Gamma-ray Induced Radiation Damage up to 200 Mrad in Various Scintillation Crystals

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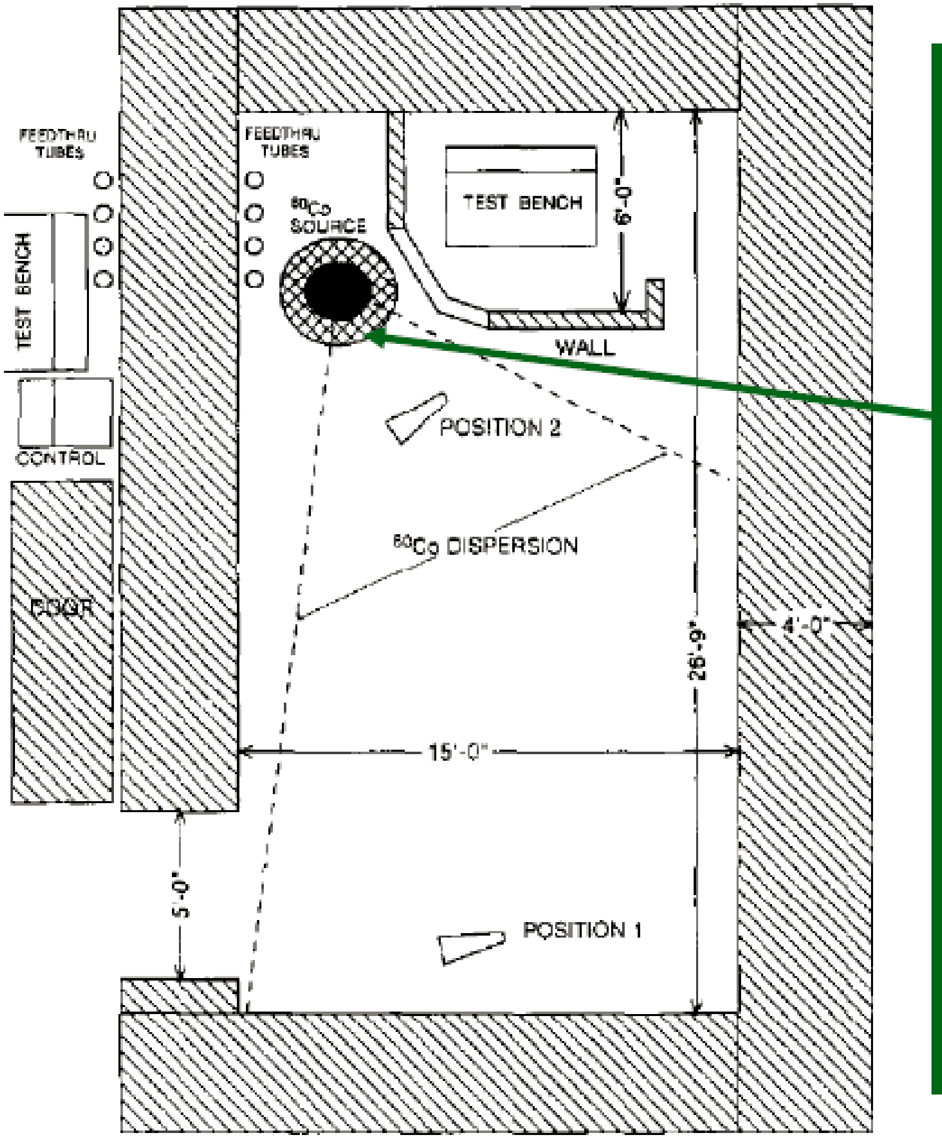
Jun 11, 2015

See also papers O6-5, O7-2, O12-1, O12-2 and O12-3

Introduction

- Gamma-ray induced radiation damage in large size crystal scintillators, including BaF_2, BGO, CeF_3, pure CsI, LSO/LYSO and PWO, was investigated.
- The irradiations were carried out at the total ionization dose (TID) facility of Jet Propulsion Laboratory (JPL) up to 200 Mrad with a dose rate up to 1 Mrad/h.
- Long crystal samples were hosted in an aluminum box of one foot square. The box was inserted in a square throat of 10" x 10" x 13.5" facing a group of Co-60 ɣ-ray sources. The entire body of crystals was uniformly irradiated.

JPL Total Absorption Dose Facility

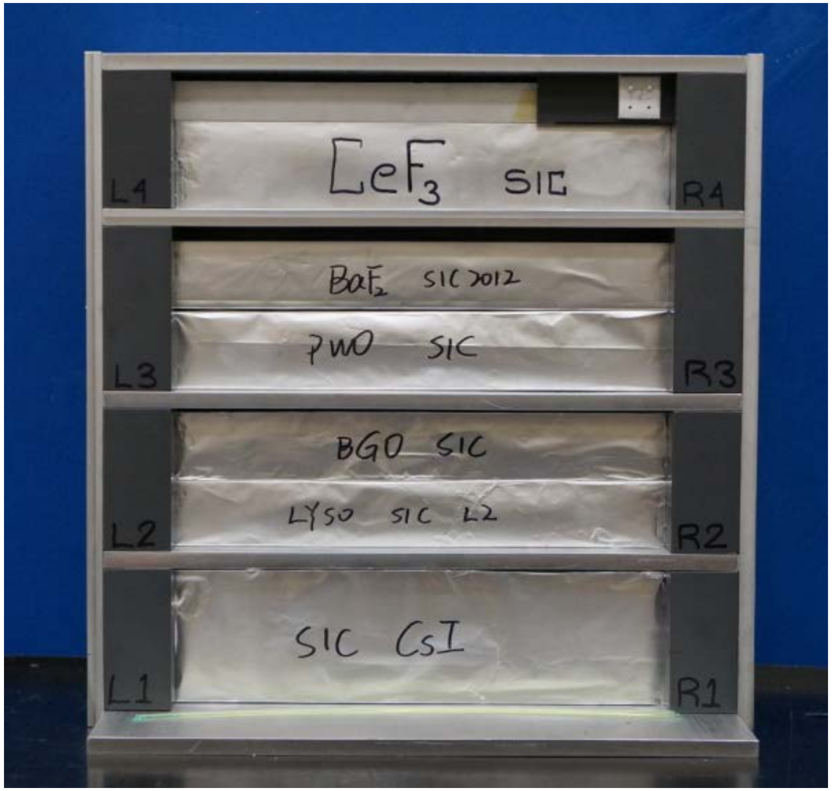


Two high intensity ^{60}Co sources provide variable dose rates up to 1 Mrad/h in an opening throat of 10" x 10" x 13.5".

Irradiations were carried out in two steps: 10 Mrad first, followed by a long weekend for additional 90 Mrad to reach 100 Mrad.

The time between the end of each irradiation and the measurement at Caltech is less than 30 minutes.

Crystals Irradiated at JPL



ID	Dimension (mm)
CeF_3	33×32×191
BaF_2	20×20×250
PWO	$28.5^2×30^2×220$
BGO	25×25×200
LYSO	25×25×200
Pure CsI	50×50×200

Experiments

- Longitudinal Transmittance (LT), Light Response Uniformity (LRU) and Light Output (LO) were measured at room temperature before and after irradiation.

Gamma-Ray Induced Damage in 20 cm Long LYSO/LSO Crystals

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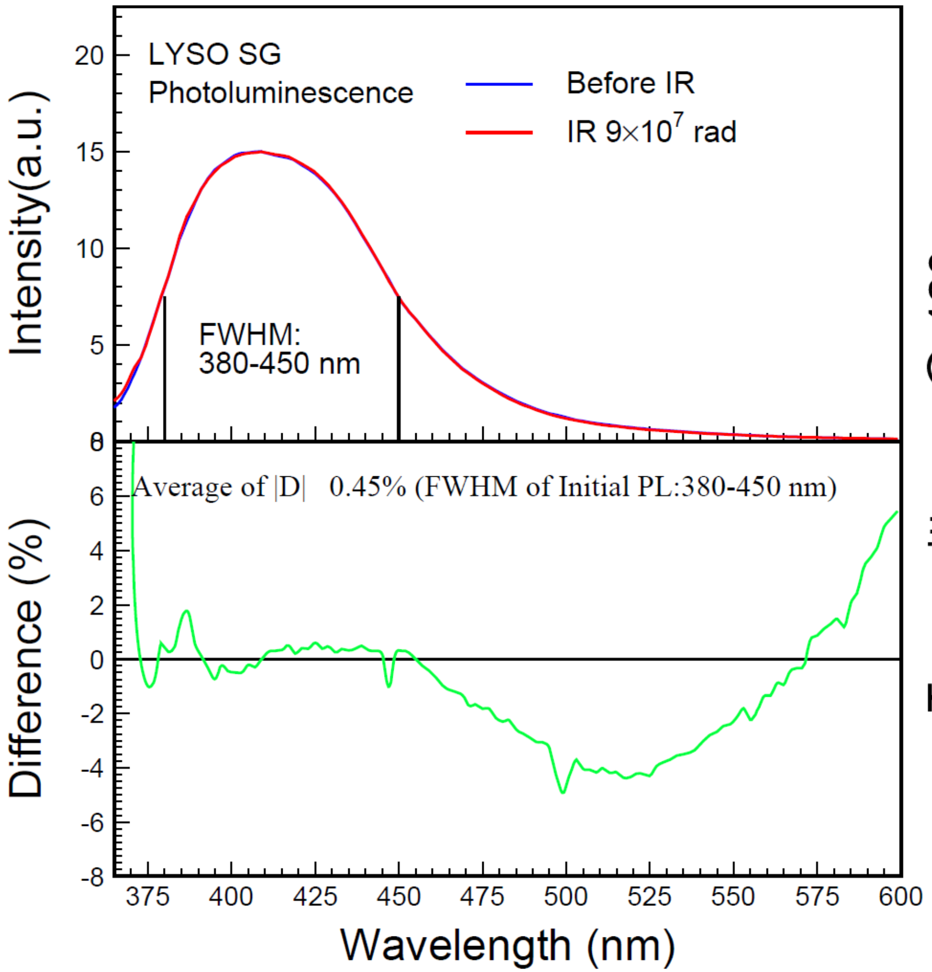
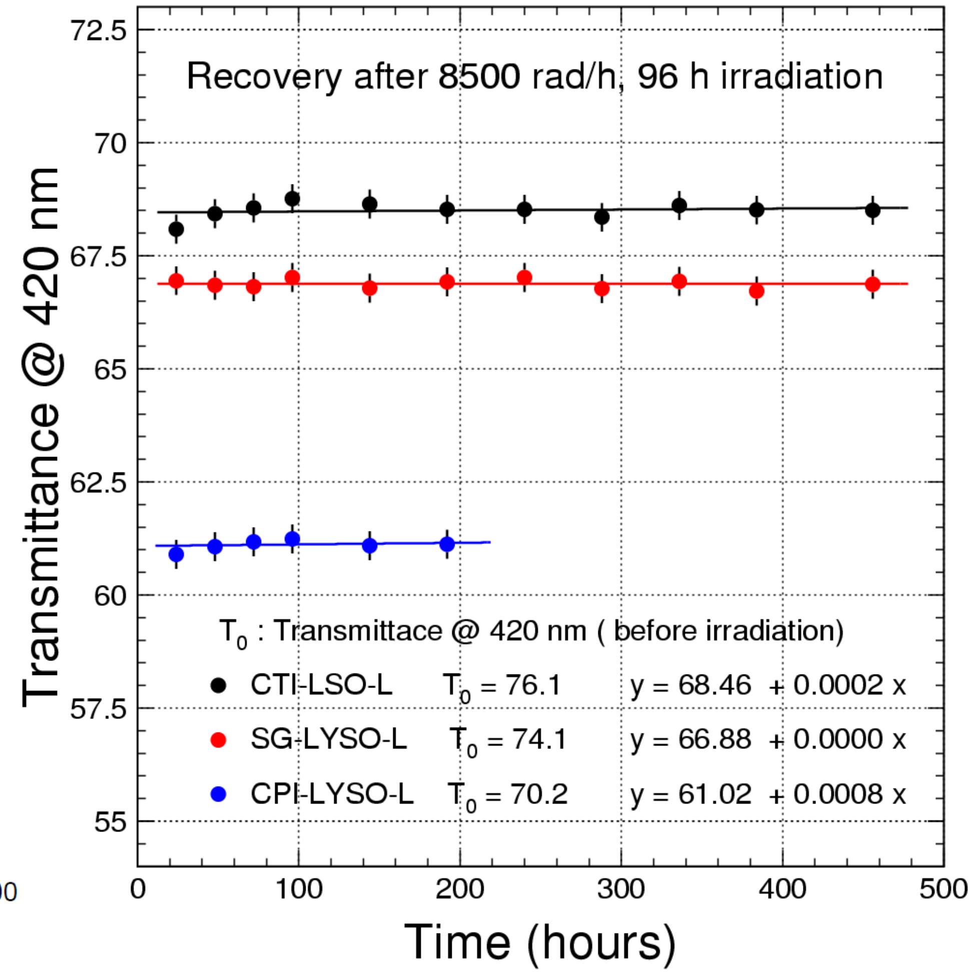
No damage in scintillation mechanism



No recovery at room temperature



LYSO/LSO/LFS: Radiation Damage in Longitudinal Transmittance (LT)

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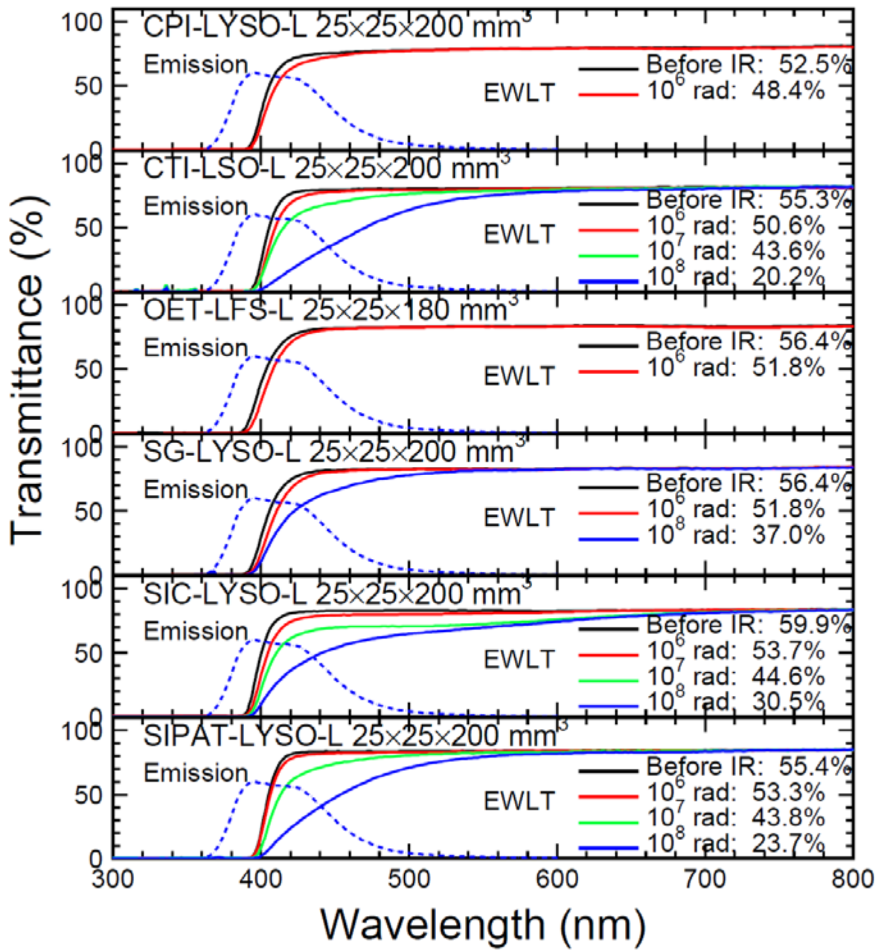
Consistent damage observed in LYSO/LSO/LFS crystals from six vendors



EWLT or emission weighted longitudinal transmittance is defined as:

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

RIAC or radiation induced absorption coefficient is defined as:

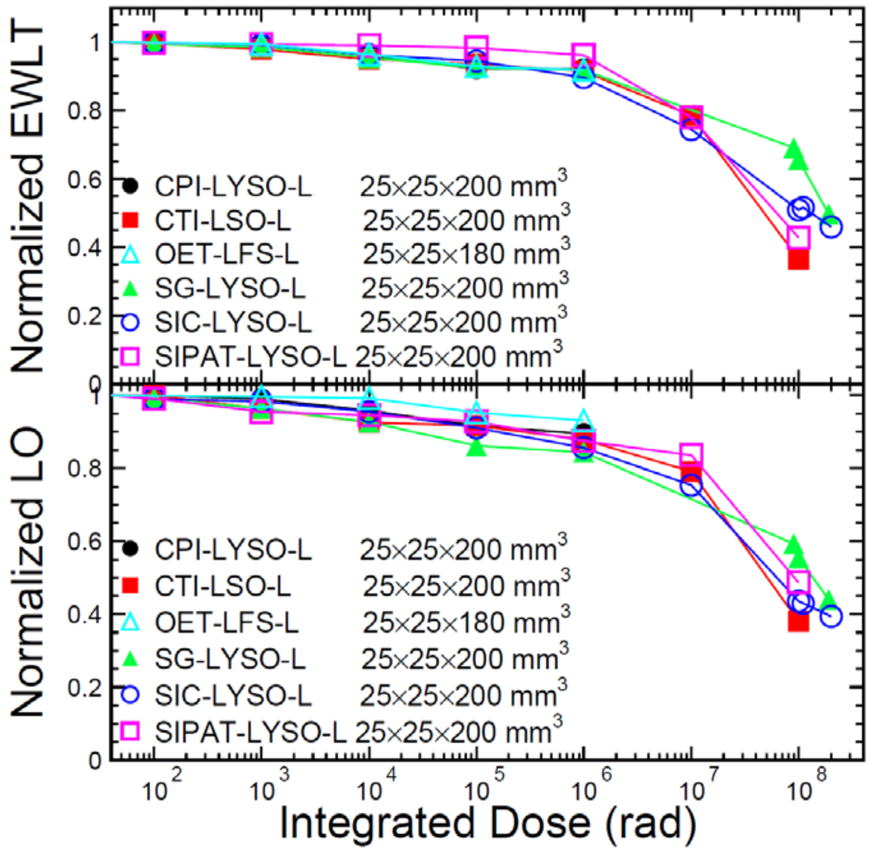
$$\mathrm{RIAC} = \frac{1}{l}\ln\frac{T_0(\lambda)}{\mathrm{T}(\lambda)}$$

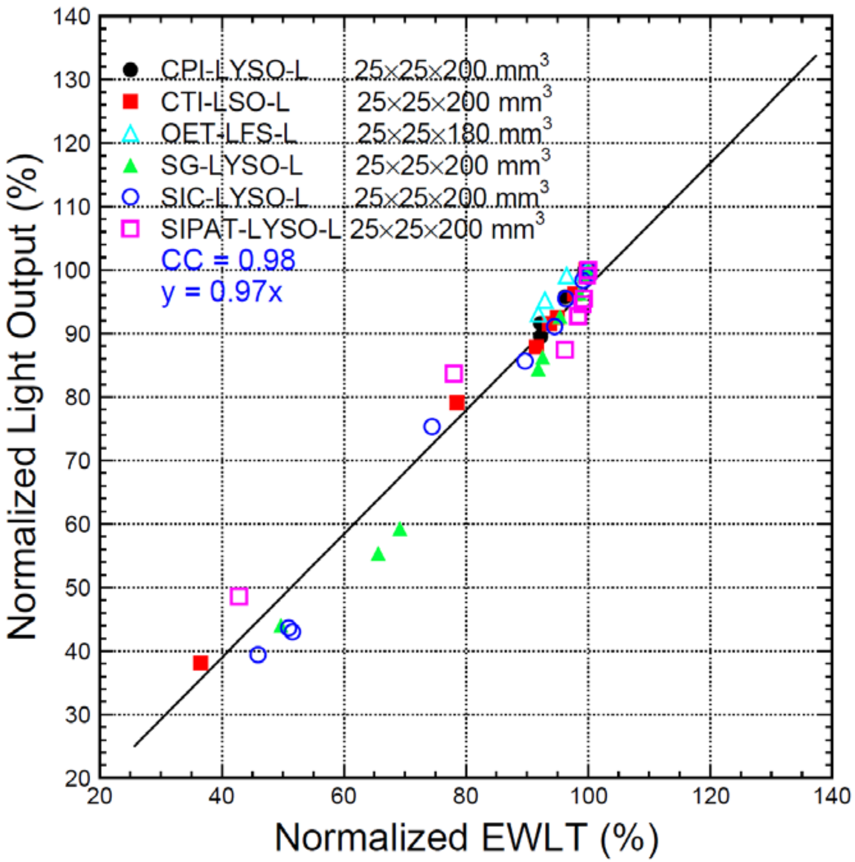
EWRIAC or emission weighted radiation induced absorption coefficient is defined as:

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

LYSO/LSO/LFS: Normalized EWLT and LO

About 20% LO loss and <5% divergence after 10 Mrad for crystals from six vendors

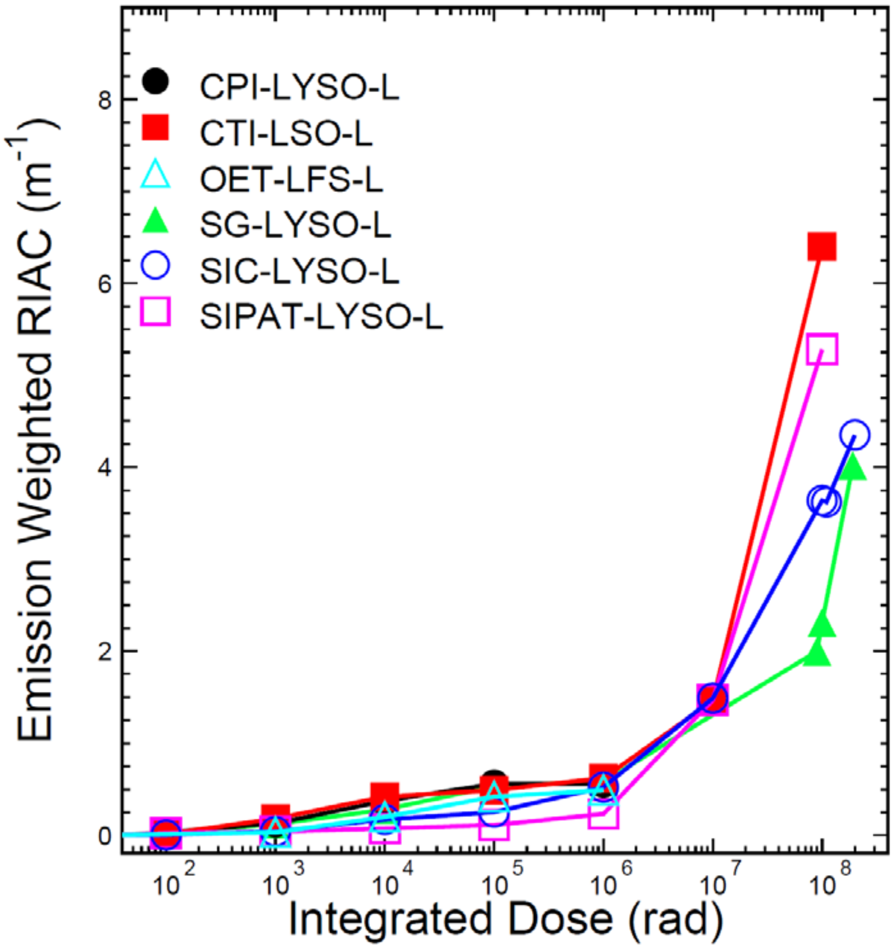


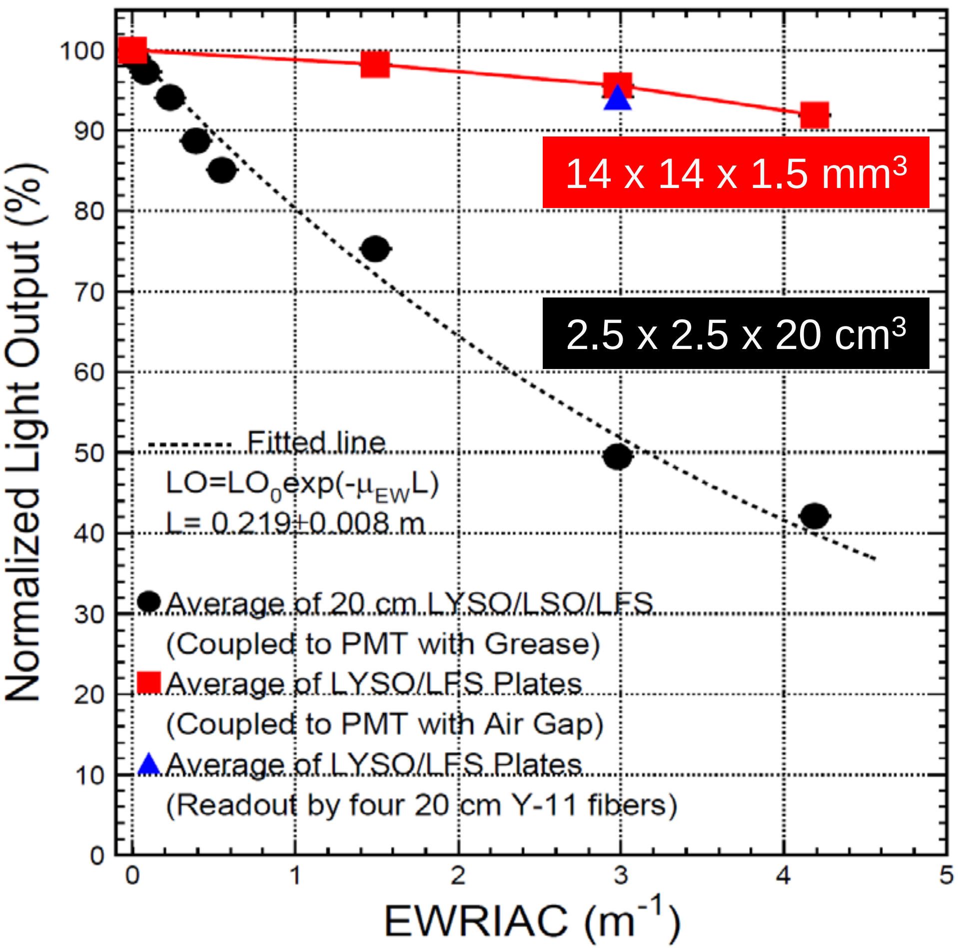


Good correlation between LO and EWLT indicates LO loss is due to LT loss

LYSO/LSO/LFS: EWRIAC as a Function of Integrated Dose and Normalized LO

In average, EWRIAC = 1.5, 3 and 4 m^{-1} after 10, 100 and 180 Mrad





LO loss of LYSO plates after 100 Mrad is 4%/6% for direct/WLS readout
Light path of 22 cm fits data obtained with 20 cm long crystals

BaF_2: Normalized EWLT and LO

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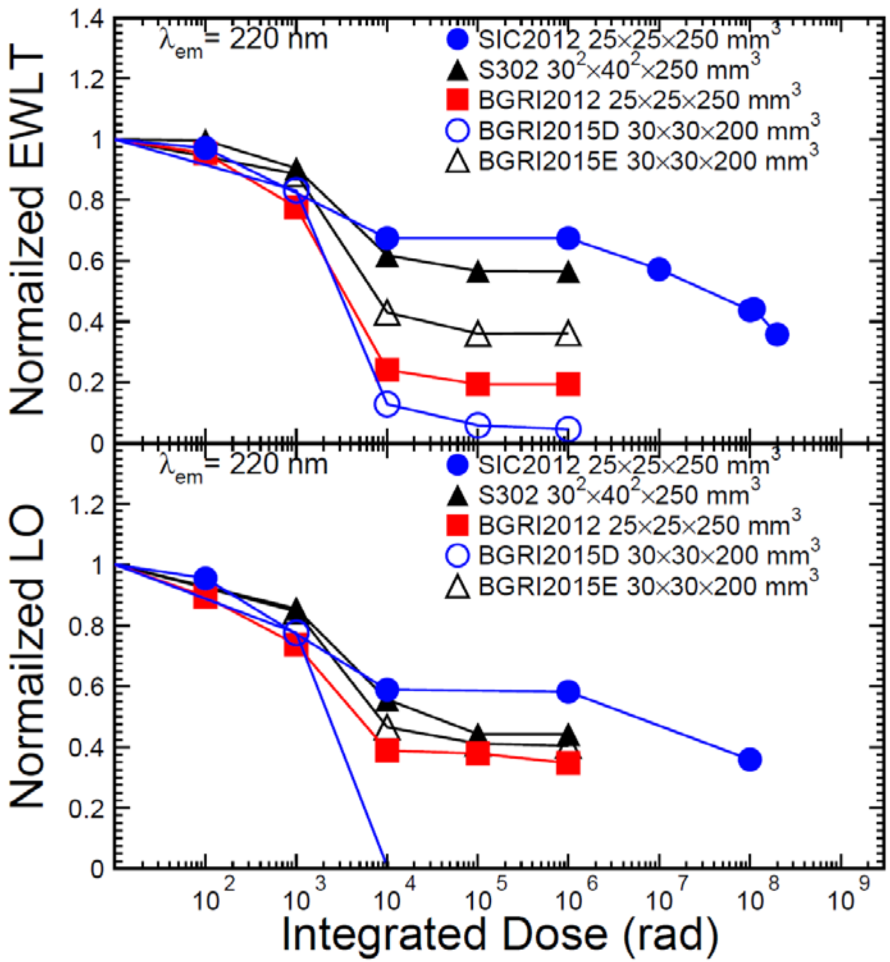
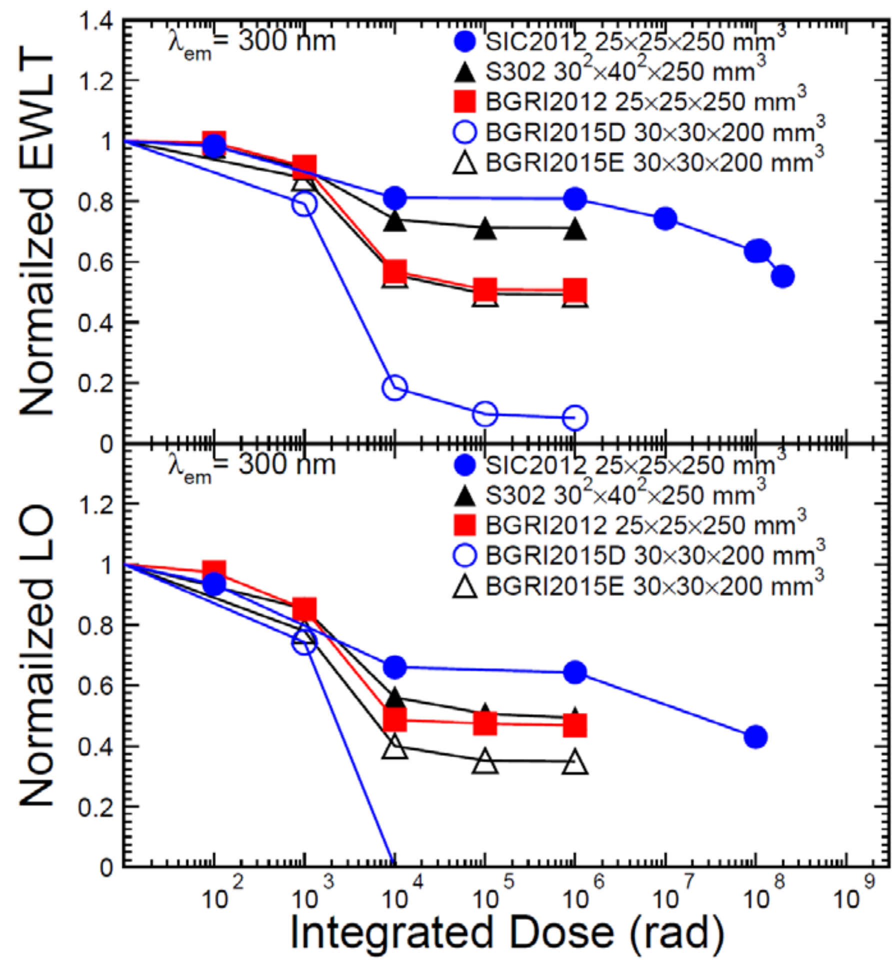
Fast component



Slow component



LO loss after 200 Mrad is 65%/53% for the fast/slow component
SIC2012 and S302 have similar quality, while BGRI samples are worse

Pure CsI: Normalized EWLT/LO and RIAC @ Emission Peak

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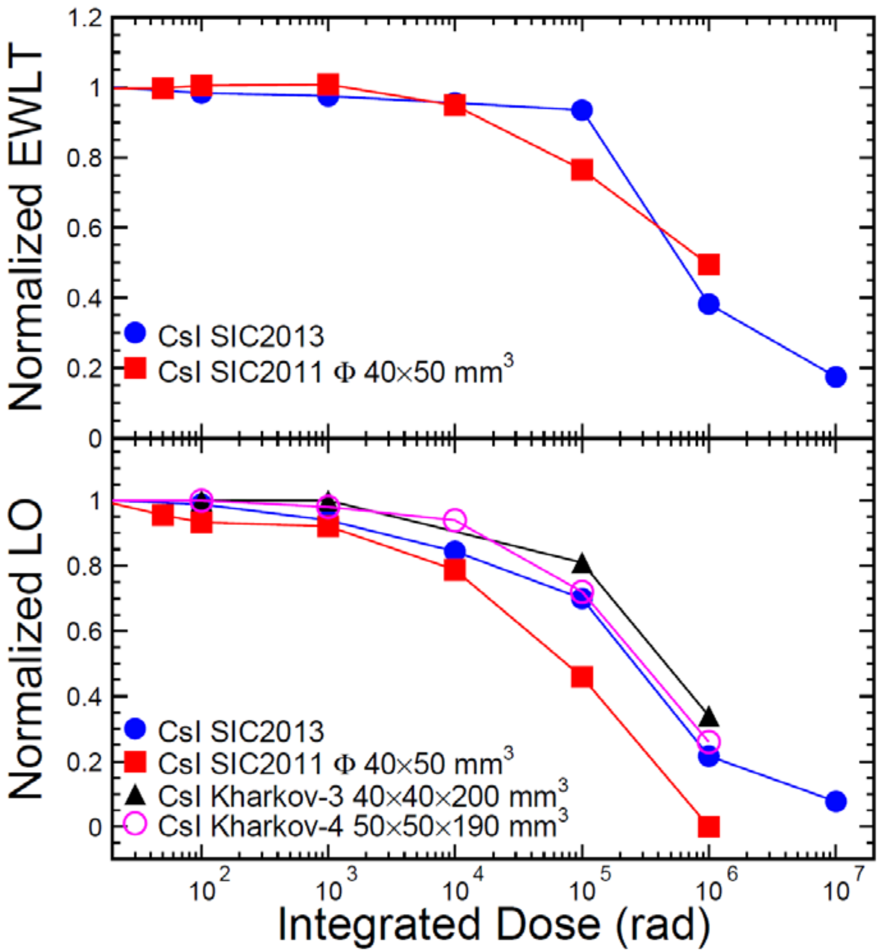
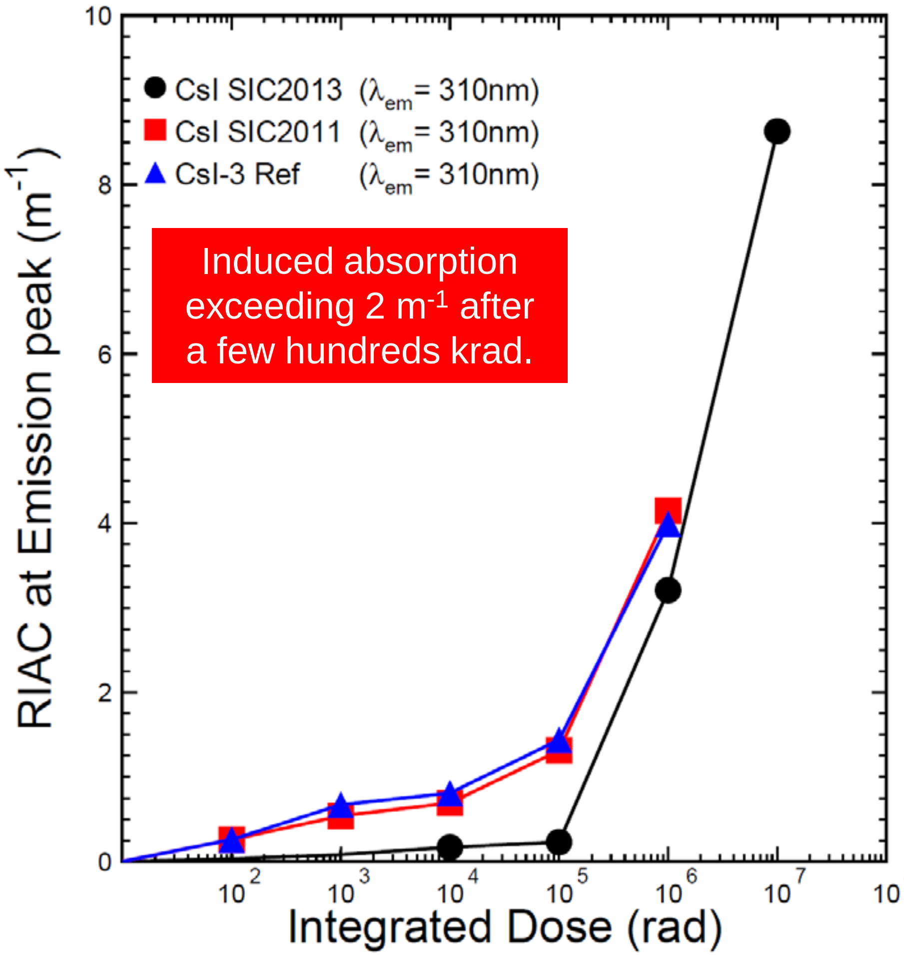
Consistent damage is observed between long pure CsI from SIC/Kharkov

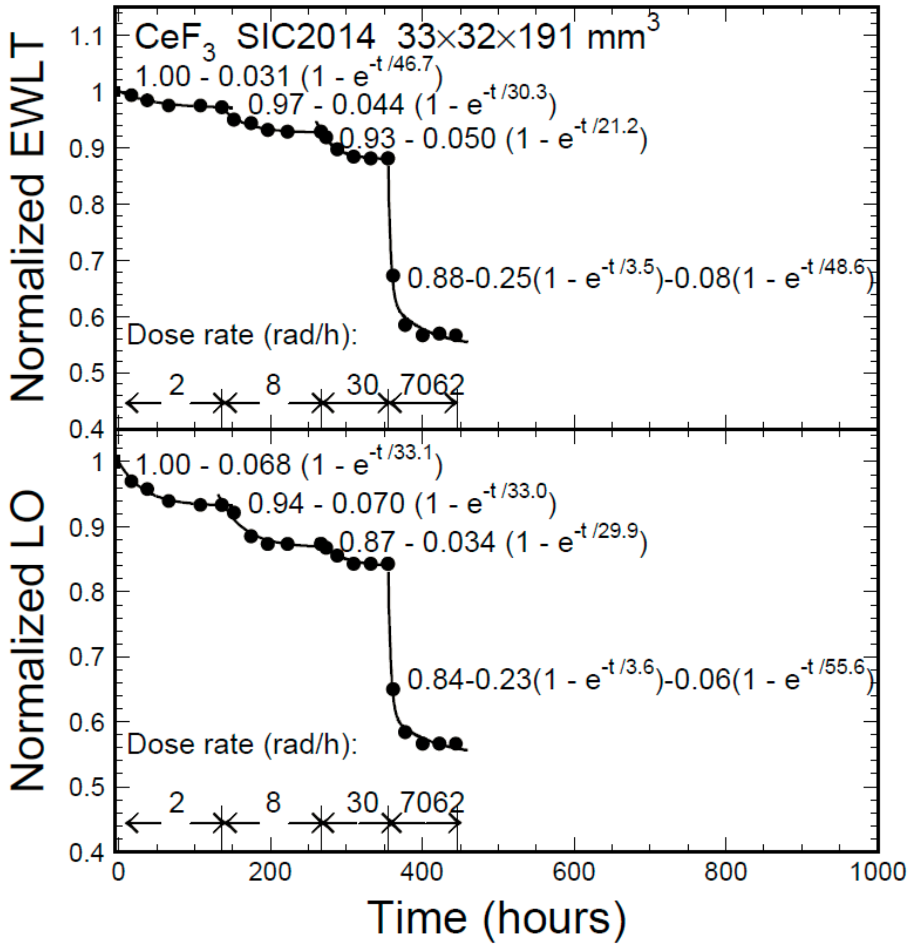


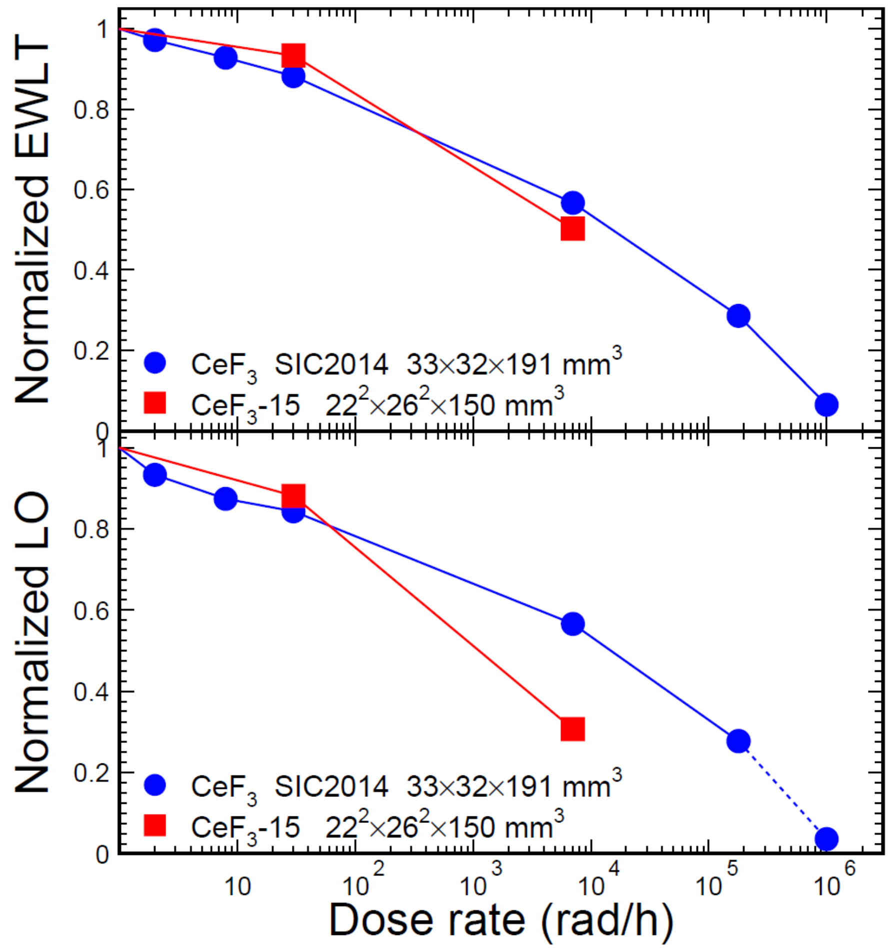


Data of Kharkov crystals: *Nucl. Ins. Meth. A* 326 (1993) 508-512

CeF_3: Normalized EWLT and LO

Dose rate dependent damage observed in both EWLT and LO
Similar damage in two CeF_3 samples grown about twenty years ago





LO of SIC2014 is too low to be measured under 1 Mrad/h in equilibrium

BGO/PWO: EWLT and LO

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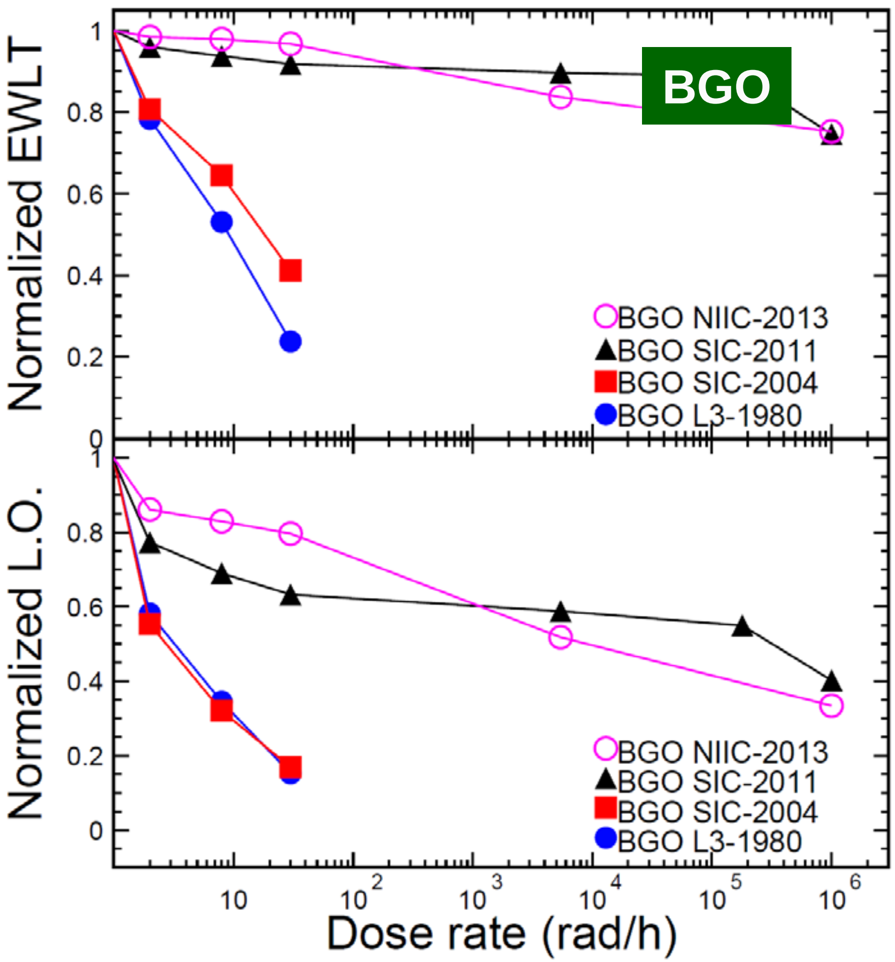
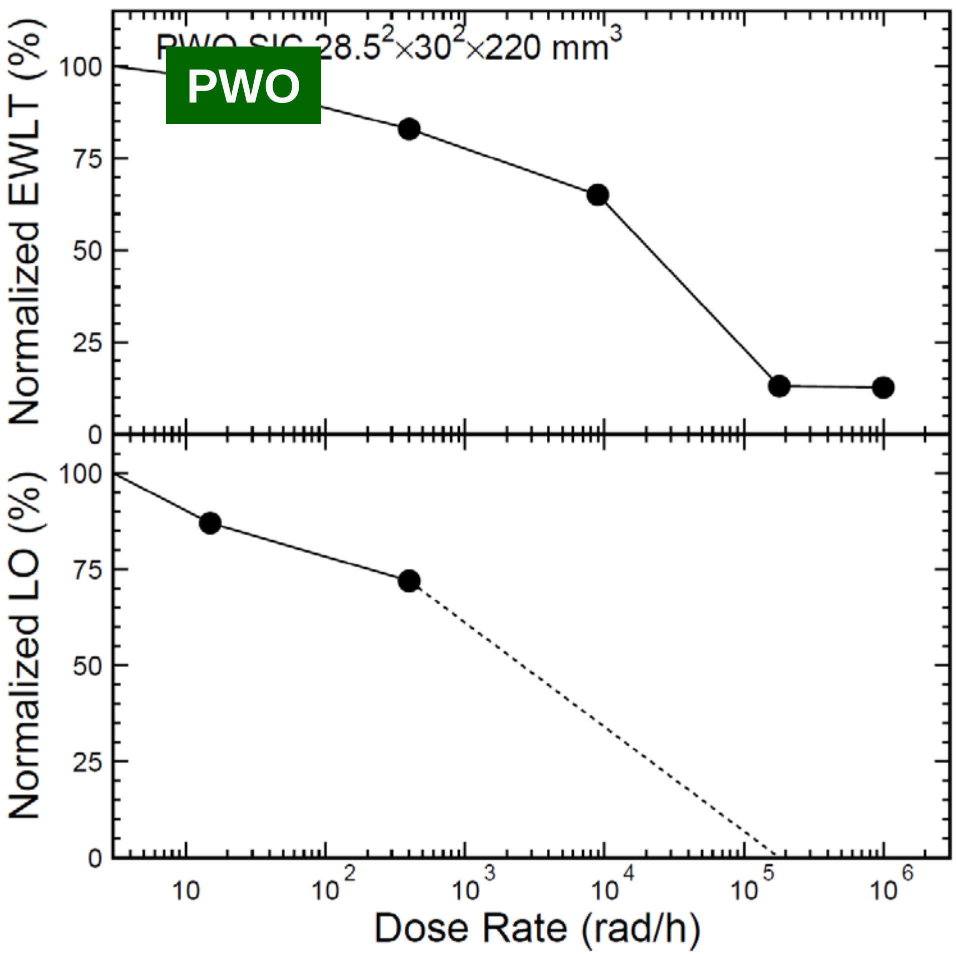
BGO crystals from two vendors show consistence damage under 1 Mrad/h

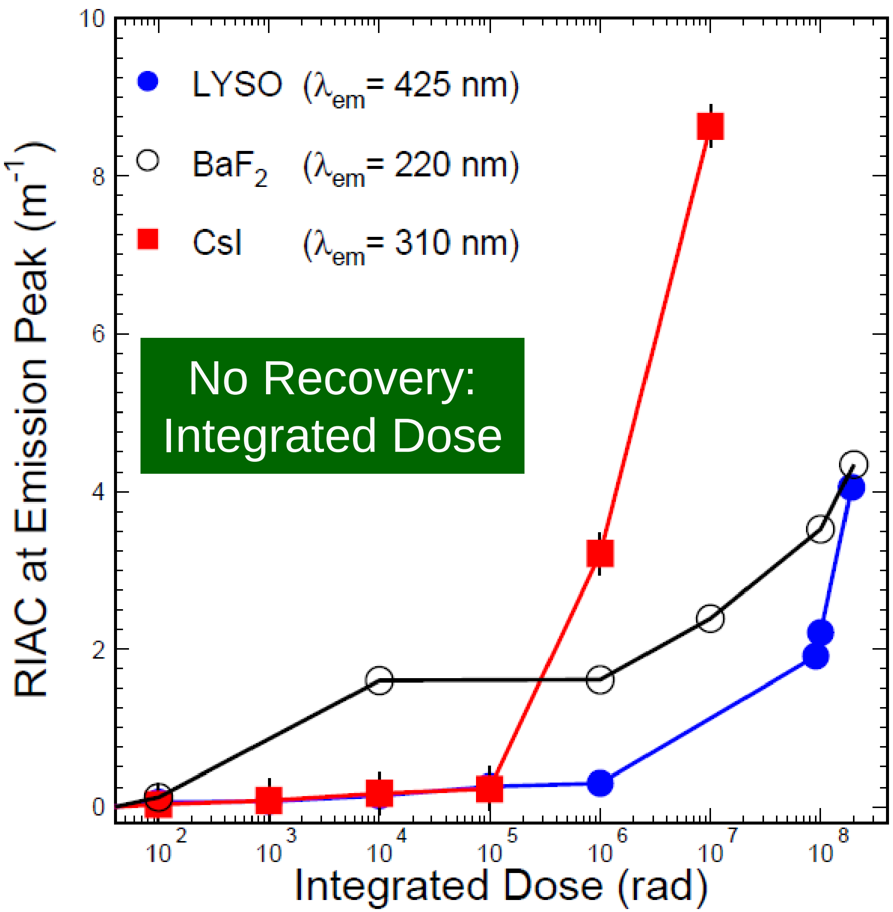
Loss of EWLT in PWO is 90% under 180 krad/h with LO too low to be measured

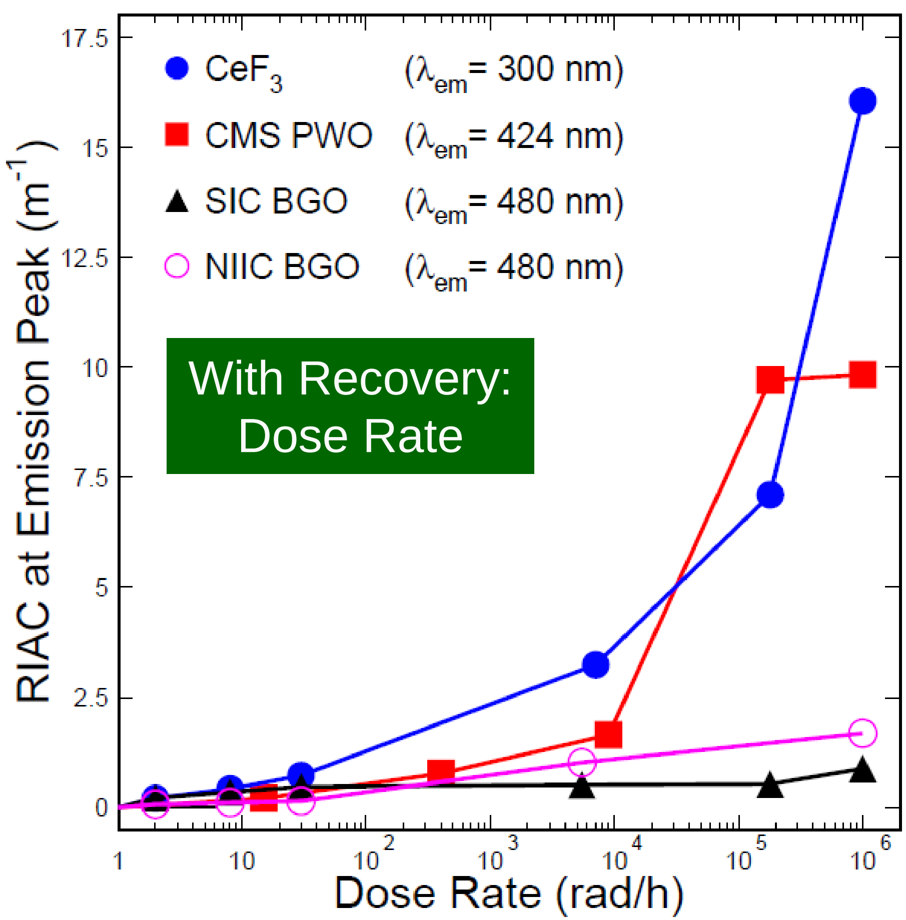




All Crystals: RIAC

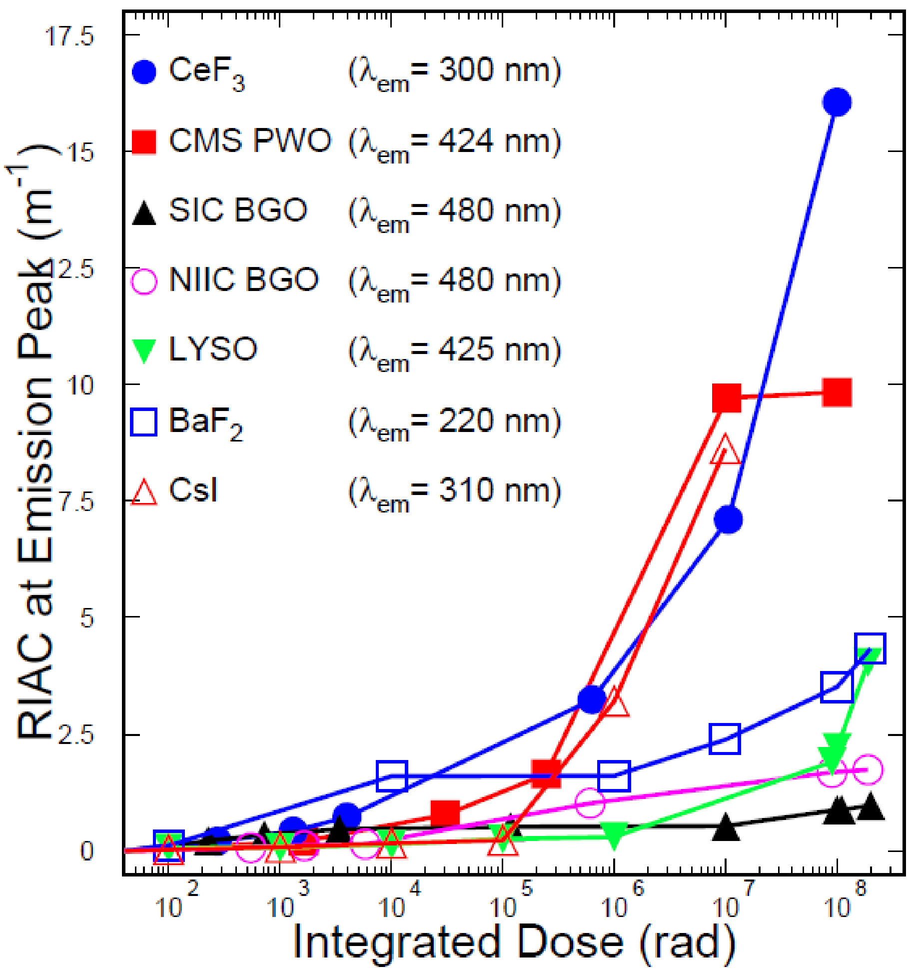
Pure CsI is good below 100 krad; BaF_2 is good beyond 1 Mrad
BGO shows small radiation induced absorption under 1 Mrad/h

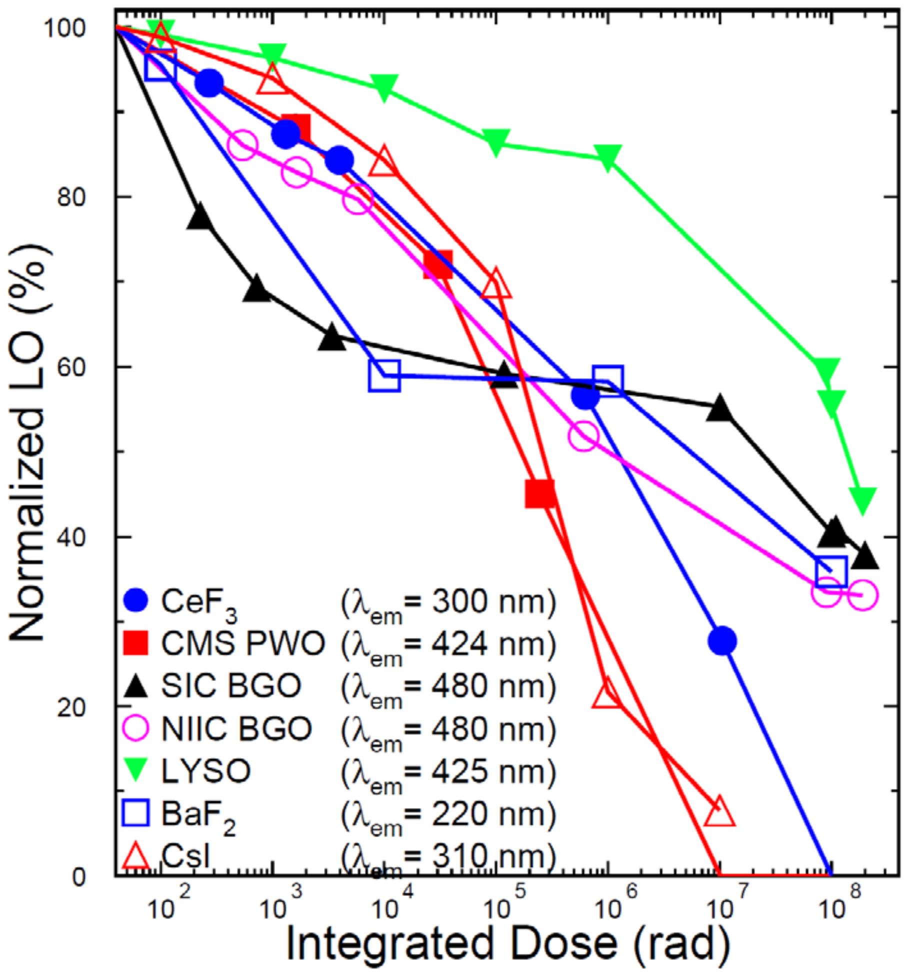




All Crystals: RIAC and LO

Ignoring dose rate dependence, the values of RIAC and normalized LO are shown as a function of integrated dose. LYSO crystals show the best radiation hardness up to 200 Mrad.





Summary

- **Gamma-ray induced radiation damage in various crystals was investigated up to 200 Mrad.**
- **Consistent degradation is observed in transmittance and light output for 20 cm long LYSO/LSO/LFS crystals from six vendors.**
- **Pure CsI shows good radiation hardness below 100 krad, BaF_2 and BGO show good radiation hardness beyond 1 Mrad.**
- **Damage in CeF_3 recovers at room temperature, so is dose rate dependent. The quality of the large size CeF_3 crystals grown 20 years ago is worse than PWO and BGO among crystals with dose rate dependent radiation damage.**
- **LYSO crystals show the best radiation hardness among all scintillation crystals up to 200 Mrad.**

BGO: Transmittance

Very different color centers are observed between BGO crystals grown at SIC and NIIC