Current Status of BGO and PWO Crystals

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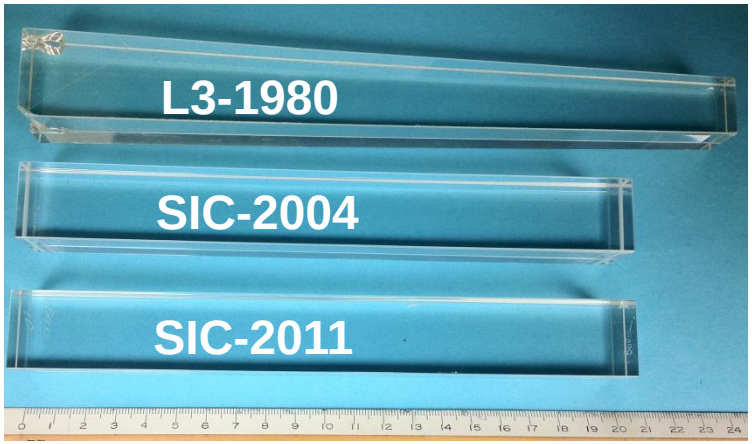
Status of SIC BGO



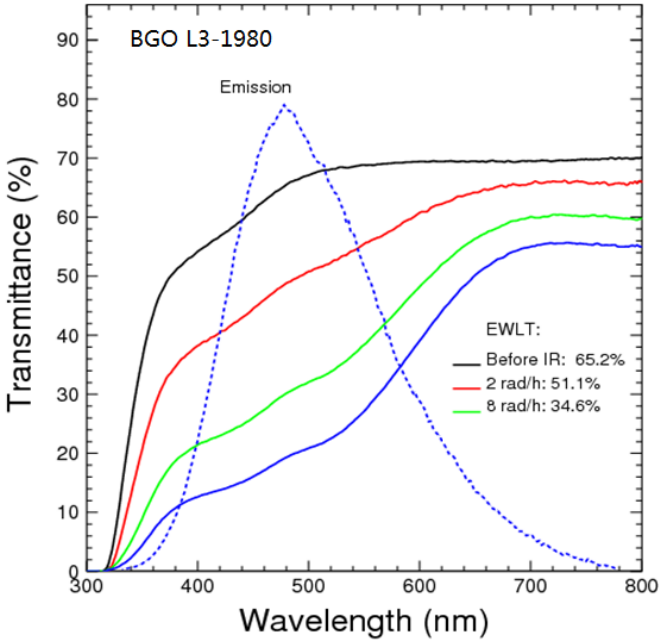
Sample ID	Date	Dimension	Polish
L3-1980	1980	20^2 x 30^2 x 240mm^3	Six faces
SIC-2004	2004	25 x 25 x 200 mm^3	Six faces
SIC-2011	11/11/2011	25 x 25 x 200 mm^3	Six faces

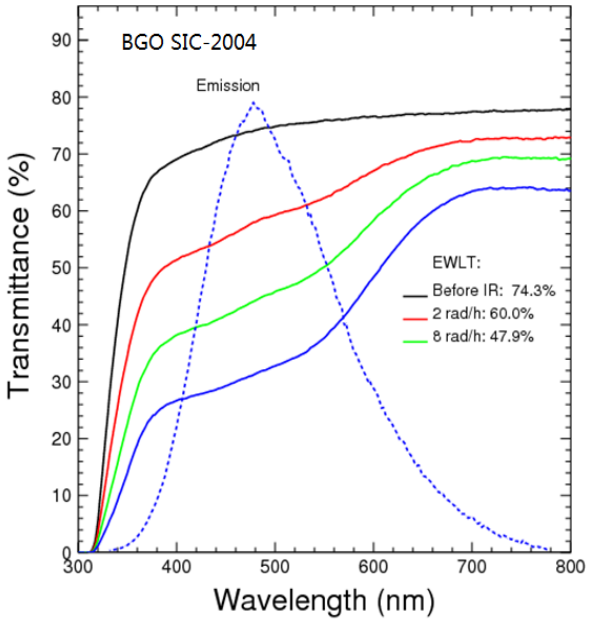
Experiments

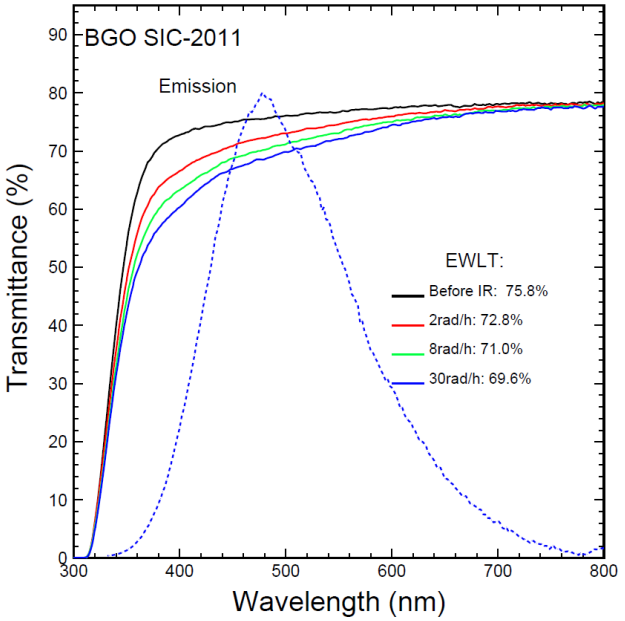
- All samples annealed at 200℃ (200 minutes)
- All samples went through Co-60 irradiations @ 2, 8 and 30 rad/h step by step until equilibrium
- Parameters measured at room temperature during the irradiation and recovery processes: Longitudinal transmittance (LT), Emission weighted longitudinal transmittance (EWLT), light output (LO) and light response uniformity (LRU)

L.T. & EWLT During Irradiations

Sample SIC-2011 has a better initial transmittance and is more radiation hard than previous two samples

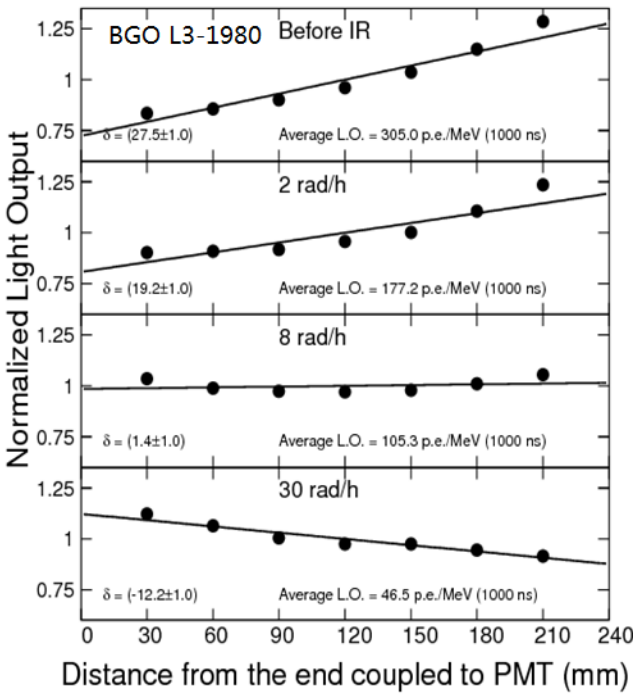


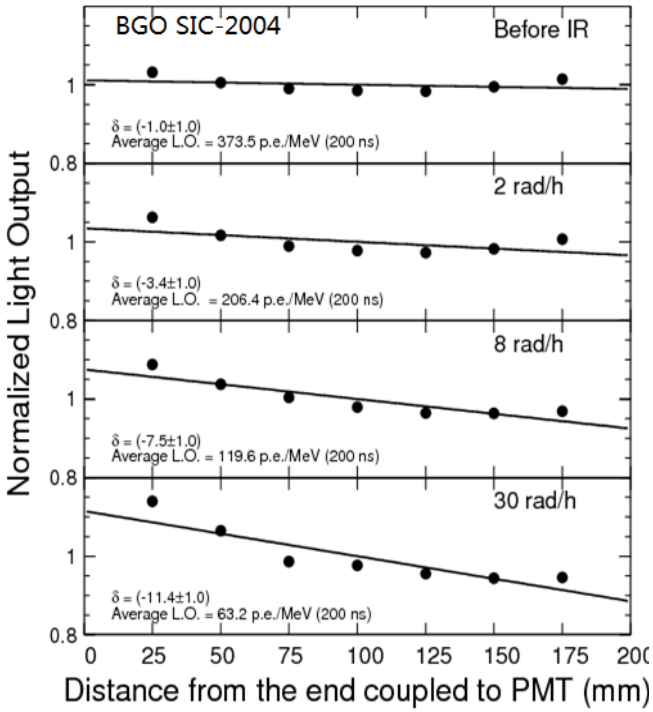


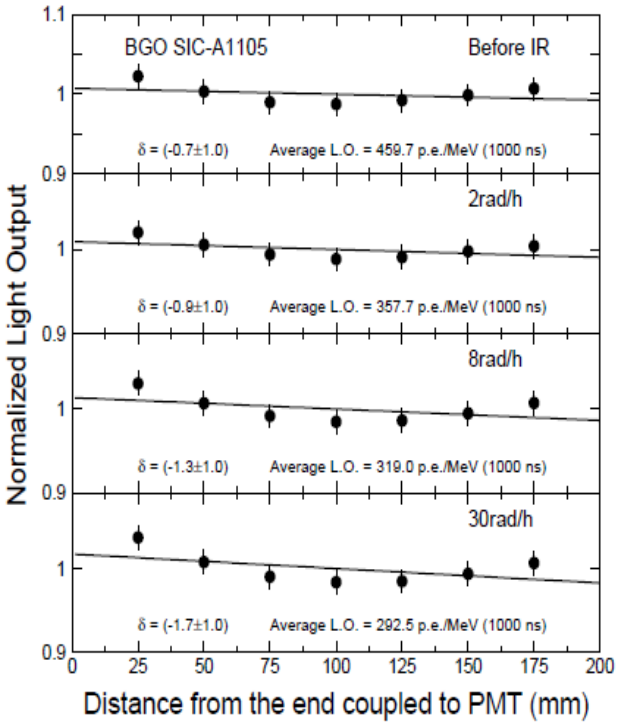


EWLT @ 30 rad/h is 15.5%, 30.6% and 69.6% for samples produced in 1980, 2004 and 2011 respectively

L.O.& L.R.U. During Irradiations

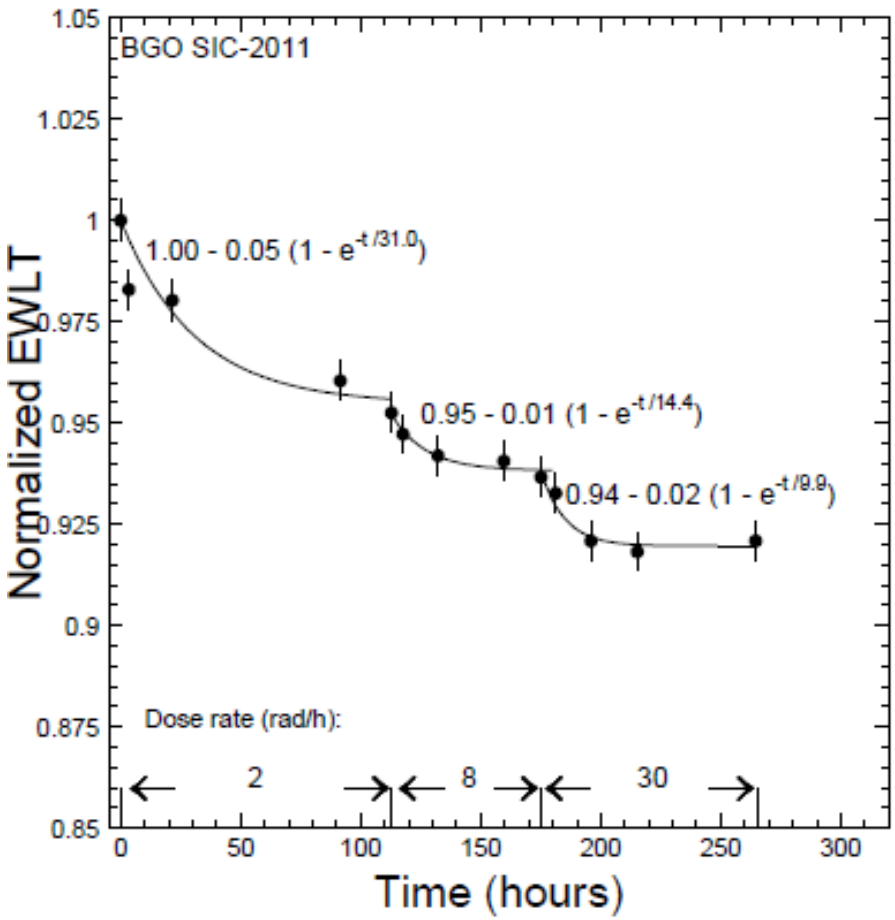


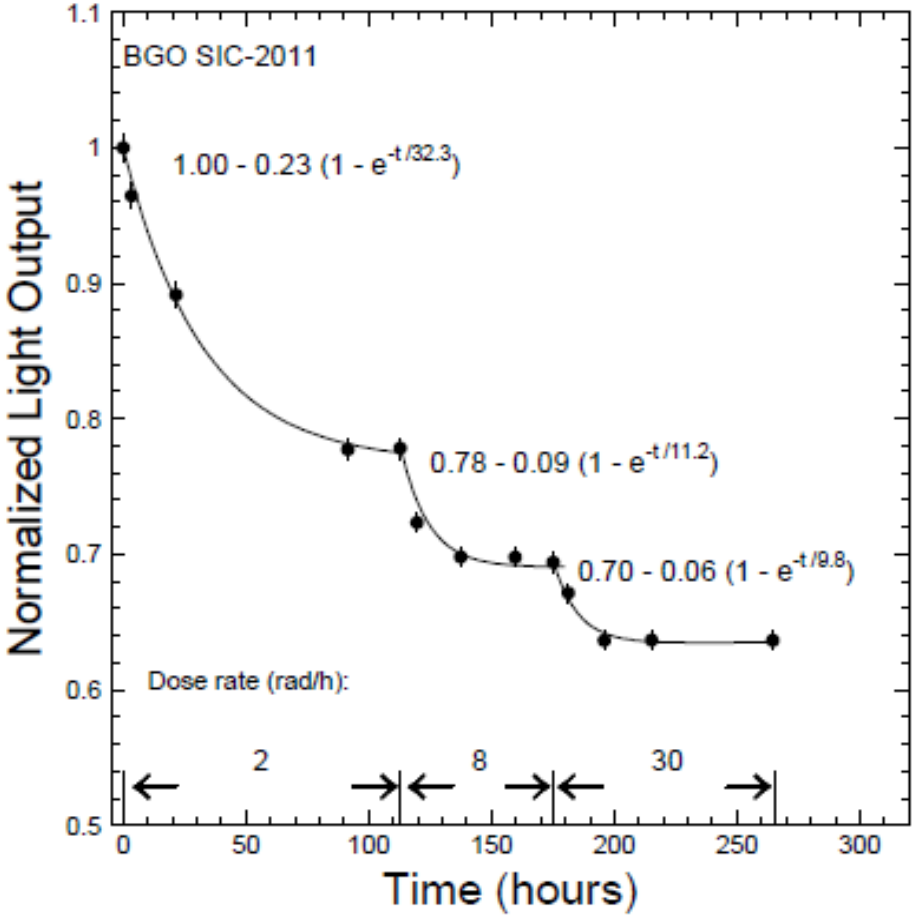




Sample SIC-2011 has a better initial light output and kept its L.R.U. during irradiations up to 30 rad/h

Normalized EWLT and L.O.: Sample 2011

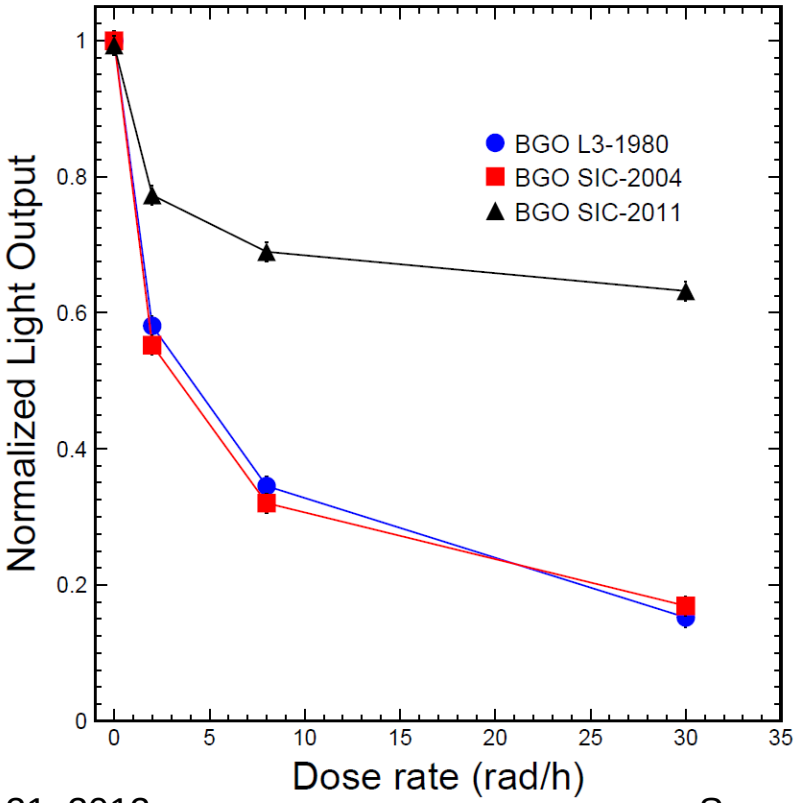


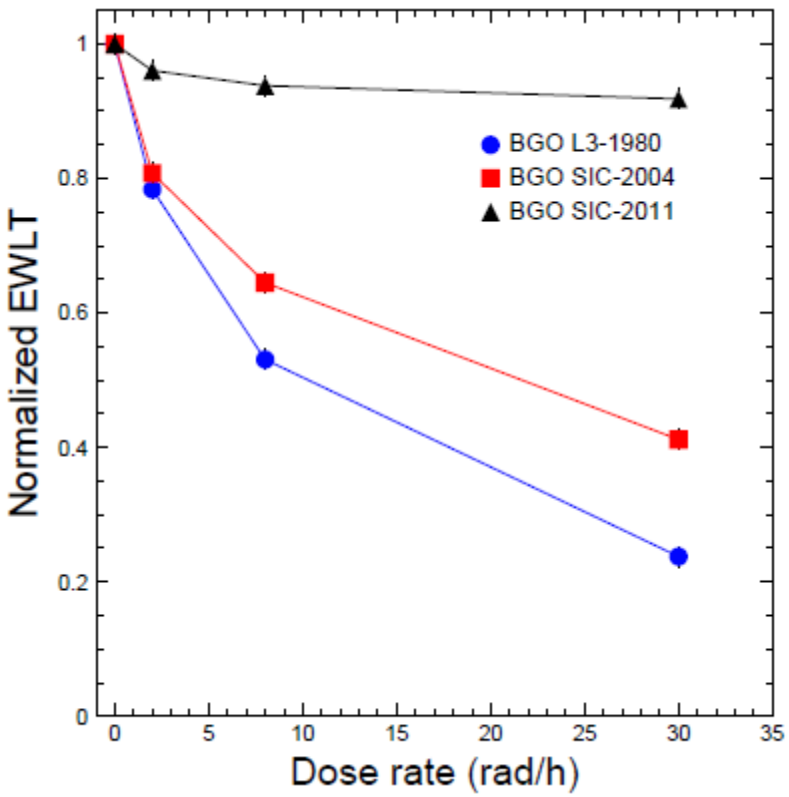


Both EWLT and LO reached equilibrium during Irradiations under a defined dose rate, showing dose rate dependent radiation damage

Normalized EWLT and L.O. in Equilibrium

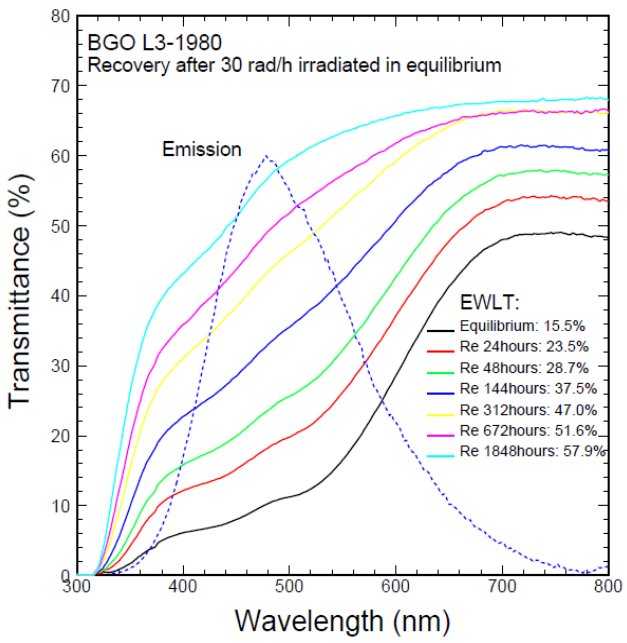
Samples	L.O. (p.e./MeV)	L.O. loss (%)			EWLT loss (%)		
		2 rad/h	8 rad/h	30 rad/h	2 rad/h	8 rad/h	30 rad/h
BGO L3-1980	305	42	66	85	22	47	76
BGO SIC-2004	373	45	68	83	19	36	59
BGO SIC-2011	460	22	31	36	4	6	8

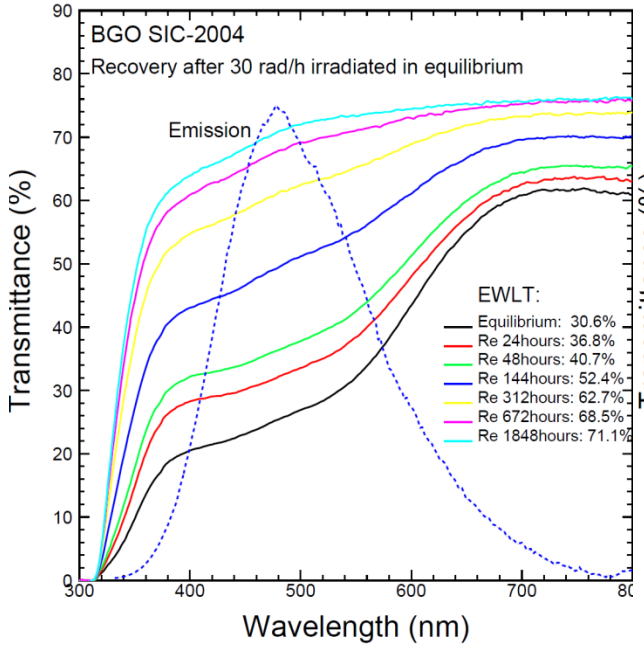


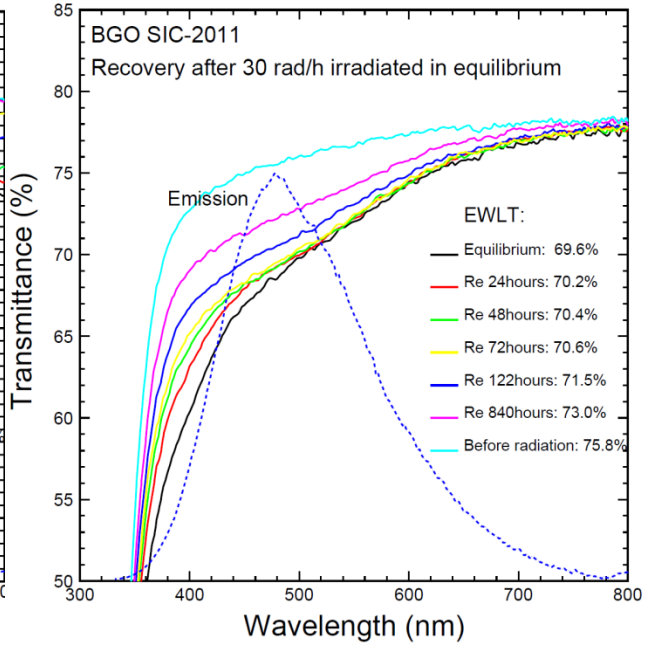


L.T. & EWLT During Recovery

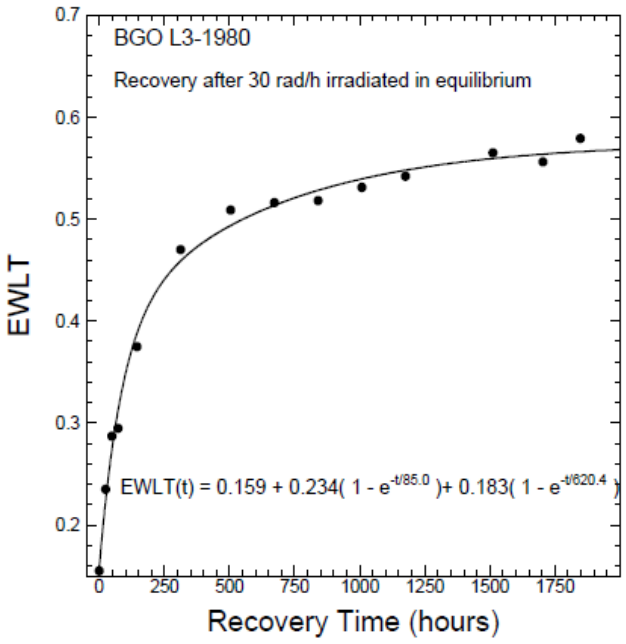
BGO radiation damage recovers under room temperature, which is the origin of dose rate dependent damage level.

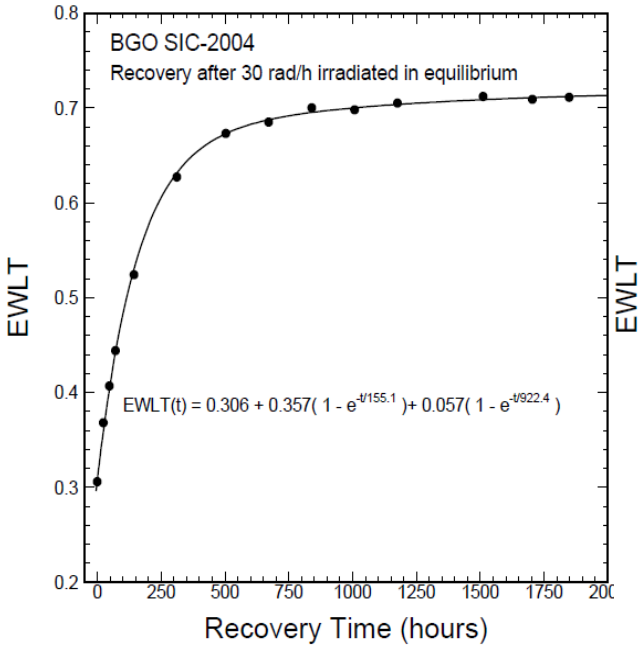


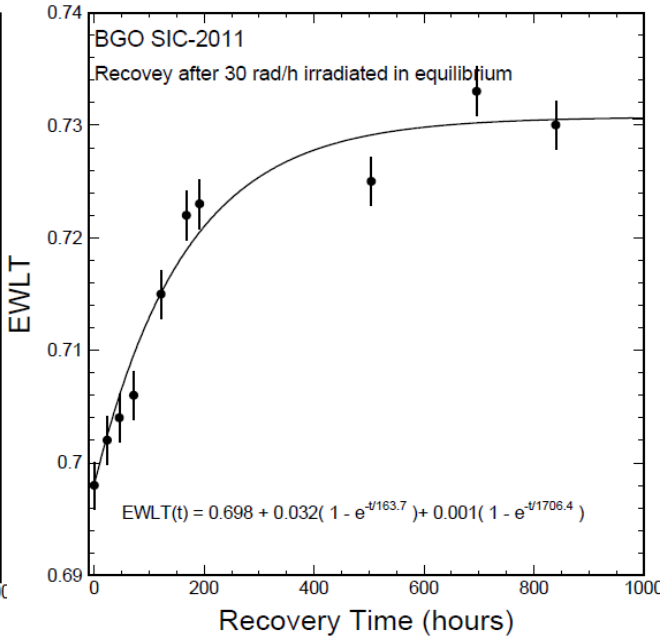




EWLT Recovery Time Constants

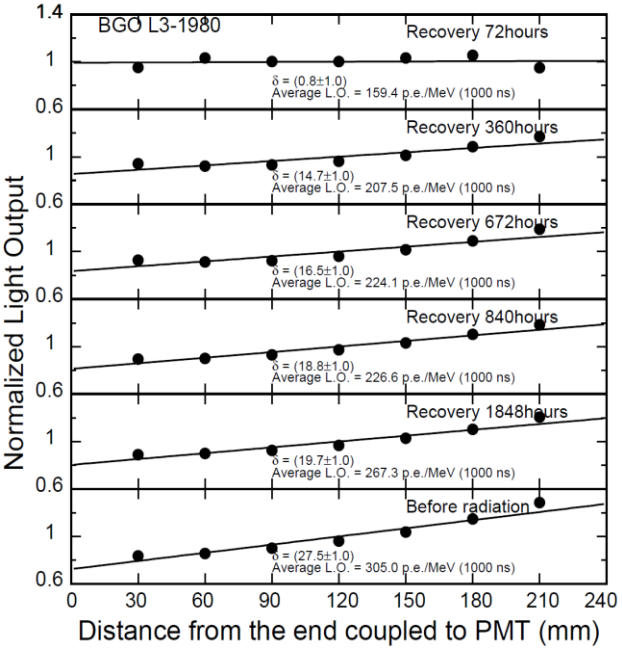


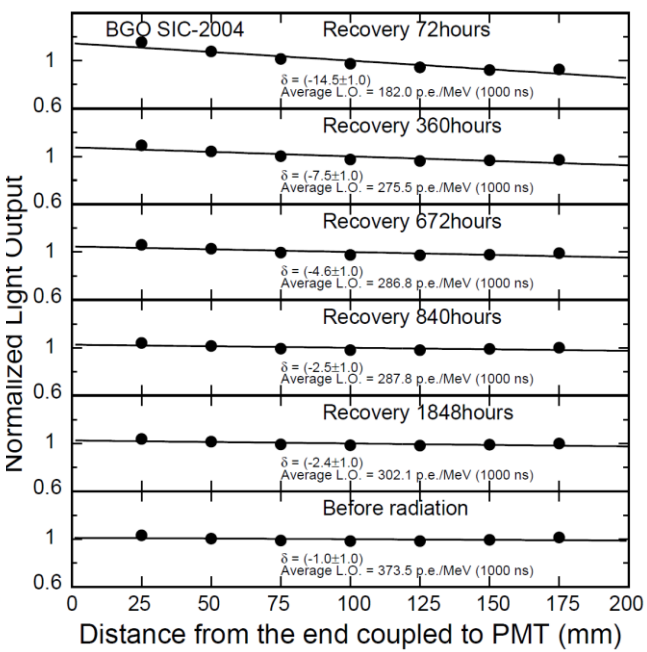


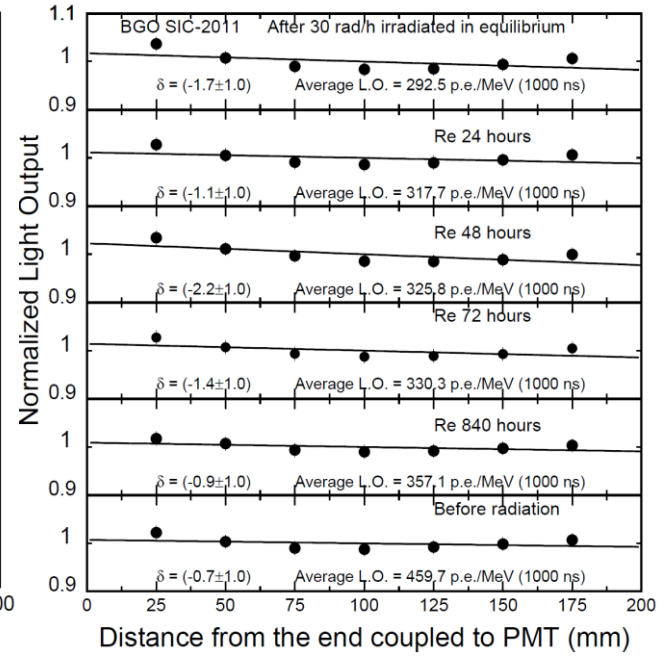


Comparing with initial EWLT: 65.2%, 74.3% and 75.8% for BGO samples 1980, 2004 and 2011, recovery under room temperature is not complete, indicating deep center existing

L.O. & L.R. U. During Recovery





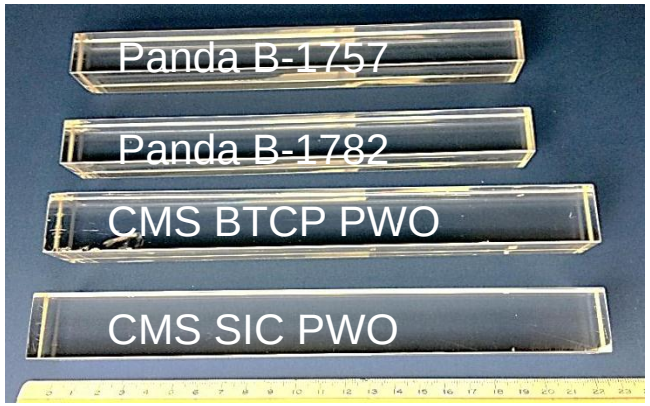


Sample SIC-2011 kept its L.R.U. during the recovery process, indicating it is radiation hard up to 30 rad/h

BGO Summary

- A BGO sample grown in 2011 has a better initial transmittance and light output than L3 BGO (eighties) and a sample grown in 2004.
- Similar to PWO, radiation damage in BGO crystals recovers at room temperature, leading to a dose rate dependent damage level.
- This BGO sample grown in 2011 has also a better radiation hardness, and keeps its light response uniformity in a radiation environment up to 30 rad/h.
- Because of the recovery precision monitoring is mandatory to preserve crystal precision.

Status of PWO

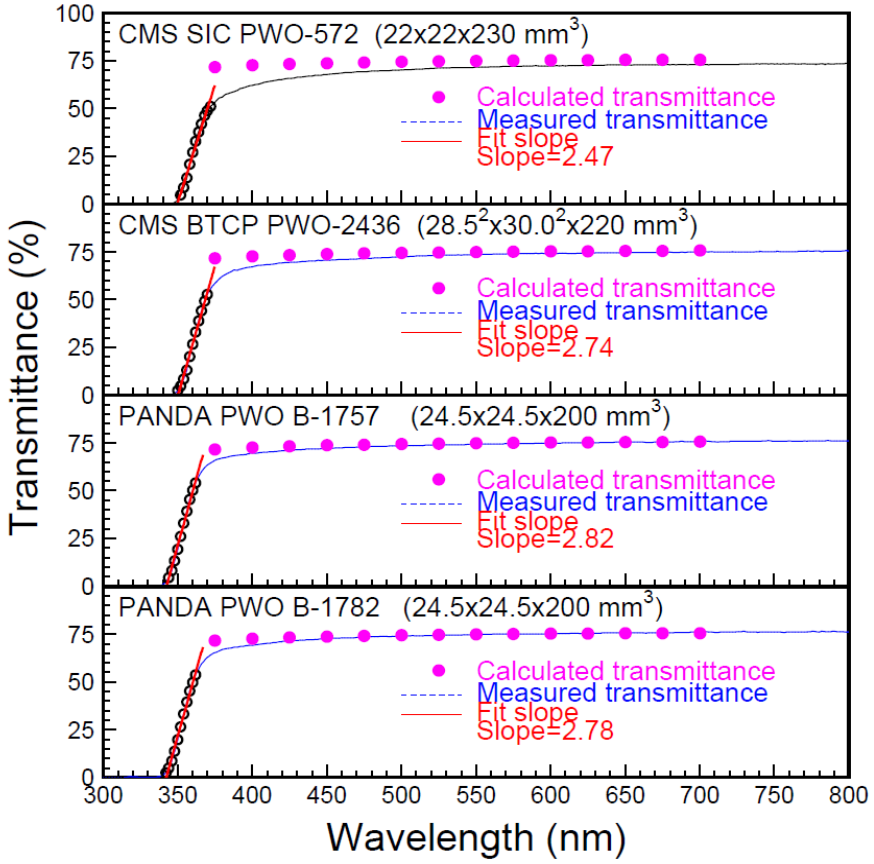


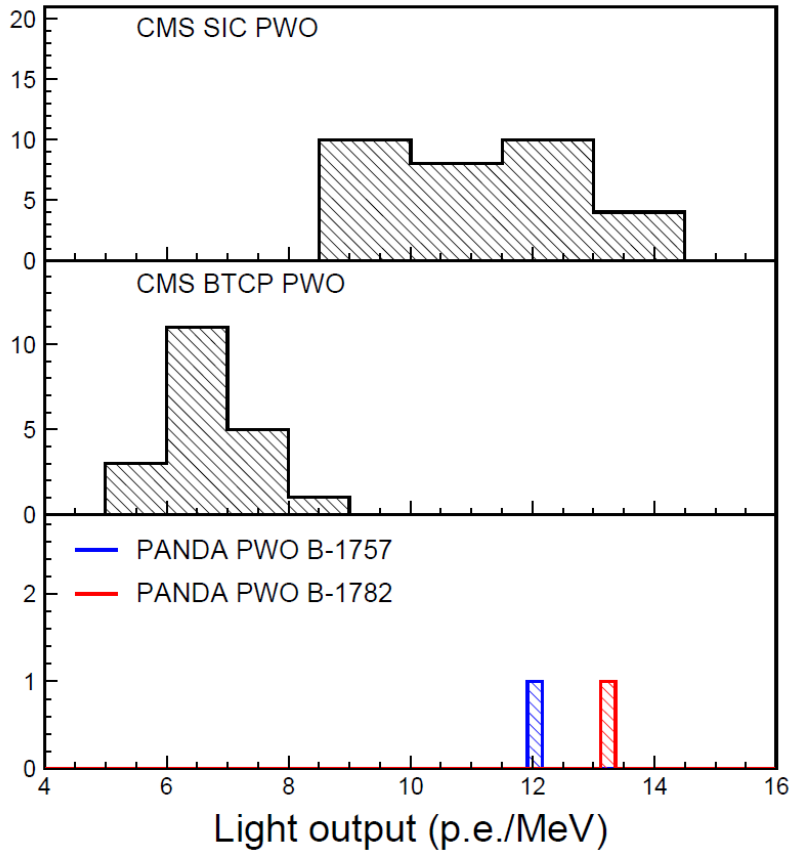
Sample ID	Dimension	Polish
PWO-B1757	24.5×24.5×200 mm^3	Six faces
PWO-B1782	24.5×24.5×200 mm^3	Six faces
CMS BTCP PWO	28.5^2×30.0^2×220 mm^3（20 crystals）	Six faces
CMS SIC PWO	28.5^2×30.0^2×220 mm^3（12 crystals） 20×20×230 mm^3（20 crystals）	Six faces

Experiments

- Samples annealed at 200℃ (200 minutes)
- PANDA PWO went through Co-60 irradiations @ 2, 8 and 30 rad/h step by step until equilibrium followed by recovery of 840 hours
- PANDA PWO went through Cs-137 irradiations @ 7,160 rad/h until equilibrium
- Parameters measured at room temperature before, during and after the irradiation & recovery processes: Longitudinal transmittance (LT), Emission weighted longitudinal transmittance (EWLT), light output (LO) and light response uniformity (LRU).

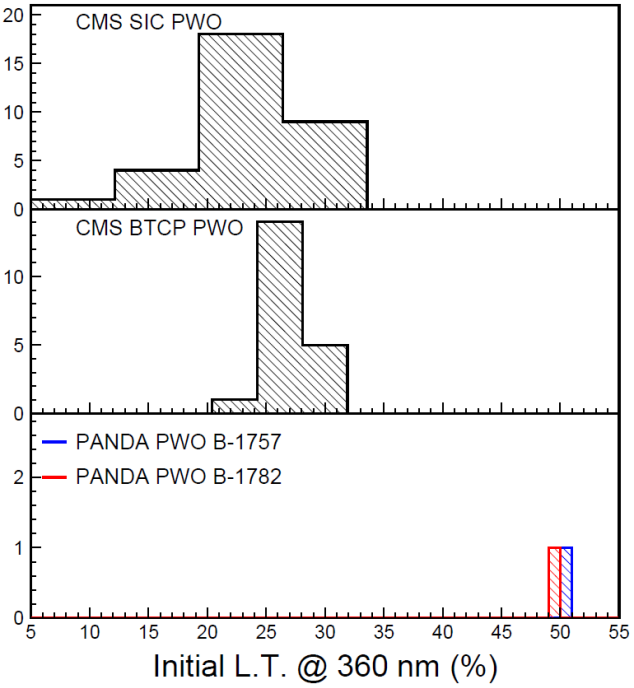
Transmittance Cut-Off Edge and LO

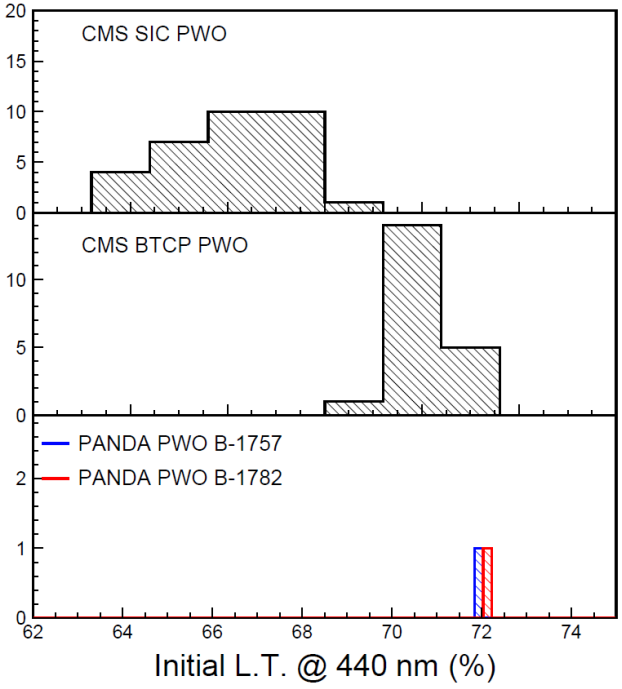


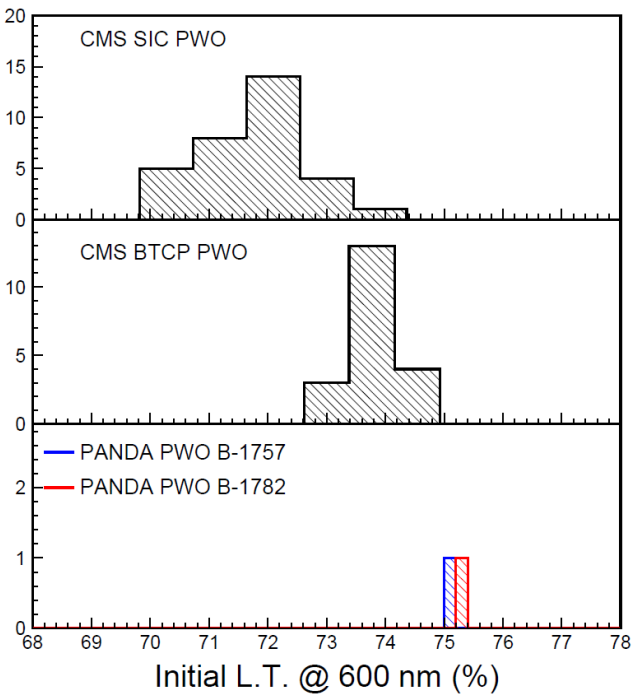


PANDA PWO have a sharper slope of LT cut-off edge.
Their L.O. is better than CMS BTCP, but similar to CMS SIC.

Longitudinal Transmittance

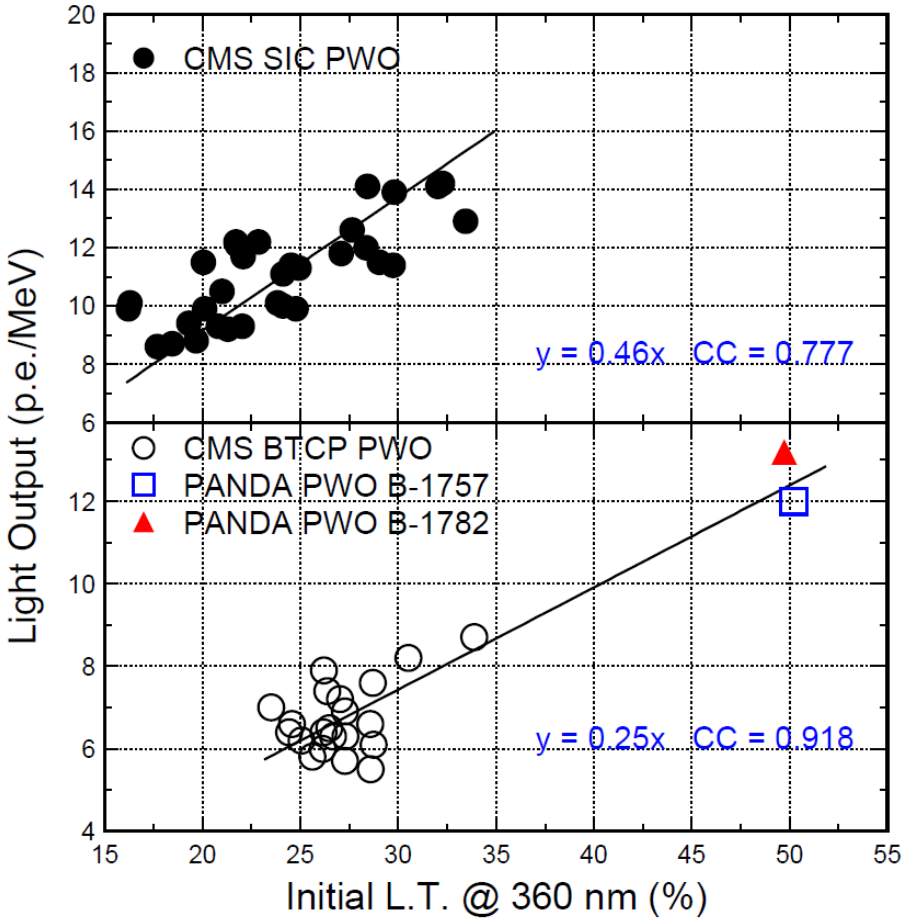






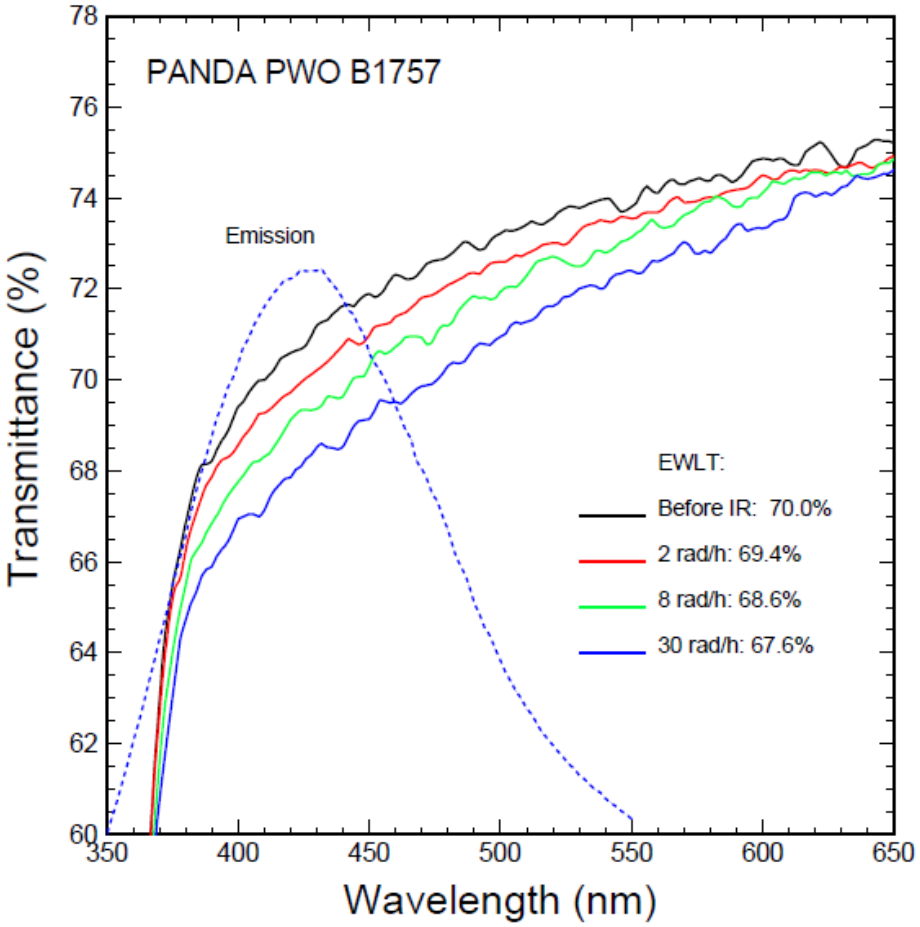
PANDA PWO have a better longitudinal transmittance, especially at 360 nm

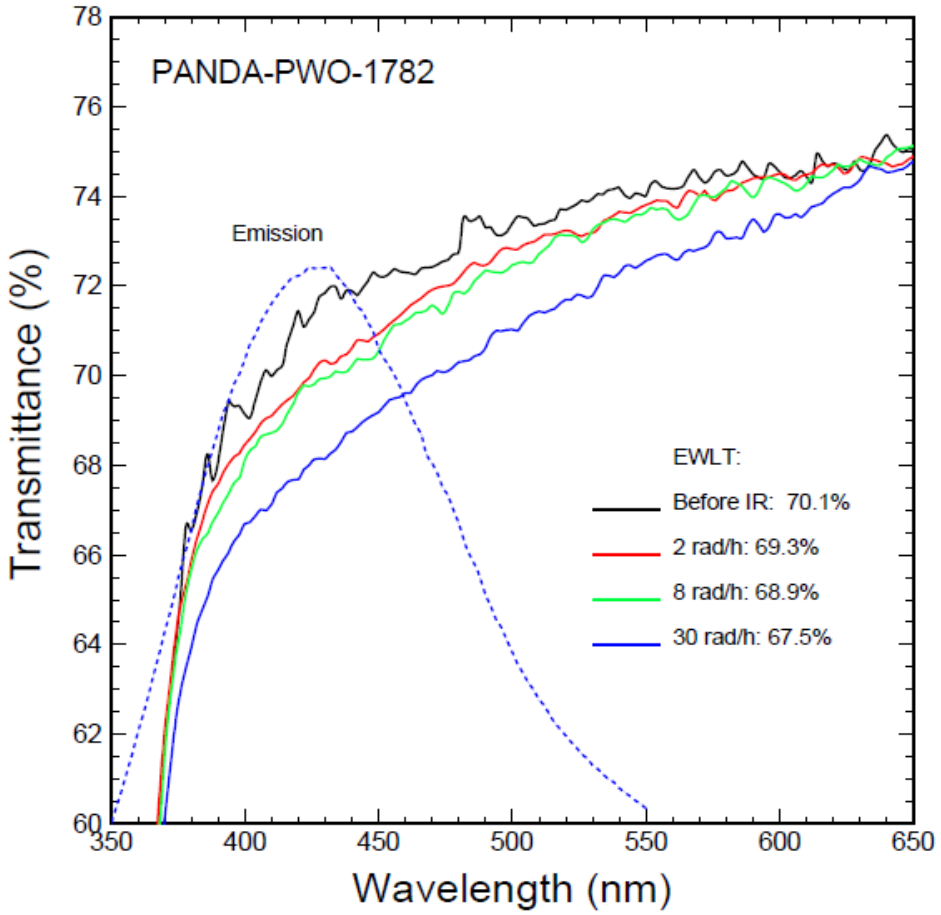
Correlations between LT @360 nm and LO



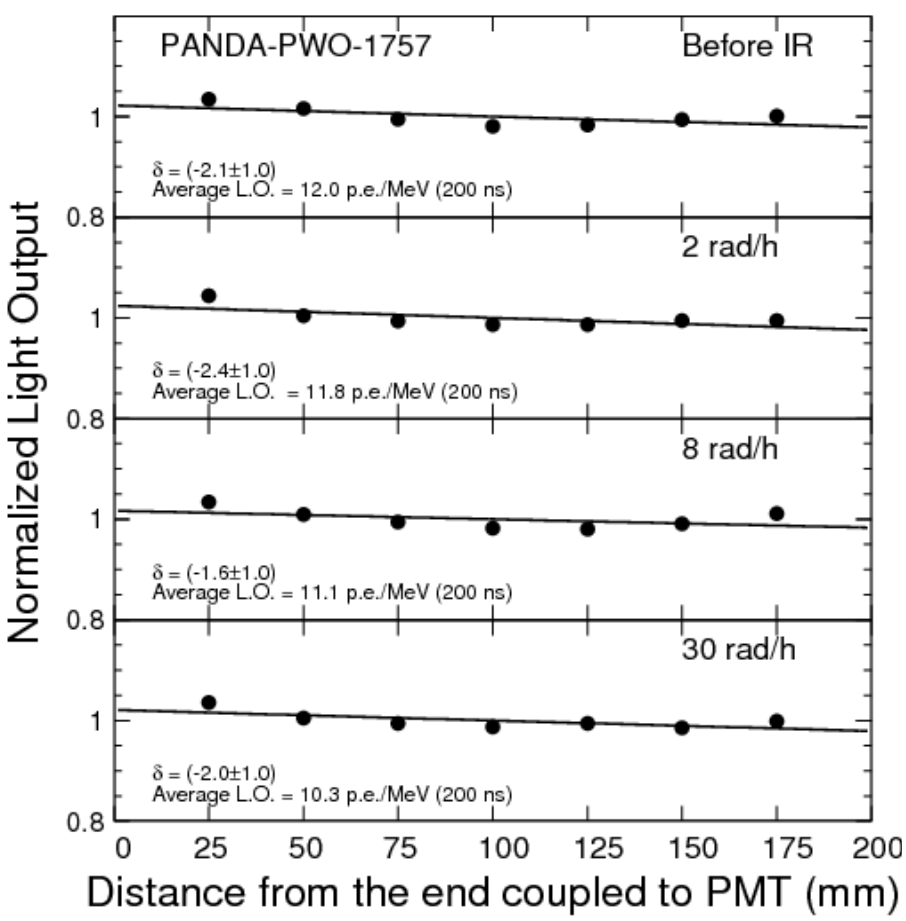
Good correlation: between the LO and initial LT at 360 nm

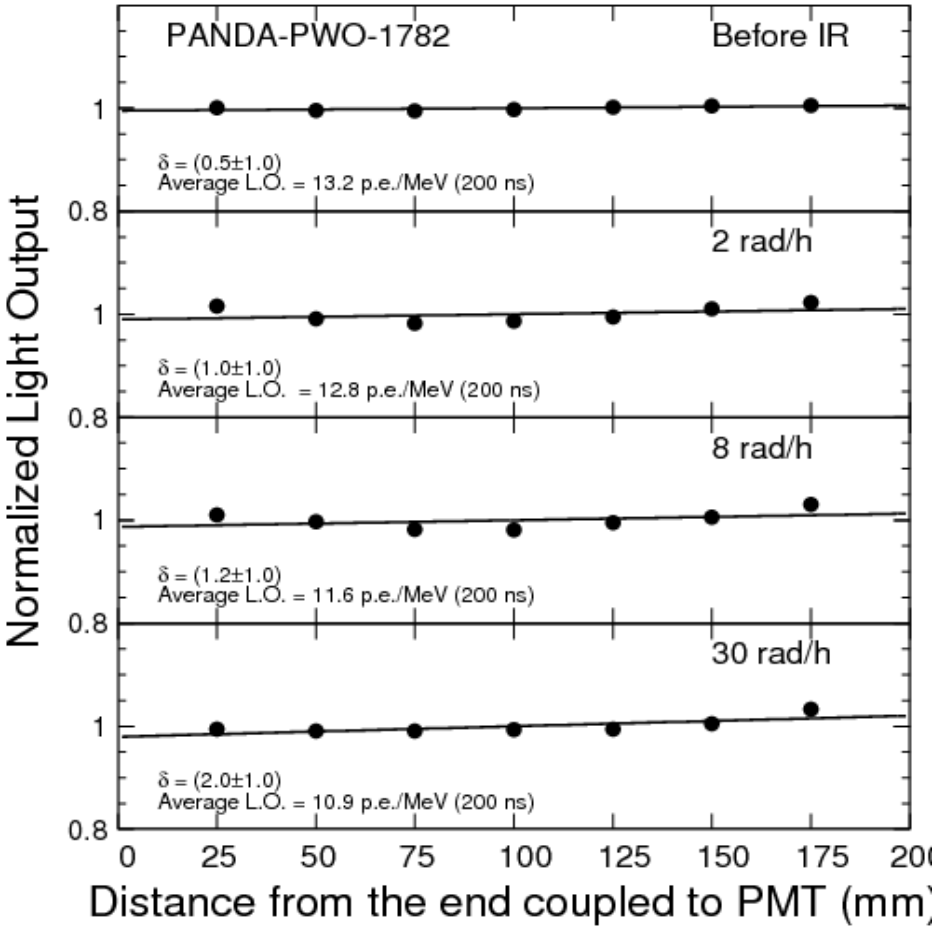
Radiation Damage in LT





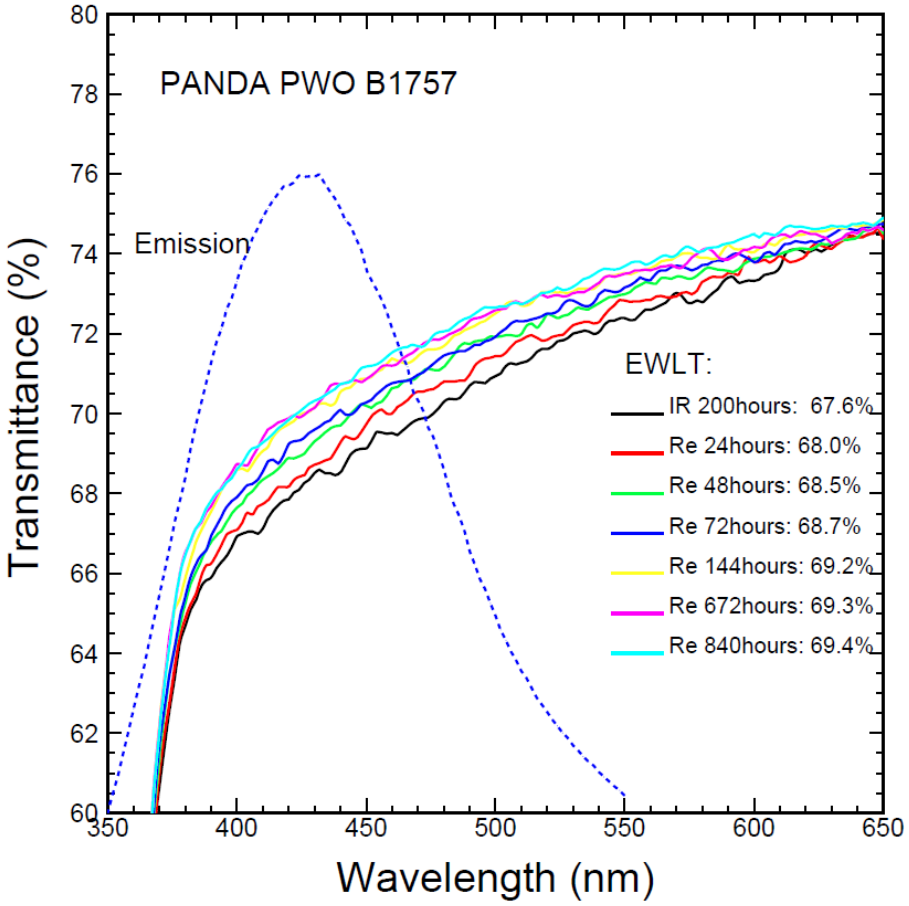
Radiation Damage in L.O.& L.R.U.

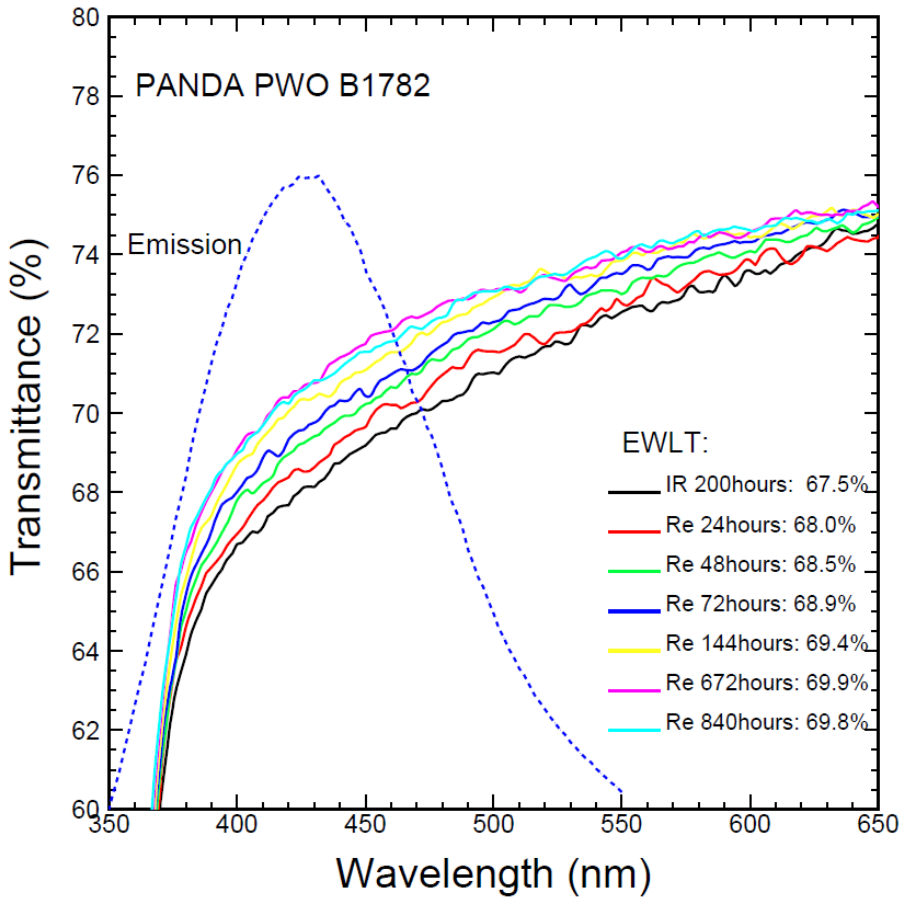




L.R.U. is not changed up to 30 rad/h

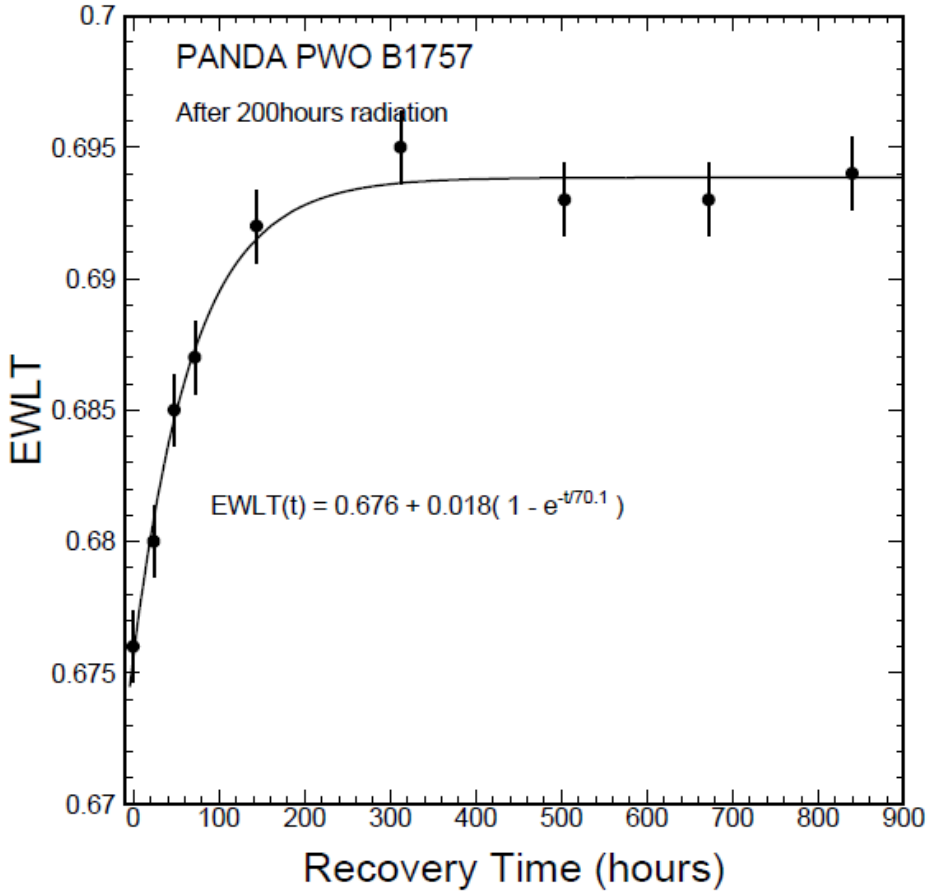
LT Recovery after 30 rad/h Irradiations

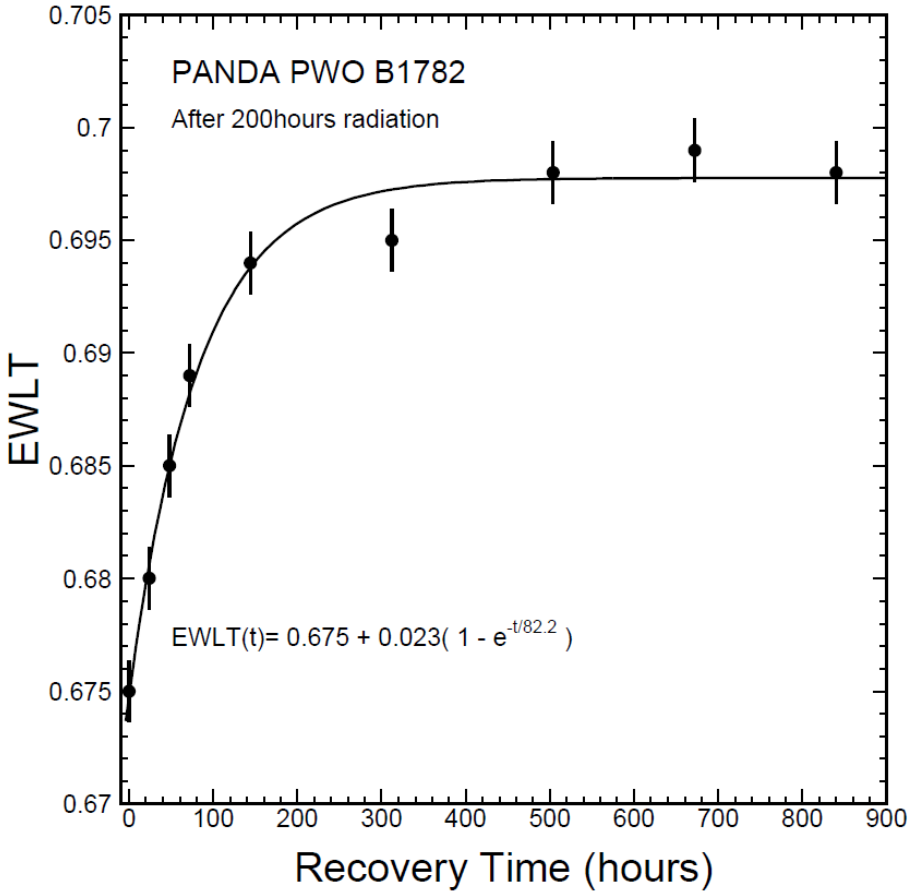




PWO radiation damage recovers under room temperature, which is the origin of dose rate dependent damage level.

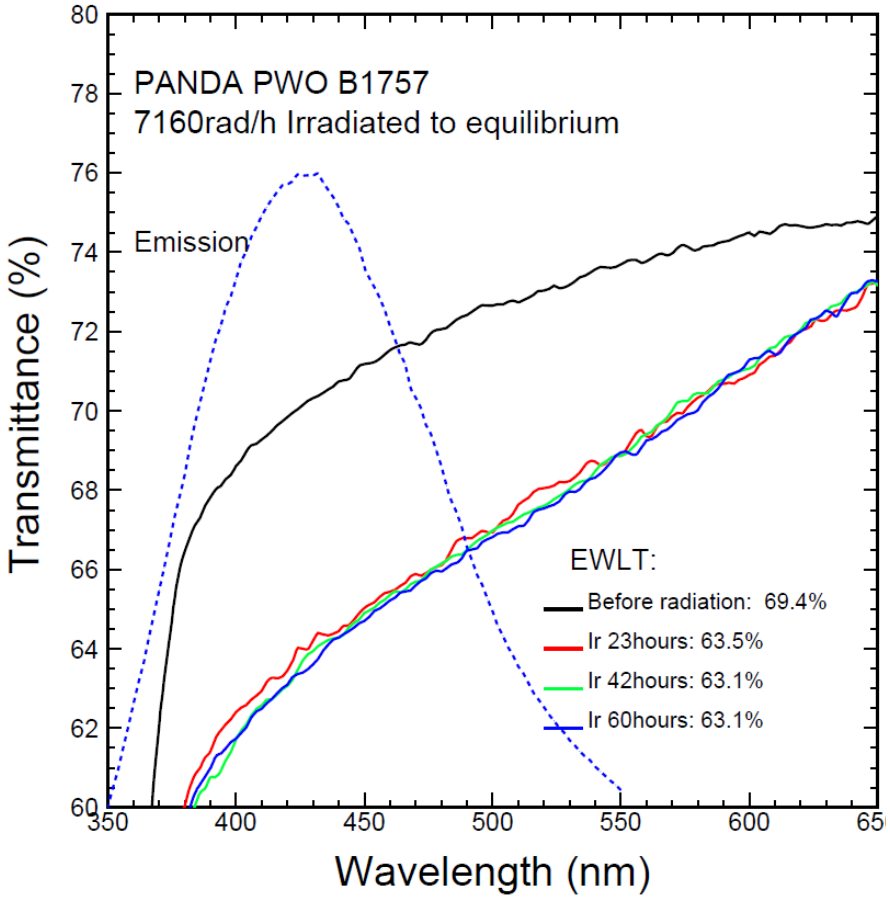
Recovery time constant: 70 to 80 h

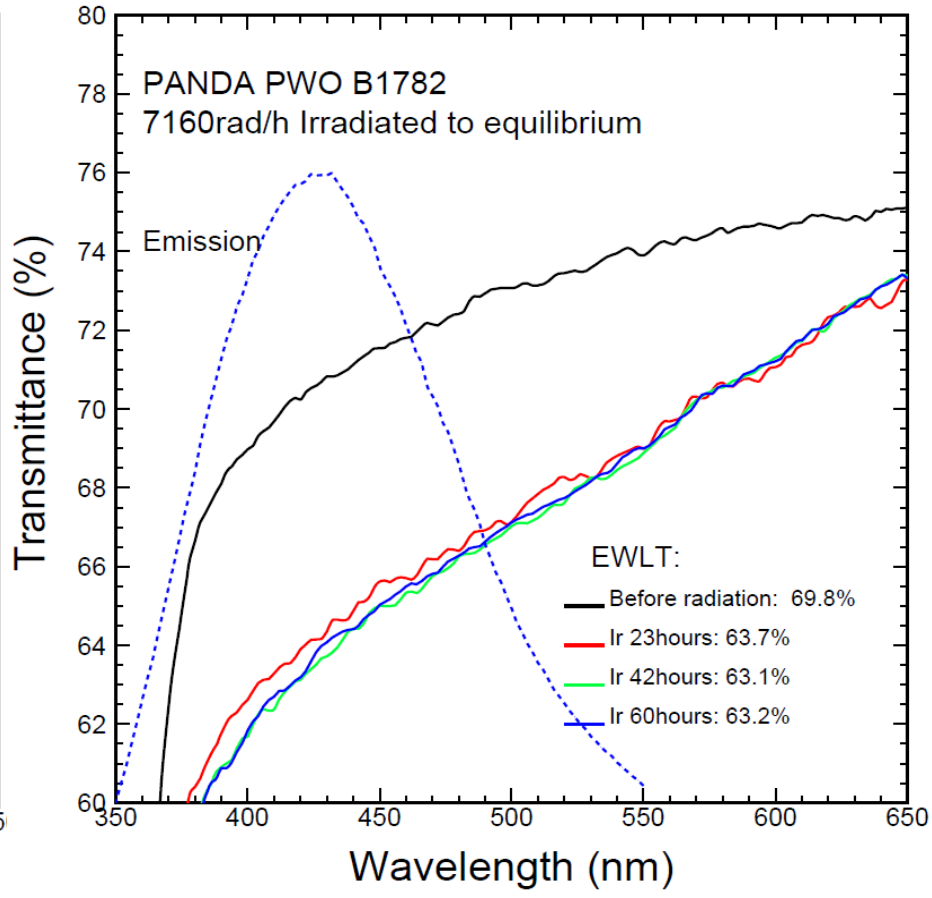




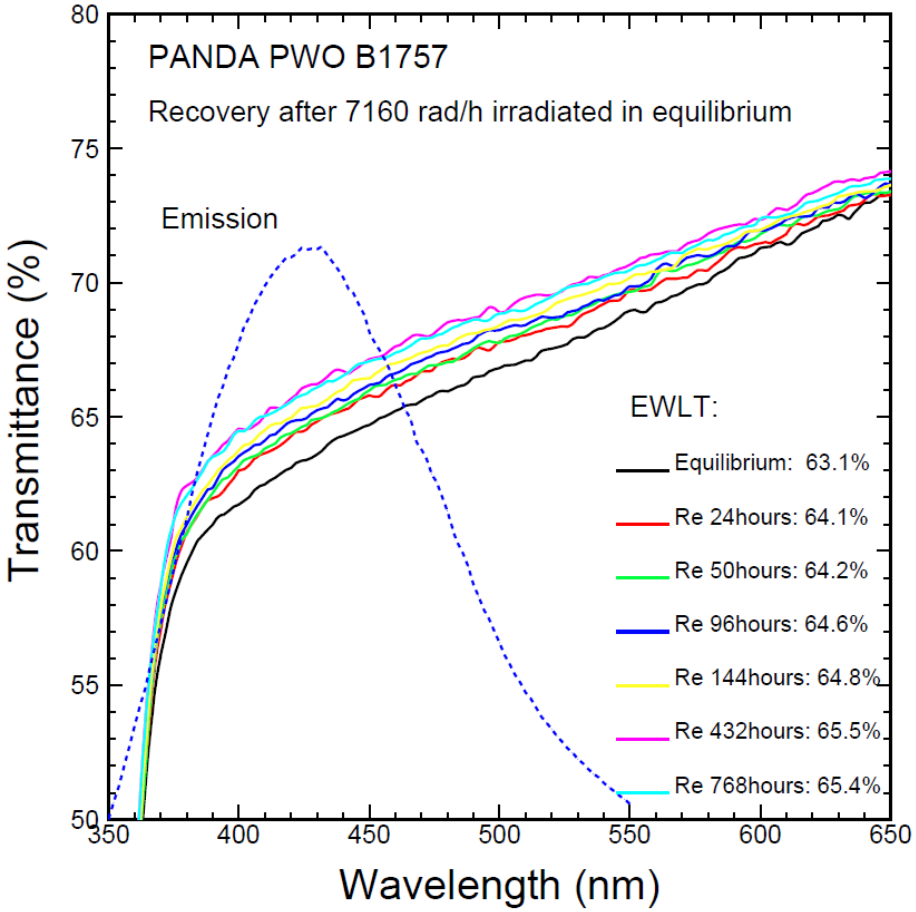
Comparing with initial EWLT: 70.0%, 70.1% recovery under room temperature is not complete, indicating existence of deep centers

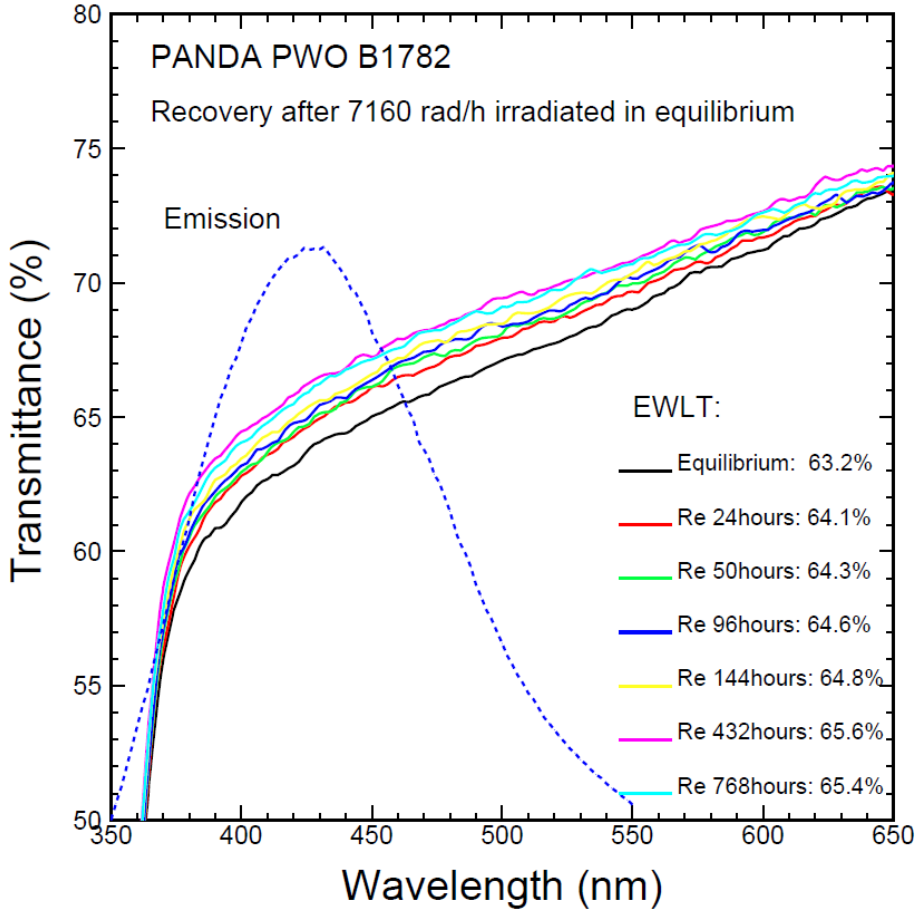
Transmittance Damage under 7160 rad/h



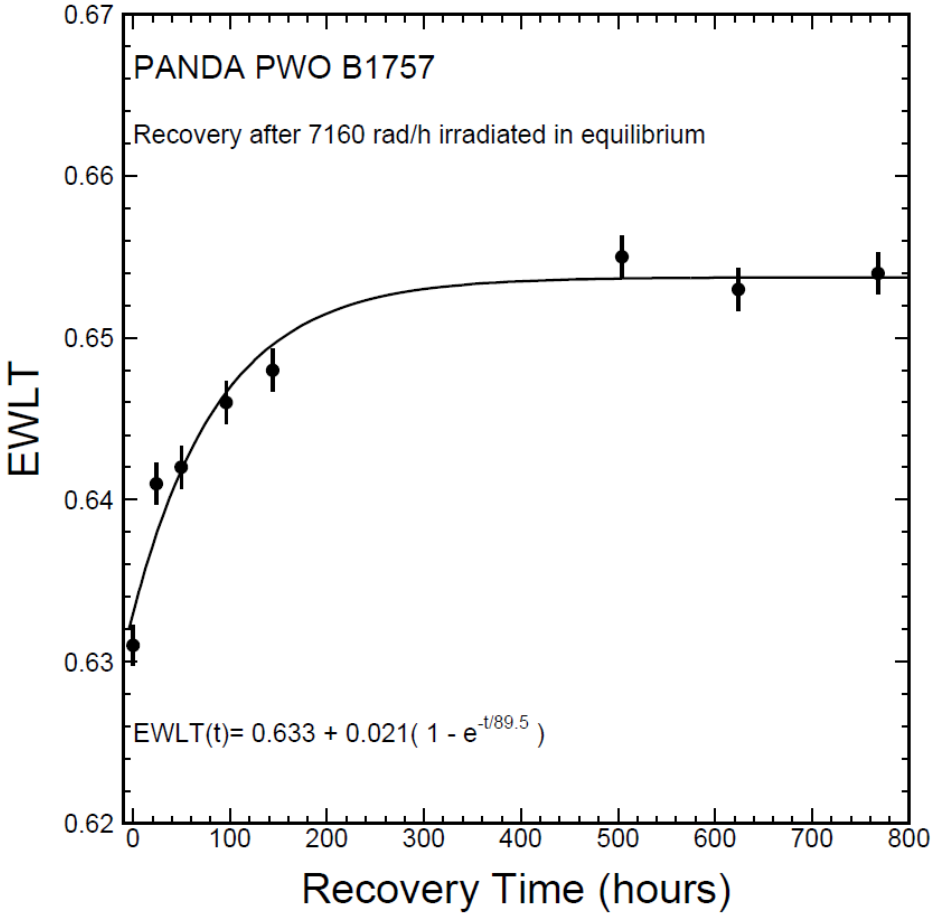


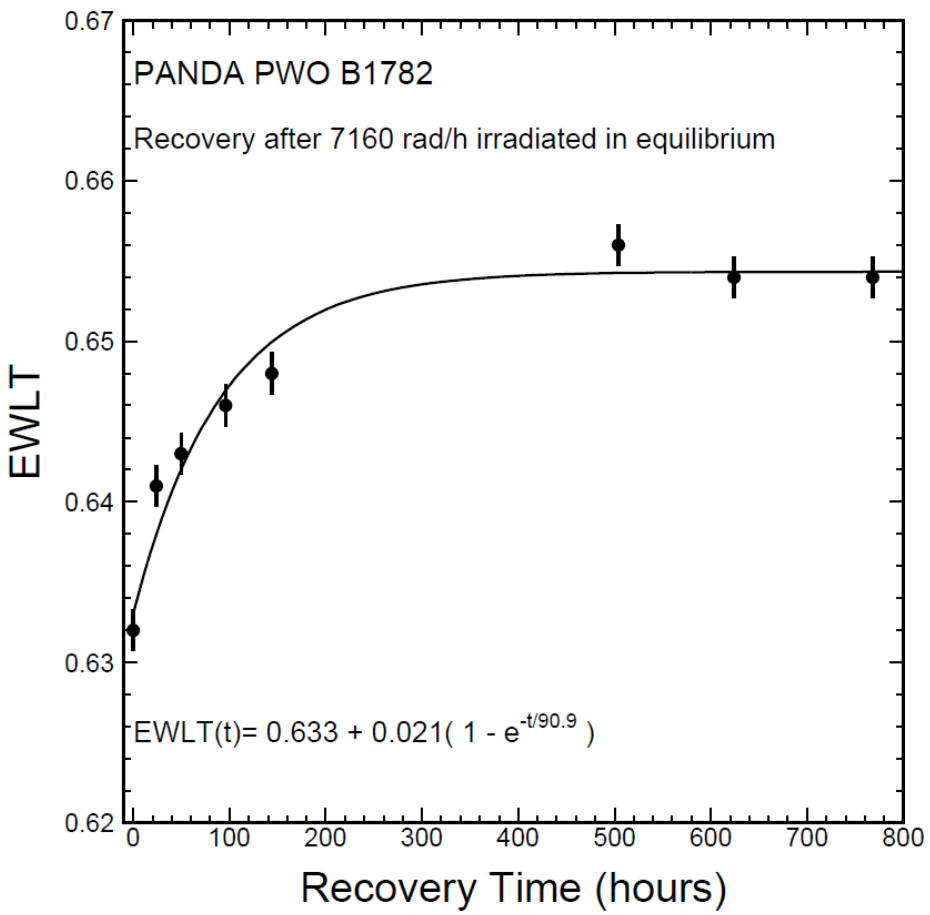
LT Recovery after Irradiations at 7160 rad/h





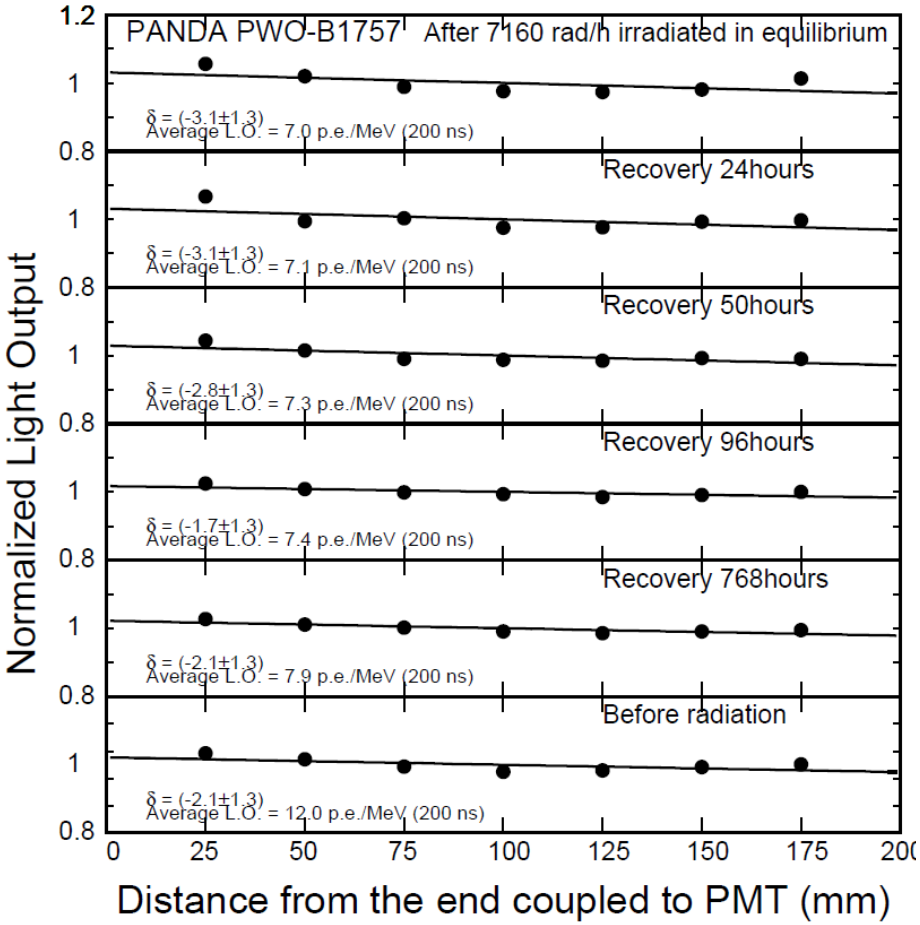
Recovery time constant: ~90 h

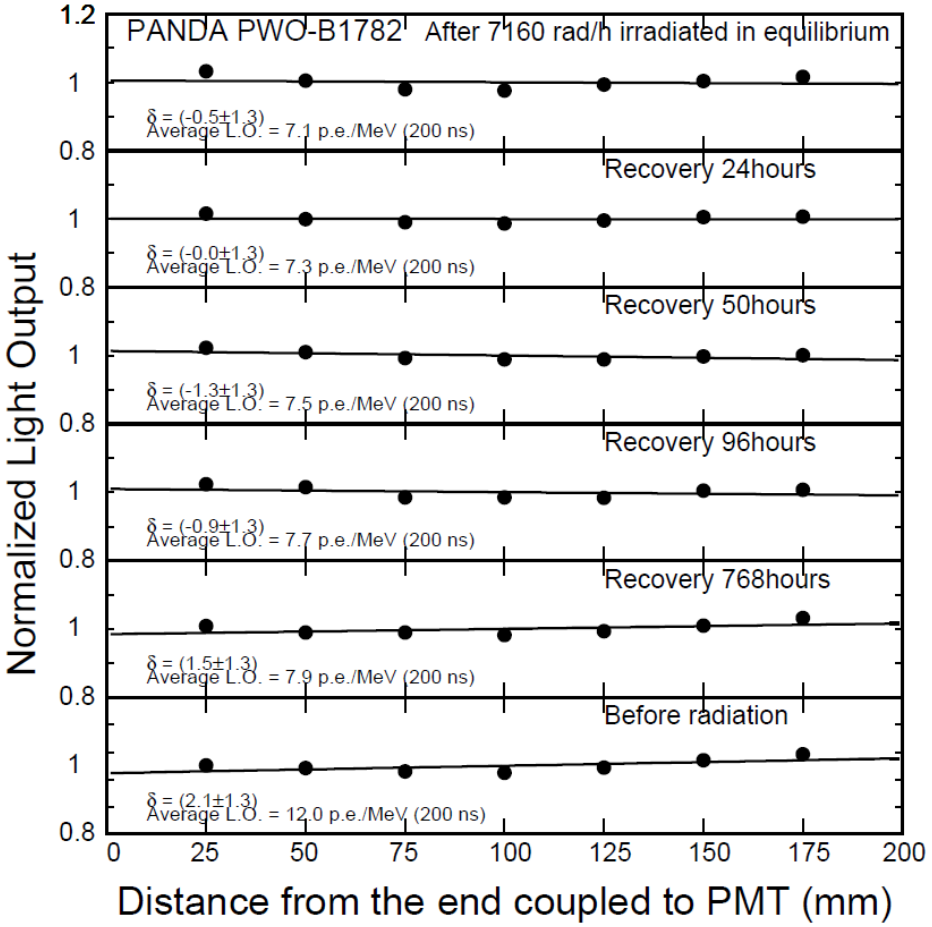




Recovery time constant is similar to that after 30 rad/h

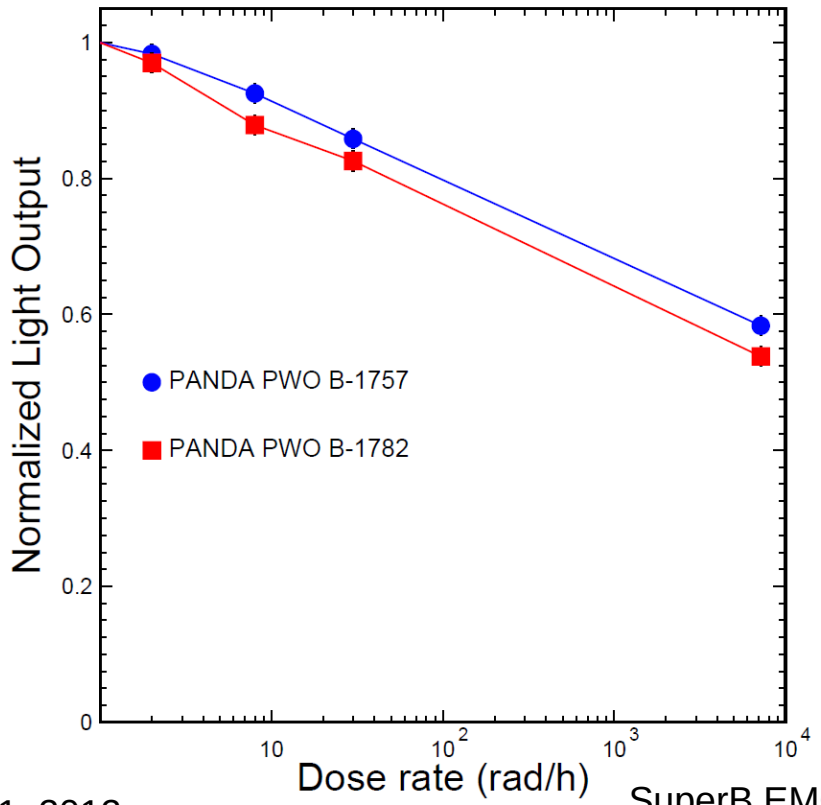
LO & LRU Recovery after Irradiations @ 7160 rad/h

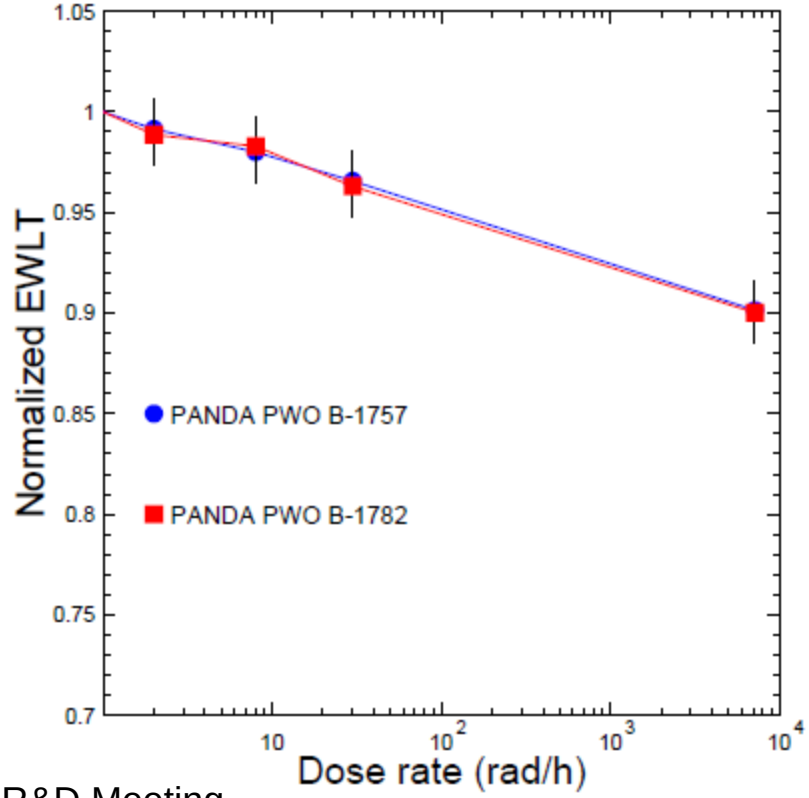




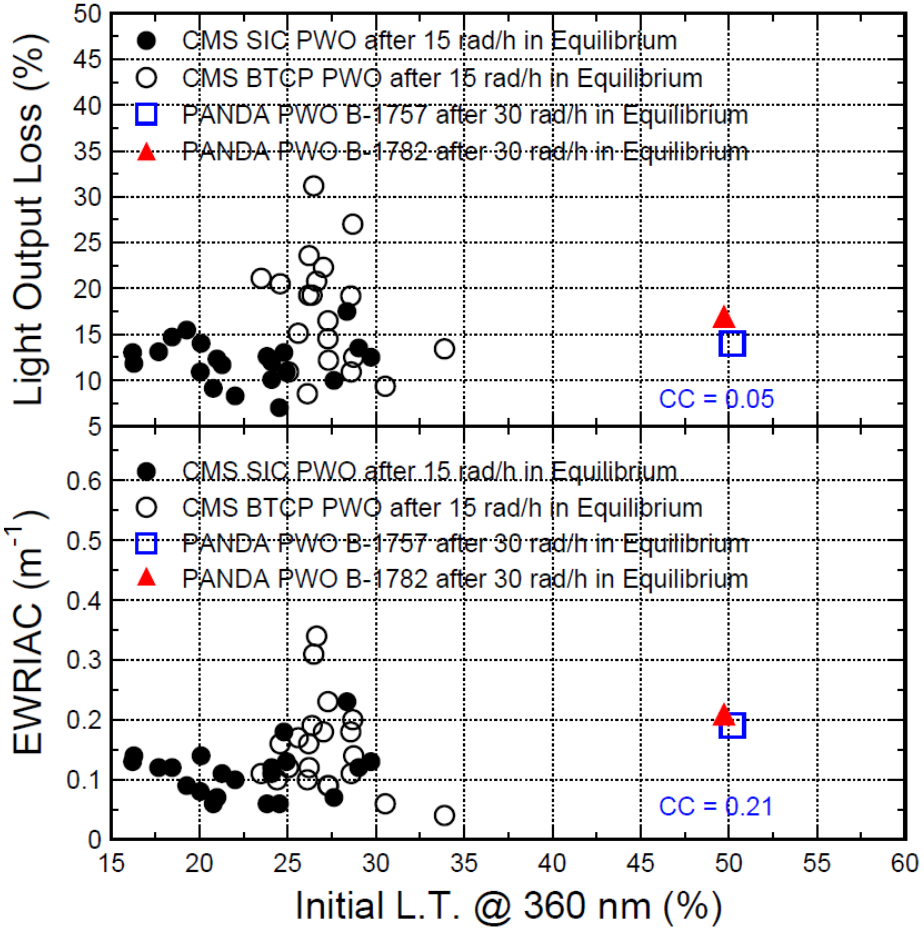
Damage as a Function of Dose Rate

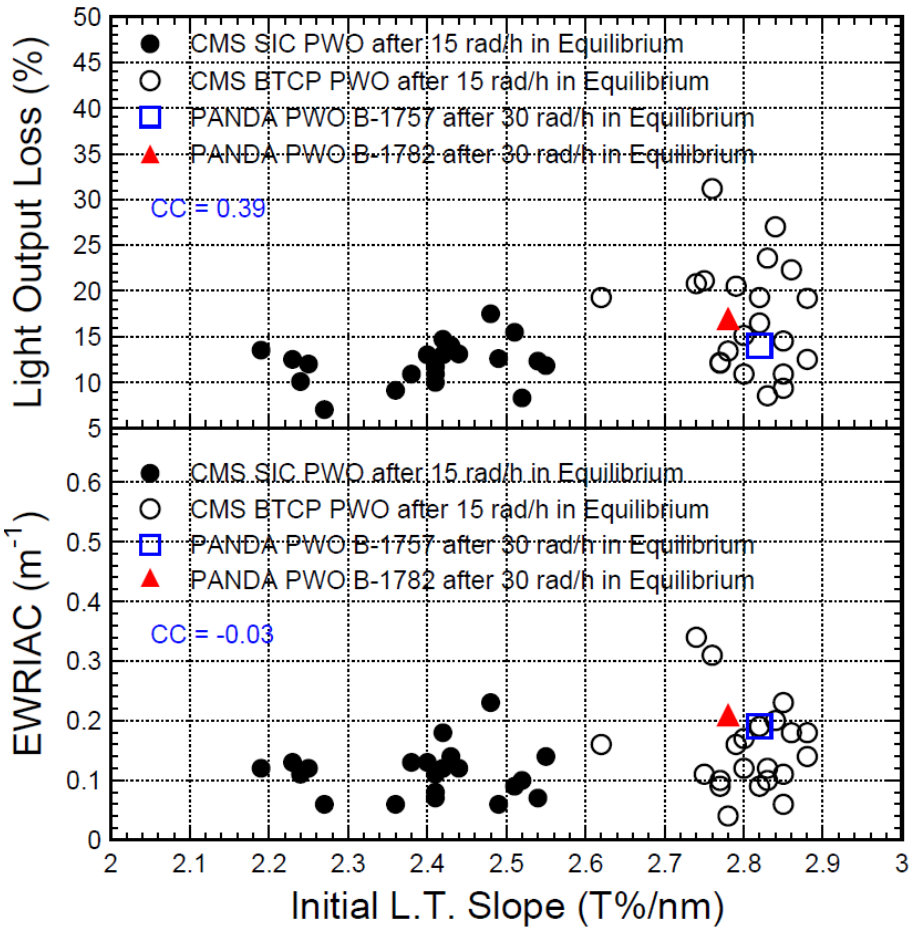
Samples	L.O. (p.e./MeV)	L.O. loss (%)				EWLT loss (%)			
		2 rad/h	8 rad/h	30 rad/h	7160 rad/h	2 rad/h	8 rad/h	30 rad/h	7160 rad/h
PWO B-1757	12.0	2	8	14	42	0.8	2.0	3.4	9.9
PWO B-1782	13.2	3	12	17	46	1.1	1.7	3.7	10.0





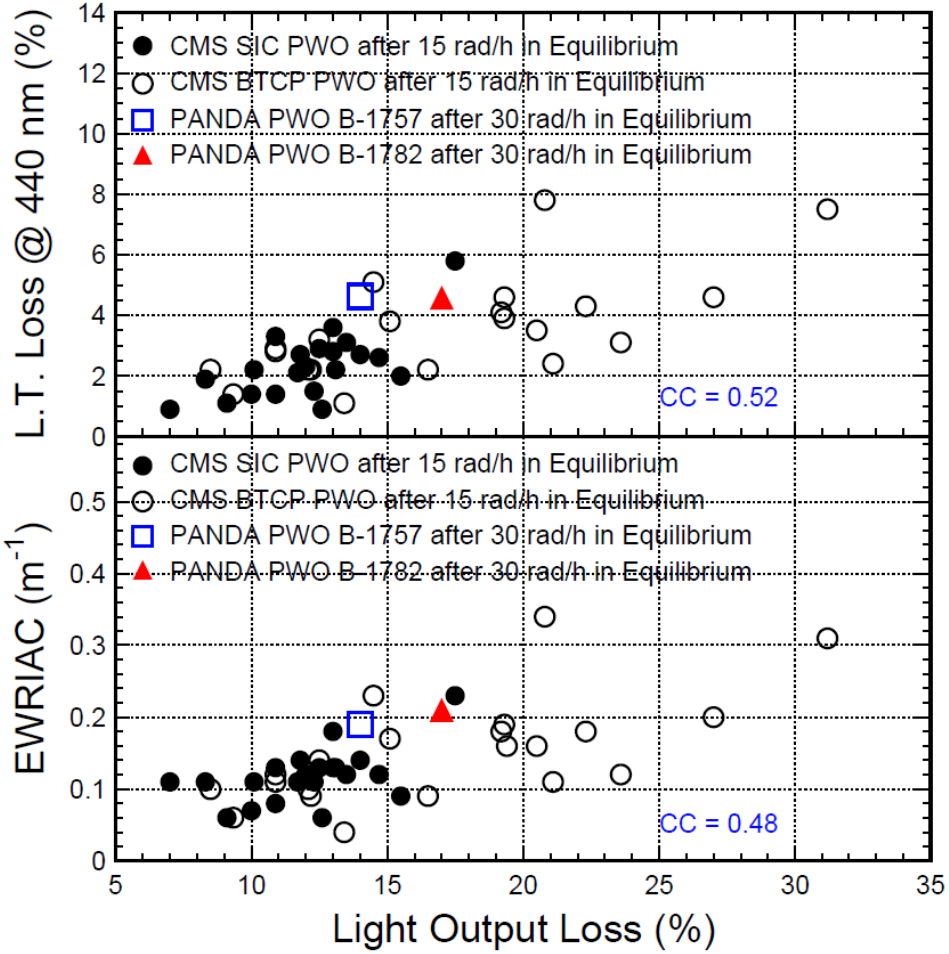
Correlation between Damage and Optical Parameter

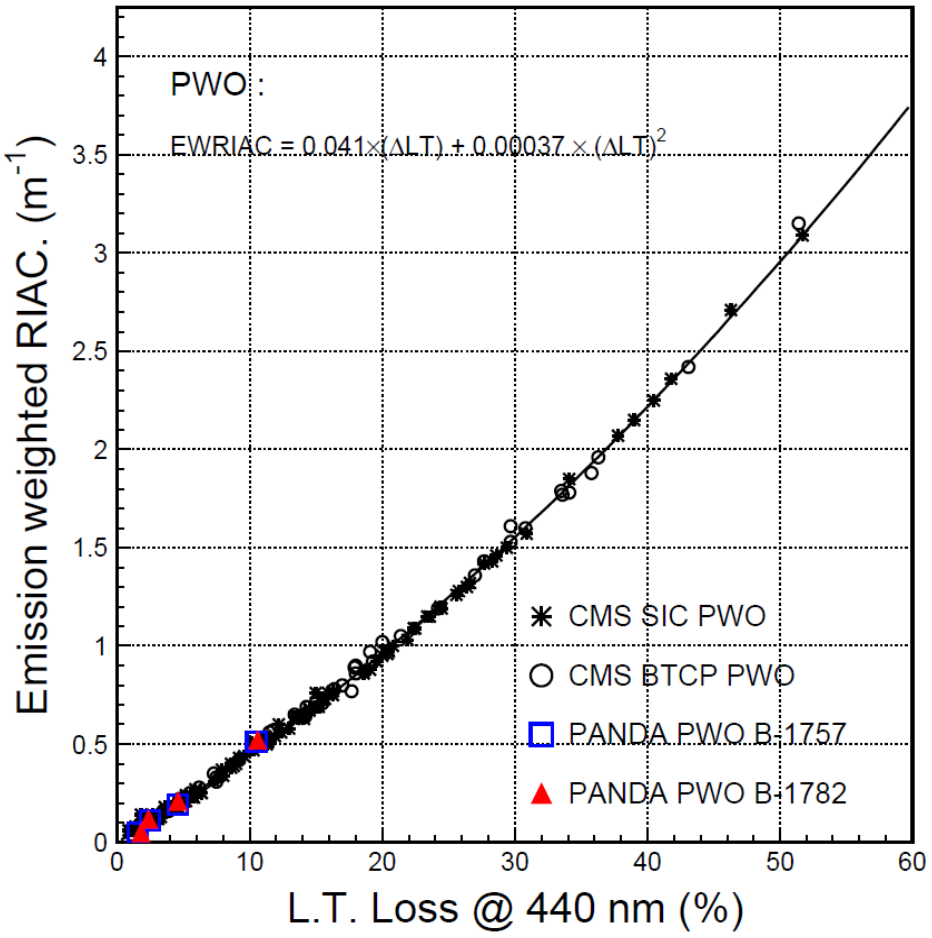




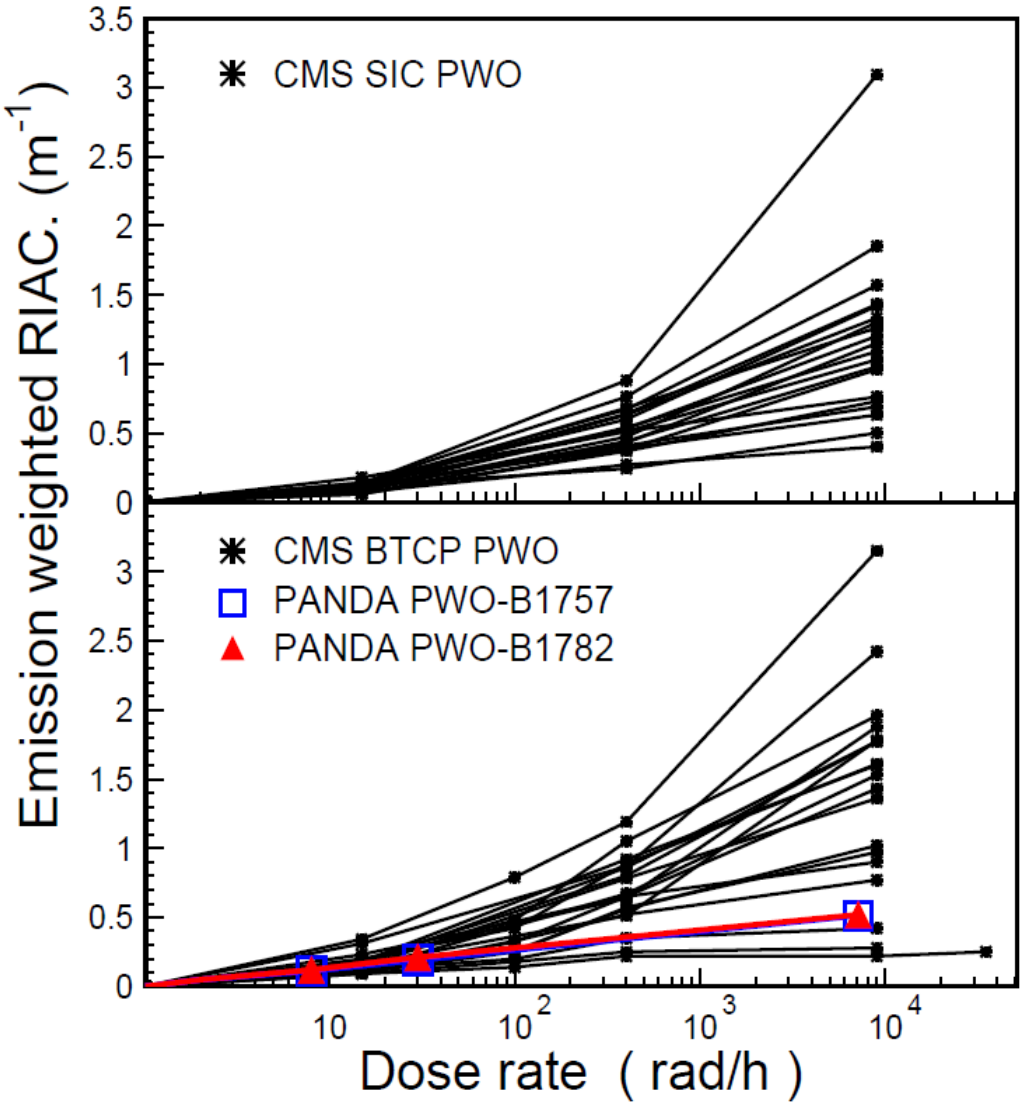
No correlation found between radiation damage (LO loss & EWRIAC) and initial optical parameters, such as the slope of the cut-off edge of the LT and the LT @ 360 nm.

Correlations: LO loss, EWRIAC and LT @ 440 nm





EWRIAC as a Function of Dose Rate



PWO Summary

- Panda PWO has higher LT at 360 nm and LO than CMS PWO.
- While the overall radiation hardness of Panda PWO is within the range of CMS PWO, two Panda samples are compatible with the better portion of CMS PWO.
- Correlations are confirmed between LO and LT @ 360 nm as well as between LO loss, EWRIAC and LT loss at 440 nm.
- No correlations are found between radiation hardness and initial optical properties, such as LT @ 360 nm and the slope of the LT cut-off edge.