch measured at Caltech, their initial transmittance and light output are good, but radiation hardness are below average, which was attributed to a raw material contamination by SIC.
- CERN data show that the January batch, which was not contaminated, is better in radiation hardness.