Fast Neutron Induced Radiation Damage in Crystals

Ren-Yuan Zhu

California Institute of Technology

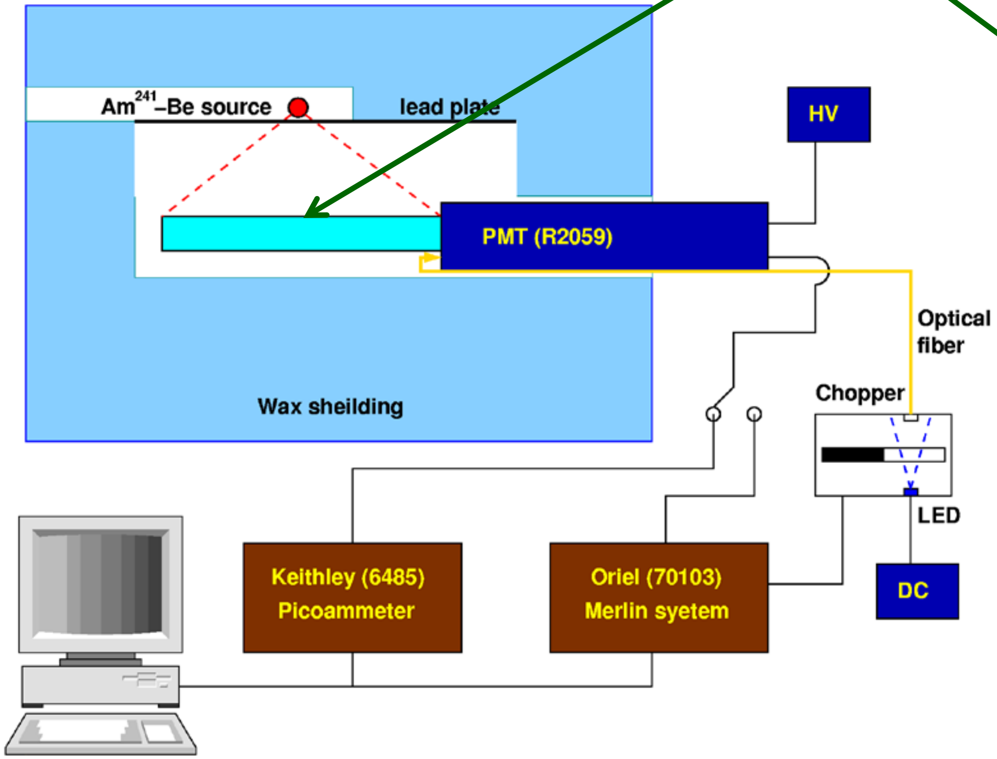
October 15, 2013

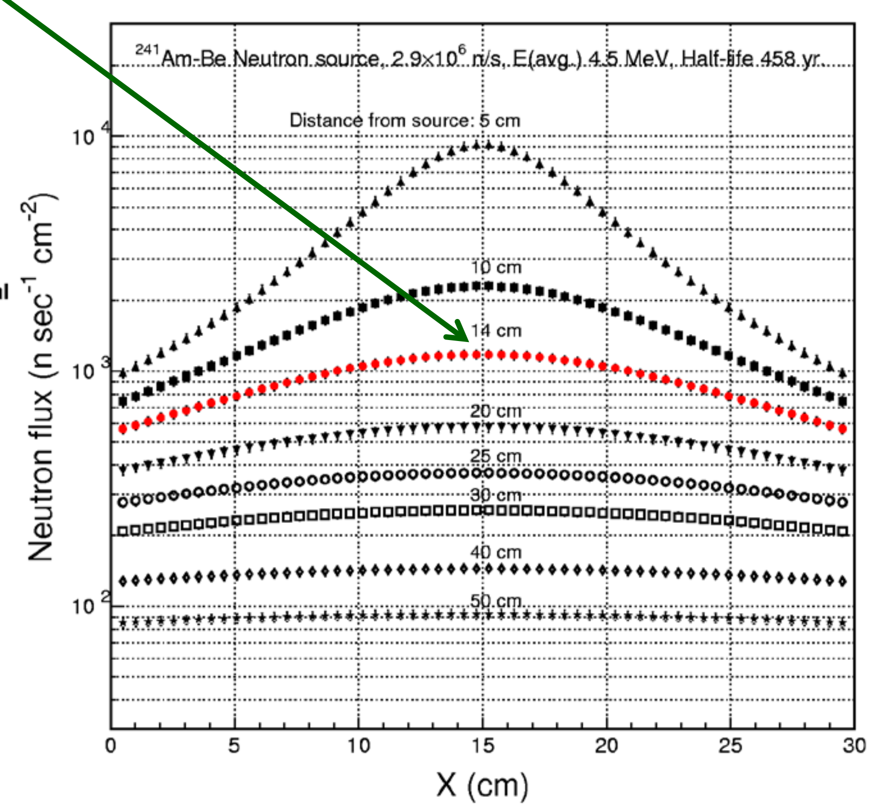
Crystal Samples Tested

ID	Dimension (mm)
SIC-BGO	25x25x200
SIC-CeF_3	30x30x140
SG-LYSO-L2	25x25x200
SIPAT-LYSO-L2	25x25x200
SIPAT-LYSO-L7	25x25x280
SIC-PWO-2781	28.5^2x220x30^2
BTCP-PWO-2376	28.5^2x220x30^2

An Am^{241}-Be Neutron Source

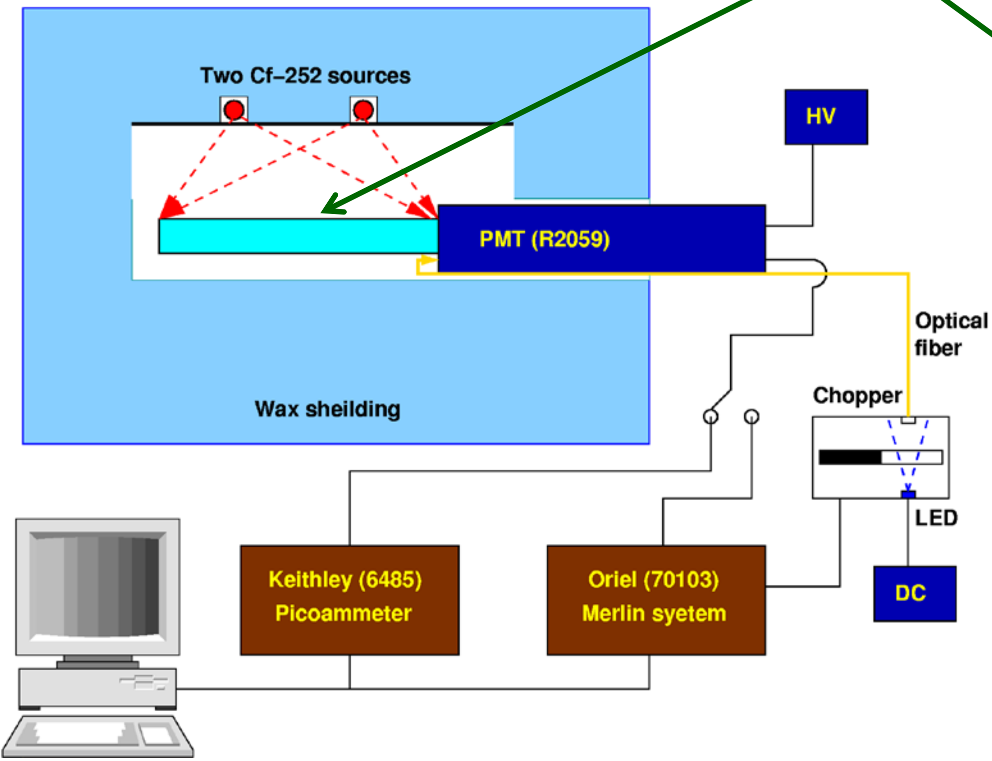
Samples were laced at 14 cm from the source.
Neutron flux at crystal surface was about 10^3 n s^{-1} cm^{-2}.

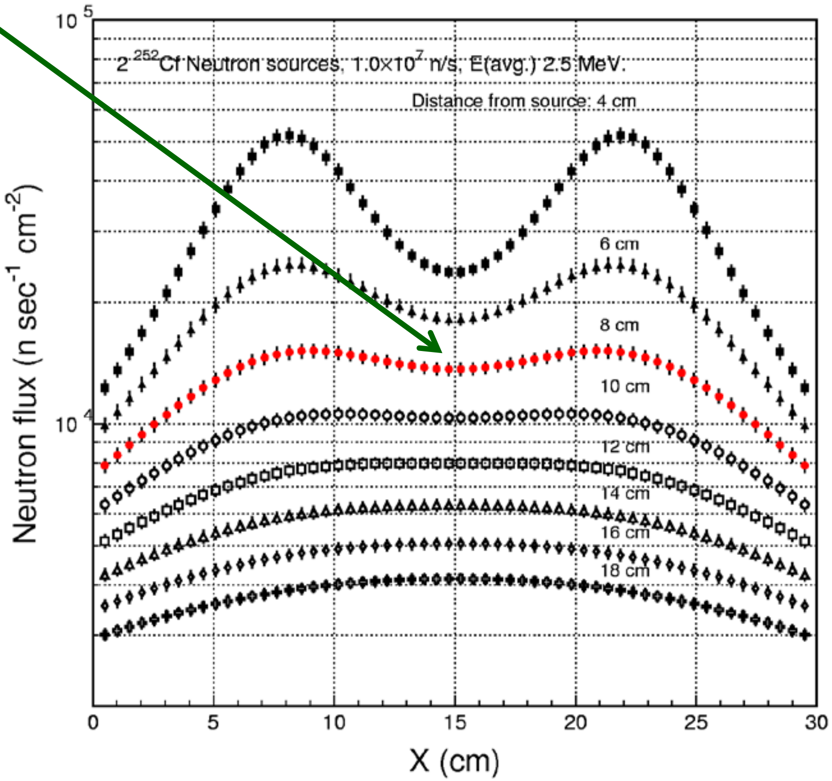




Two ^{252}Cf Neutron Sources

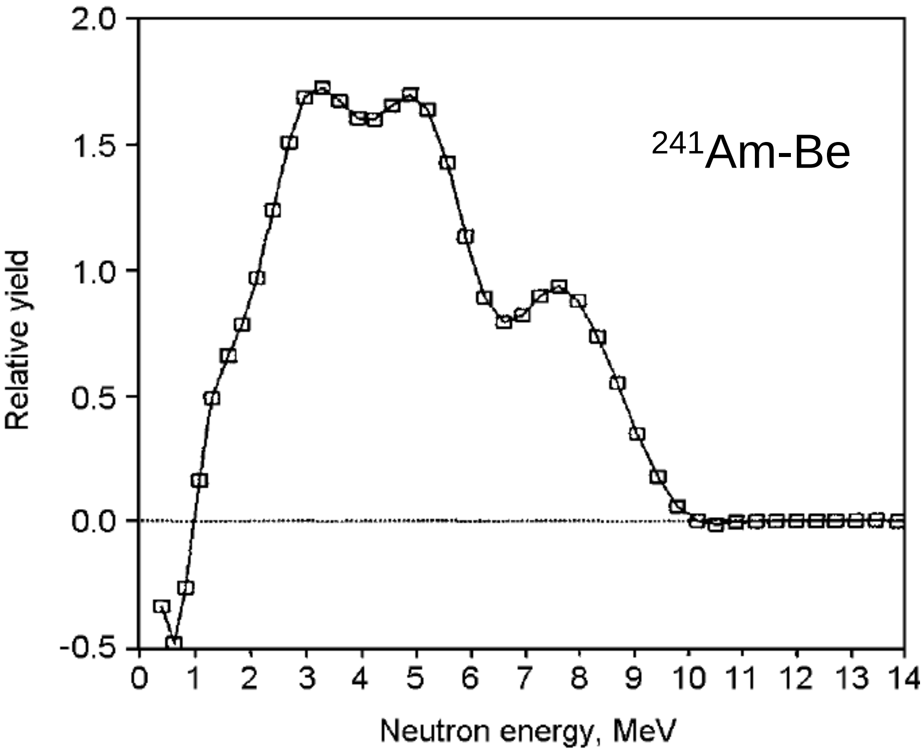
Samples were placed at 8 cm from two sources.
Neutron flux at crystal surface was about
1.4×10^4 (10/09) & 1.0×10^4 n s^{-1} cm^{-2} (9/10)

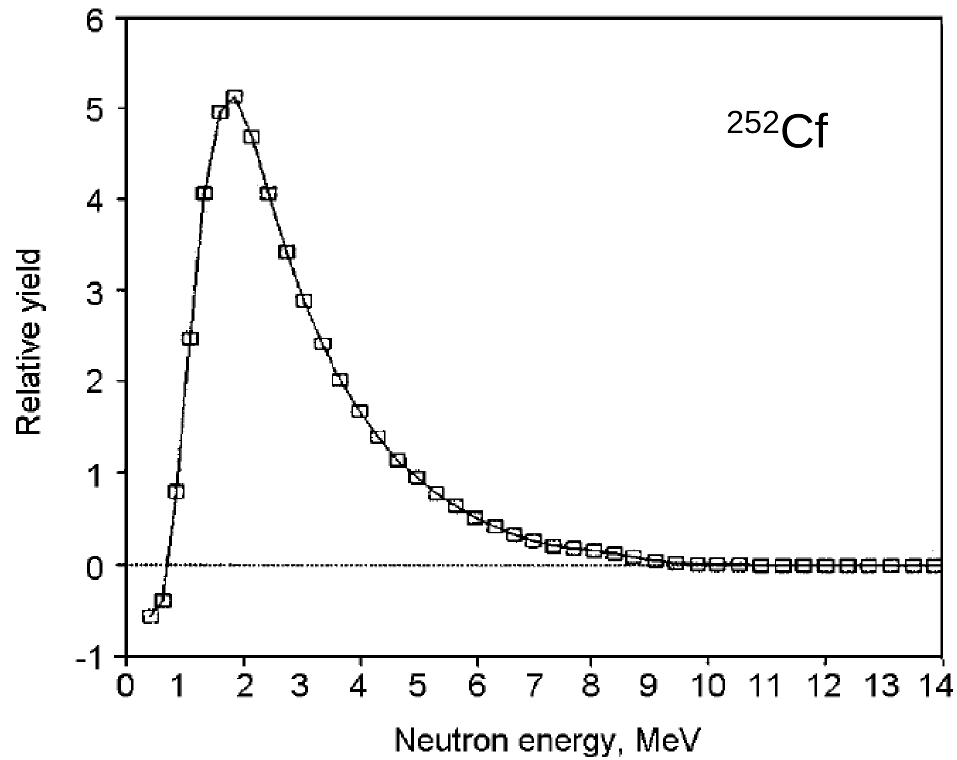




$E_{Neutron}$ from ^{241}Am-Be & ^{252}Cf

Neutrons from the ^{241}Am-Be source have a broad distribution from 1 to 10 MeV with an average of 4.5 MeV, and are peaked at 2.2 MeV with a range of 1-10 MeV from the ^{252}Cf sources.





S.-T. Park, J. Rad. & Nucl. Chem., **Vol 256** (2003) 163

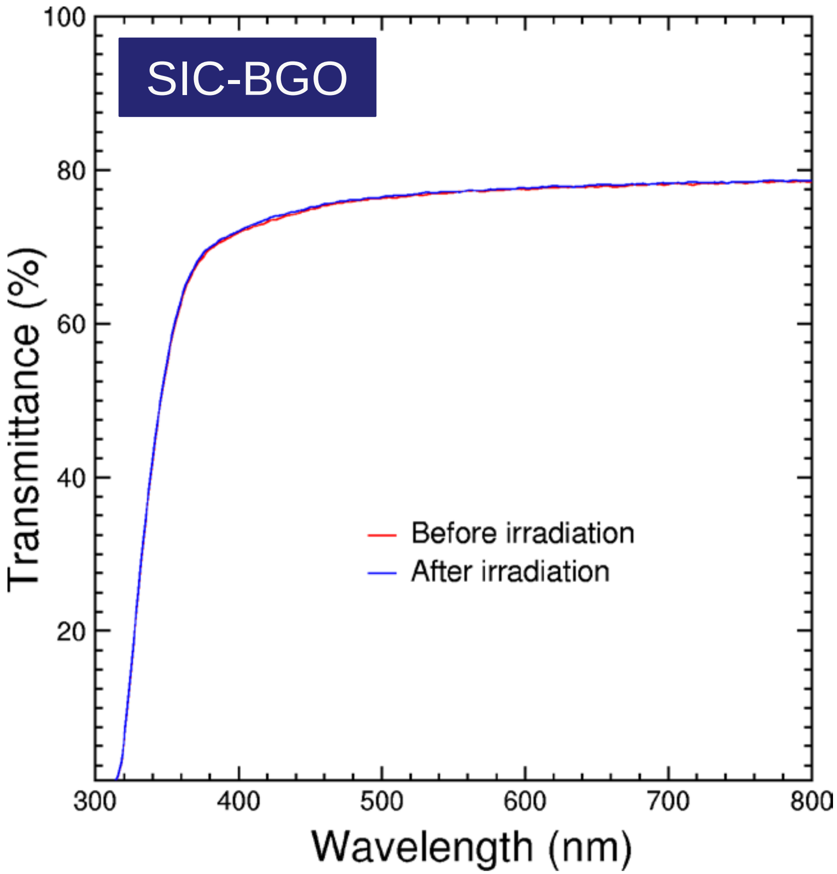
Integrated Neutron Fluence

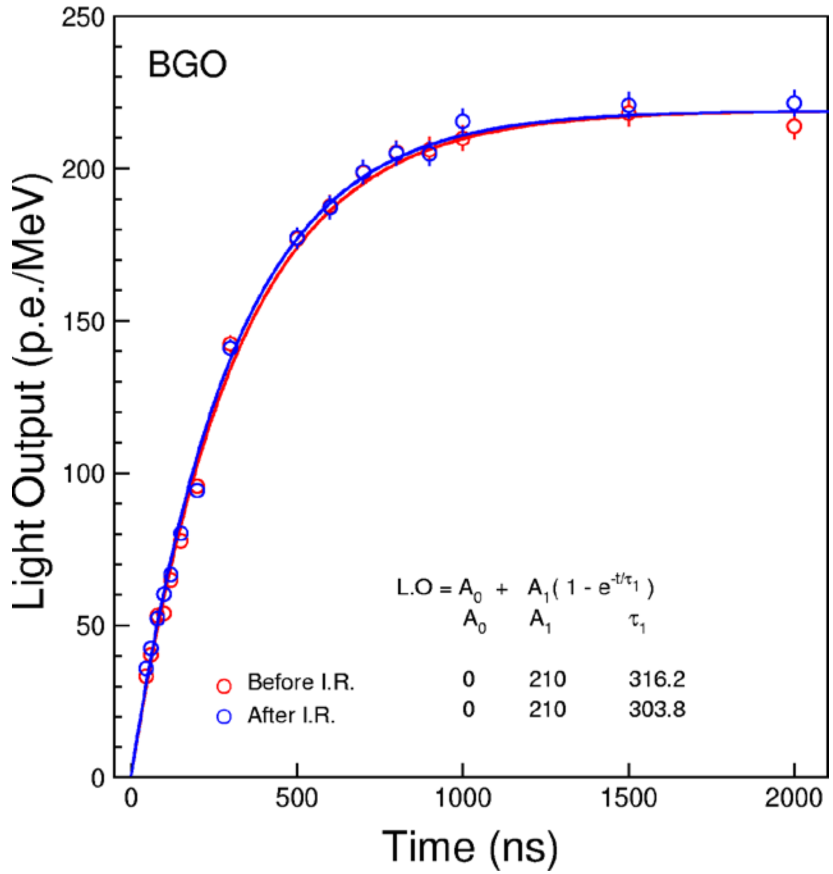
Radiation effects on LT, LO and readout noise measured

- 6x10^{8} n/cm (^{241}Am-Be) for all but SIPAT-LYSO-L7: No obvious change was observed. Effect of neutron induced phosphorescence to readout noise was determined.
- 1x10^{10} n/cm (^{252}Cf) for all but SIPAT-LYSO-L7: Damage observed in transmittance at a few percent and light output at several percent.
- 6x10^{10} n/cm (^{252}Cf) for SIPAT-LYSO-L7: Damage in transmittance and light output were observed.

6×10^8 n/cm^2: SIC-BGO

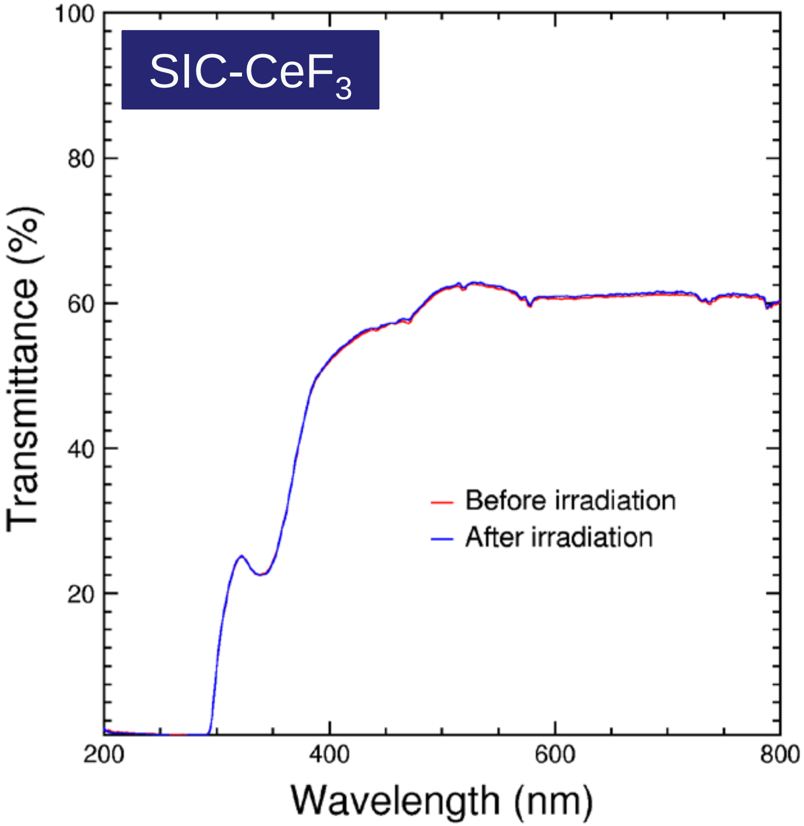
No change was observed

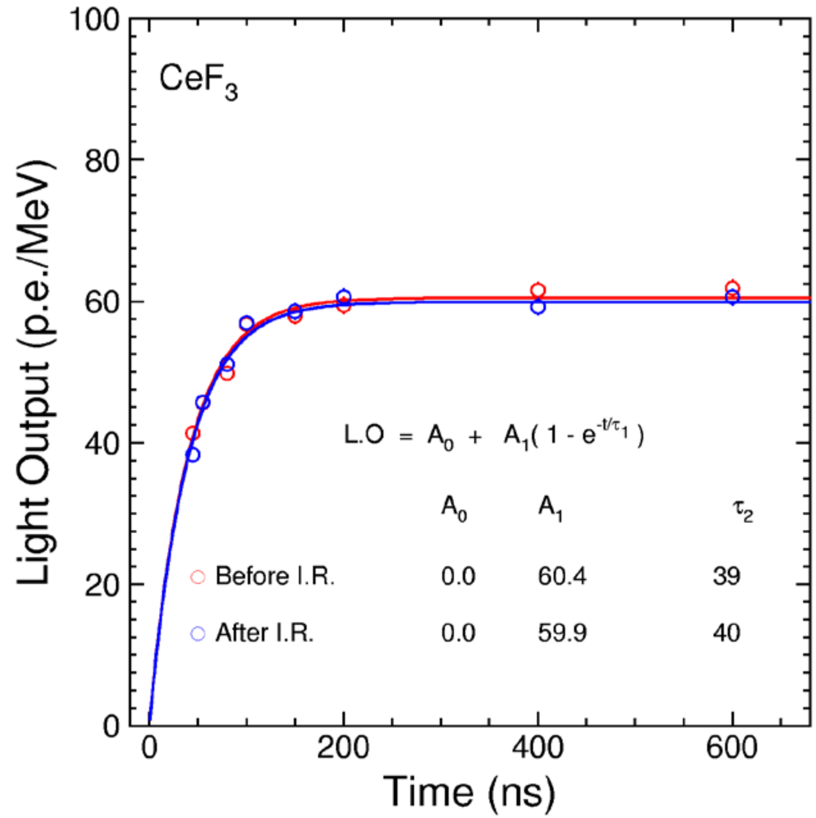




6×10^{8} n/cm^2: SIC-CeF_3

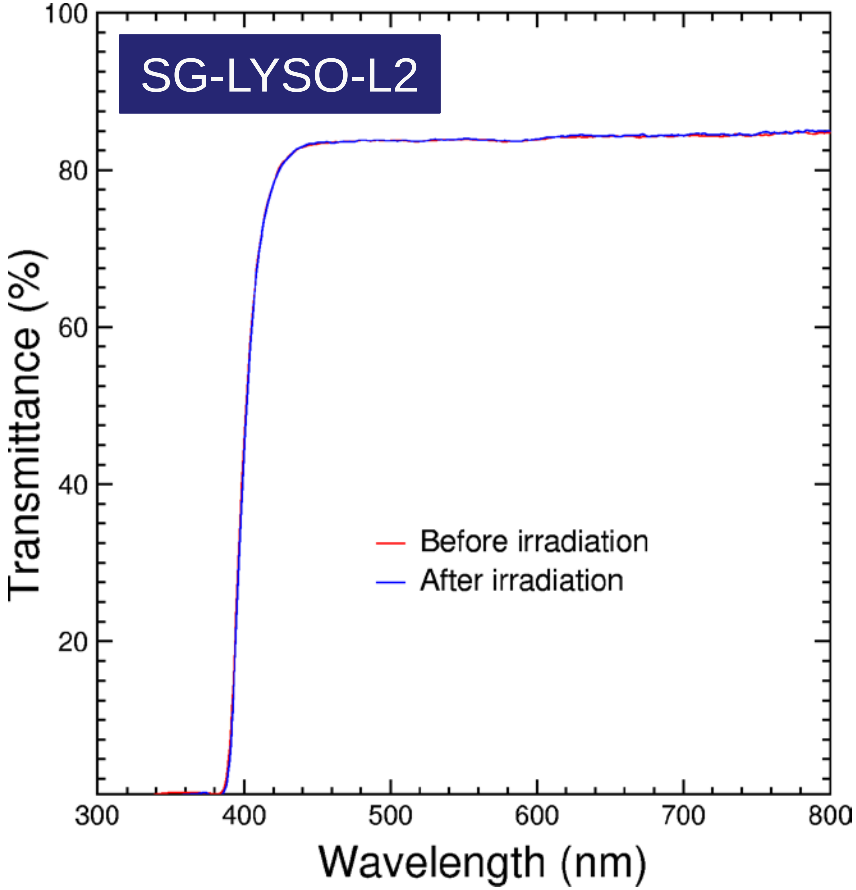
No change was observed

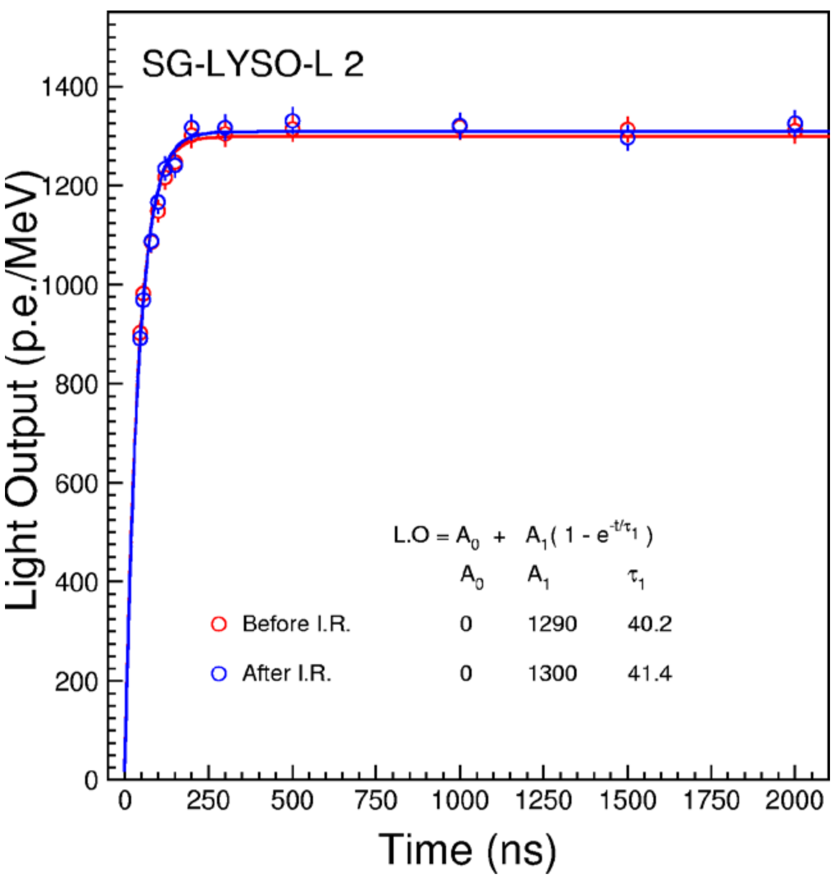




6×10^8 n/cm^2: SG-LYSO-L2

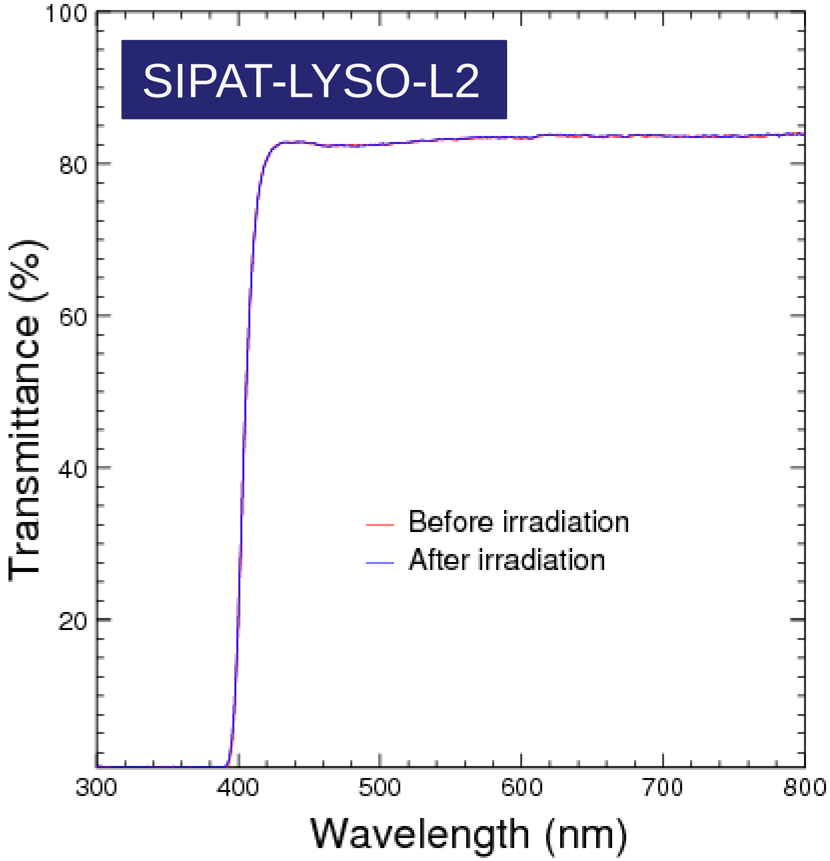
No change was observed

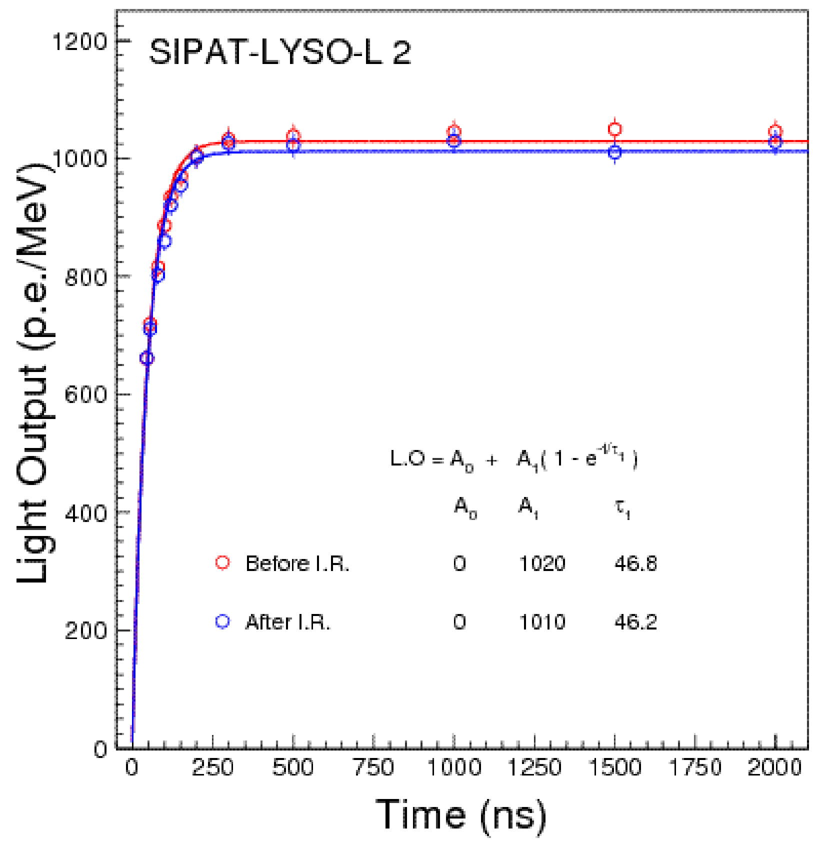




6×10^8 n/cm^2: SIPAT-LYSO-L2

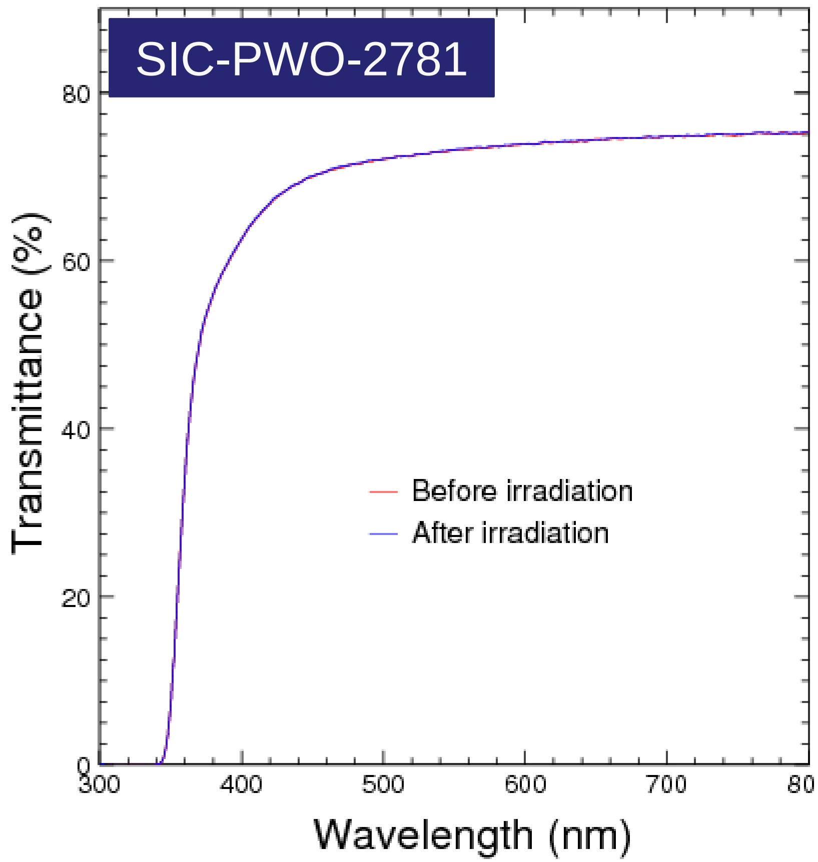
No change was observed

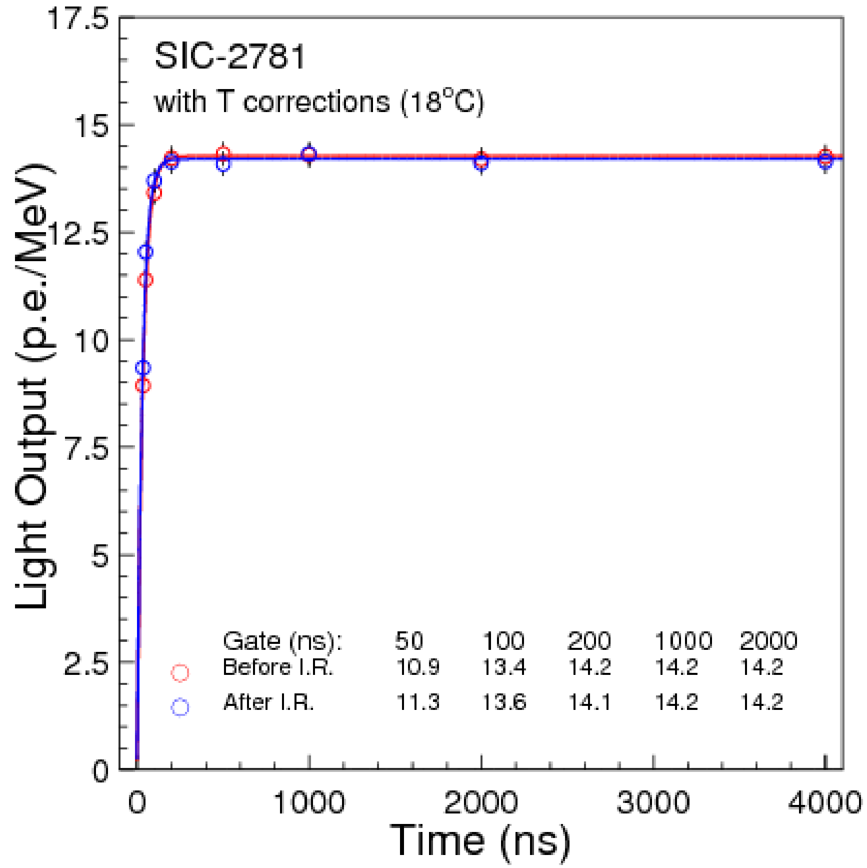




6×10⁸ n/cm²: SIC-PWO-2781

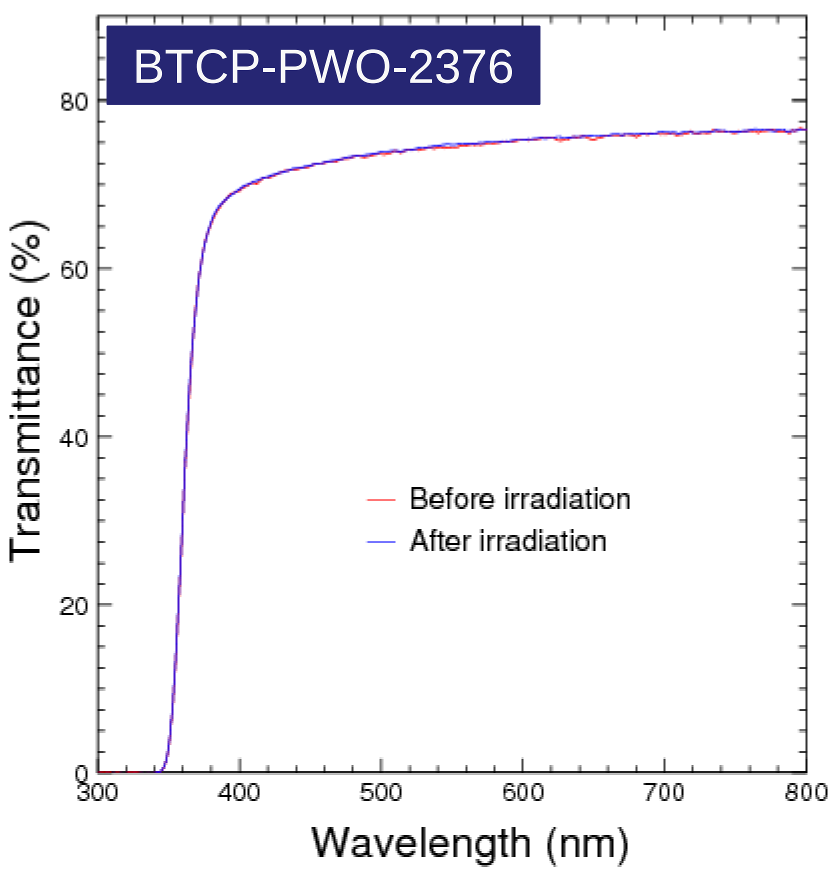
No change was observed

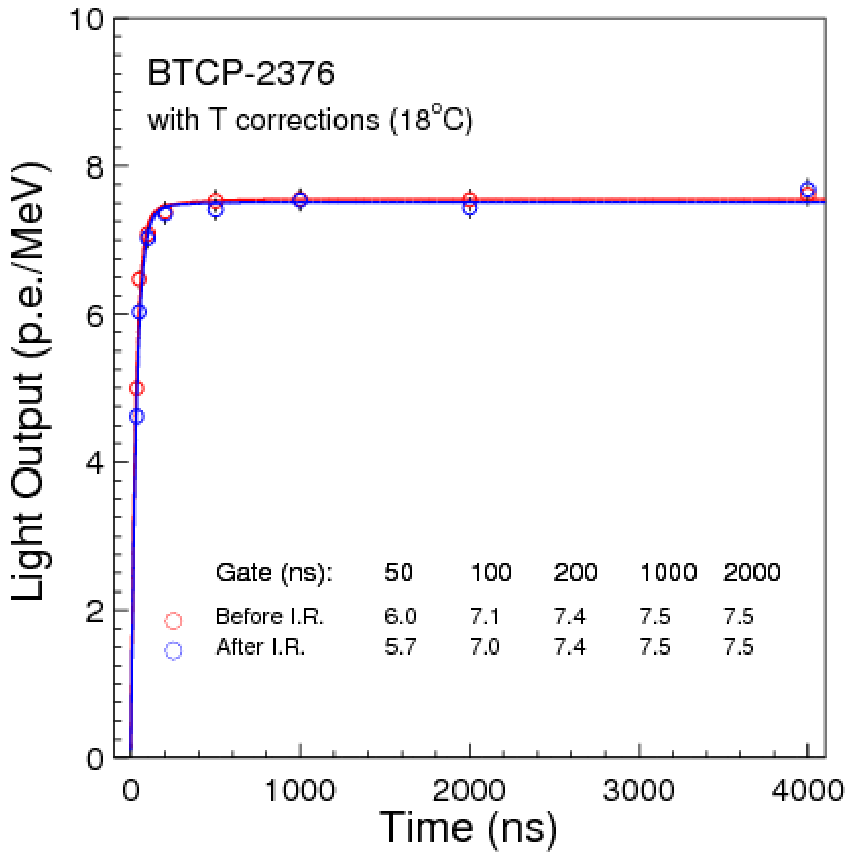




6×10^8 n/cm^2: BTCP-PWO-2376

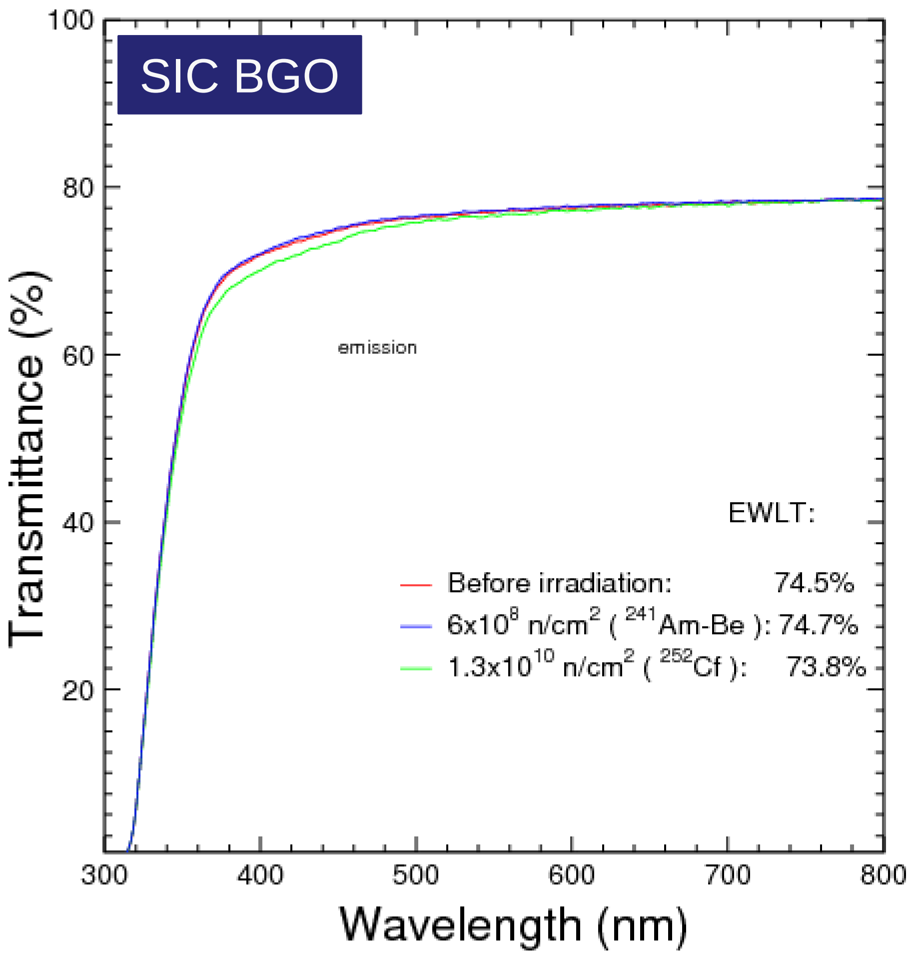
No change was observed

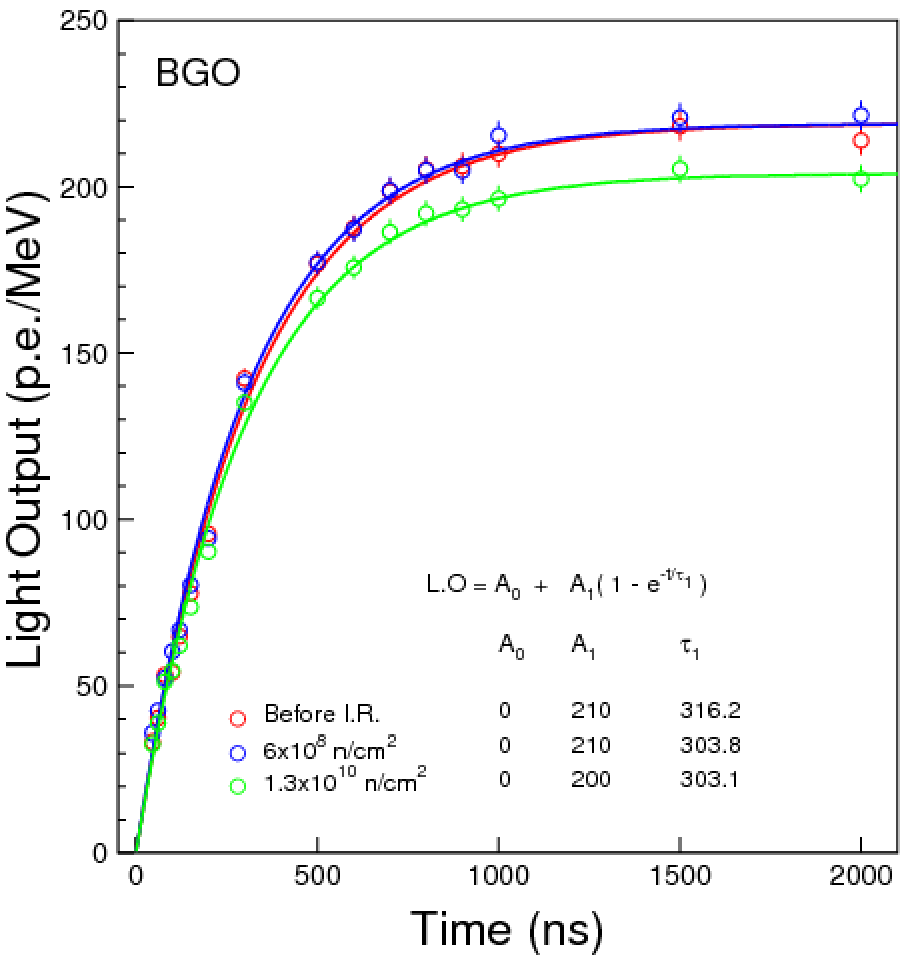




10^{10} n/cm^2: SIC-BGO

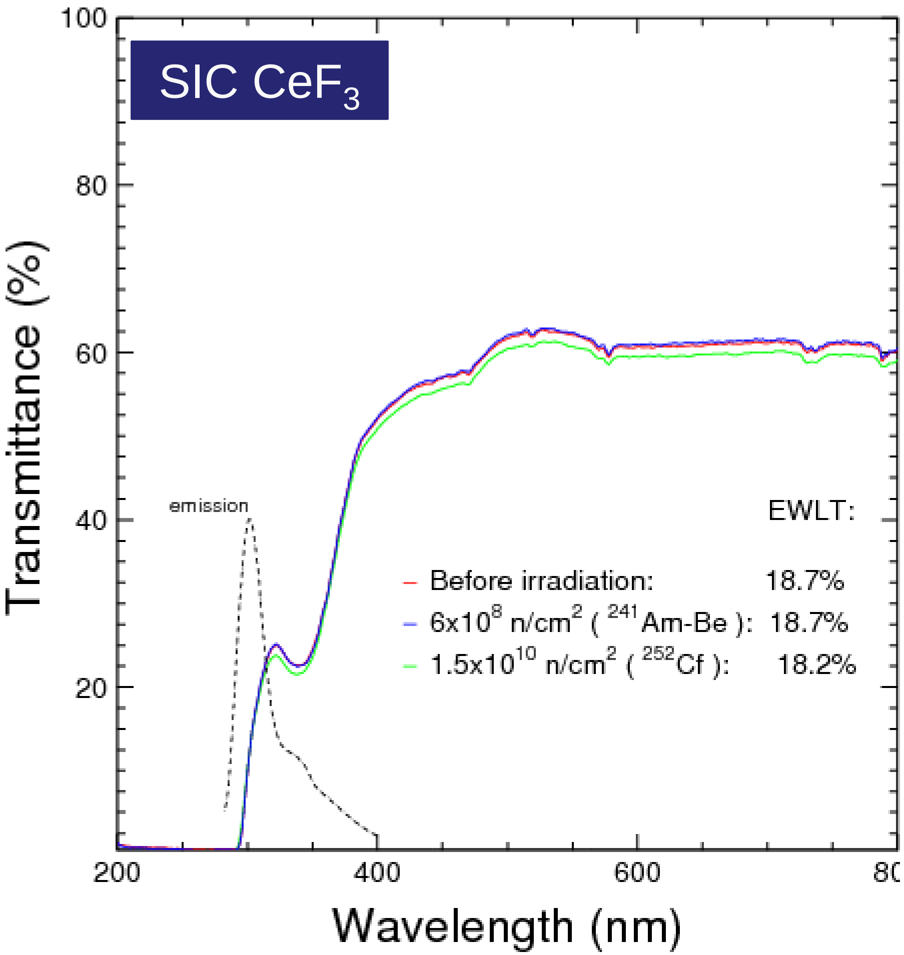
Damage: EWLT 1%, LO 5%

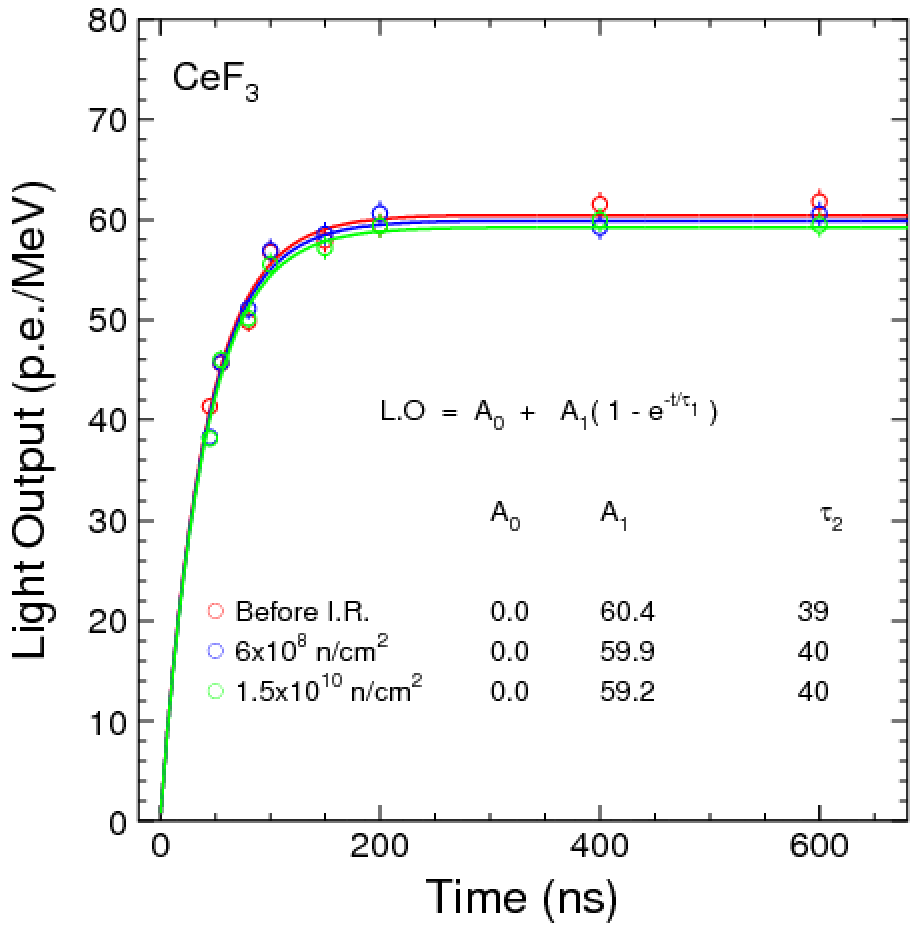




10^{10} n/cm^2: SIC-CeF_3

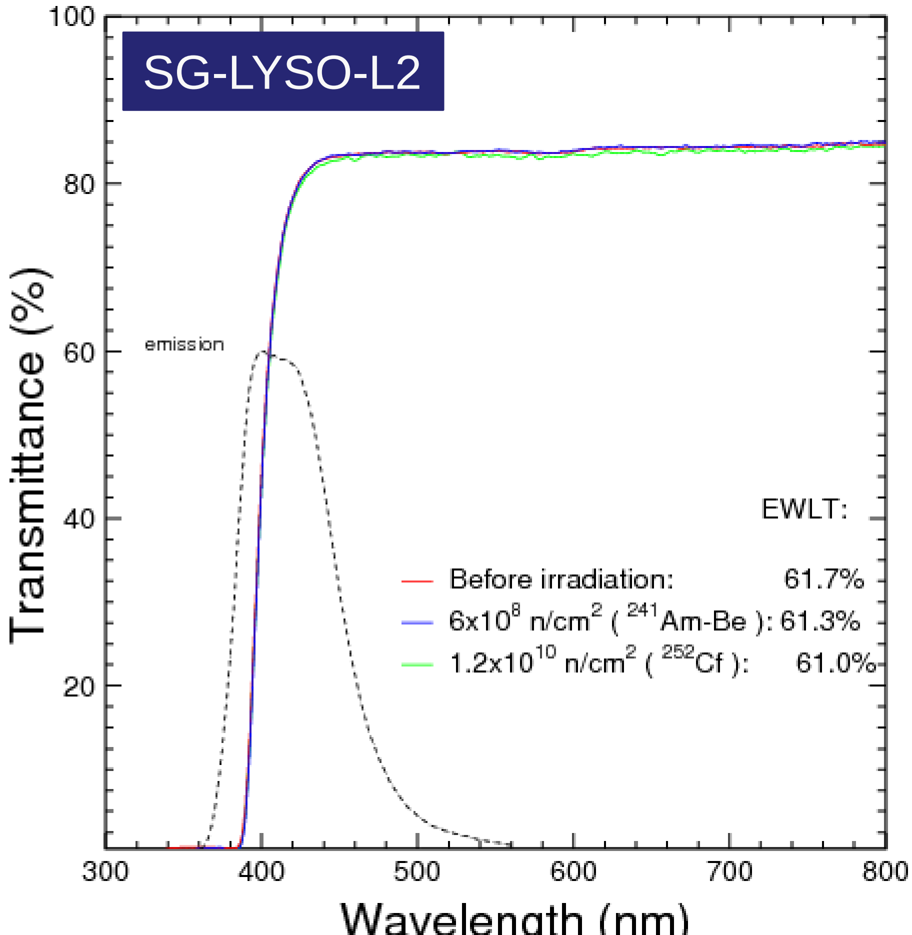
Damage: EWLT 3%, LO 2%

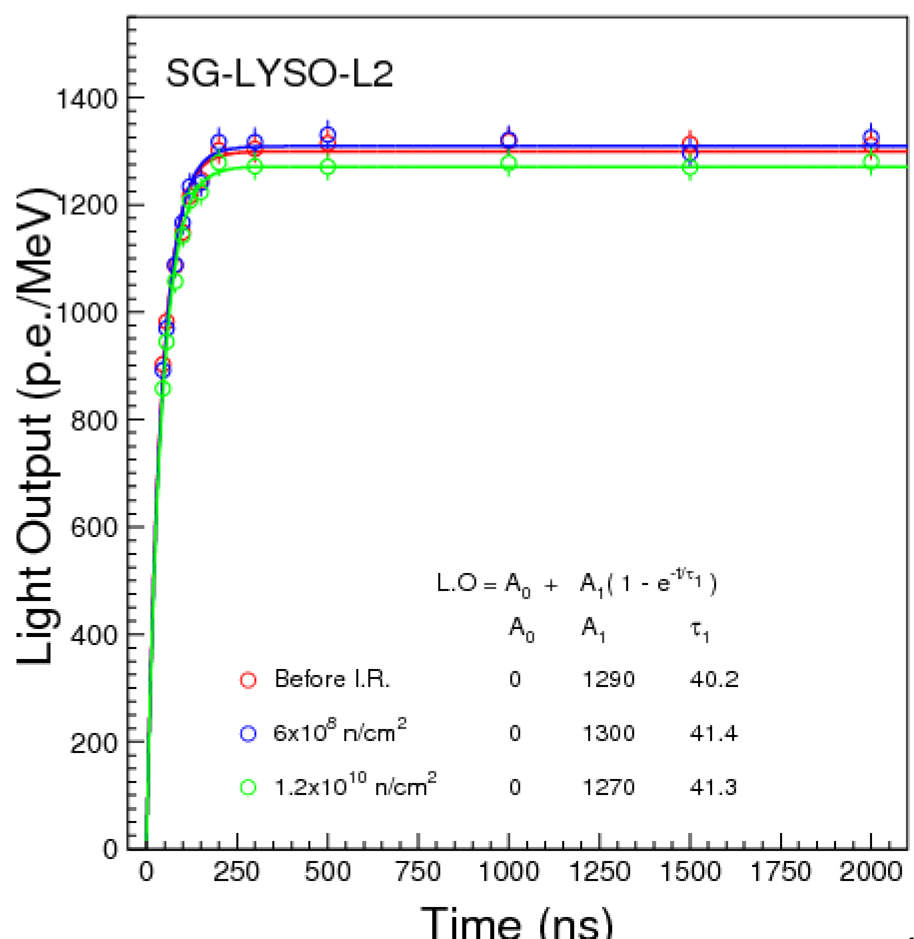




10^{10} n/cm^2: SG-LYSO-L2

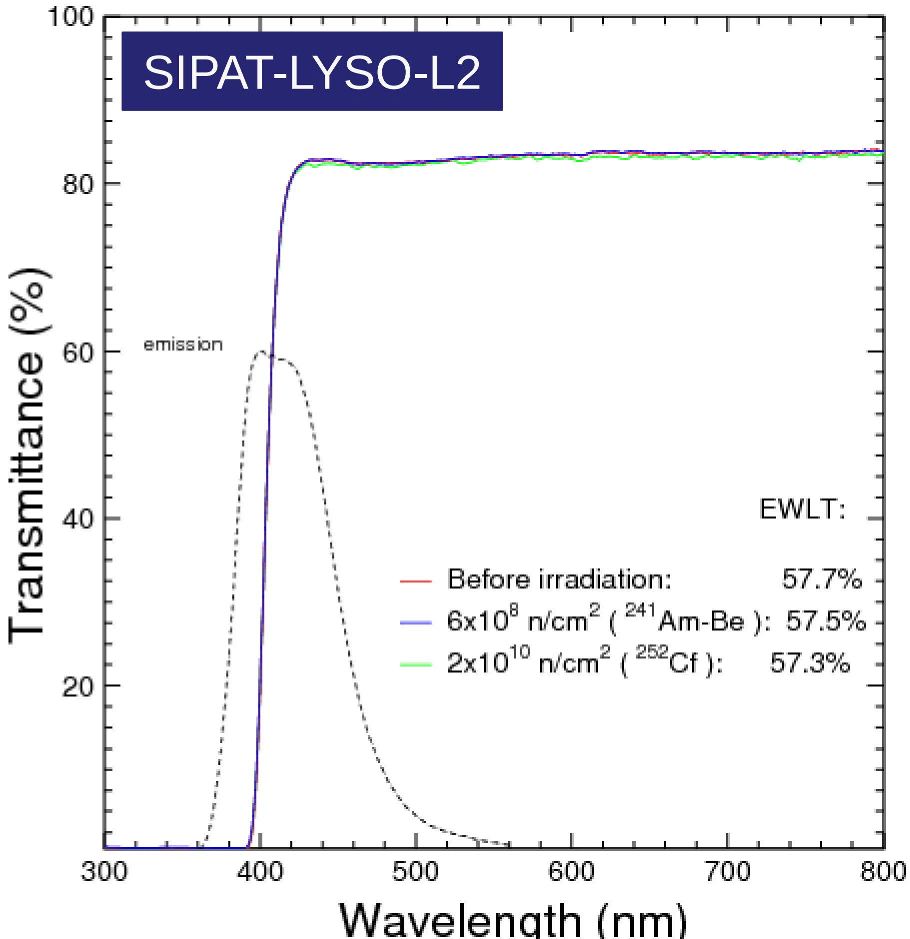
Damage: EWLT 1%, LO 2%

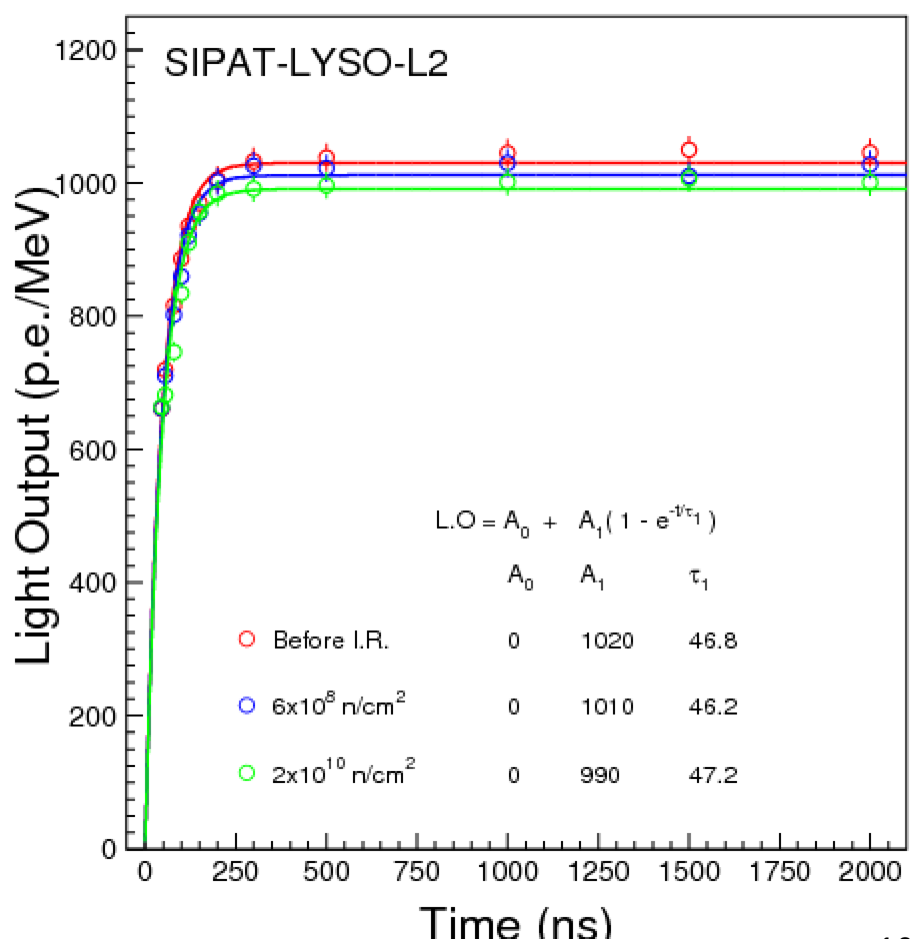




10^{10} n/cm^2: SIPAT-LYSO-L2

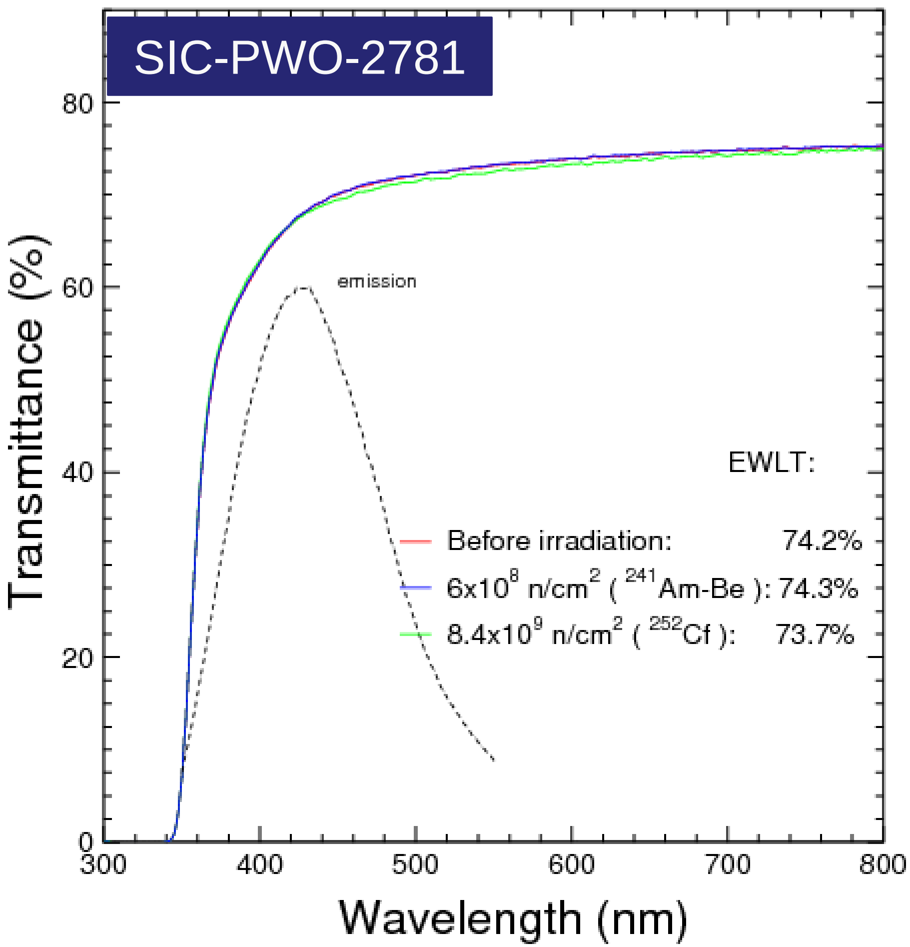
Damage: EWLT 1%, LO 3%

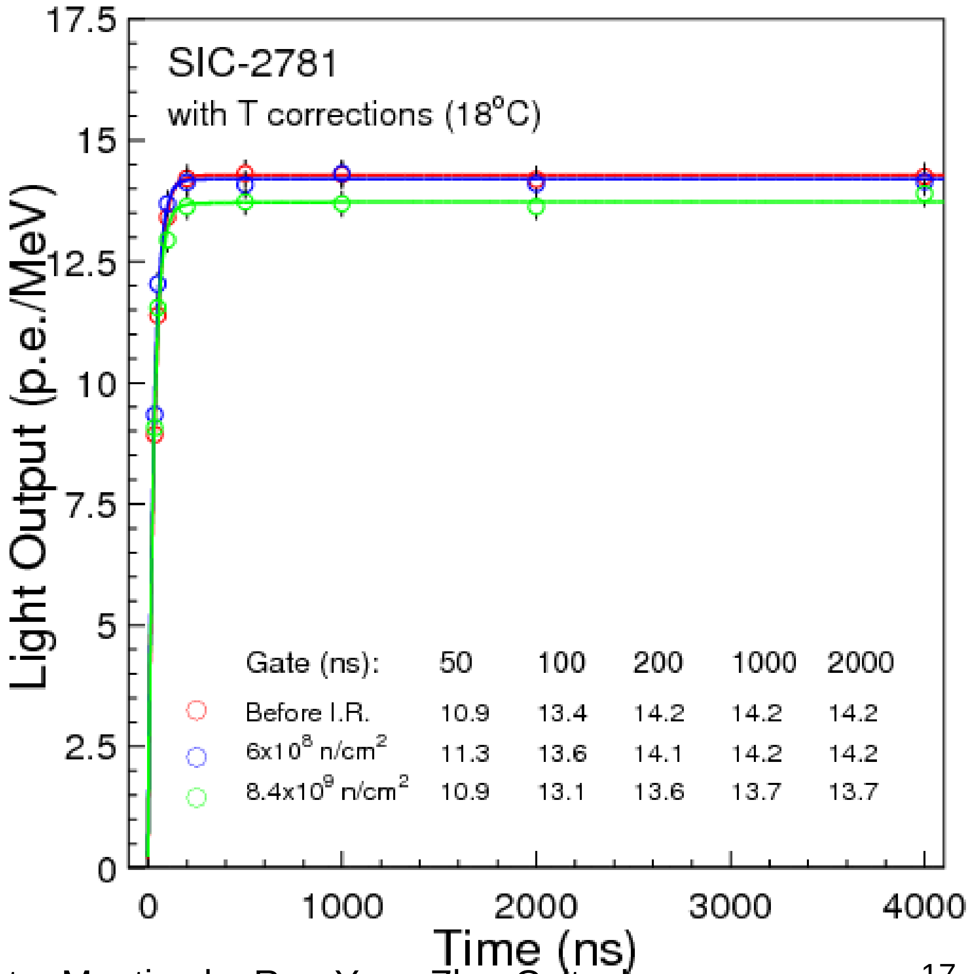




10^{10} n/cm^2: SIC-PWO-2781

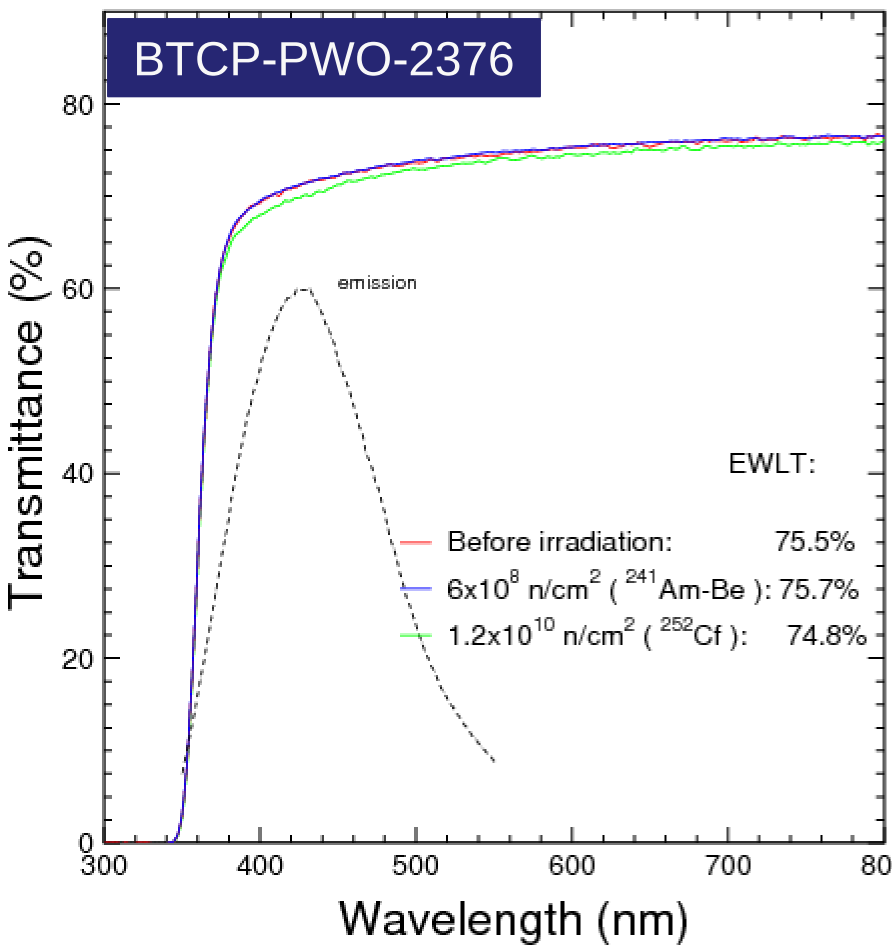
Damage: EWLT 1%, LO 4%

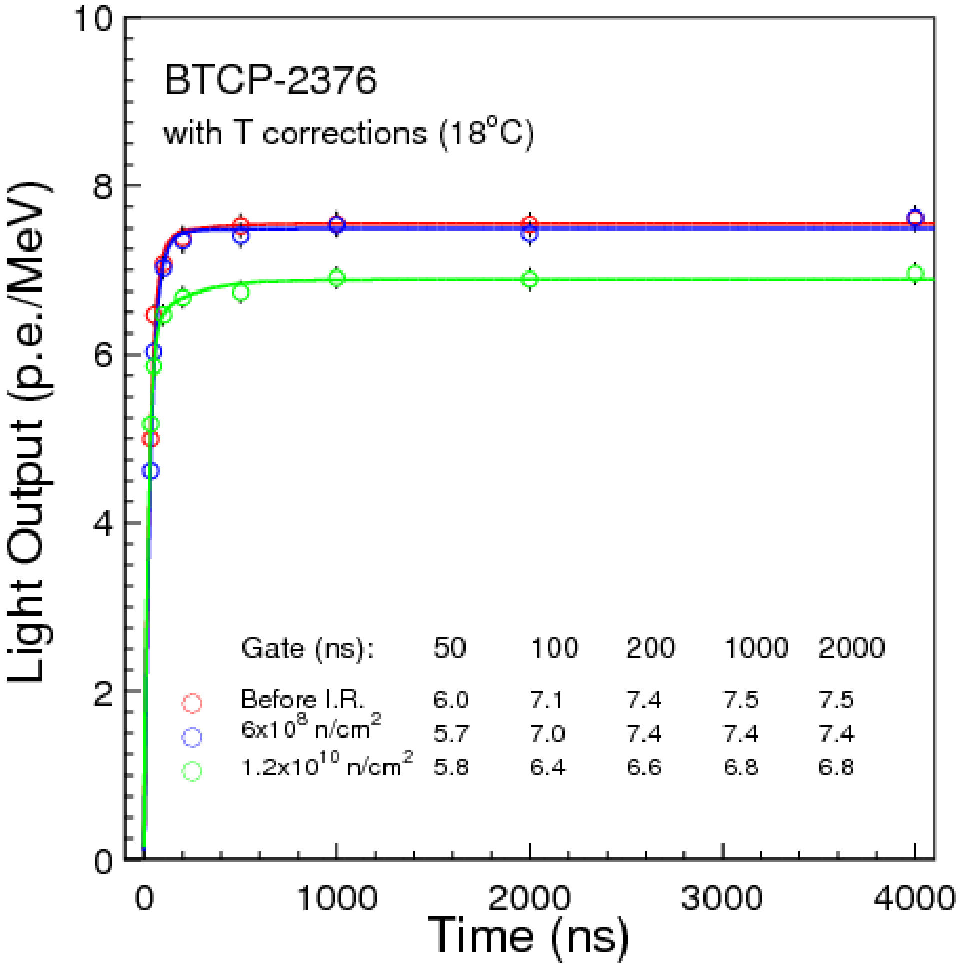




10^{10} n/cm^2: BTCP-PWO-L2

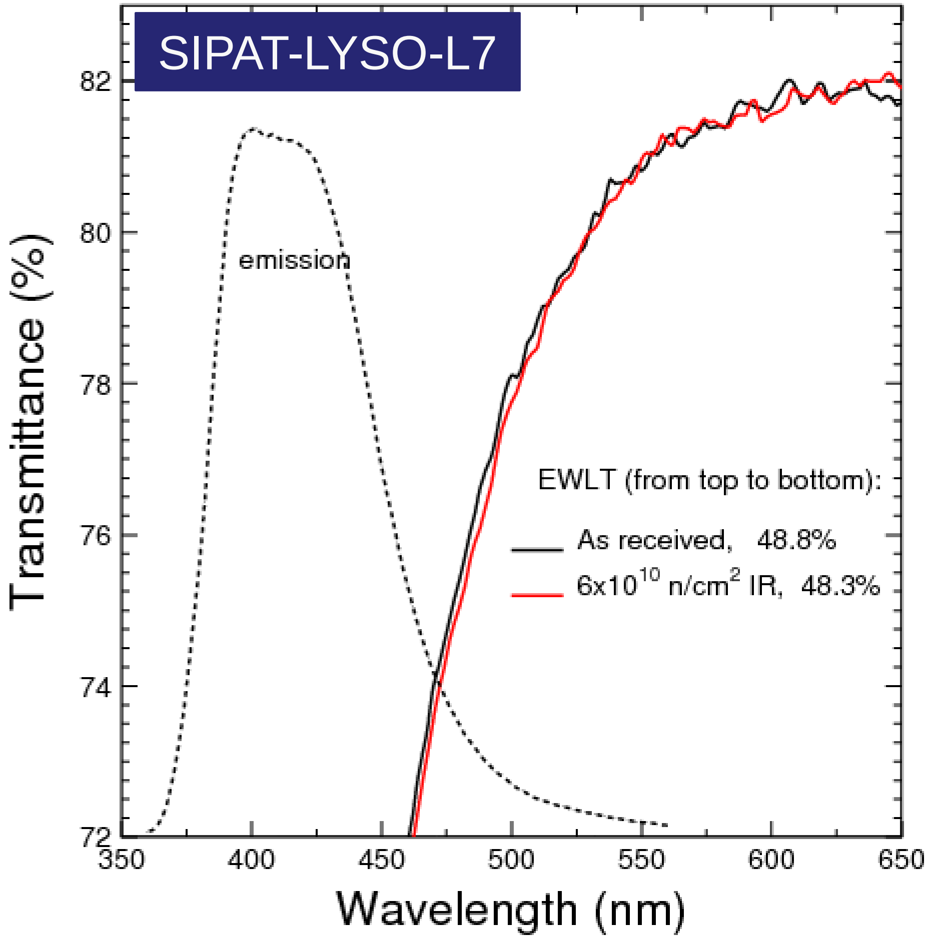
Damage: EWLT 1%, LO 9%

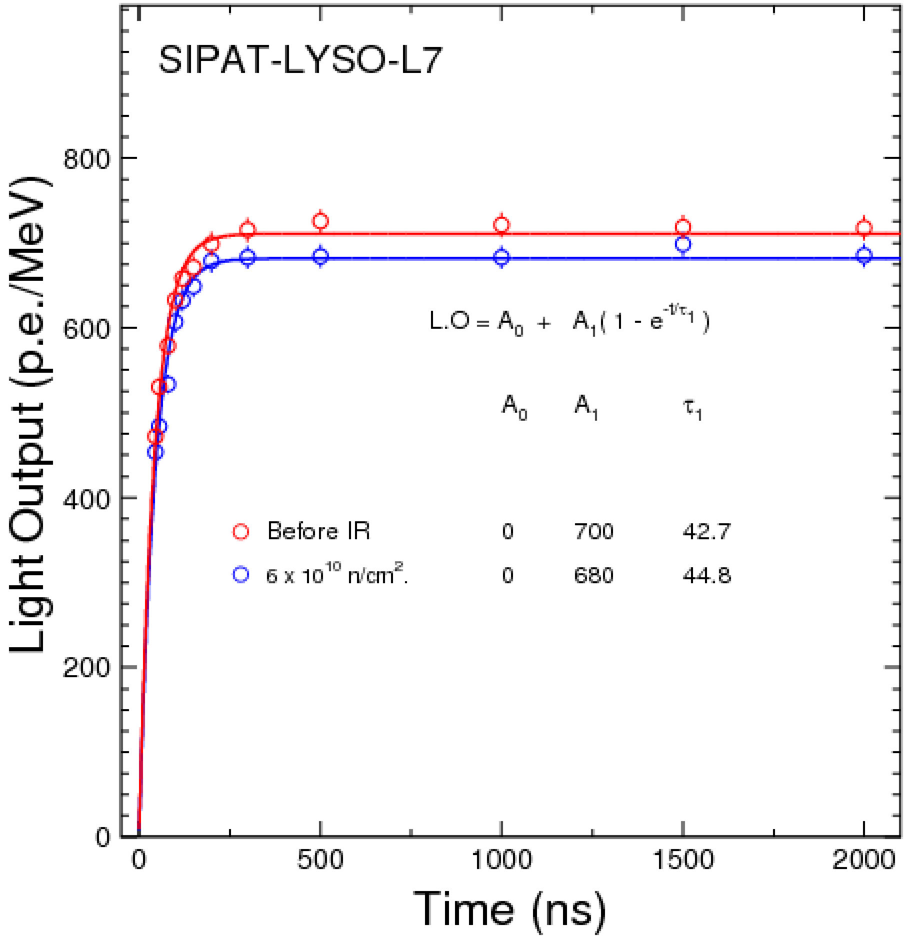




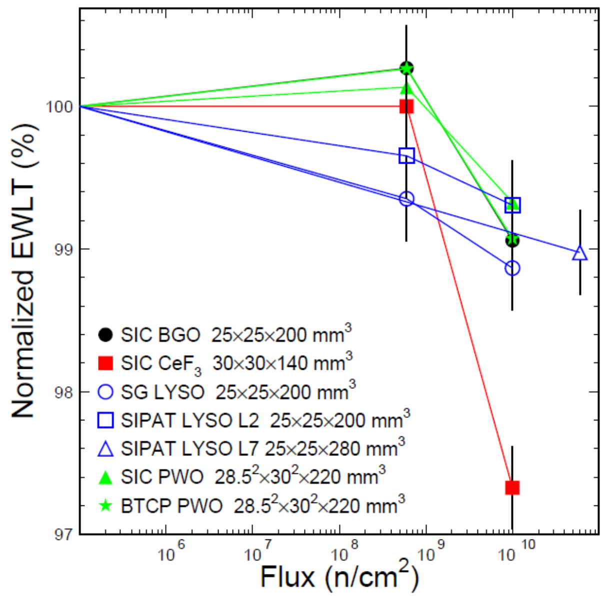
6×10^{10} n/cm^2: SIPAT-LYSO-L7

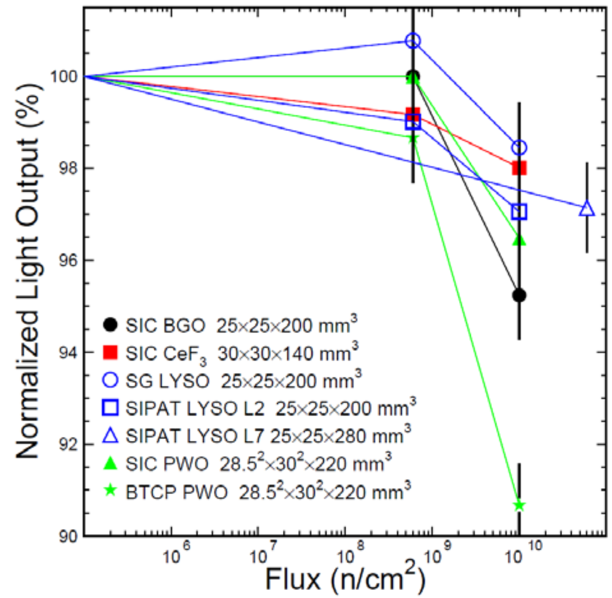
Damage: EWLT 1%, LO 3%





LT & LO Damage Summary

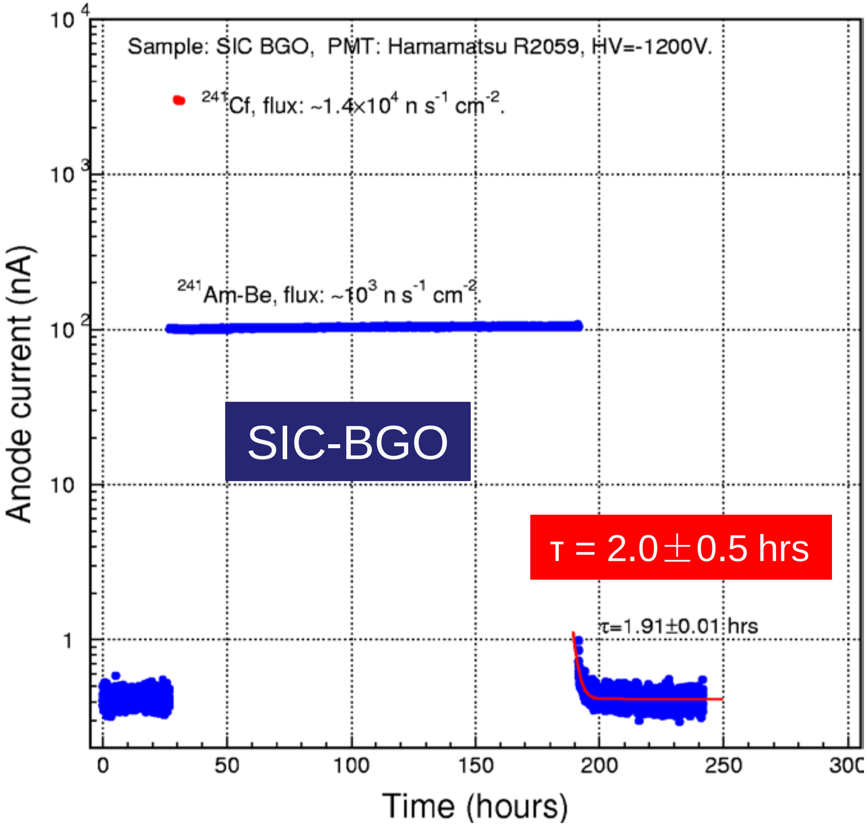


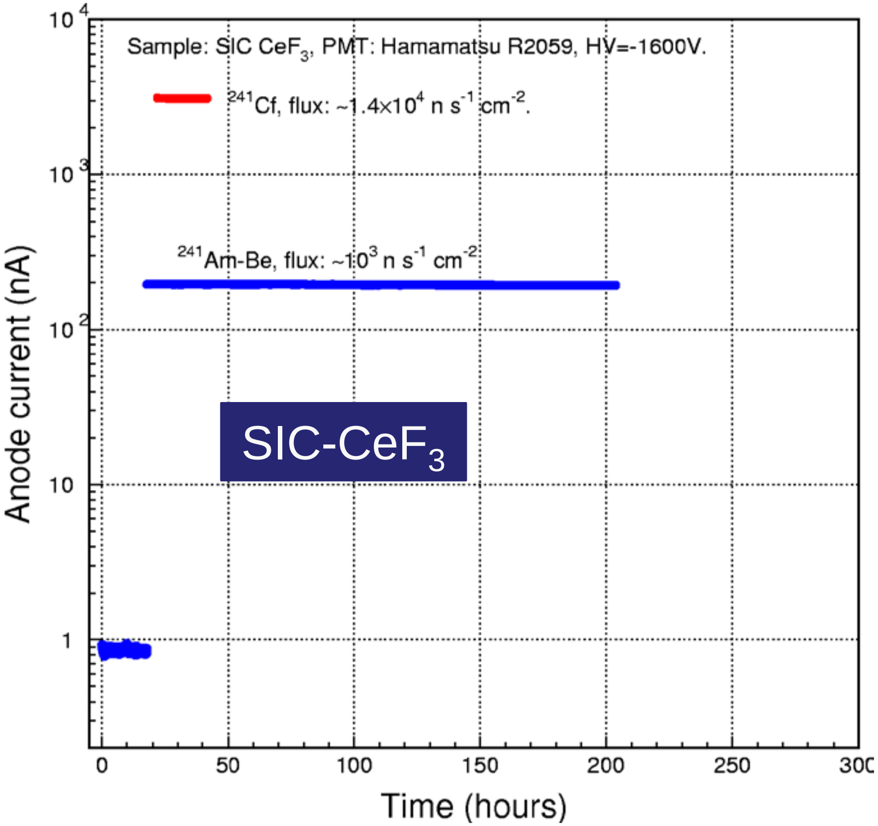


ID	Radiation Damage Effect							
Fluence (n/cm^2)	EWLT (%)				LO (p.e./MeV)			
	0	6×10^8	1×10^{10}	6×10^{10}	0	6×10^8	1×10^{10}	6×10^{10}
SIC BGO	74.5±0.2	74.7±0.2	73.8±0.2		210±2	210±2	200±2	
SIC CeF_3	18.7±0.1	18.7±0.1	18.2±0.1		60.4±0.6	59.9±0.6	59.2±0.6	
SG LYSO L2	61.7±0.2	61.3±0.2	61.0±0.2		1290±13	1300±13	1270±13	
SIPAT LYSO L2	57.7±0.2	57.5±0.2	57.3±0.2		1020±10	1010±10	990±10	
SIPAT LYSO L7	48.8±0.2			48.3±0.2	700±7			680±7
SIC PWO	74.2±0.2	74.3±0.2	73.7±0.2		14.2±0.1	14.2±0.1	13.7±0.1	
BTCO PWO	75.5±0.2	75.7±0.2	74.8±0.2		7.5±0.1	7.4±0.1	6.8±0.1	

Neutron Induced Phosphorescence

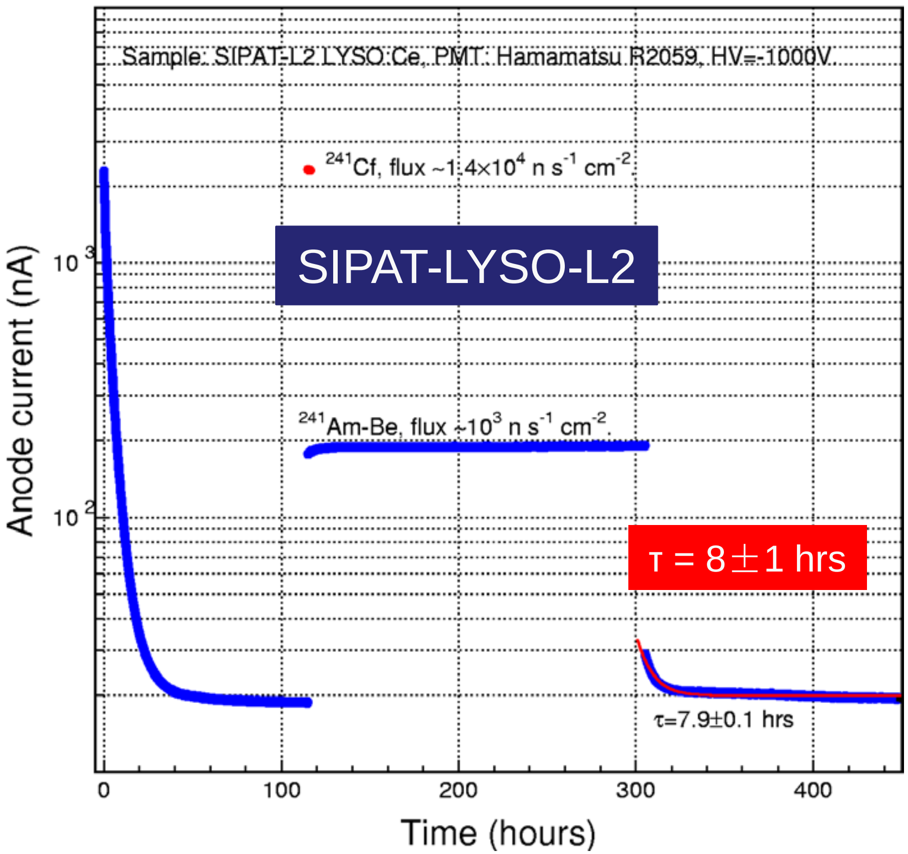
Phosphorescence decay time is about 2 hrs for BGO

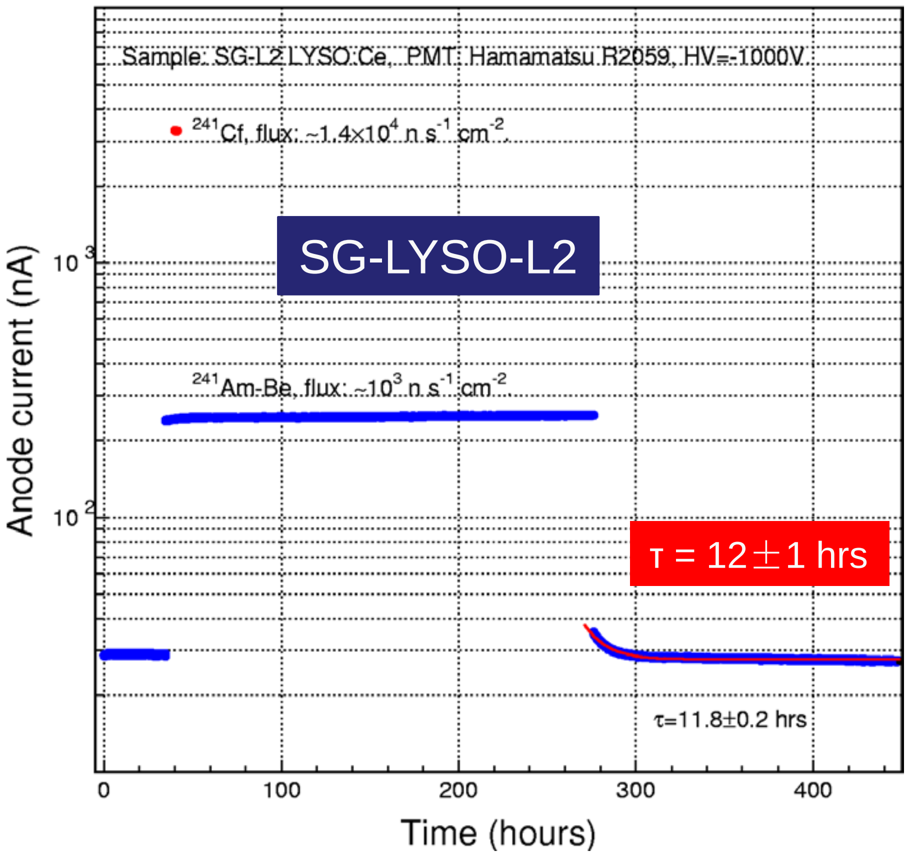




Neutron Induced Phosphorescence

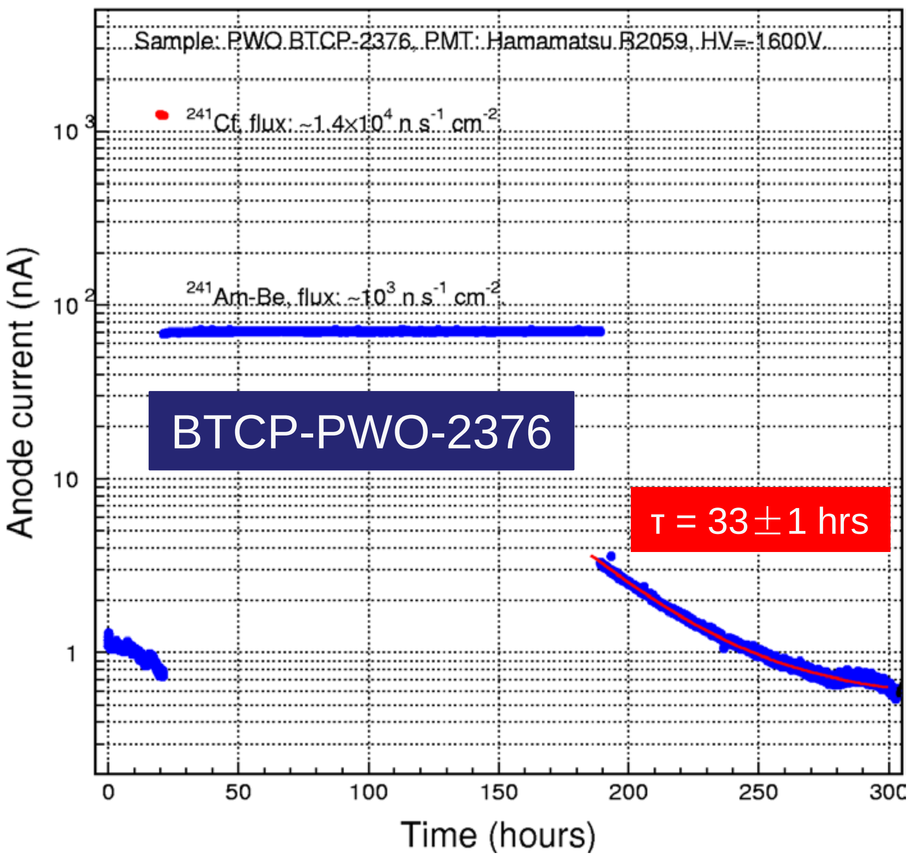
Phosphorescence decay time is about 10 hrs for LYSO

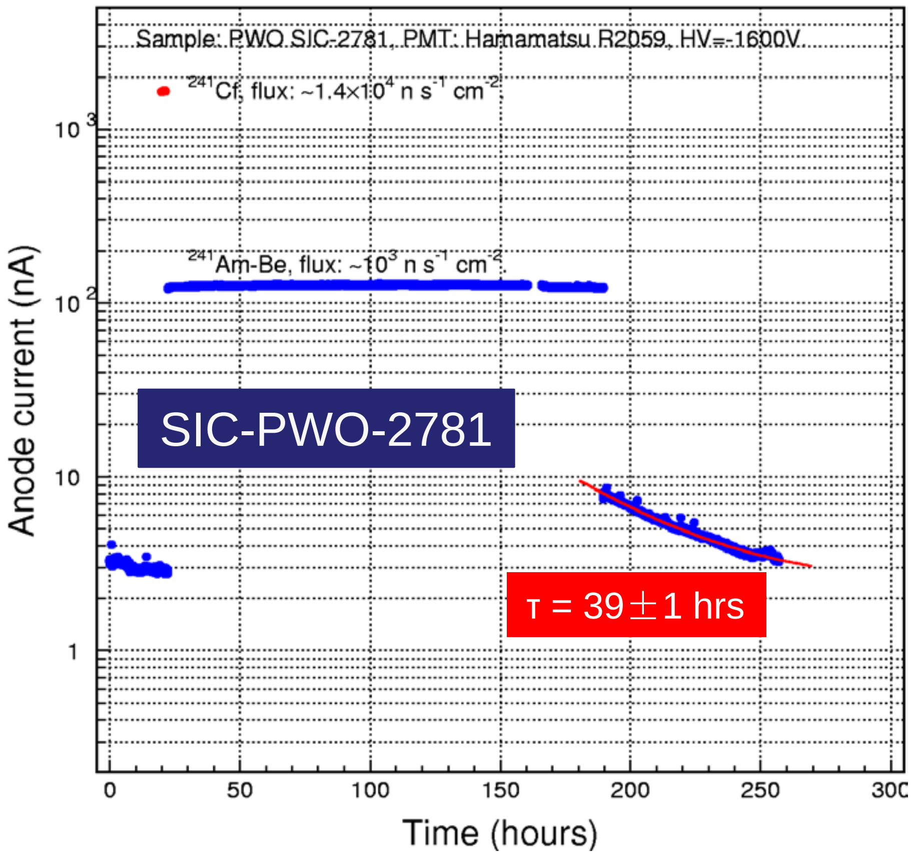




Neutron Induced Phosphorescence

Phosphorescence decay time is about 30 to 40 hrs for PWO





Photoelectron Current Coefficient

F is defined as the neutron induced photoelectron number under unit neutron flux, which can be determined by using the measured anode current:

$$F = \frac{\frac{Photocurrent}{Charge_{electron} \times Gain_{PMT}}}{Flux_{crystal}}$$

(p.e. n^{-1} cm^{2})

Because of the difficulty to properly subtract the contribution of the gamma components of the neutron sources all numerical values, including F, are considered as a upper limit.

Neutron Induced Readout Noise

Cumulated neutron fluence at the LHC are estimated to be up to 5.3×10^{13} n/cm^2 and 1.7×10^{15} n/cm^2 for CMS ECAL barrel and endcap respectively (CMS NOTE, 2008/000). Ten times higher neutron fluence are expected at the HL-LHC.

The photoelectron number in the readout gate can be extrapolated as following:

$$Q = \frac{10 \times Fluence_{10yr} \times Gate_{readout} \times F}{5.0 \times 10^{7}\,(s)} \quad \text{(p.e.)}$$

and the energy equivalent noise is derived as the standard deviation of photoelectron number :

$$\sigma = \frac{\sqrt{Q}}{LO} \quad \text{(MeV)}$$

Readout Noise Summary

Gates of 100 ns, 200 ns and 1μs are used for PWO, LYSO and CeF, and BGO respectively. LYSO shows the smallest neutron induced readout noise.

Sample	Dimension cm^3	L.Y. p.e./MeV	F $p.e.n^{-1}cm^2$ (Am241-Be)	F $p.e.n^{-1}cm^2$ (Cf252)	σ_{bar} MeV (Am241-Be)	σ_{bar} MeV (Cf252)	σ_{end} MeV (Am241-Be)	σ_{end} MeV (Cf252)
SIC-2781 PWO	2.8×22×3.0	14.2	1.7×10^3	1.6×10^3	2.5	2.4	26.3	25.5
BTCP-2376 PWO	2.8×22×3.0	7.5	1.0×10^3	1.2×10^3	4.1	4.5	37.0	40.5
SIPAT-L2 LYSO	2.5×20×2.5	1940	2.6×10^5	2.3×10^5	0.3	0.3	3.4	3.2
SG-L2 LYSO	2.5×20×2.5	2480	3.4×10^5	3.2×10^5	0.3	0.3	2.9	2.8
SIC BGO	2.5×20×2.5	340	2.0×10^4	4.1×10^4	1.4	1.9	11.7	16.3
SIC-CeF_3	3.0×14×3.0	60	2.6×10^3	3.0×10^3	0.4	0.4	2. 2	2. 4

Am^{241}-Be	Cf^{252}

Summary

No damage was observed in optical and scintillation properties in large size BGO, CeF_3, LYSO and PWO crystals with cumulated fast fluence of 6×10^8 n cm^{-2}.

Damage in LT at a few percent and LO at several percent was observed with cumulated fluence of 1×10^{10} n cm^{-2}.

The neutron induced photocurrent during irradiation was measured and was used to estimate the readout noise. The results show that LYSO has the smallest neutron induced readout noise because of its high LO.

Further studies are needed to go through higher neutron influence and to clear up γ-ray effects.