Gamma-ray Induced Radiation Damage in Six Preproduction CsI Crystals

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Introduction

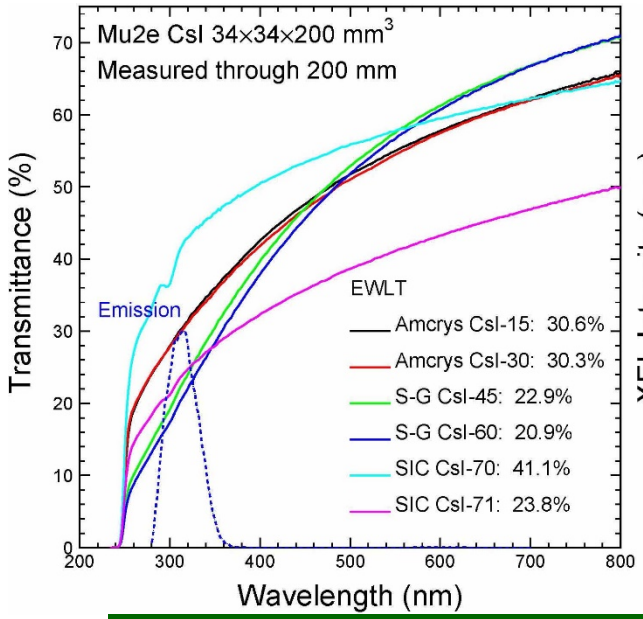
- Mu2e specifications for CsI crystals were defined in early August. A total of 72 crystals from three vendors were delivered to Fermilab early December.
- After QA on visual and dimension by a CMM machine at Fermilab, 36 CsI crystals arrived Caltech late December. Reports of QA on scintillation properties and radiation induced noise with PMT readout were given on January 11 and 17, 2017.
- Reported today is radiation damage data measured after 10 and 100 krad ɣ-rays for six CsI samples (2 from each vendor) which failed mechanical specifications:
  - AMCRYS 15 and 30: low LO, failed RIN, 15 also failed F/T;
  - Saint-Gobain 45 and 60;
  - SICCAS 70 and 71: 71 failed LRU.

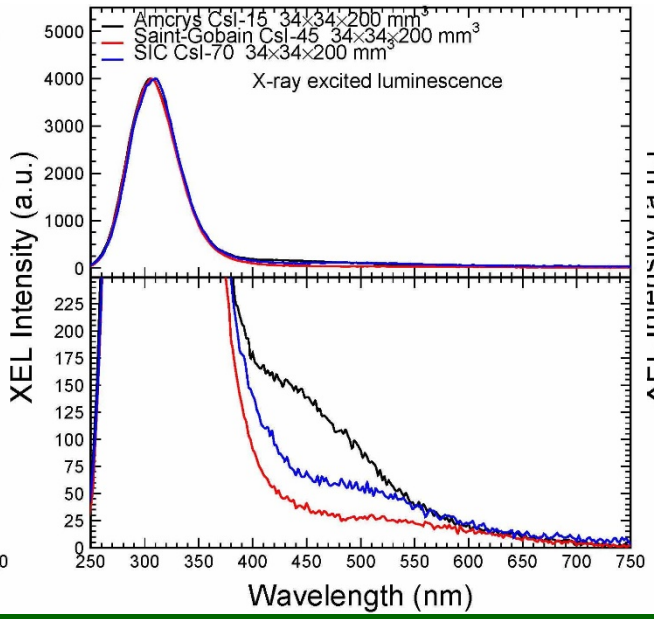
Specifications for Undoped CsI

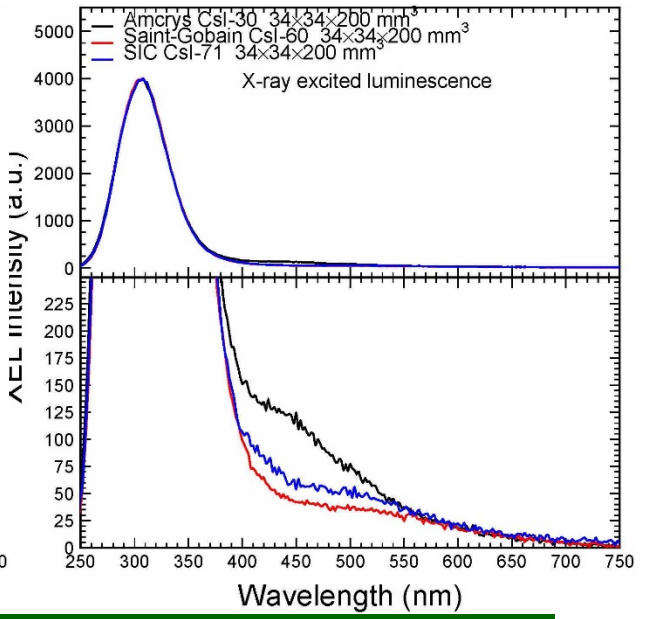
- Crystal lateral dimension: ±100 μ, length: ±100 μ.
- Scintillation properties at seven points along the crystal wrapped by two layers of Tyvek paper of 150 μm for alternative end coupled to a bi-alkali PMT with an air gap. Light output and FWHM resolution are the average of seven points with 200 ns integration time. The light response uniformity is the rms of seven points. F/T is measured at the point of 2.5 cm to the PMT.
  - Light output (LO): > **100 p.e./MeV** with 200 ns gate, will be compared to reference for cross-calibration;
  - FWHM Energy resolution: **< 45%** for Na-22 peak;
  - Light response uniformity (LRU, rms of seven points): **< 5%**;
  - Fast (200 ns)/Total (3000 ns) Ratio: **> 75%**.
- Radiation hardness:
  - Radiation Induced noise **@ 1.8 rad/h: < 0.6 MeV**;
  - Normalized LO **after 10/100 krad: > 85/60%.**

Initial Performance before Irradiation

Crystal ID	Batch Number	Coupling end	EWLT (%)	F/T (%)-1st	F/T (%)-2rd	LRU (%)-1st	LRU (%)-2rd
C0015	Amcrys-007	a	30.6	**68.2**	**69.0**	1.65	0.98
C0030	Amcrys-001	a	30.3	76.6	77.0	2.40	1.49
C0045	SG-A11827	a	22.9	98.9	98.7	0.92	0.92
C0060	SG-A11804	a	20.9	98.3	97.3	1.96	1.08
C0070	SIC-2016 A20	a	41.1	93.0	92.6	1.39	2.04
C0071	SIC-2016 A23	a	23.8	97.1	95.8	**5.63**	**5.61**



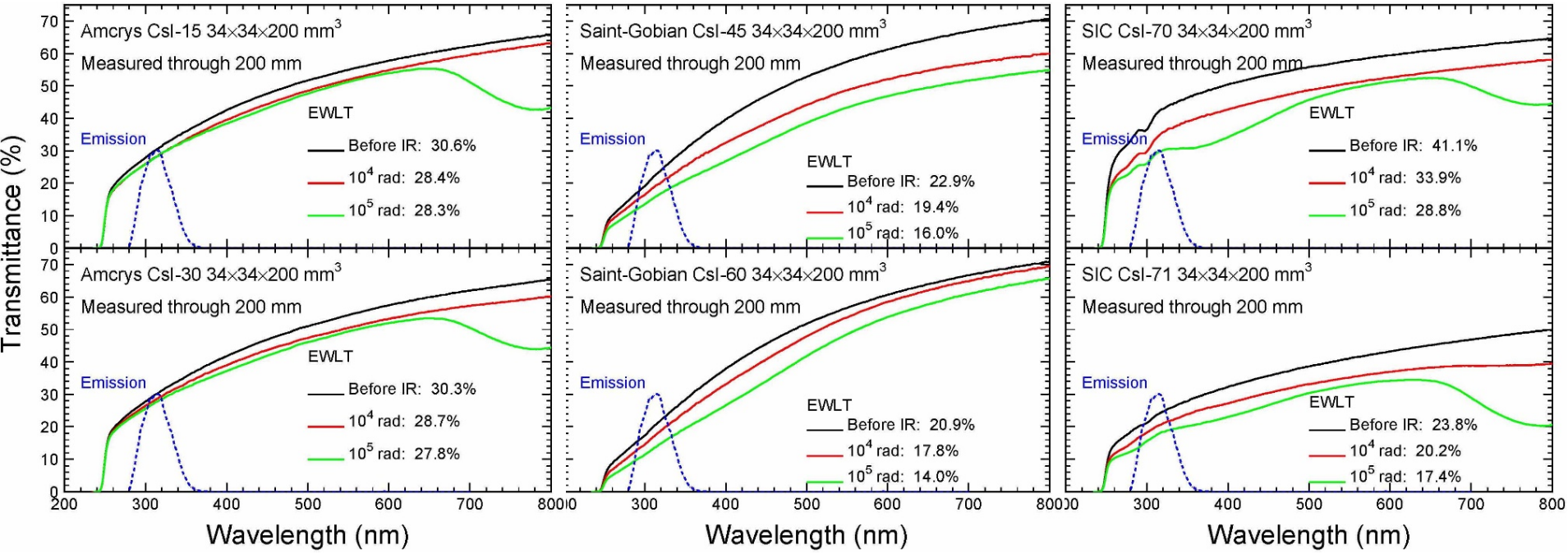




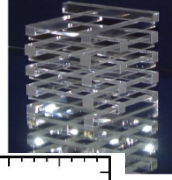
Surface dependent transmittance and slow emission confirmed

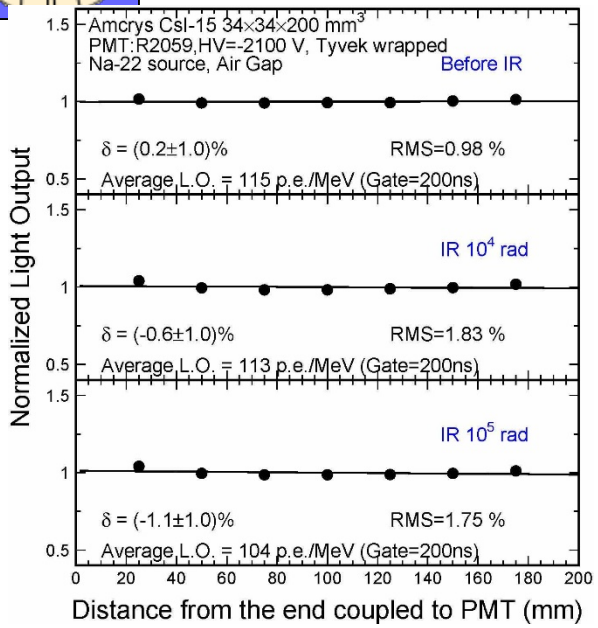
Longitudinal Transmittance

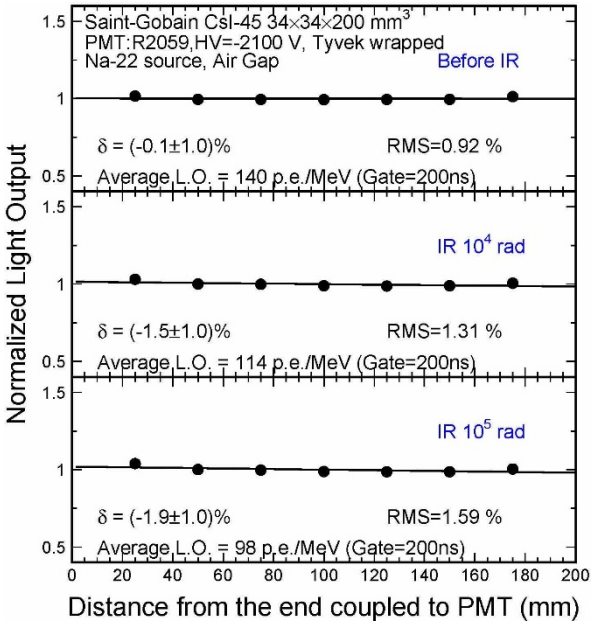
While initial longitudinal transmittance spectra (LT) are surface dependent, variations of the LT spectrum and the numerical values of emission weighted LT can be used to represent CsI radiation damage

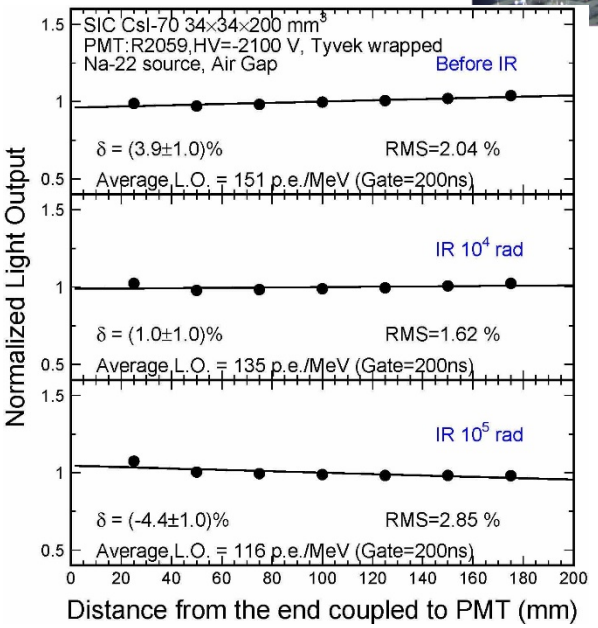


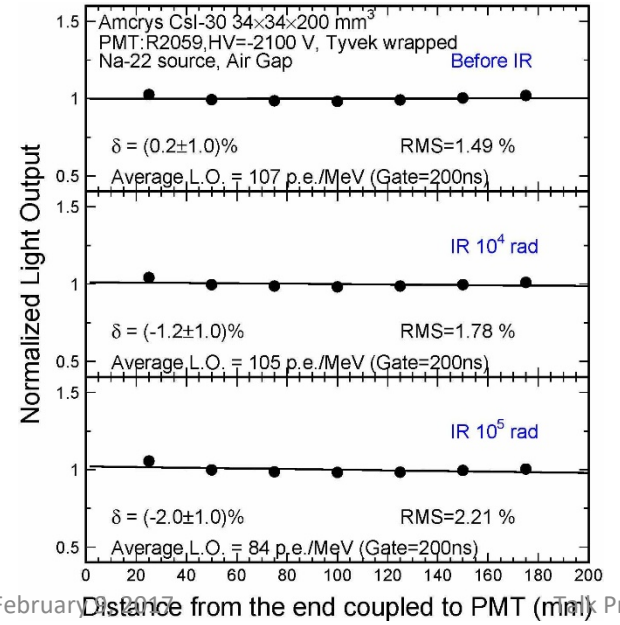
LO & LRU after Radiation

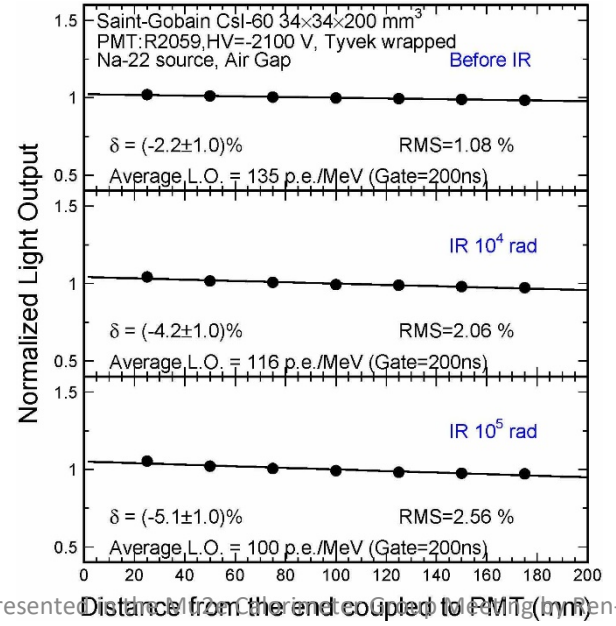


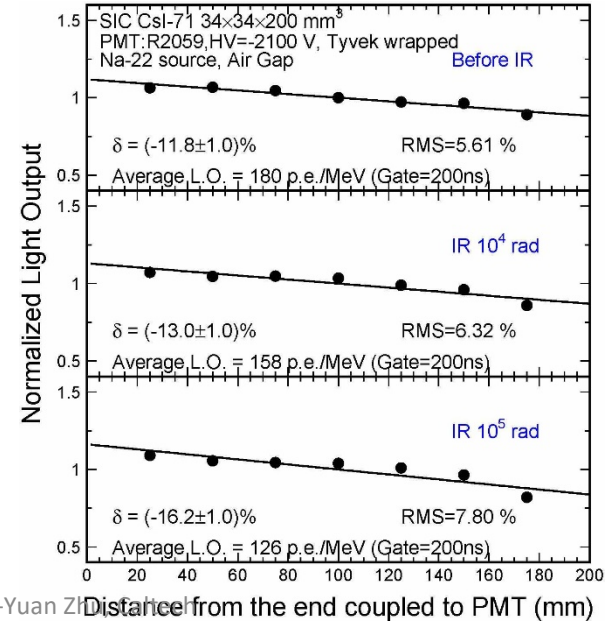










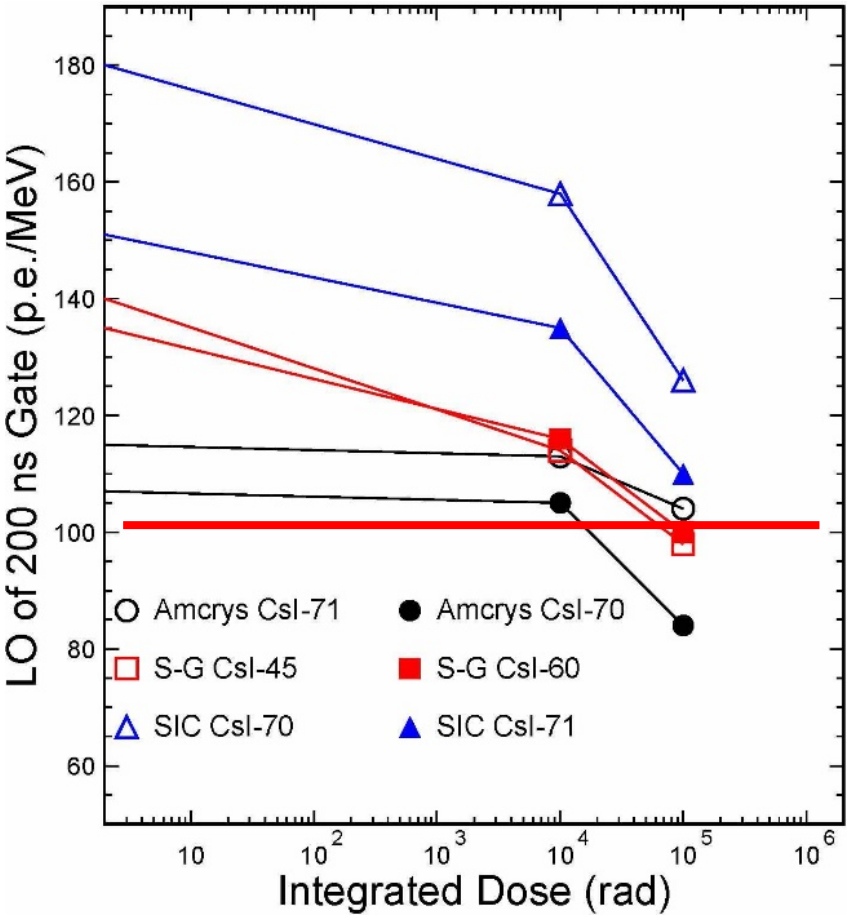


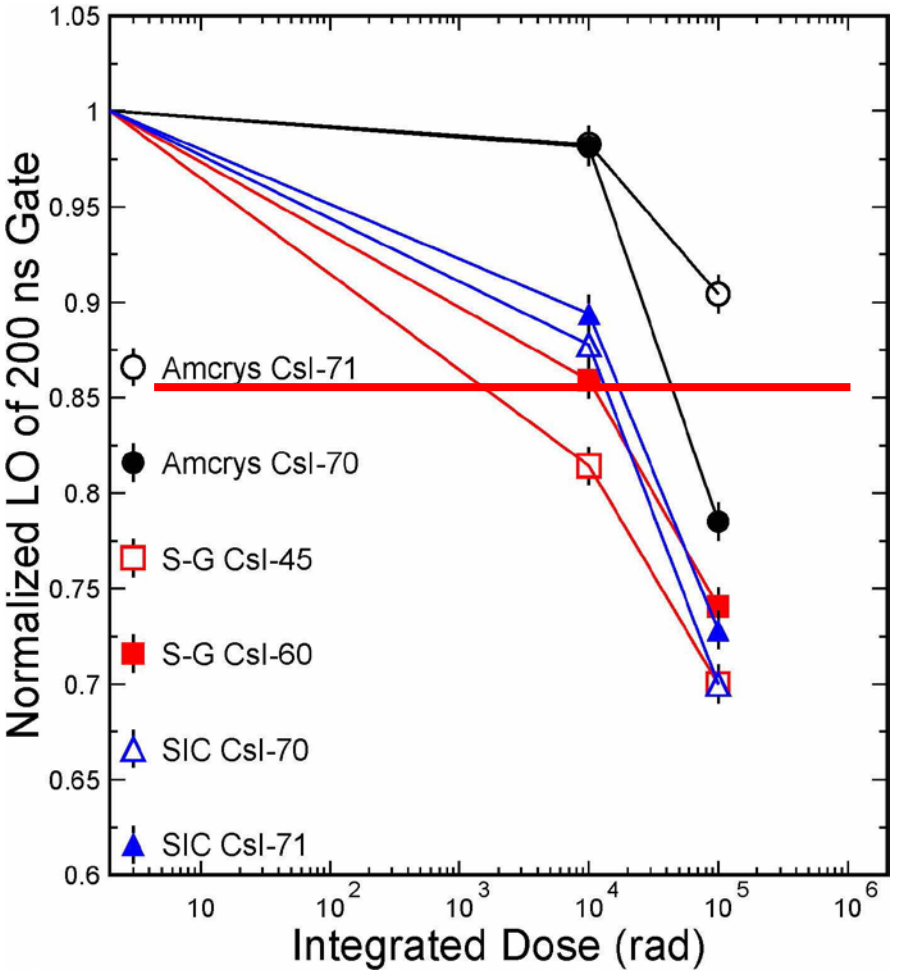
Radiation Damage Results

Crystal ID	Batch Number	Dose (krad)	EWLT (%)	Normalized EWLT (%)	L.O. (p.e./MeV)	Normalized L.O. (%)	E.R. (%)	F/T (%)	LRU (%)	δ (%)
C0015	Amcrys-007	0	30.6	100	115	100	38	**69.0**	0.98	0.2
		10	28.4	92.8	113	98.1	38	**70.6**	1.83	-0.6
		100	28.3	92.5	104	90.2	39	**73.2**	1.75	-1.1
C0030	Amcrys-001	0	30.3	100	107	100	40	77.0	1.49	0.2
		10	28.7	94.7	105	98.4	39	78.4	1.78	-1.2
		100	27.8	91.7	84	79.7	41	80.5	2.21	-2.0
C0045	SG-A11827	0	22.9	100	140	100	34	98.7	0.92	-0.1
		10	19.4	84.7	**114**	**81.2**	38	98.2	1.31	-1.5
		100	16.0	69.9	98	69.6	41	100.0	1.59	-1.9
C0060	SG-A11804	0	20.9	100	135	100	34	97.3	1.08	-2.2
		10	17.8	85.2	116	85.7	38	97.8	2.06	-4.2
		100	14.0	67.0	100	73.8	41	99.9	2.56	-5.1
C0070	SIC-2016 A20	0	41.1	100	151	100	35	92.6	2.04	3.9
		10	33.9	82.5	135	89.3	37	90.0	1.62	1.0
		100	28.8	70.1	116	77.1	40	91.4	2.85	-4.4
C0071	SIC-2016 A23	0	23.8	100	180	100	33	95.8	**5.61**	-11.8
		10	20.2	84.9	158	87.5	37	98.4	**6.32**	-13.0
		100	17.4	73.1	126	69.9	42	98.3	**7.80**	-16.2

Damage in Light Output

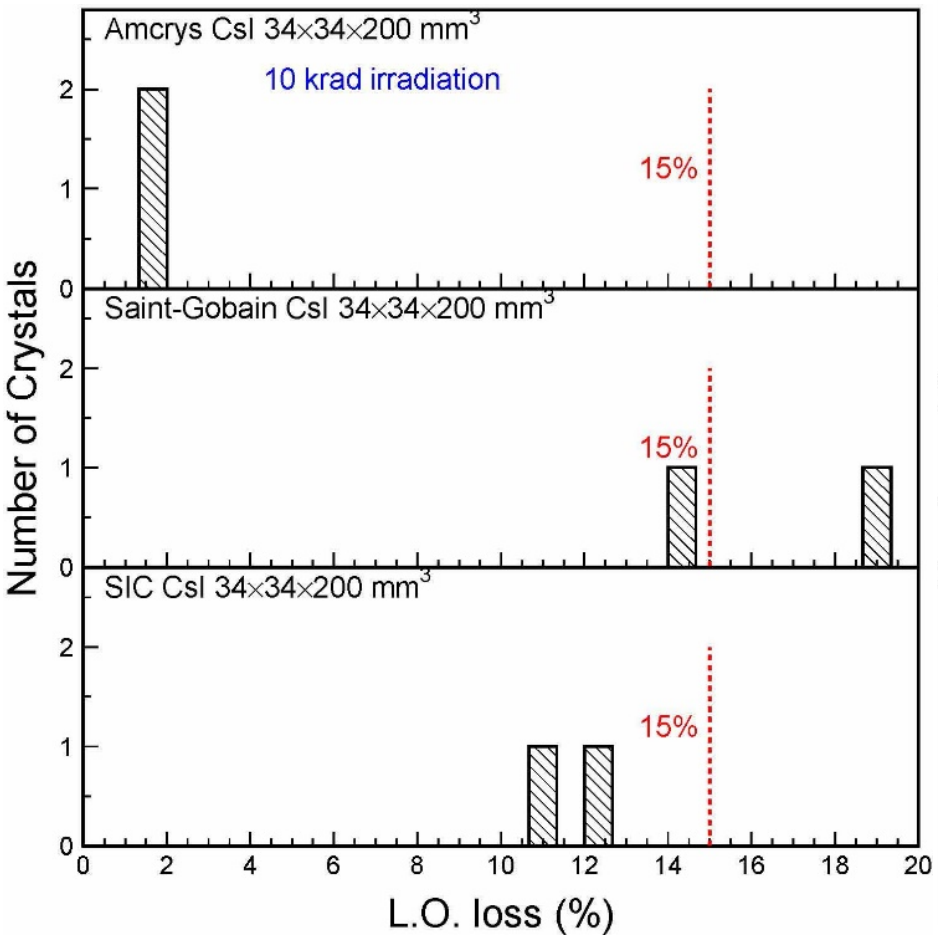
Most CsI with LO > 100 p.e./MeV after 100 krad
All satisfy radiation spec, except S-G 45 failed 10k

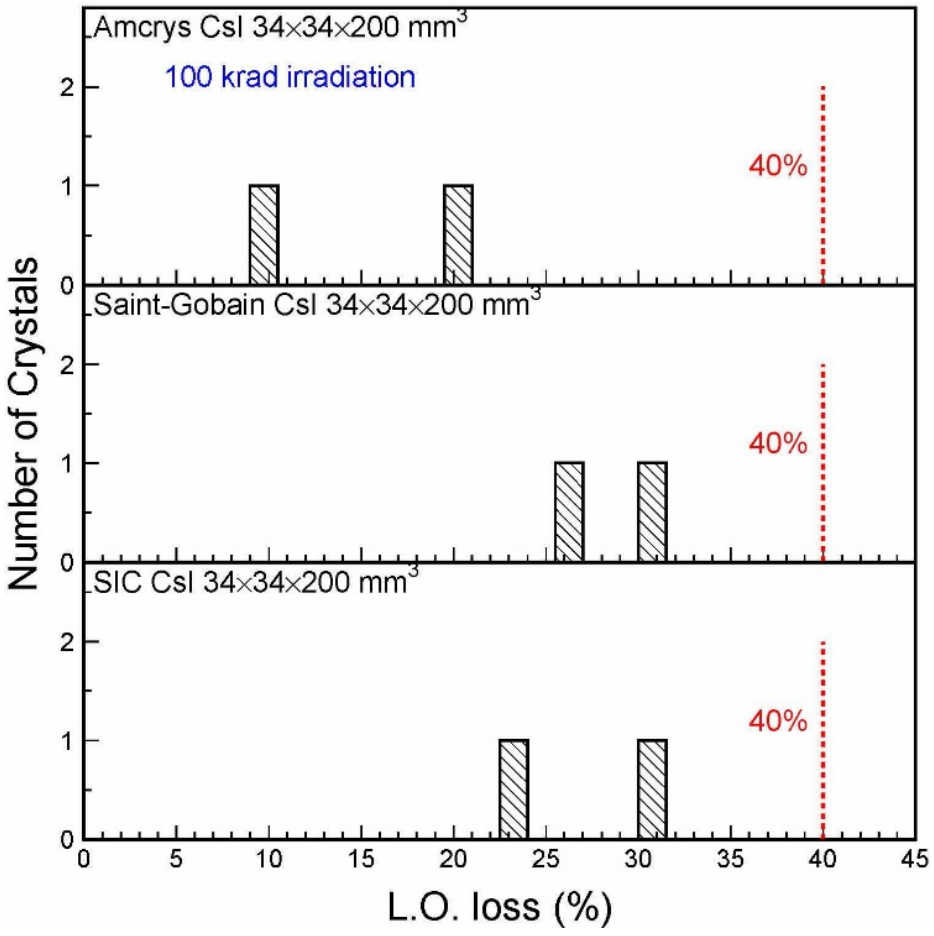




Summary of LO Degradation

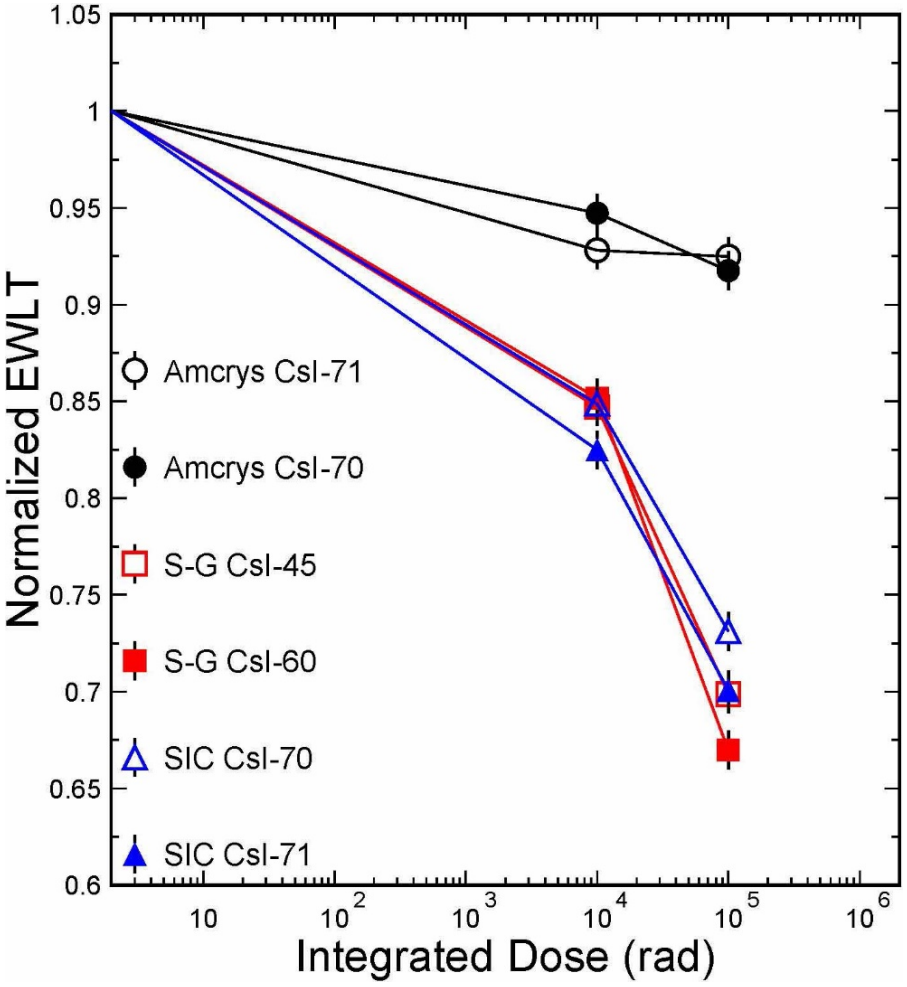
All satisfy radiation spec except S-G 45 after 10 krad
Rank: Kharkov, SIC and S-G

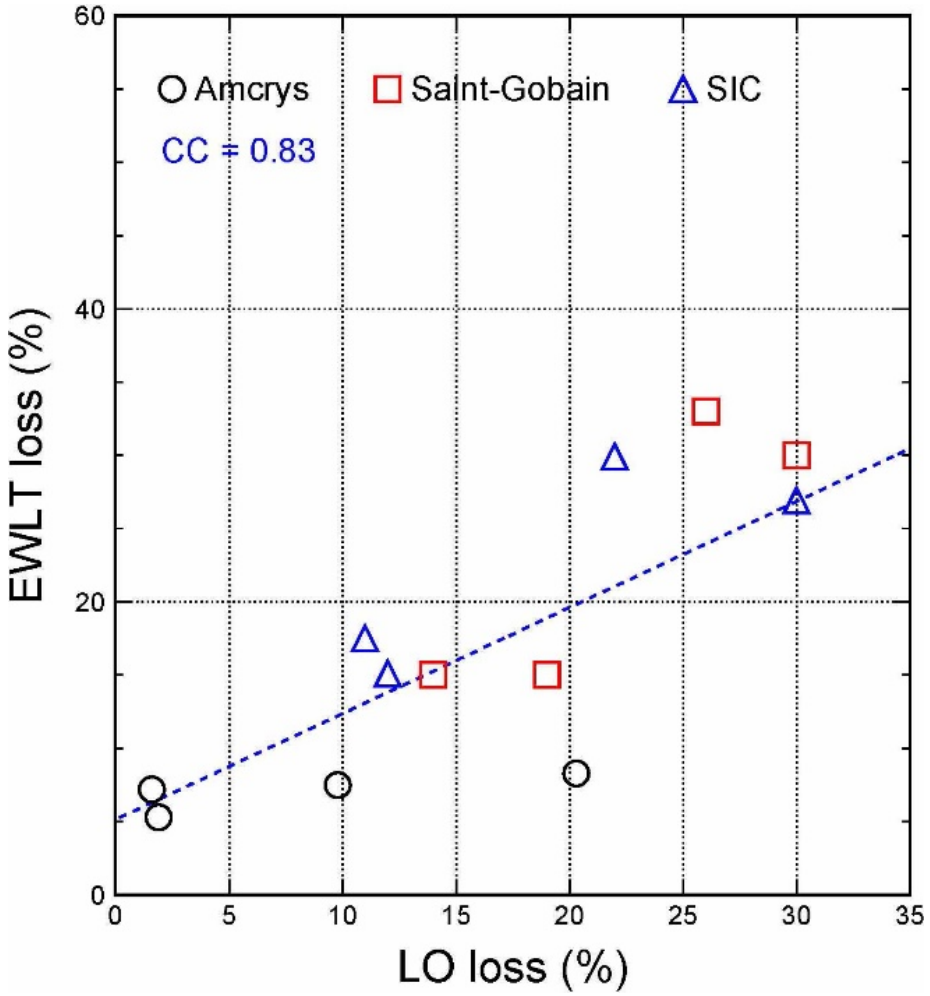




EWLT Damage & Correlation with LO

Good correlation between variations of LT and LO





Summary

- Gamma-ray induced radiation damages in both transmittance and light output are measured after 10 and 100 krad for six Mu2e preproduction CsI crystals which failed the mechanical specifications.
- All crystals meet the Mu2e radiation damage specifications, except one Saint-Gobain sample (#45) which does not meet damage spec after 10 krad but meets that after 100 krad.
- Most crystals have light output larger than 100 p.e./MeV after 100 krad, promising a robust CsI calorimeter.
- Good correlation is observed between variations of LT and LO, indicating a feasibility of light monitoring.
- 24 samples will be shipped to Frascati for Module 0 construction. Six samples will remain at Caltech for further investigation.

QC on CsI Radiation Damage

- Most crystal vendors do not have a capability to test radiation hardness, so this will be our responsibility
- Crystals are grown in ingots, either a large size ingot or multiple small ones in each growth. We may test small samples, e.g. ϕ1” x 1”, cut from ingots from each growth for radiation damage QC.
- Crystals are delivered in batches. We may measure two randomly selected samples in each batch for radiation damage QC.
- Prompt feedback to, and communications with, vendors are important for QC of mass produced CsI crystals.