ɣ-Ray Induced Radiation Damage in PWO and LSO/LYSO

Rihua Mao, Liyuan Zhang, Ren-yuan Zhu

California Institute of Technology

October 28, 2009

Paper N32-5, 2009 NSS/MIC at Orlando, USA

Introduction

- Crystal scintillators suffer from radiation damage originated from electromagnetic energy deposition (ɣ-rays), neutrons and charged hadrons. This paper compares ɣ-ray induced radiation damage effects in two heavy crystal scintillators: PWO and LSO/LYSO.

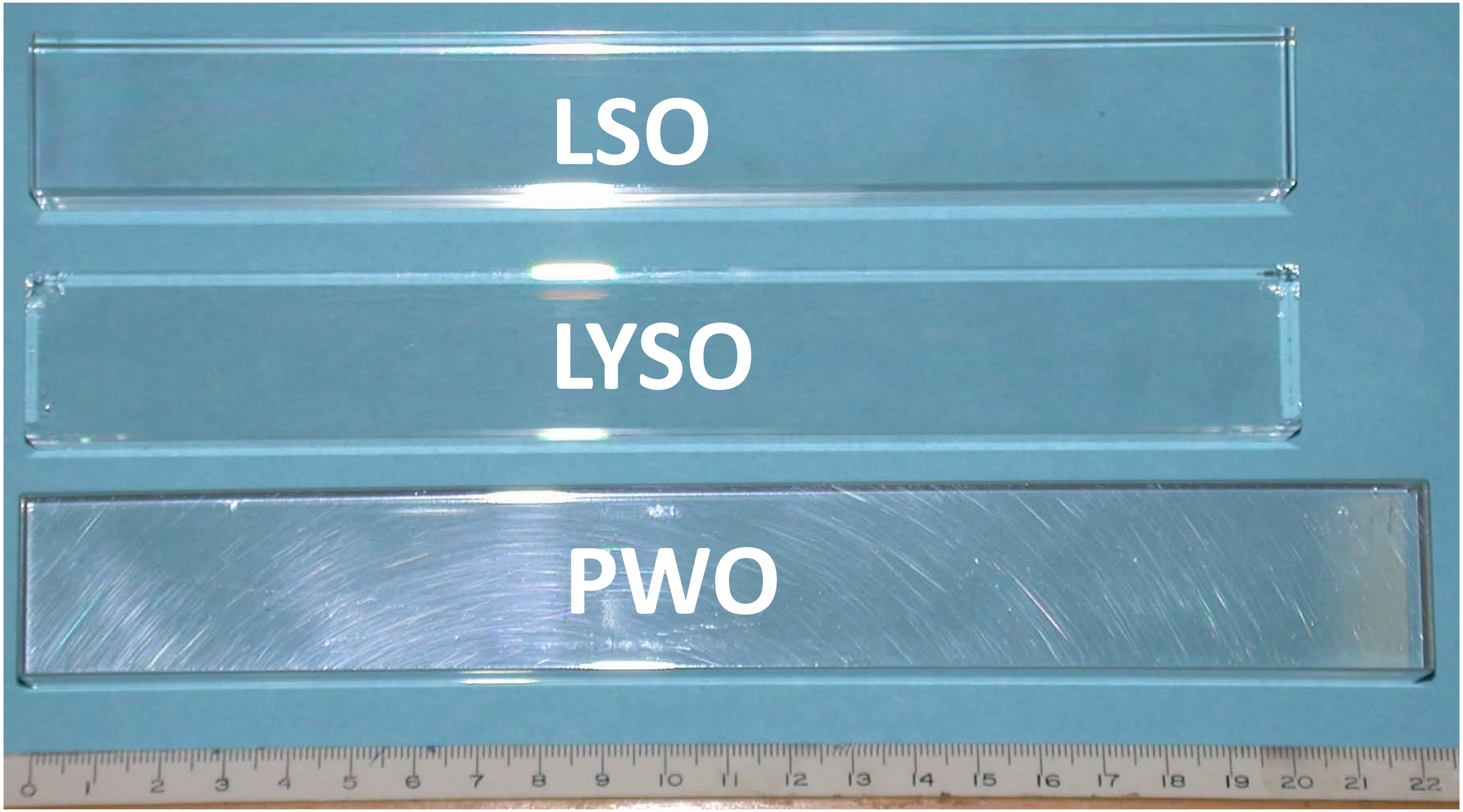
- Possible effects of ɣ-ray induced radiation damage include (1) damage to the scintillation mechanism; (2) radiation induced absorption; and (3) radiation induced phosphorescence (afterglow), which would cause an increase of the electronic readout noise.

- Photo-luminescence and transmission spectra, light output and response uniformity, ɣ-ray induced phosphorescence are measured.

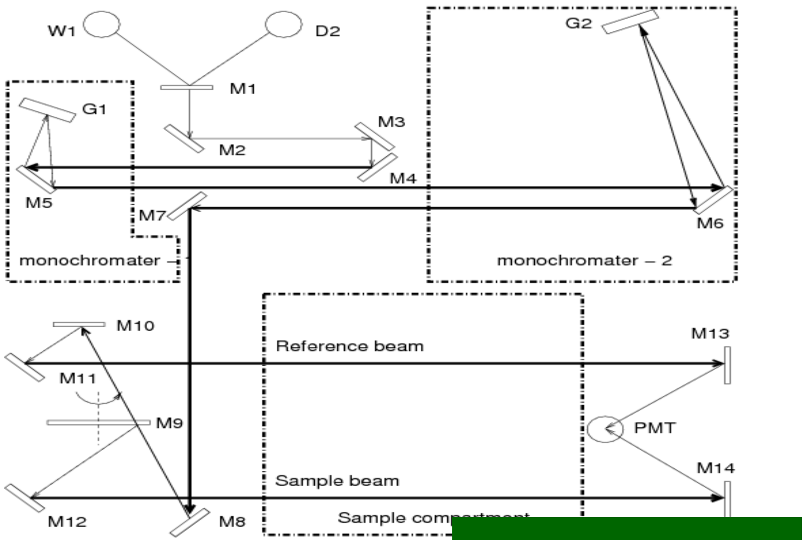
Samples

LSO/LYSO samples: 2 x 2 x 20 cm

PWO samples: 2.85^2 x 22 x 3^2 cm



Instruments Used in This Study



Transmittance

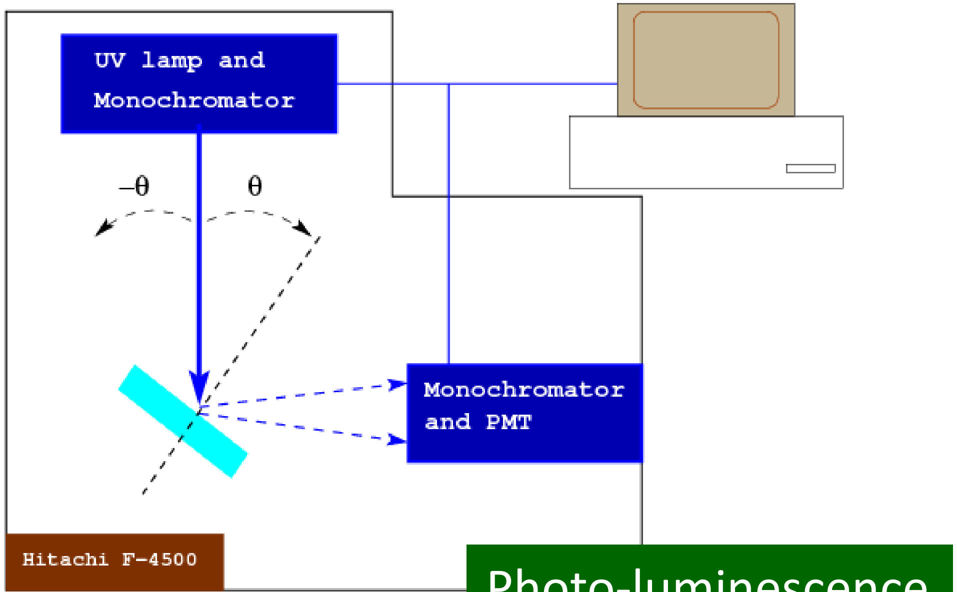
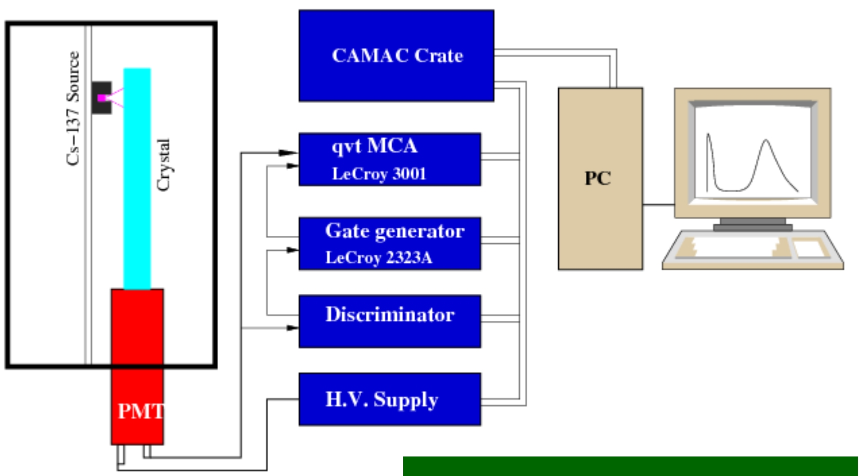
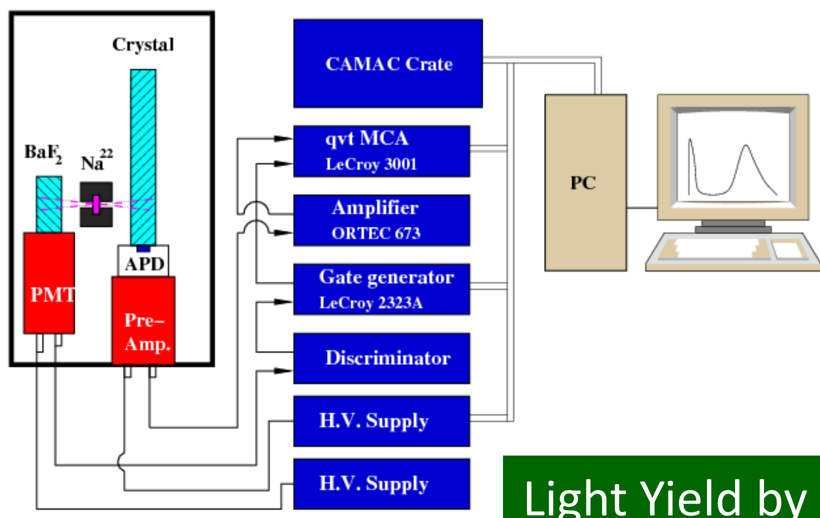


Photo-luminescence



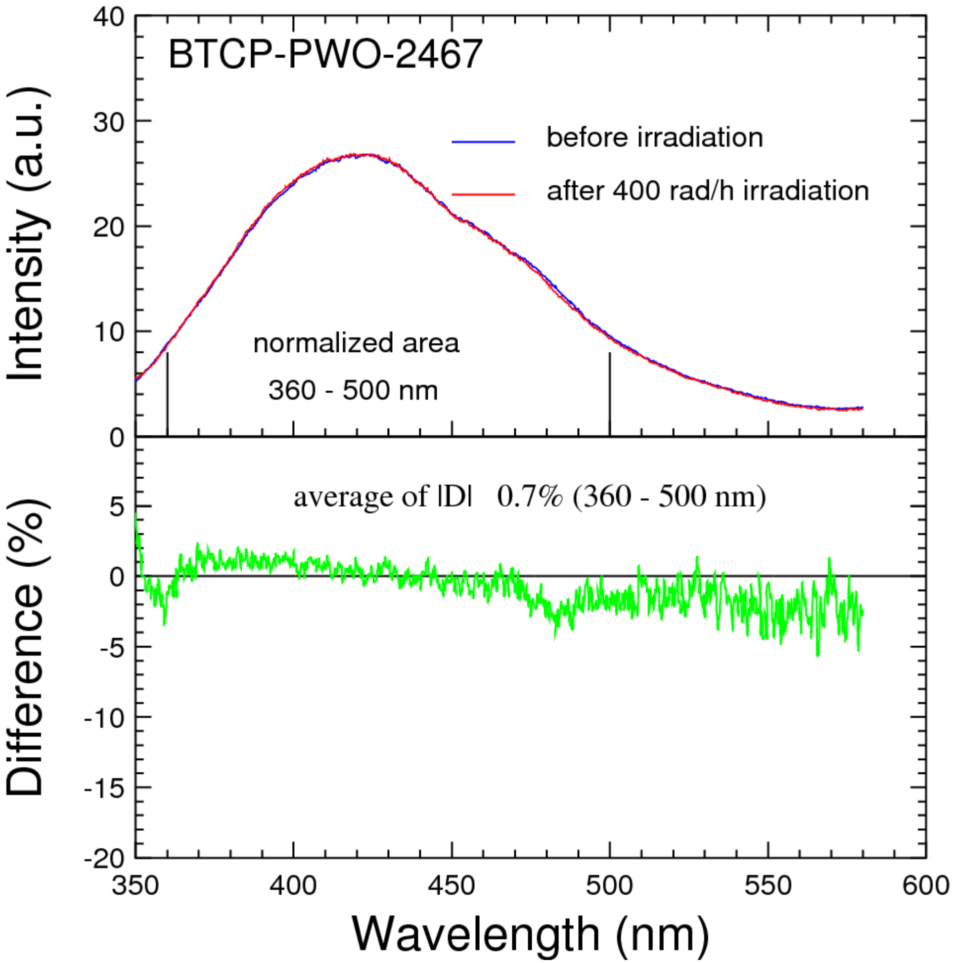
Light yield by ^{137}Cs

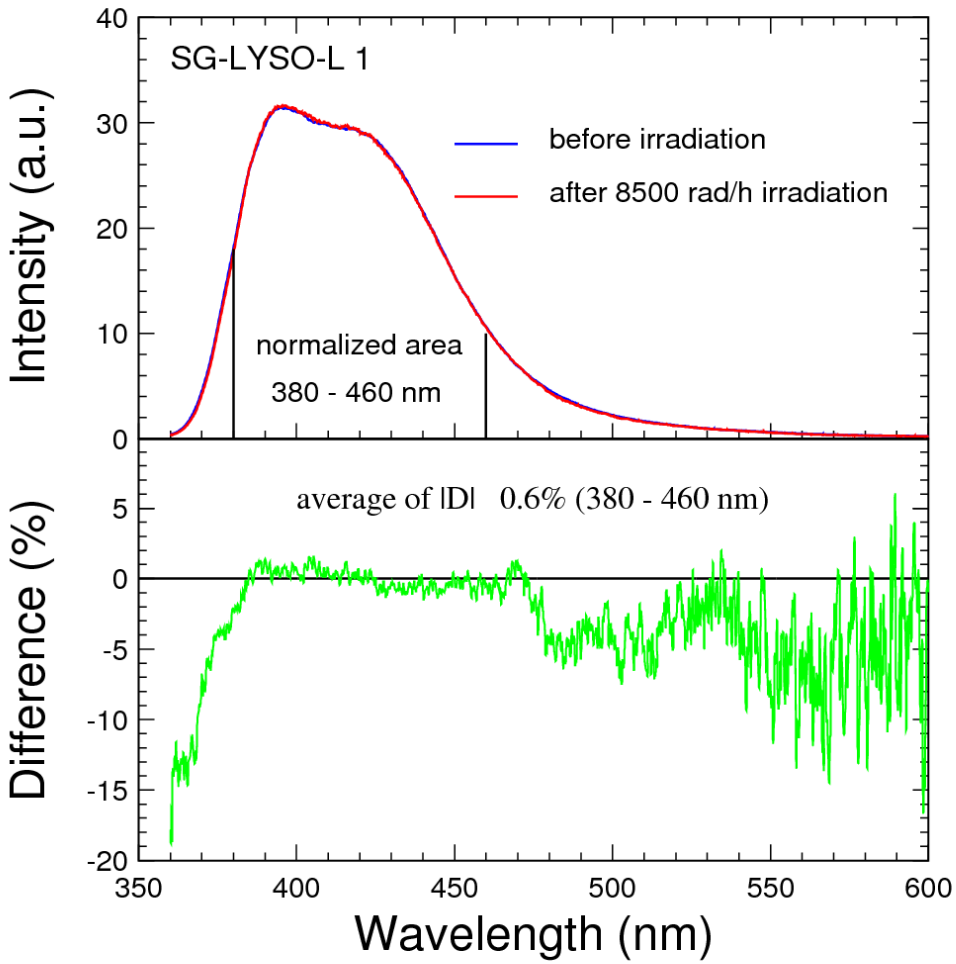


Light Yield by ^{22}Na

No Damage on Photo-luminescence

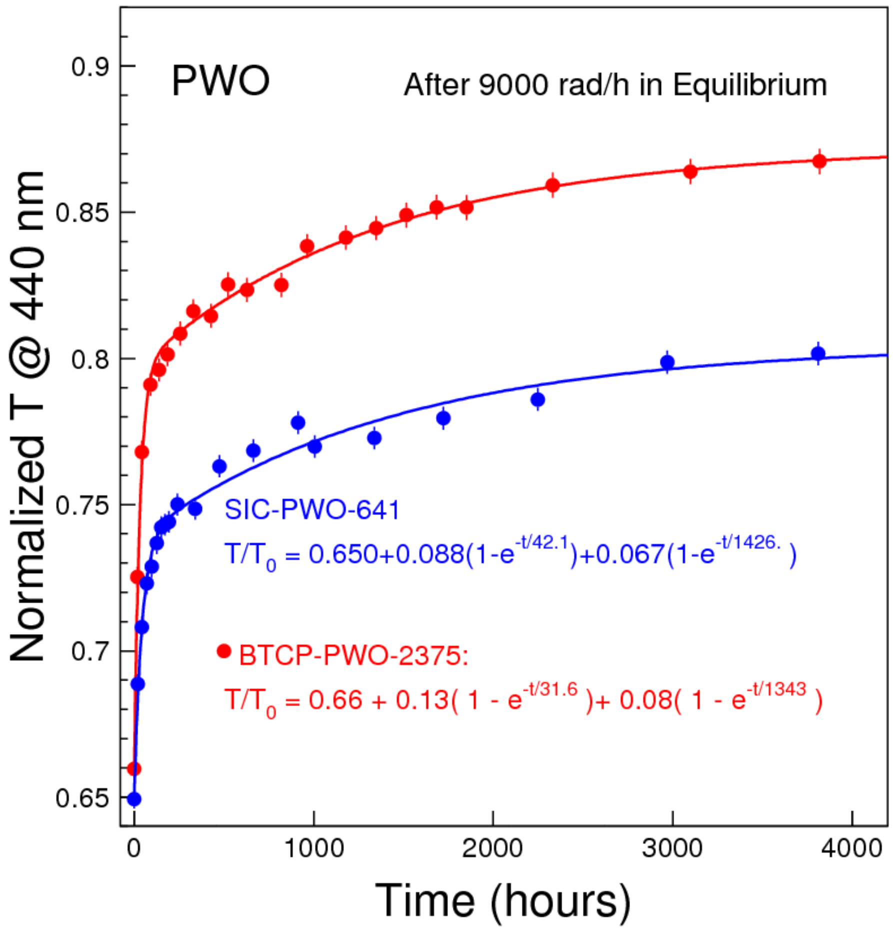
No difference was found between spectra measured before and after irradiations for both PWO and LSO/LYSO

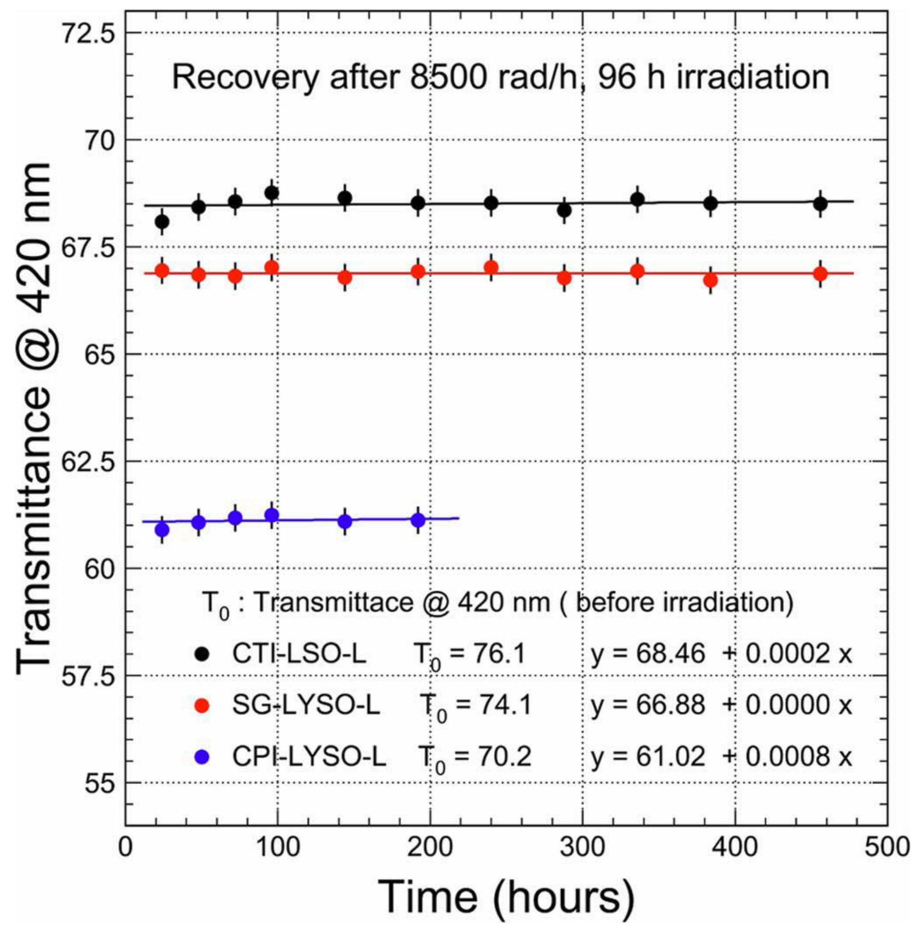




Very Different Damage Recovery

PWO: 3 components: a few tens hours, a few thousand hours and a longer one equivalent to no recovery. LSO/LYSO: no recovery at room temperature.





Dose rate dependent damage

No dose rate dependence

Damage may Depend on Dose Rate

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

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

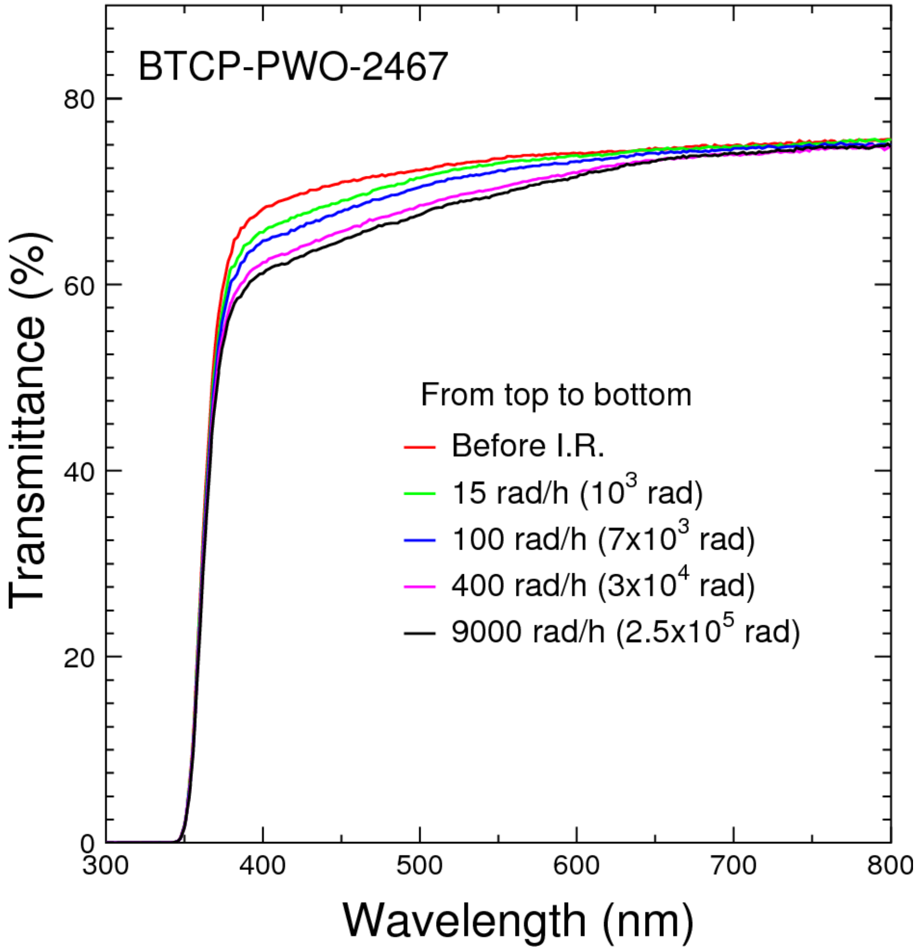
- D_i: color center density in units of m^{-1};
- D_i^0: initial color center density;
- D_i^{all} is the total density of trap related to the color center in the crystal;
- a_i: recovery costant in units of hr^{-1};
- b_i: damage contant in units of kRad^{-1};
- R: the radiation dose rate in units of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

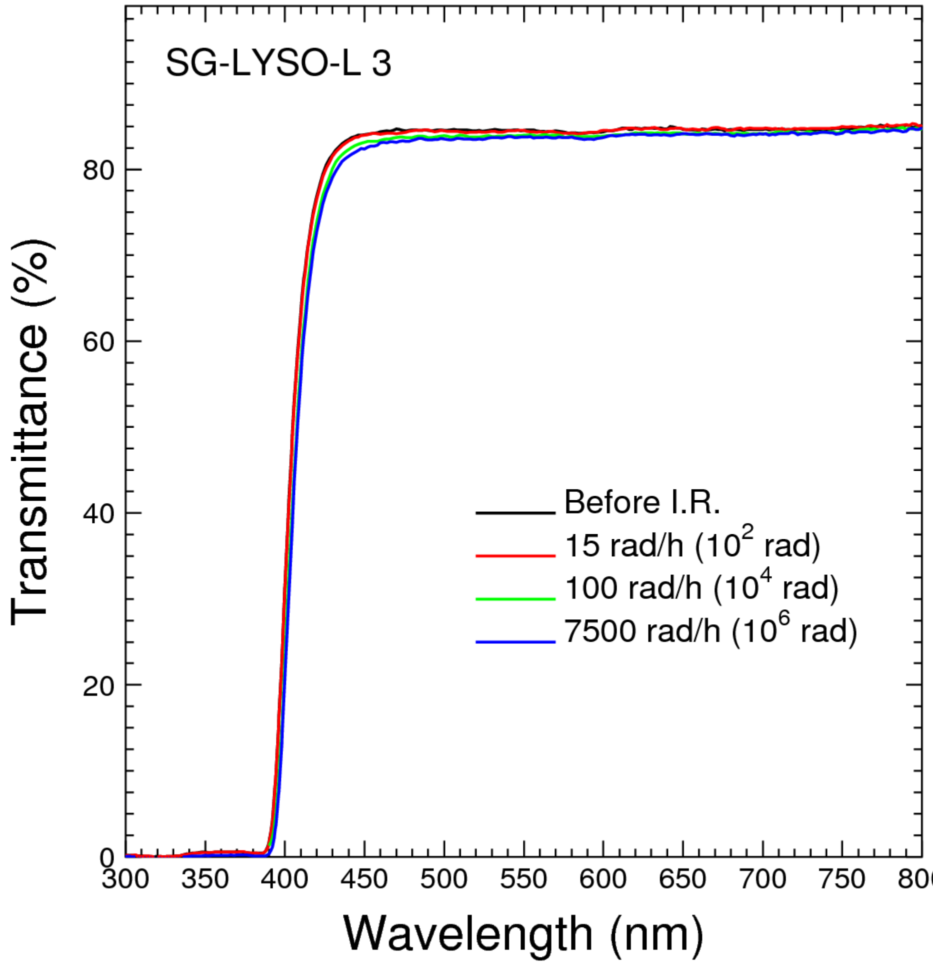
$$D_{eq} = \sum_{i=1}^{n}\frac{b_i R D_i^{all}}{a_i + b_i R}$$

A simple model was published in NIM A 332 (1993) 113-120 for the kinetics of radiation induced color center densities in crystal scintillators. It was used to explain the dose rate dependent damage for PWO crystals in a paper presented in NSS96 and published in IEEE Trans. Nucl. Sci., Vol. 44 (1997) 468-476.

Damage on Optical Transmission-1

PWO: dose rate dependent damage; LSO/LYSO: No dose rate dependence.
Thermal annealing was found effective to remove ɣ-ray induced damages.

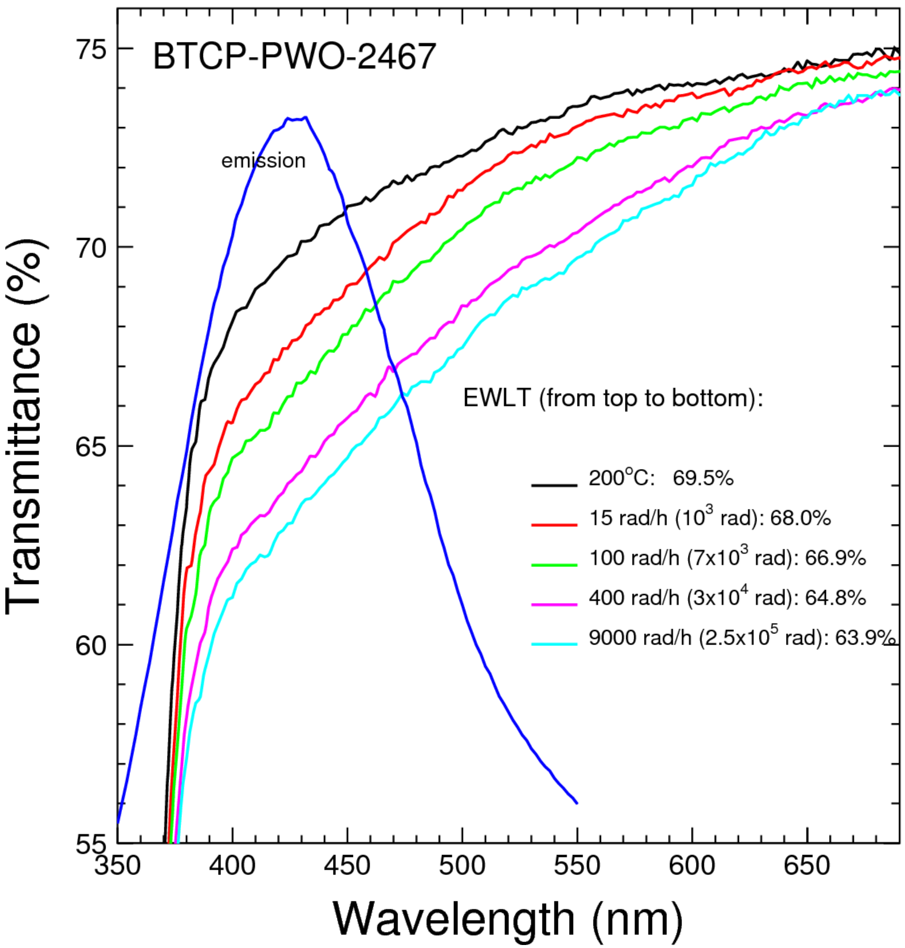


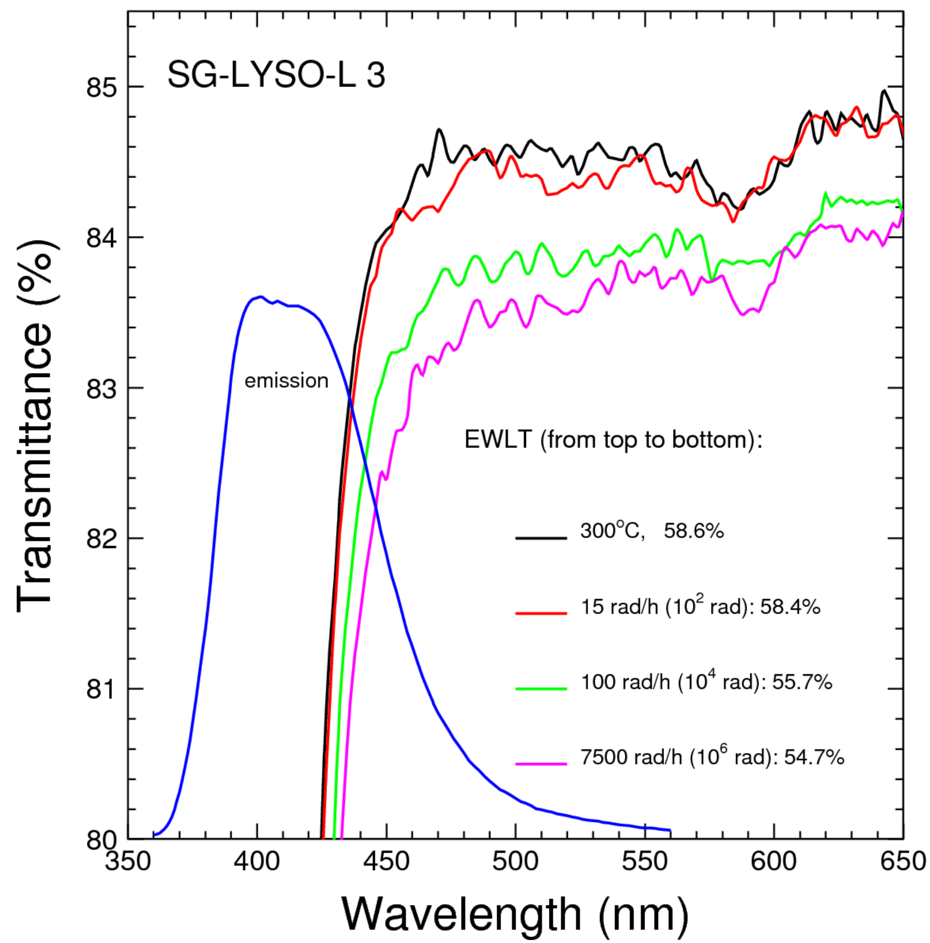


Damage on Optical Transmission-2

Emission weighted longitudinal transmittance:

$$EWLT = \frac{\int LT(\lambda)Em(\lambda)d\lambda}{\int Em(\lambda)d\lambda}.$$

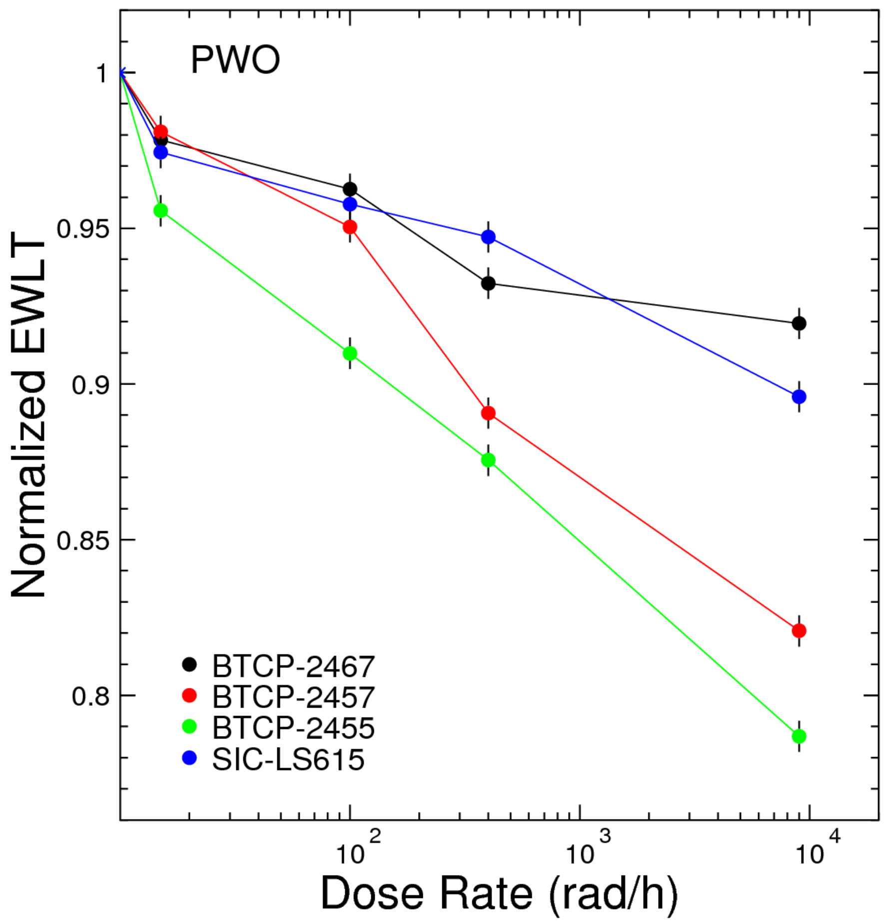


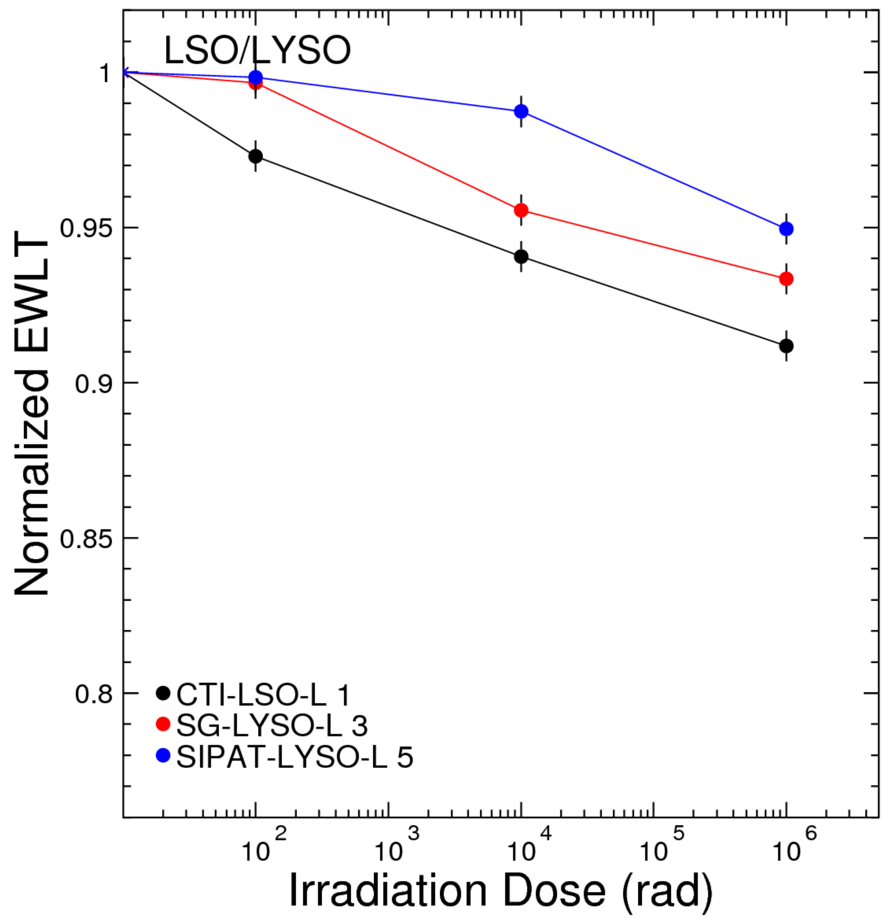


Damage on Optical Transmission-3

8-21% loss after 10^5 rad @9 krad/h

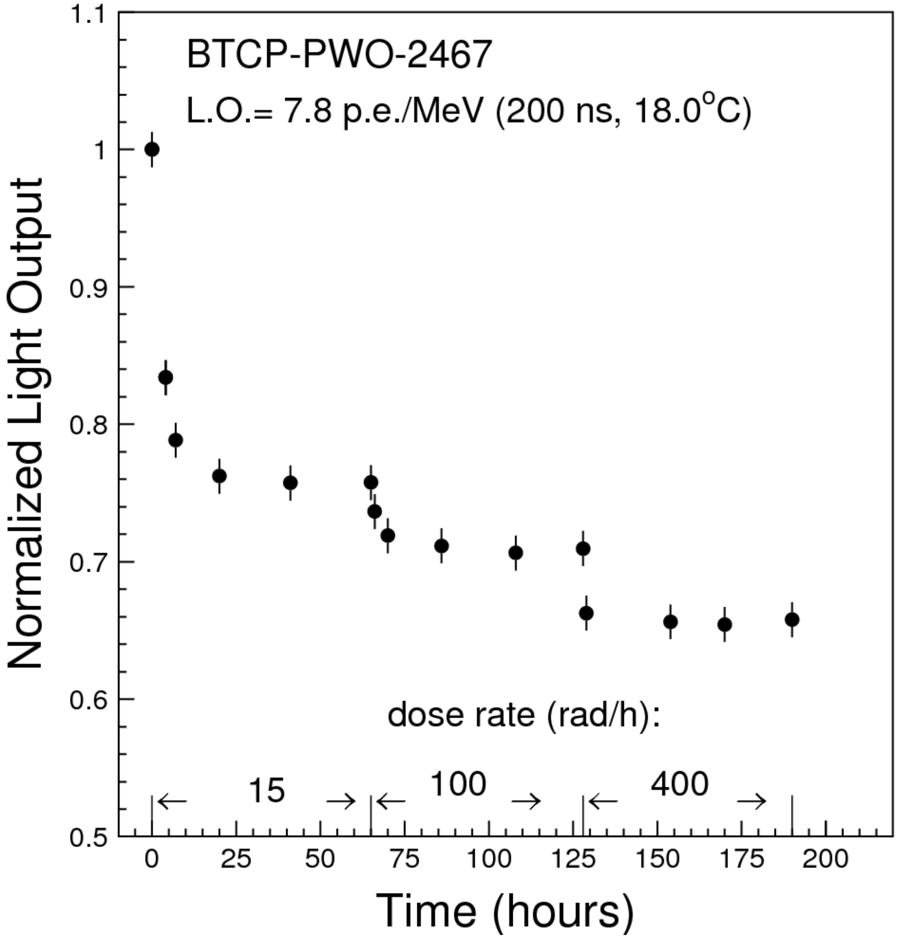
5-9% loss after 10^6 rad

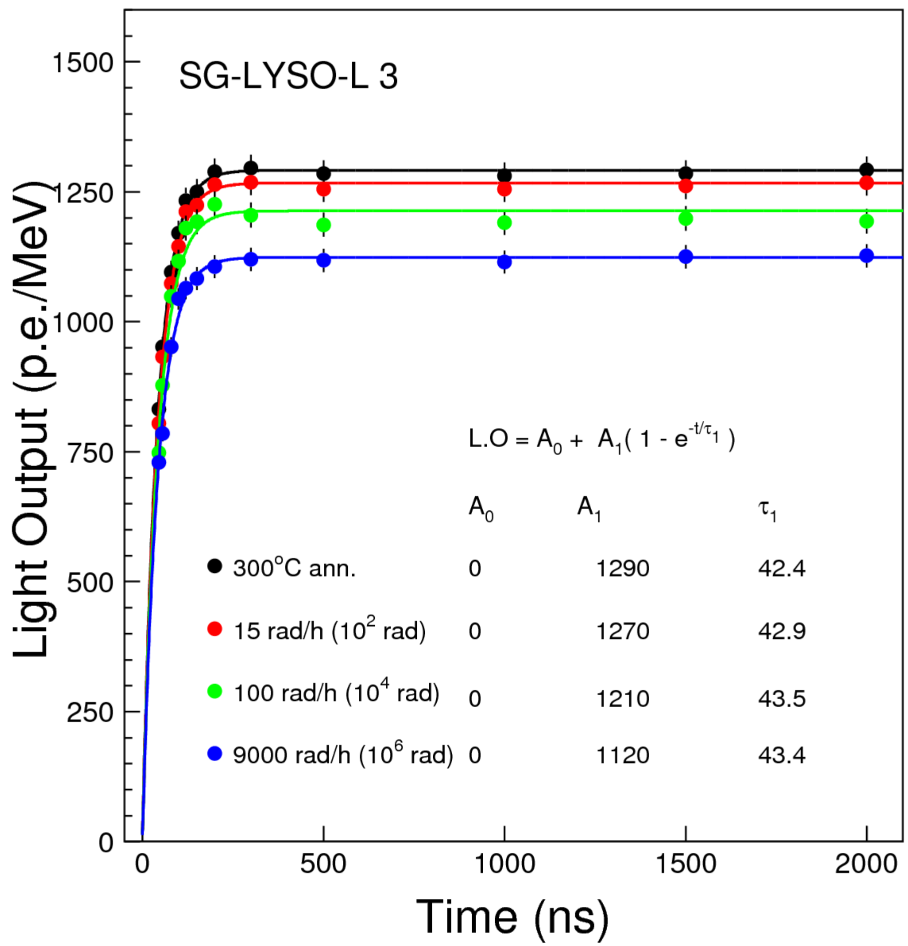




Damage of Light Output-1

PWO: dose rate dependent damage; LSO/LYSO: No dose rate dependence

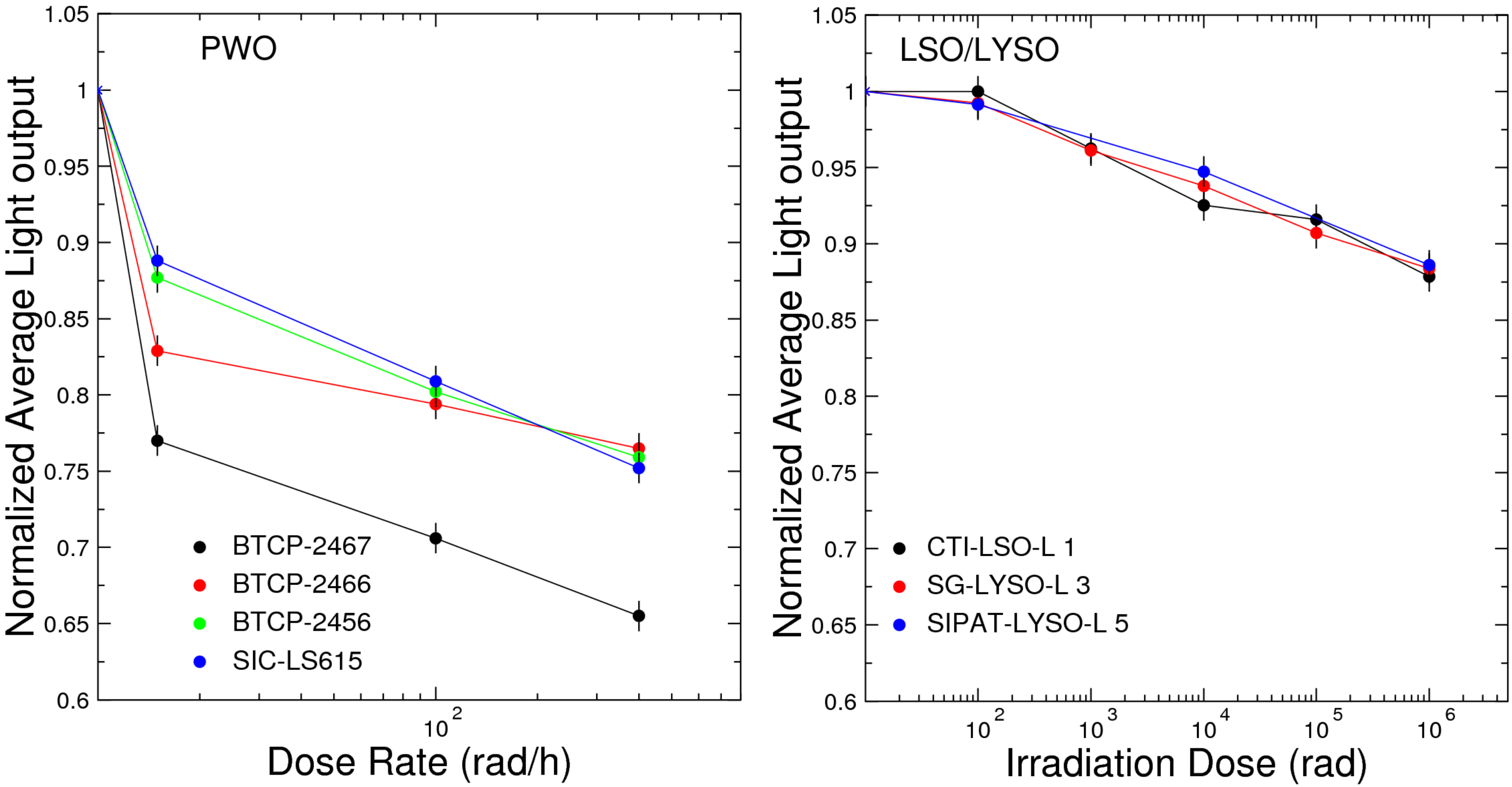




Damage of Light Output-2

22-35% loss after 10^4 rad @400 rad/h

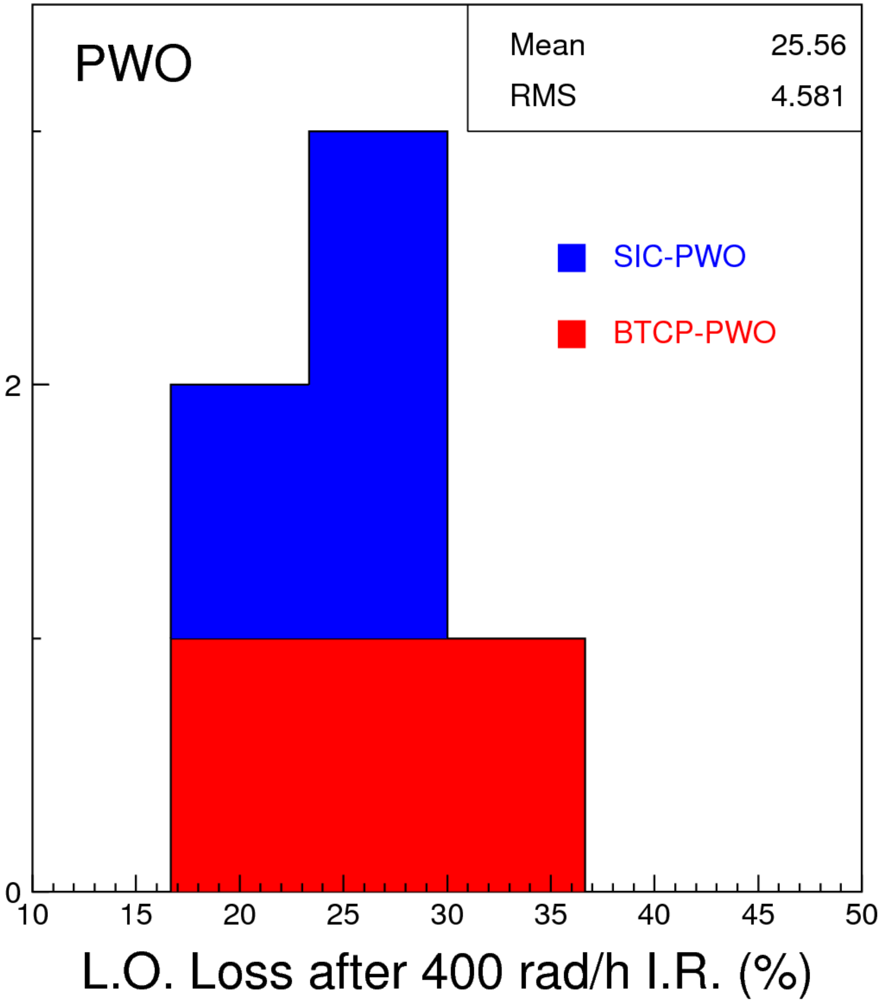
About 10% loss after 10^6 rad

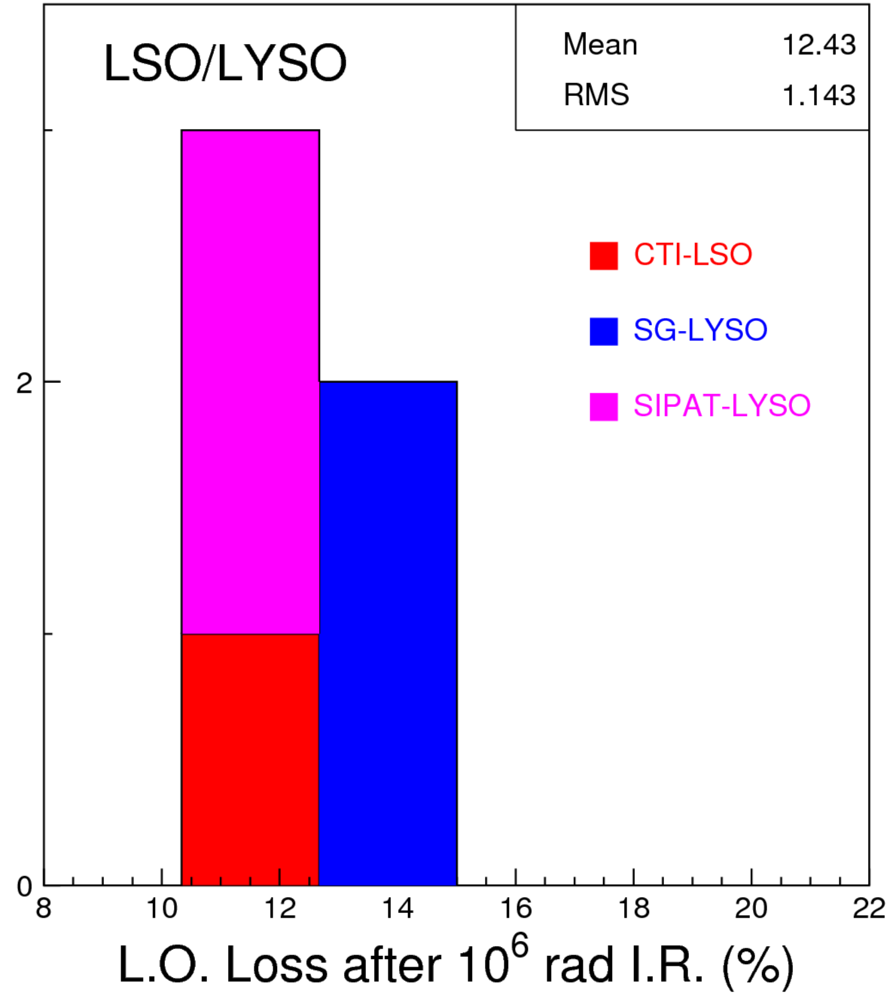


Damage of Light Output-3

25.6% loss after 10^4 rad @400 rad/h

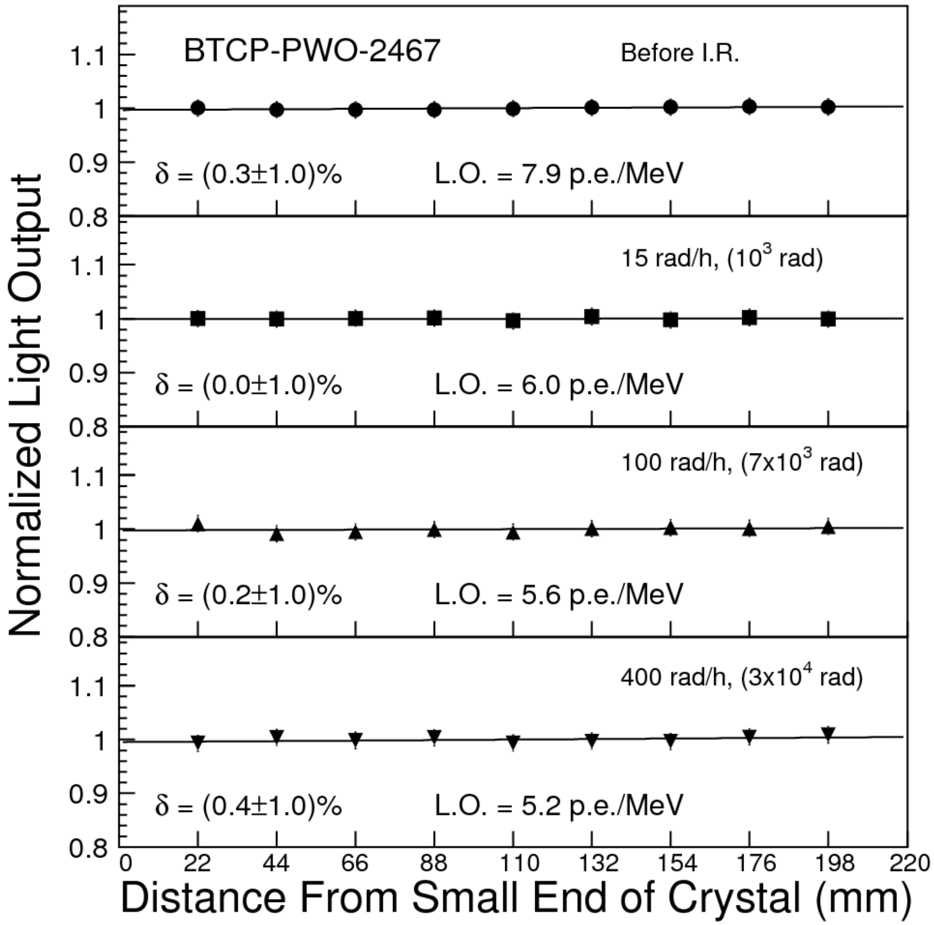
12.4% loss after 10^6 rad

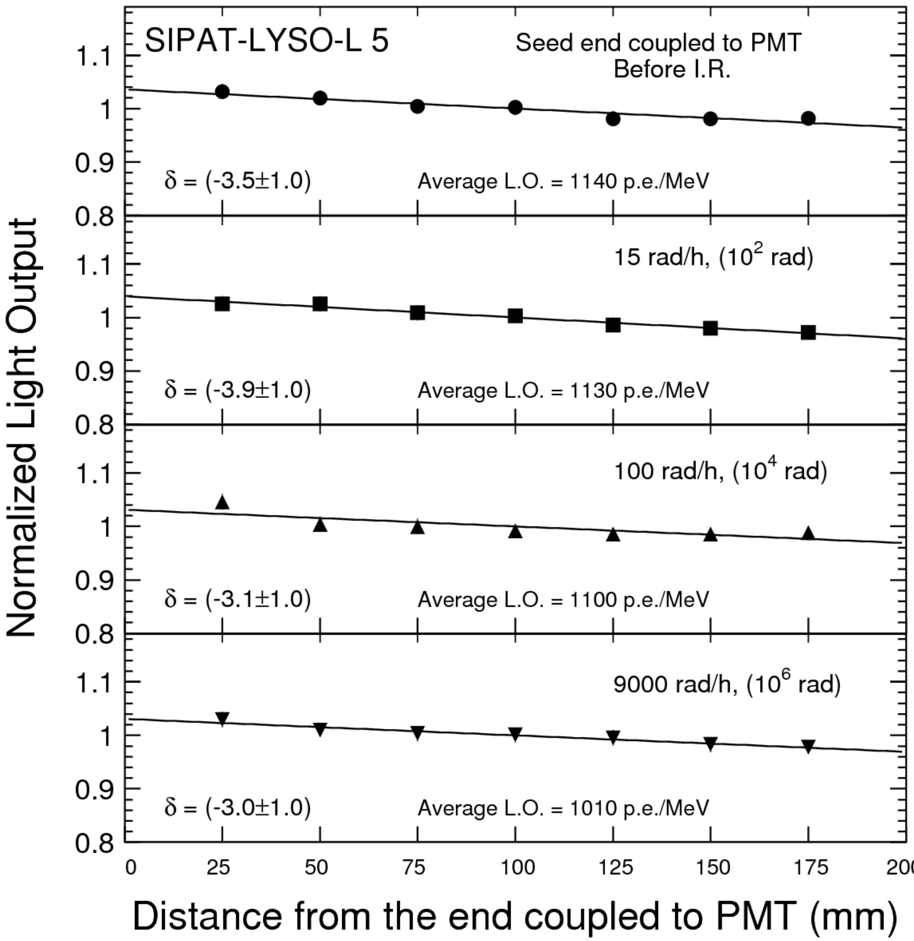




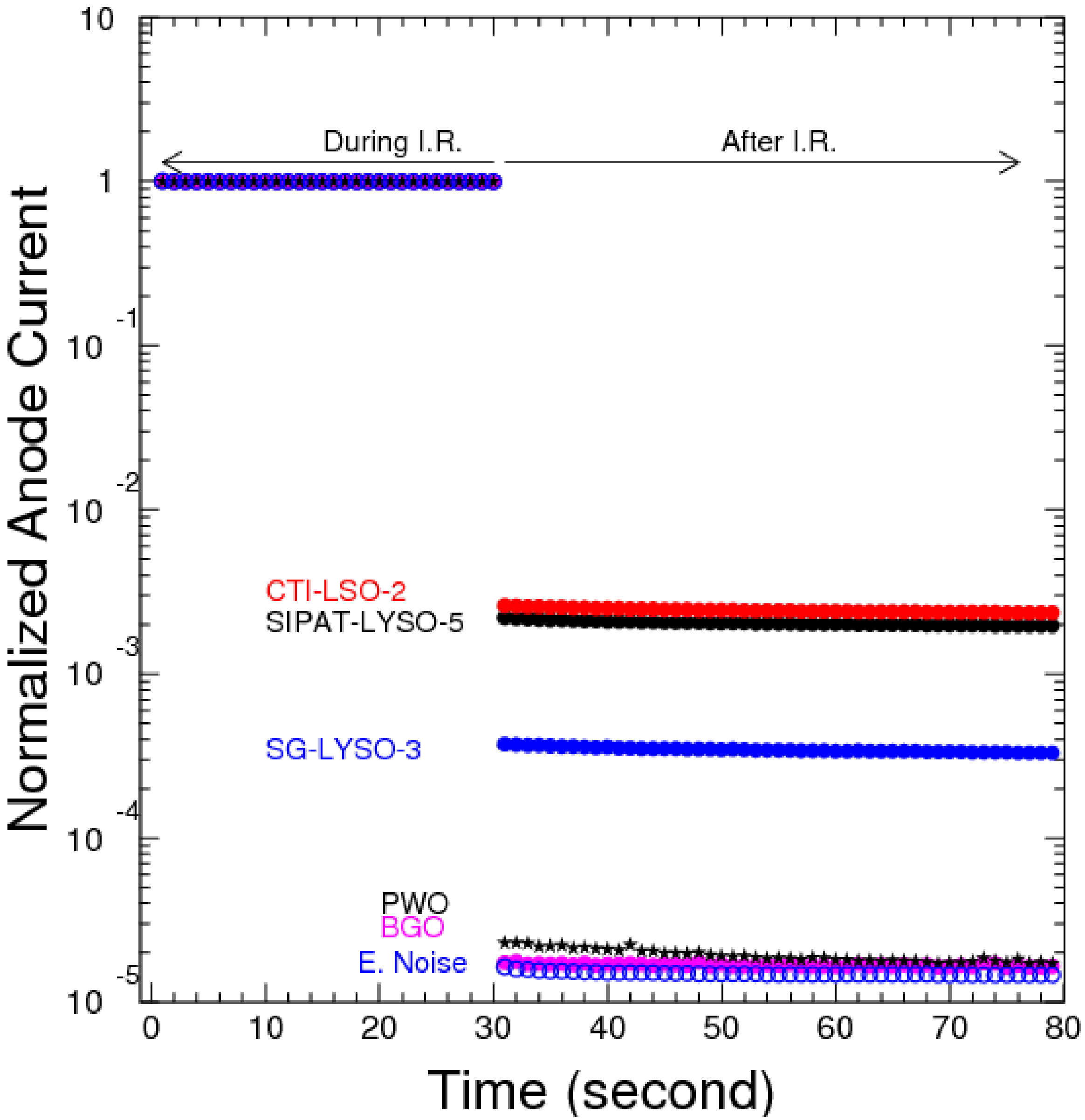
No Damage in LRU if $\mu < 1\ m^{-1}$

Unchanged LRU maintains the constant term in resolution





γ-ray Induced Phosphorescence

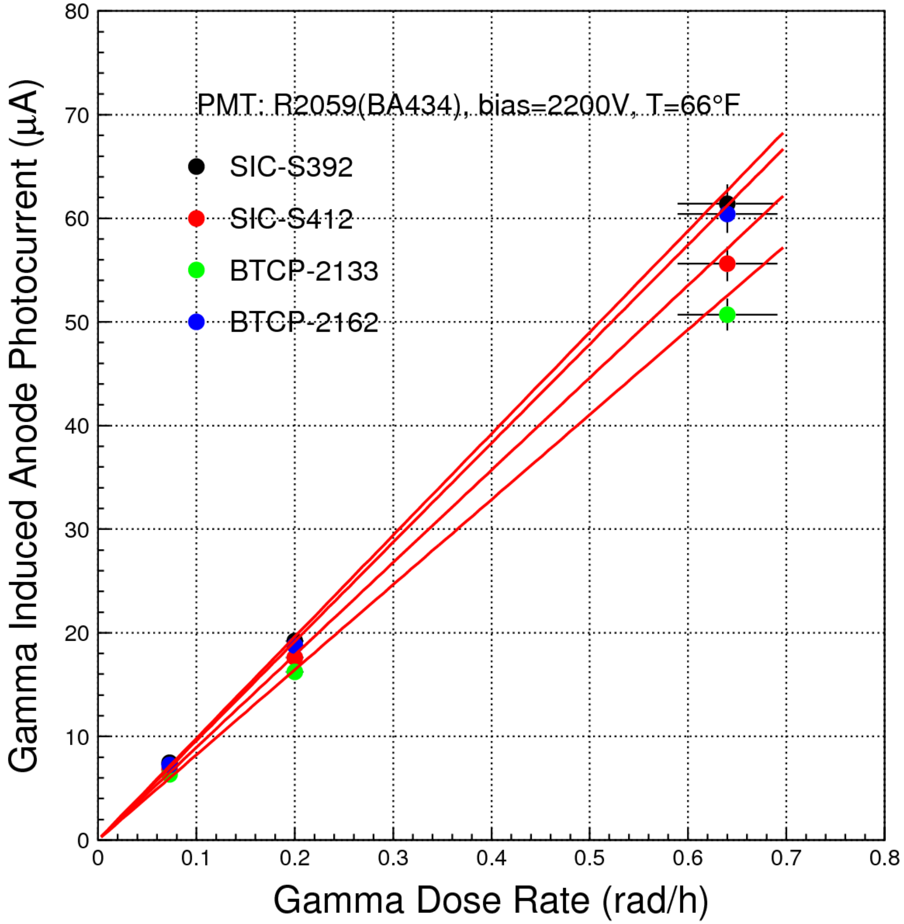


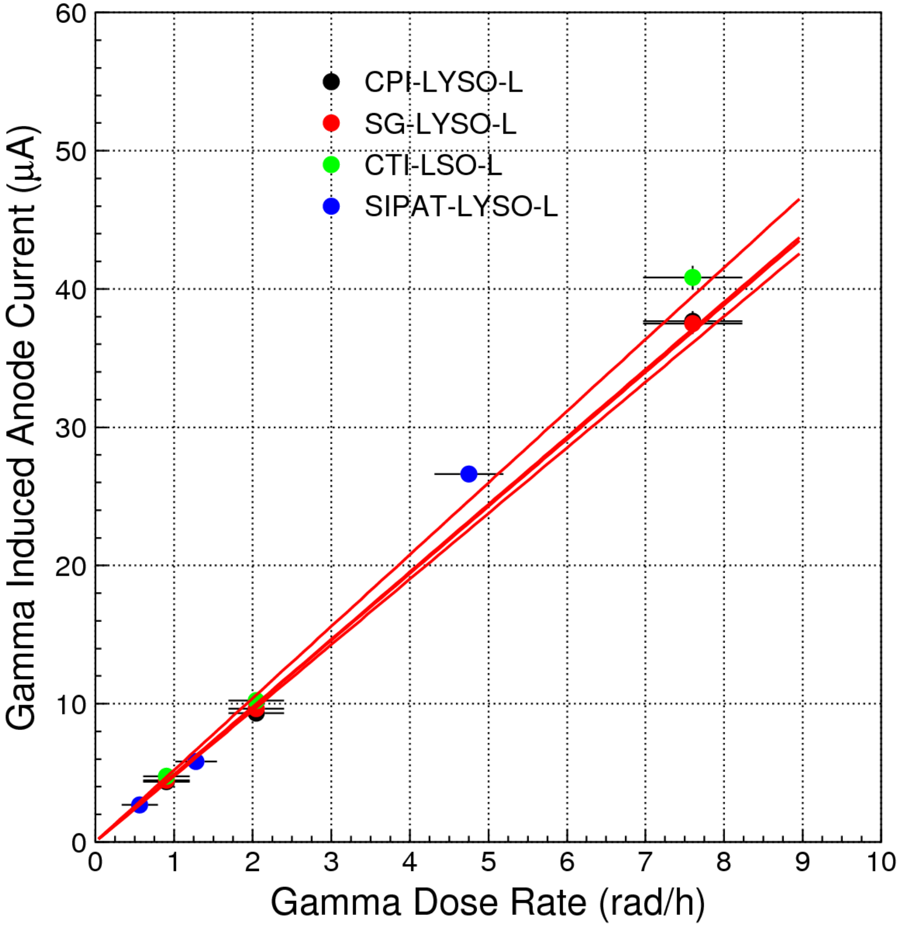
PWO and BGO have small (10^{-5}) afterglow.

Afterglow for LSO/LYSO varies between 10^{-3} to 10^{-4}. LYSO from Saint-Gobain has the lowest afterglow.

γ-ray Induced Readout Noise-1

γ-ray induced anode current was measured for samples at different dose rate





γ-ray Induced Readout Noise-2

γ−ray Induced Readout Noise in $PbWO_4$ Crystals						
Sample	L.Y. p.e./MeV	F μA $rad^{-1}h$	Q_{bar} p.e.	Q_{end} p.e.	σ_{bar} MeV	σ_{end} MeV
SIC−S392	7.13	97.9	290.7	9690	2.39	13.8
SIC−S411	6.70	89.2	264.7	8822	2.43	14.0
BTCP−2133	5.79	82.1	243.6	8119	2.69	15.6
BTCP−2162	7.12	95.7	283.9	9466	2.37	13.7

- L.Y. is defined as the averaged light yield of nine points measured along crystals (to reduce systematic uncertainty of peak finding) in a gate of 100 ns at 66F.
- F is the gamma induced photoelectron coefficient, defined as gamma induced photo-electron number under unit dose rate.
- Q_{bar} and Q_{end} are the derived photoelectron number per 100 ns induced by LHC averaged dose rate in barrel (15 rad/h) and endcaps (500 rad/h) respectively.
- σ_{bar} and σ_{end} are the equivelent readout noise induced by LHC gamma radiation, derived as standard deviation of gamma induced photoelectrons in 100 ns.

γ-ray Induced Readout Noise-3

γ-ray Induced Readout Noise in LSO/LYSO Crystals						
Sample	L.Y. p.e./MeV	F μA $rad^{-1}h$	Q_{bar} p.e.	Q_{end} p.e.	σ bar MeV	σ end MeV
CPI-LYSO-L	2606	4.8	3.44×10^4	1.15×10^6	0.13	0.74
SG-LYSO-L	2305	4.9	3.51×10^4	1.17×10^6	0.12	0.67
CTI-LSO-L	2020	5.2	3.75×10^4	1.25×10^6	0.14	0.79
SIPAT-LYSO-L	2155	4.9	3.56×10^4	1.18×10^6	0.12	0. 72

- L.Y. is defined as the averaged light yield of nine points measured along crystals (to reduce systematic uncertainty of peak finding) in a gate of 100 ns at 66F.
- F is the gamma induced photoelectron coefficient, defined as gamma induced photoelectron number under unit dose rate.
- Q_{bar} and Q_{end} are the derived photoelectron number per 100 ns induced by LHC averaged dose rate in barrel (15 rad/h) and endcaps (500 rad/h) respectively.
- σ_{bar} and σ_{end} are the equivelent readout noise induced by LHC gamma radiation, derived as standard deviation of gamma induced photoelectrons in 100 ns.

Summary

- γ-ray induced radiation damage in large size PWO and LSO/LYSO crystals are evaluated. No damage in the scintillation mechanism was observed in both crystals. While PWO crystals recover at room temperature, leading to a dose rate dependent damage, LSO/LYSO shows no recovery so no dose rate dependence.
- Light output loss was found 26% after 10^4 rad @400 rad/h for PWO, and 12.4% after 10^6 rad for LSO/LYSO.
- γ-ray induced phosphorescence was found at 10^{-5} level for PWO, and was between 10^{-3} to 10^{-4} for LSO/LYSO. Saint-Gobain LYSO has the lowest afterglow.
- The equivalent readout noise induced by γ-ray dose at CMS Barrel and Endcap are about 2.5 MeV and 15 MeV, respectively, for PWO. The corresponding numbers for LSO/LYSO are 0.15 MeV and 0.8 MeV.