Gamma Ray-Induced Radiation Damage in Ultrafast Lu_2O_3:Yb Ceramic Scintillators

Liyuan Zhang, Chen Hu, Ren-Yuan Zhu

California Institute of Technology

Lakshmi S. Pandian, Yimin Wang, Jarek Glodo and Matthias Muller

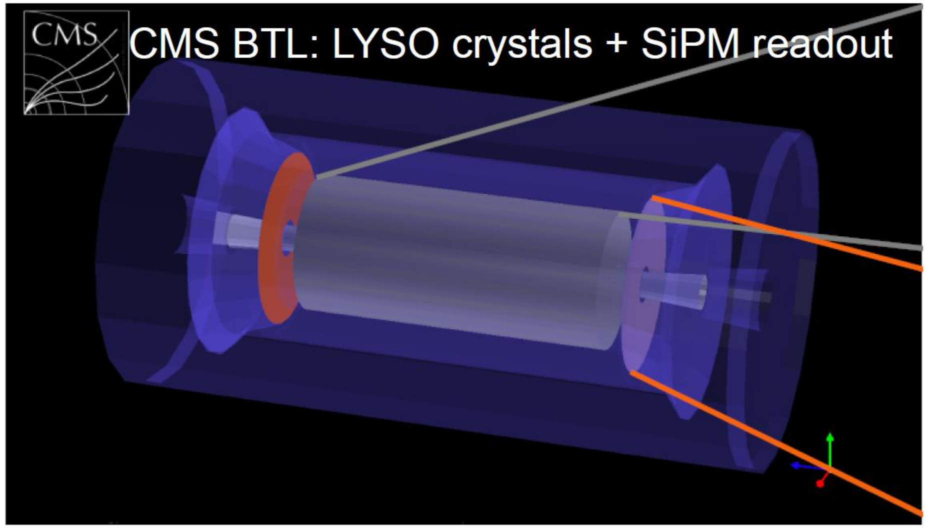
Radiation Monitoring Devices, Inc.

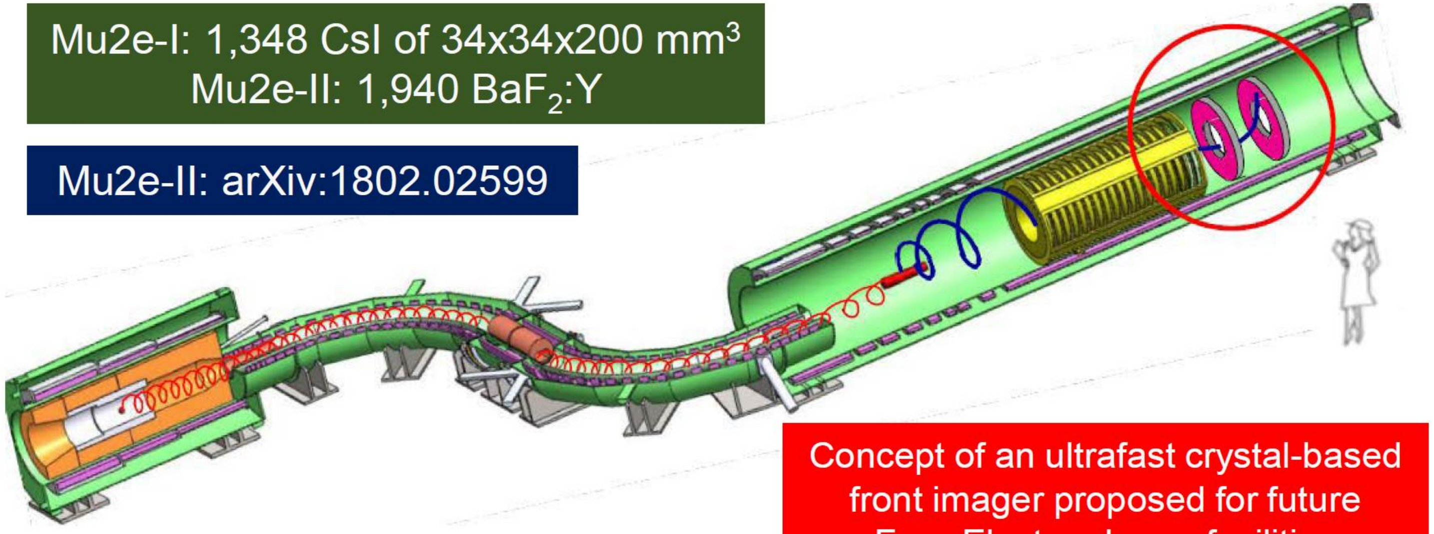
November 7, 2023

Presentation N06-2 in the IEEE NSS 2023 Conference, Vancouver, Canada

Application of Ultrafast Crystals

Figures of merit for TOF: light yield in the 1st ns & the ratio between fast and total



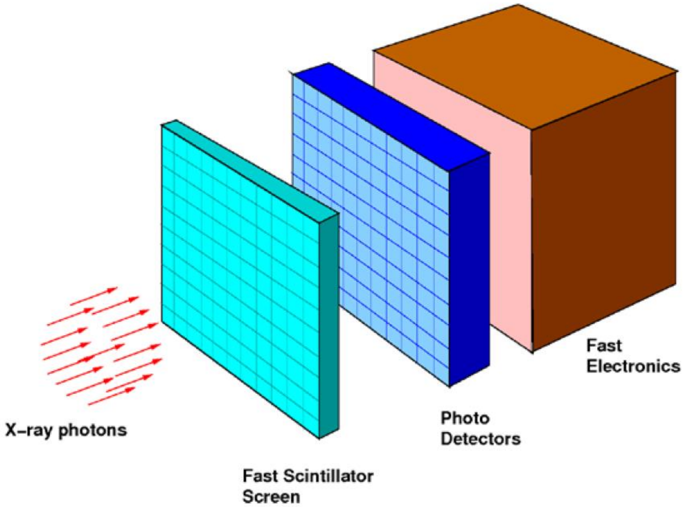


Concept of an ultrafast crystal-based front imager proposed for future Free-Electron Laser facilities

GHz Hard X-ray Imaging for Free-Electron Lasers

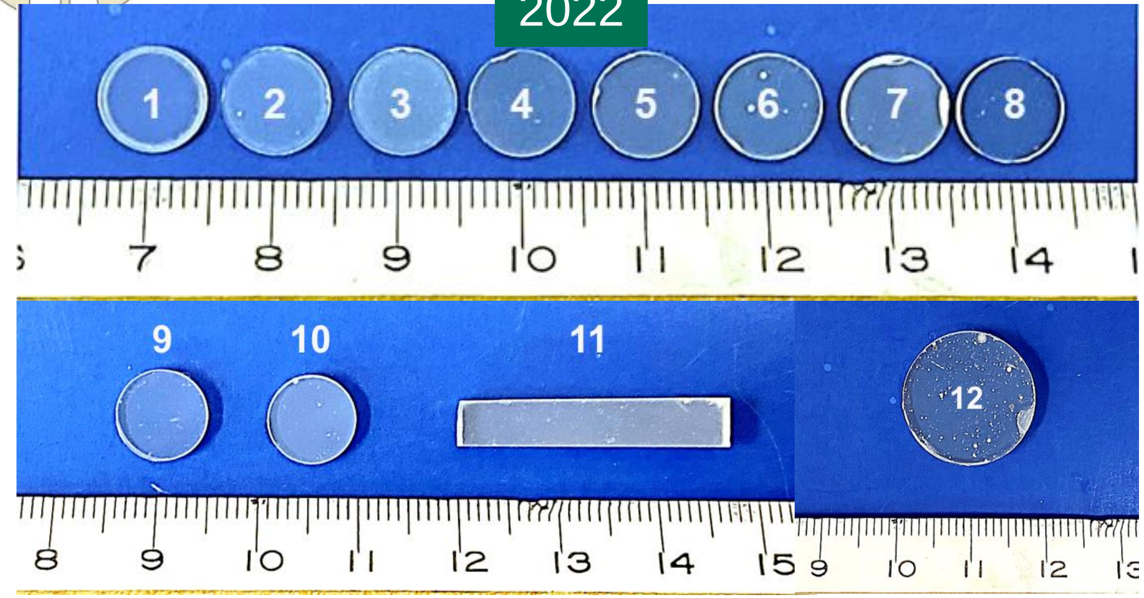
Fast frame rate & hard x-ray require ultrafast crystals

Performance	Type I imager	Type II imager
X-ray energy	**up to 30 keV**	**42-126 keV**
Frame-rate/inter-frame time	**0.5 GHz / 2 ns**	**3 GHz / 300 ps**
Number of frames per burst	≥ 10	10 - 30
X-ray detection efficiency	above 50%	above 80%
Pixel size/pitch	**≤ 300 μm**	**< 300 μm**
Dynamic range	10^3 X-ray Photons/pixel/frame	≥ 10^4 X-ray Photons/pixel/frame
Pixel format	64 × 64[a] (scalable to 1 Mpix)	1 Mpix

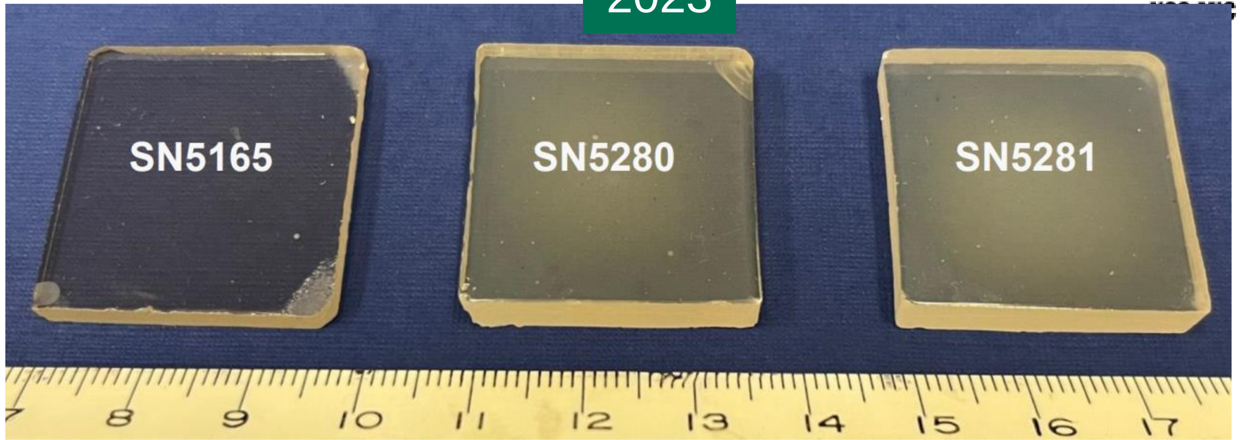


$(Lu,Y)_2O_3$:Yb Ceramic Samples from RMD Inc.

2022



2023



See paper N36-02 for recent progress in RMD inc.

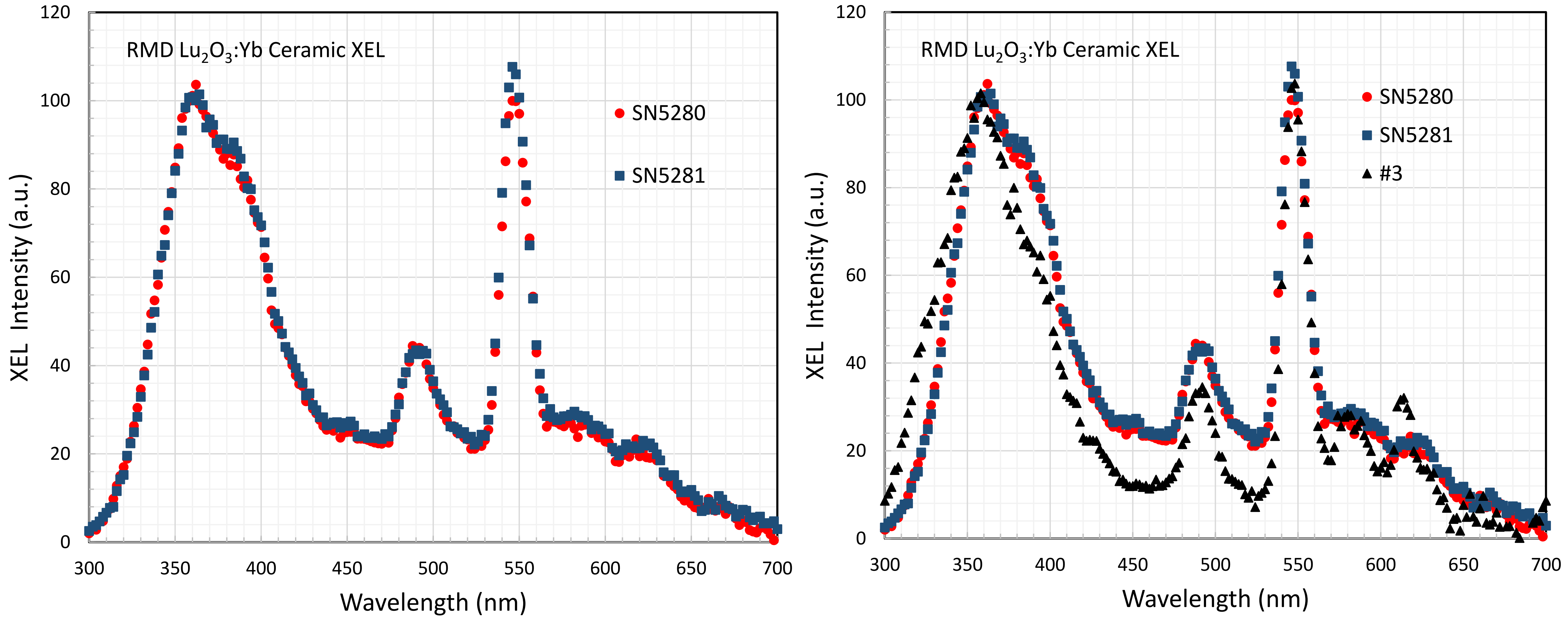
ID	Dimension (mm^3)	#	Polishing
RMD $(Lu,Y)_2O_3$-1 to 12	Φ9×1~Φ17×3	12	All faces
SN5165, 5280 & 5281	27×27×3, 27×27x5, 27×27x5	3	All faces
Samples #1-12 received between Dec 2021 and May 2022, Three square samples received Jun 2023.			

Experiments

Properties measured at room temperature: X-ray Excited Luminescence (XEL), Pulse Height Spectrum (PHS), Light Output (LO) and decay kinetics, before and after gamma irradiation.

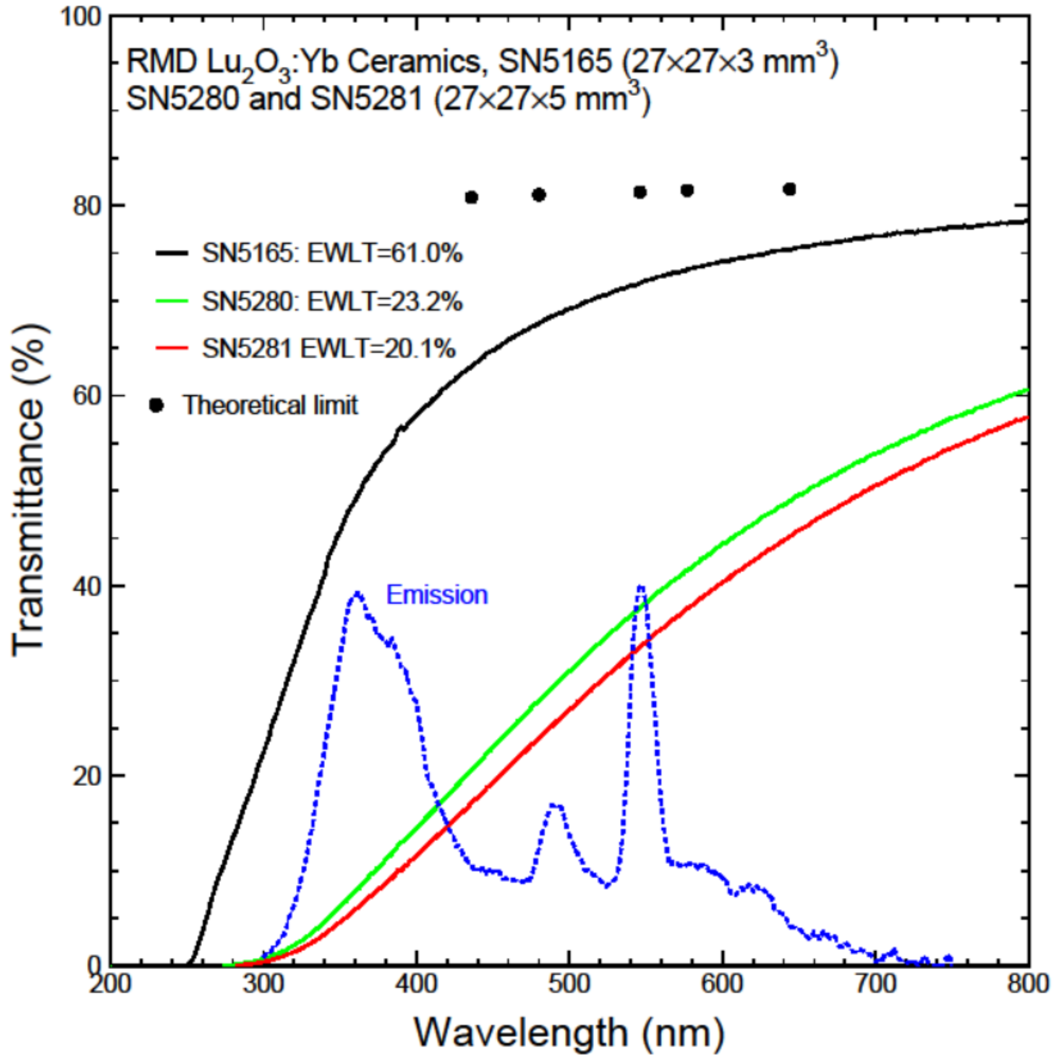
XEL of SN5280/5281 (2023) and SN2682 (2022)

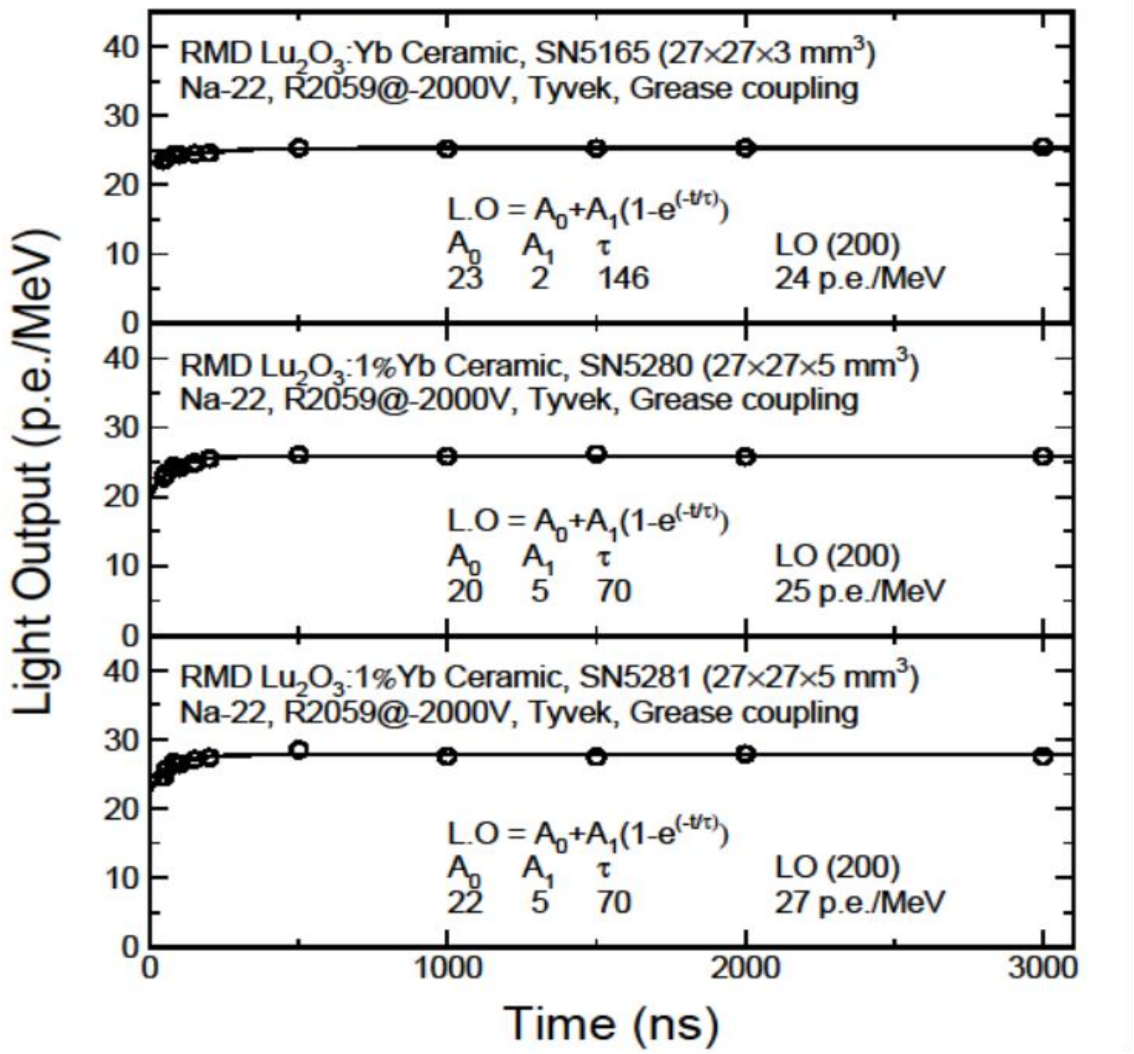
SN5280, 5281 and 2682 show consistent XEL with clear peaks at 360, 490 and 545 nm



Transmittance and LO of 2023 Samples

SN5165 shows good transmittance and small slow component
SN5280 and 5281 show low transmittance, but similar light output

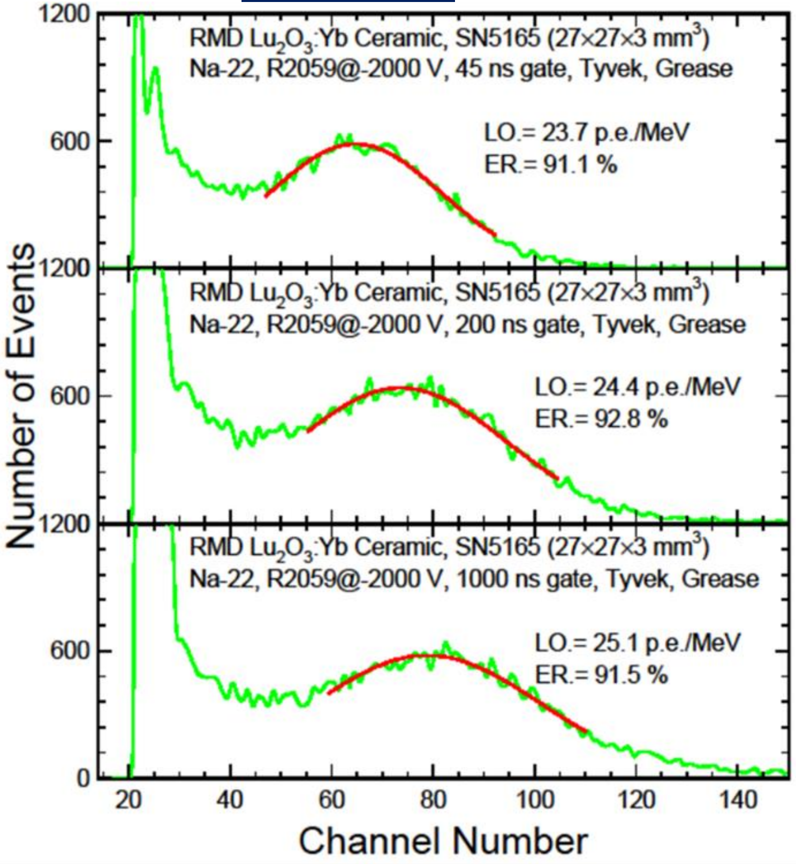




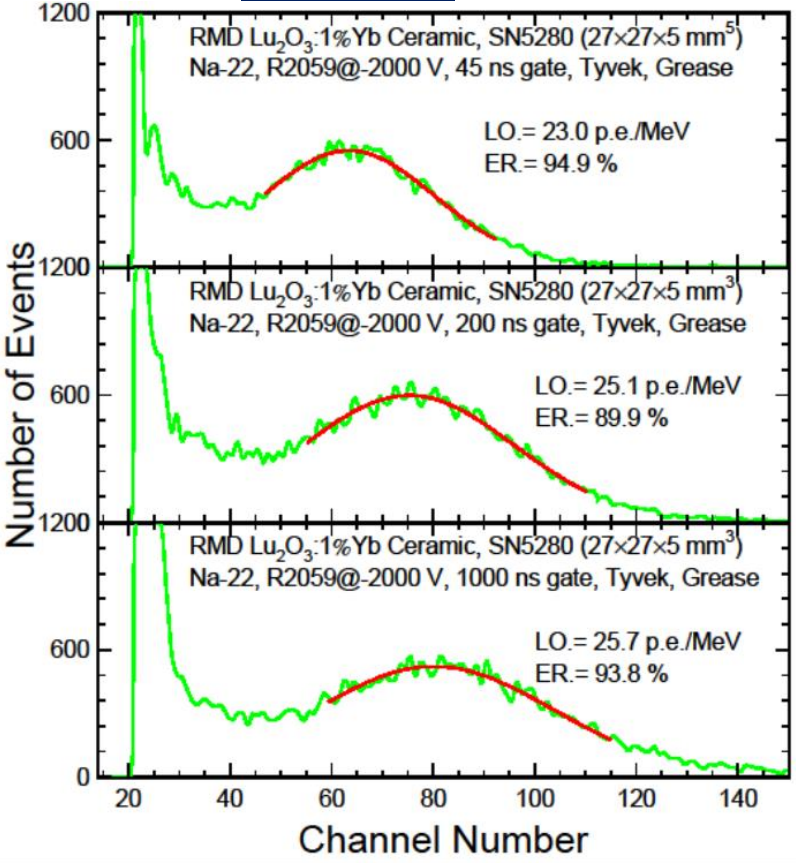
PHS of 2023 Samples

All samples show well resolved ^{22}Na γ-ray peak of 511 keV
SN5165 shows lower light output than SN5280 and 5281

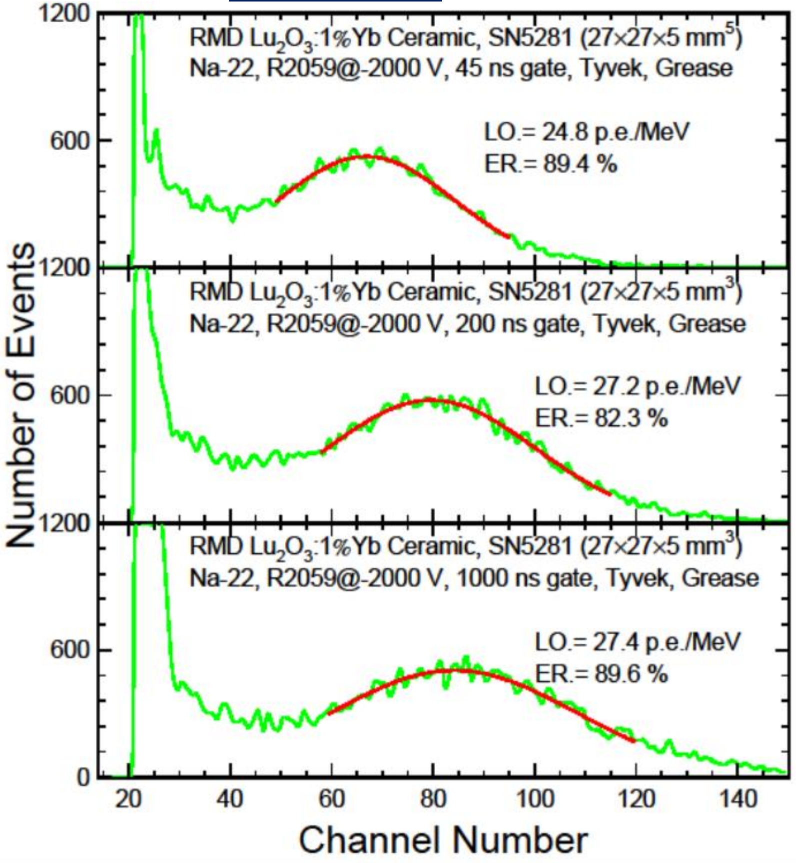
SN5165



SN5280



SN5281



Six Irradiated RMD Samples

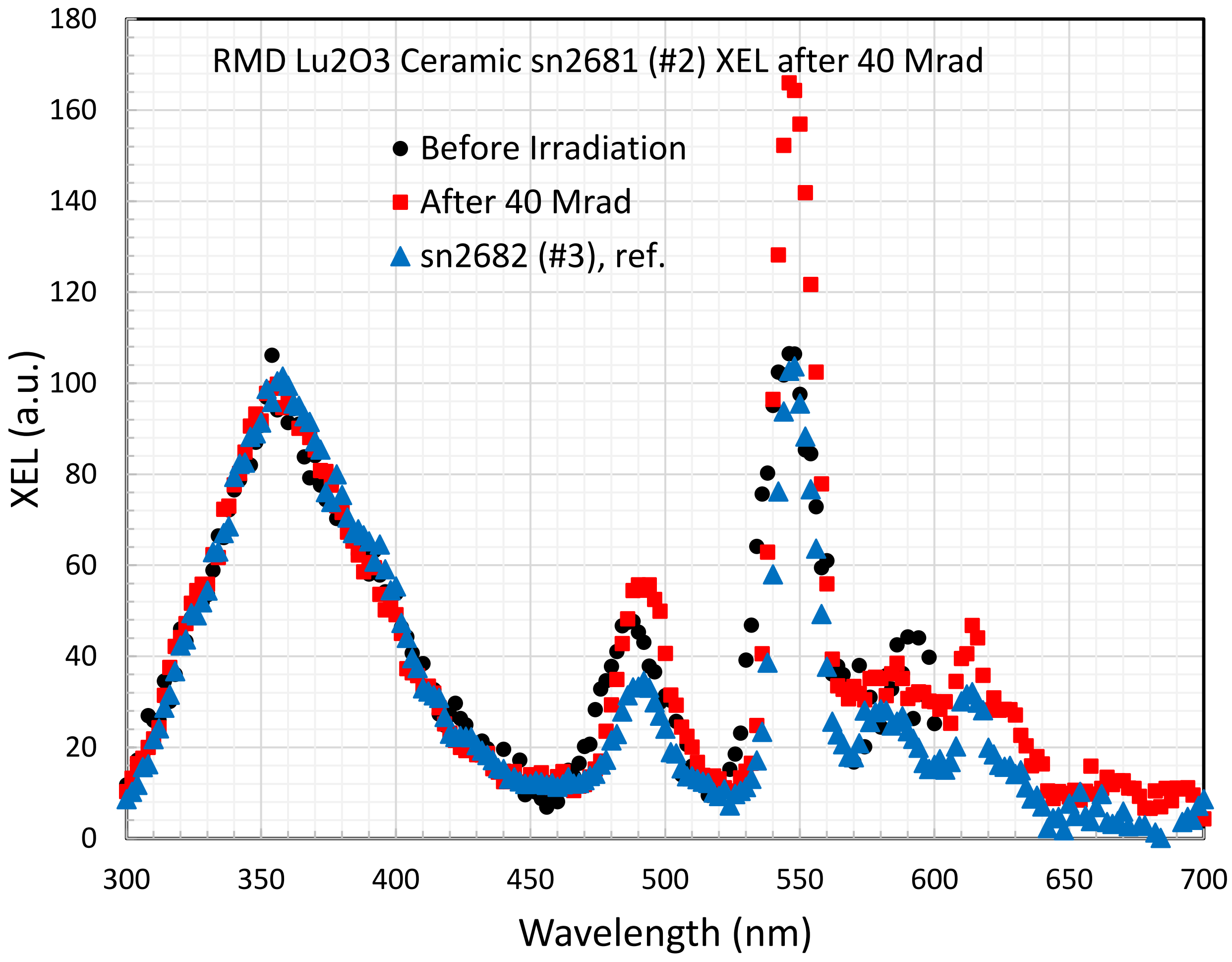
SN2681 survives 50 Mrad, while others show larger degradation

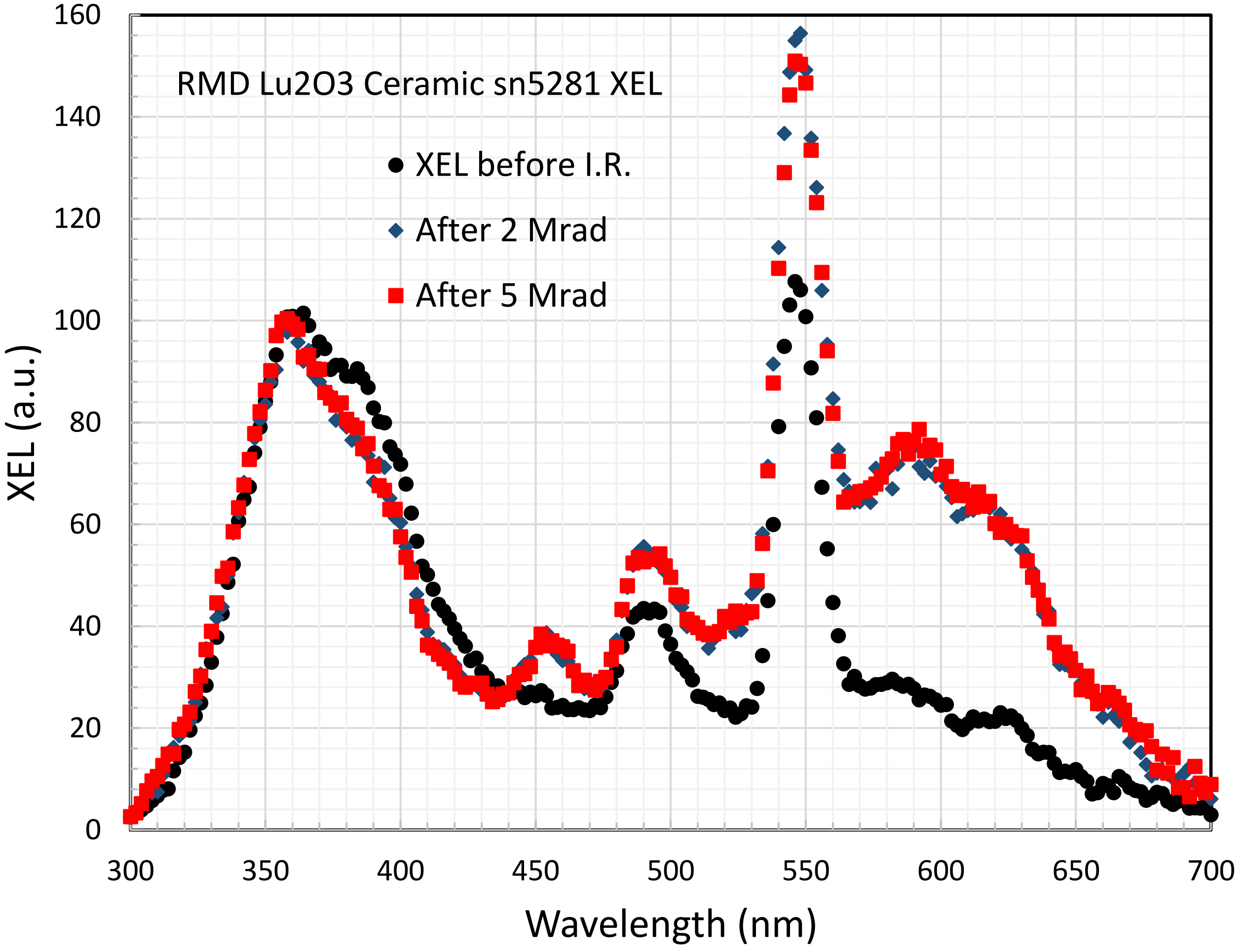
Caltech ID	RMD ID	Dimension (mm^3)	Composite	EWLT	200 ns LO (p.e./MeV)	200 ns LY (ph/MeV)	1^{st} ns LY*	LY(200) /LY(3000)	TID of γ-IR (Mrad)	Comment
2	sn2681	Φ9×1.5	1%Yb:Lu_2O_3	44.2%	54	307	183	100%	5.1, 10.1, 15.1, 20.1, up to 50.4	Measured up to 50 Mrad
7	sn4494	Φ9×2	1%Yb:$(Lu_{0.5},Y_{0.5})_2O_3$	26.6%	42	239	129	86%	5, 10, 15.3	Measured up to 10 Mrad
8	sn4496	Φ9×1	1%Yb:Lu_2O_3	62.3%	45	257	153	98%	5, 10, 15.3	Measured up to 10 Mrad
12	sn4805	Φ17×3	0.2%Yb:$(Lu,Y)_2O_3$	36.0%	51	290	99	54%	5, 10, 15.3	Measured up to 10 Mrad
14	sn5280	27×27×5	1%Yb:Lu_2O_3	23.2%	25	125	60	100%	2.0, 5.0	Measured up to 5 Mrad
15	sn5281	27×27×5	1%Yb:Lu_2O_3	20.1%	27	135	66	100%	2.0, 5.0	Measured up to 5 Mrad
13	sn5165	27×27×3	Yb:Lu_2O_3	61%	24	120	69	96%	-	Not Irradiated

* Assuming ultrafast component decay time ~1.1 ns.

XEL: Before and After γ-ray Irradiation

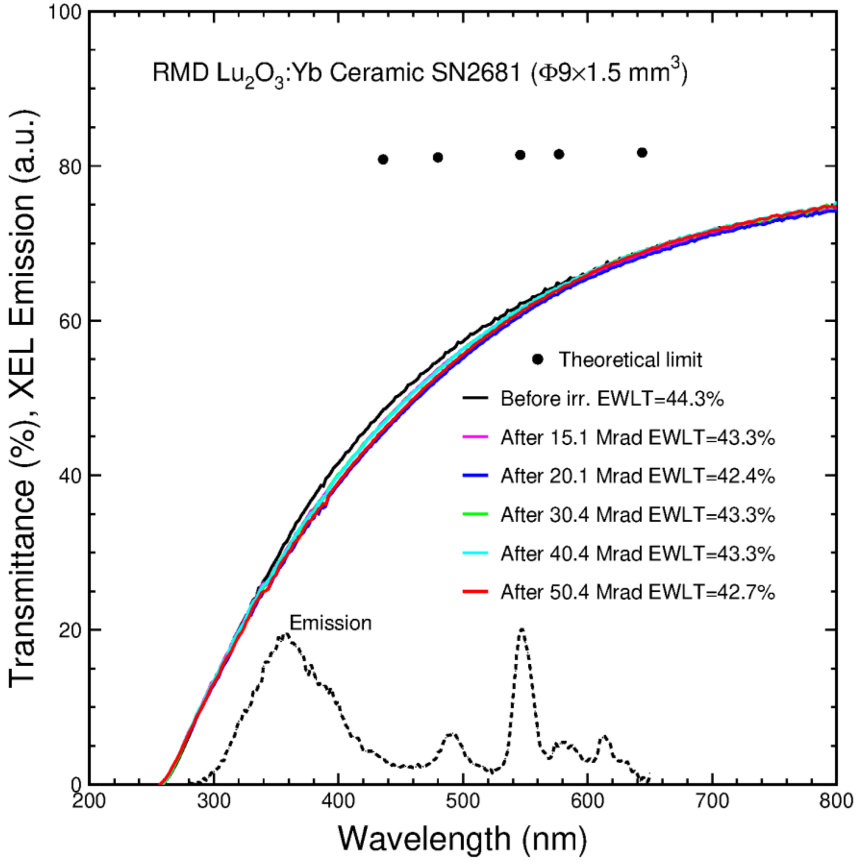
SN 2681/2682 show consistent emission
All show enhanced peaks at 495 and 545 nm after irradiation

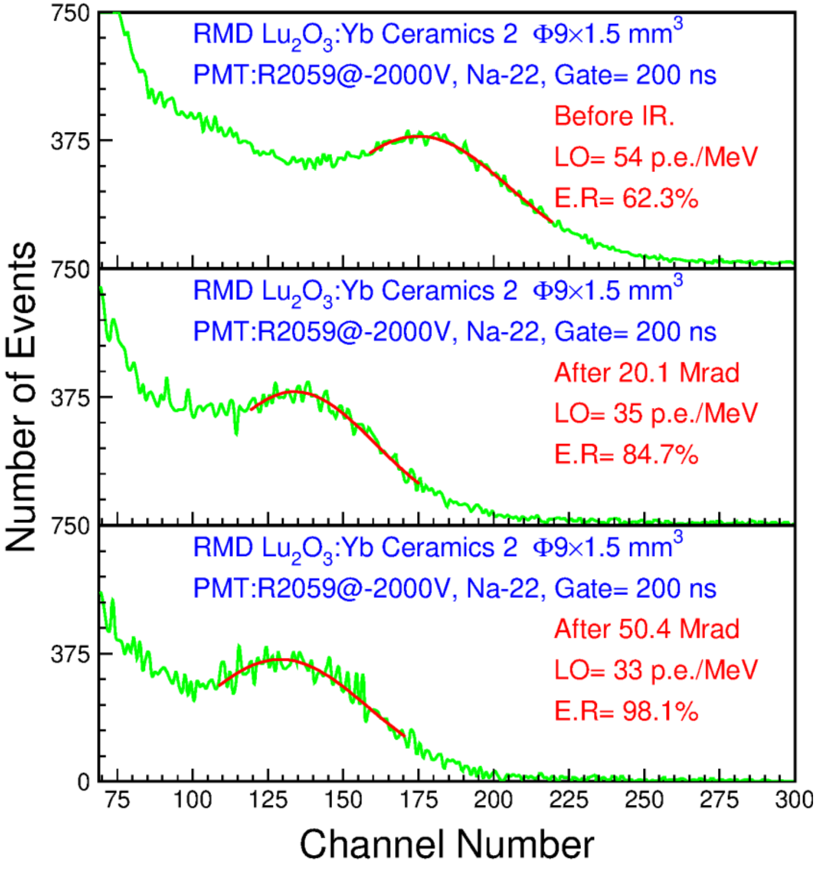


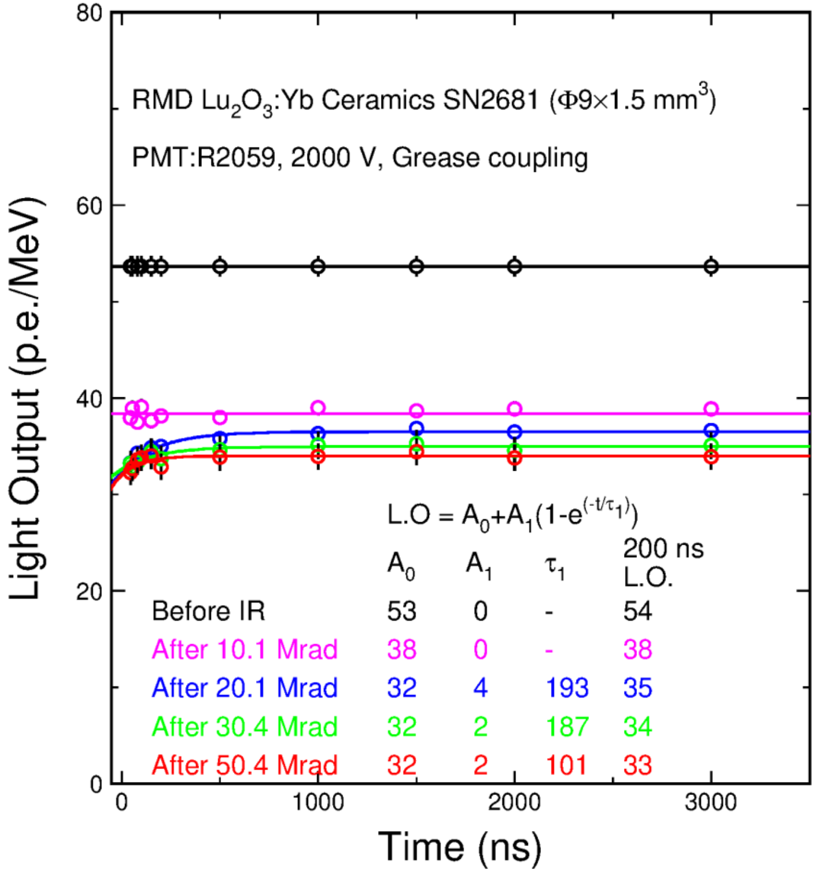


SN2681 Measured up to 50 Mrad

^{22}Na peak measurable after 5.1, 10.1, 15.1 20.1 25.4, 30.4, 40,4 and 50.4 Mrad
Slow component appears after 15 Mrad



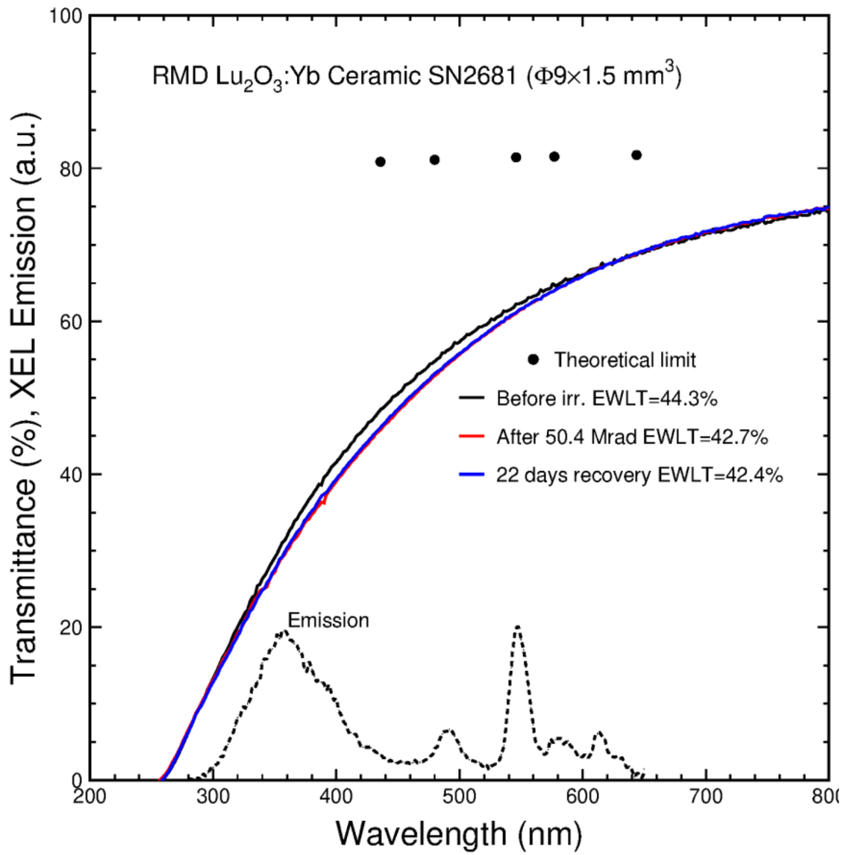


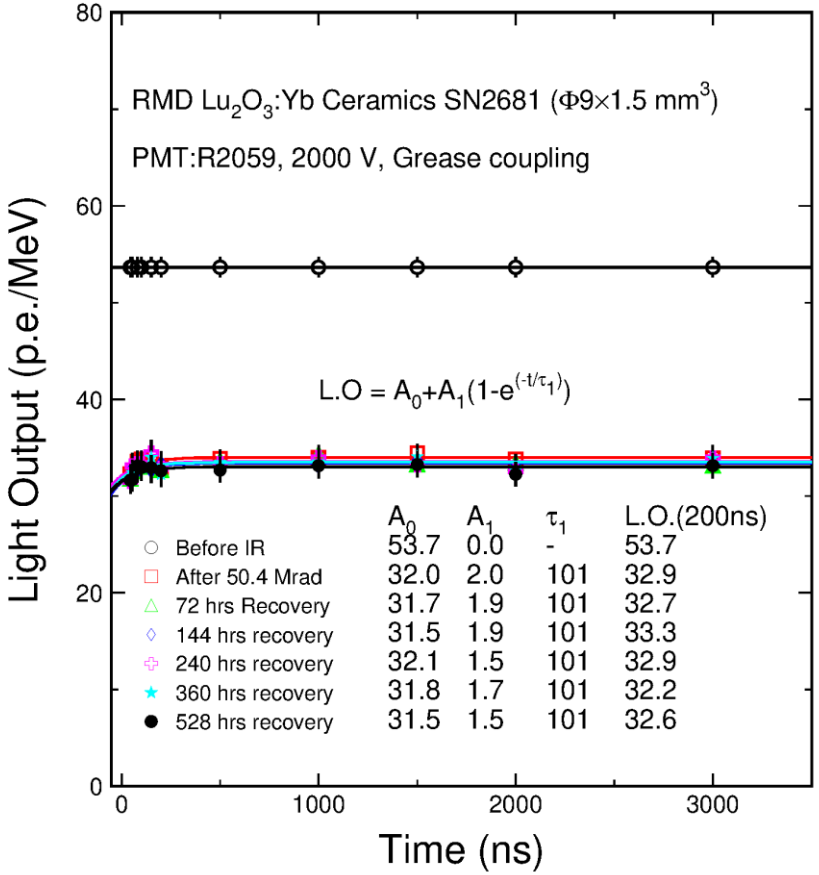


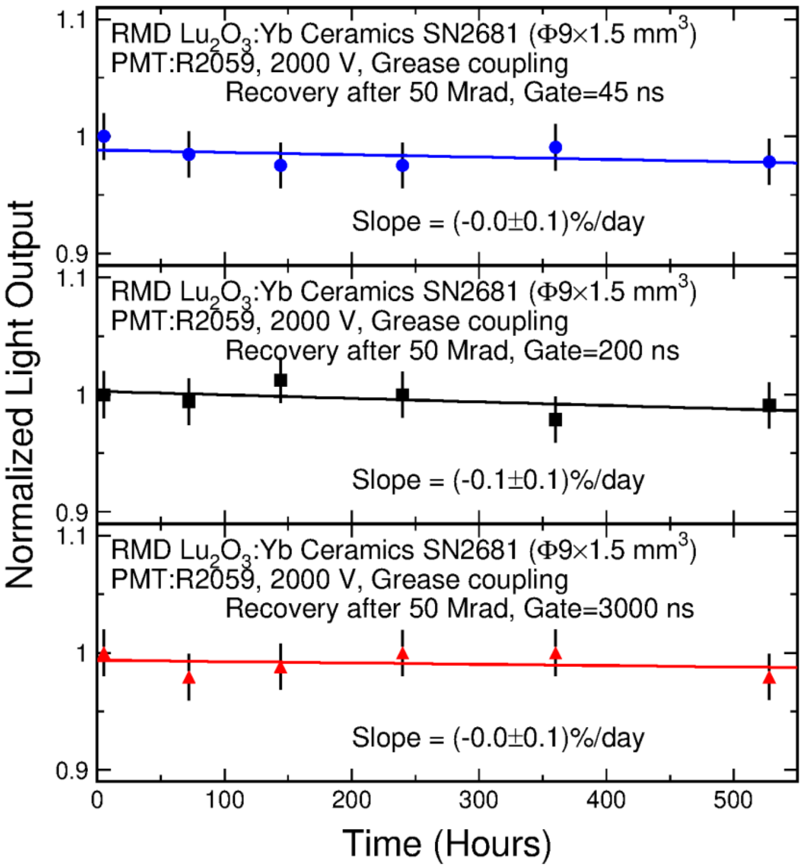
	A_0	A_1	τ_1	200 ns L.O.
Before IR	53	0	-	54
After 10.1 Mrad	38	0	-	38
After 20.1 Mrad	32	4	193	35
After 30.4 Mrad	32	2	187	34
After 50.4 Mrad	32	2	101	33

SN2681 Recovery after 50 Mrad

No recovery in transmittance and LO up to 22 days after 50 Mrad

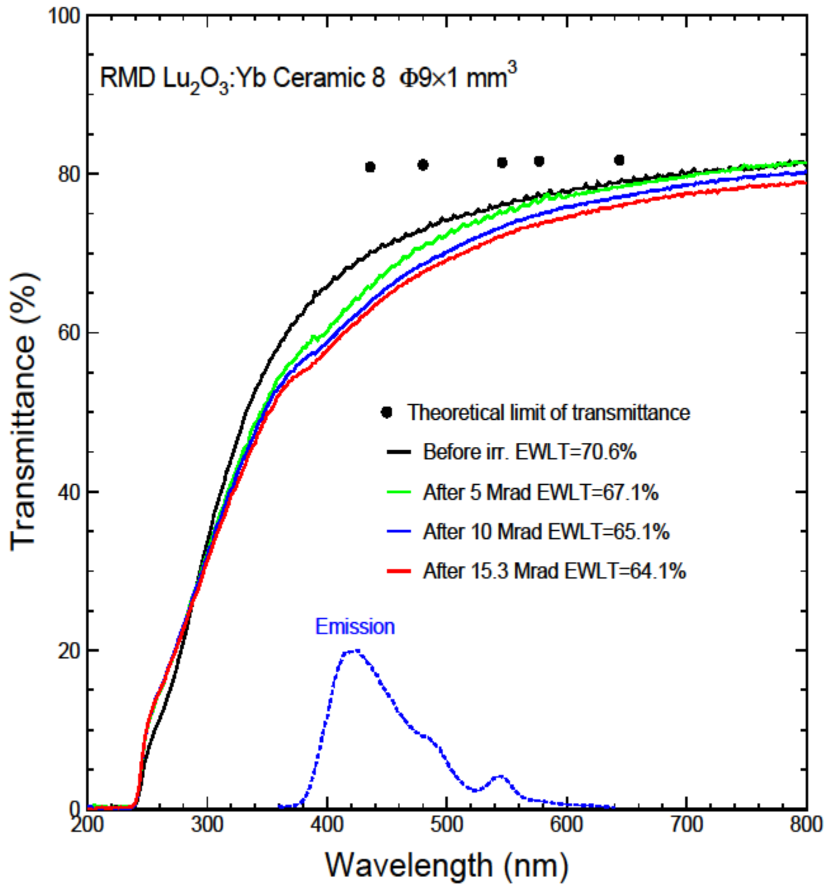


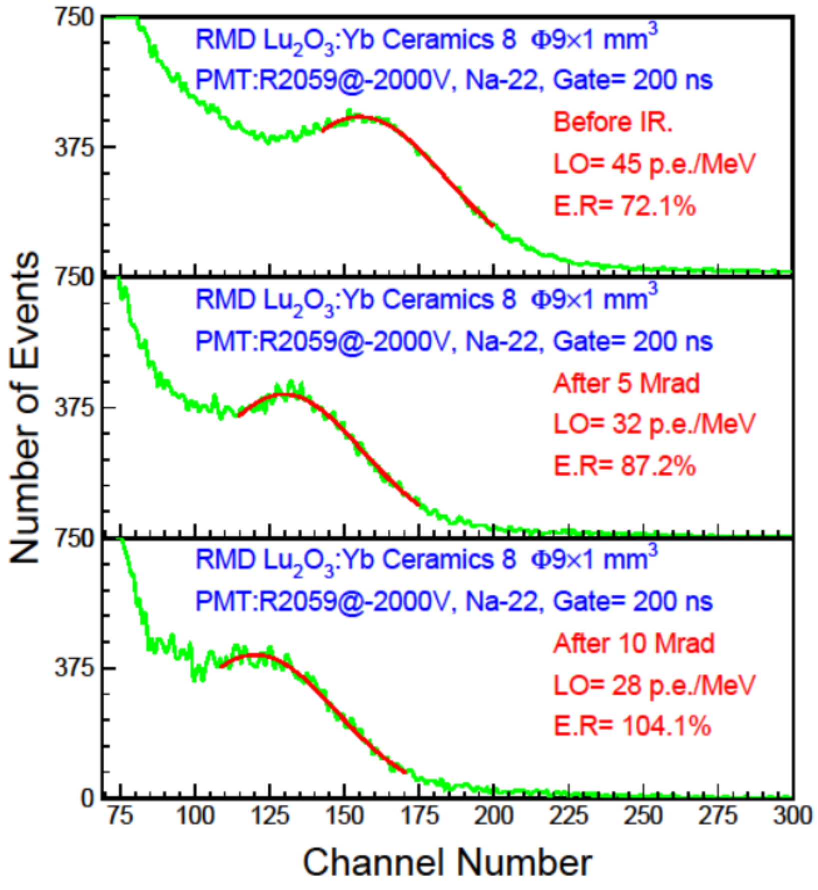


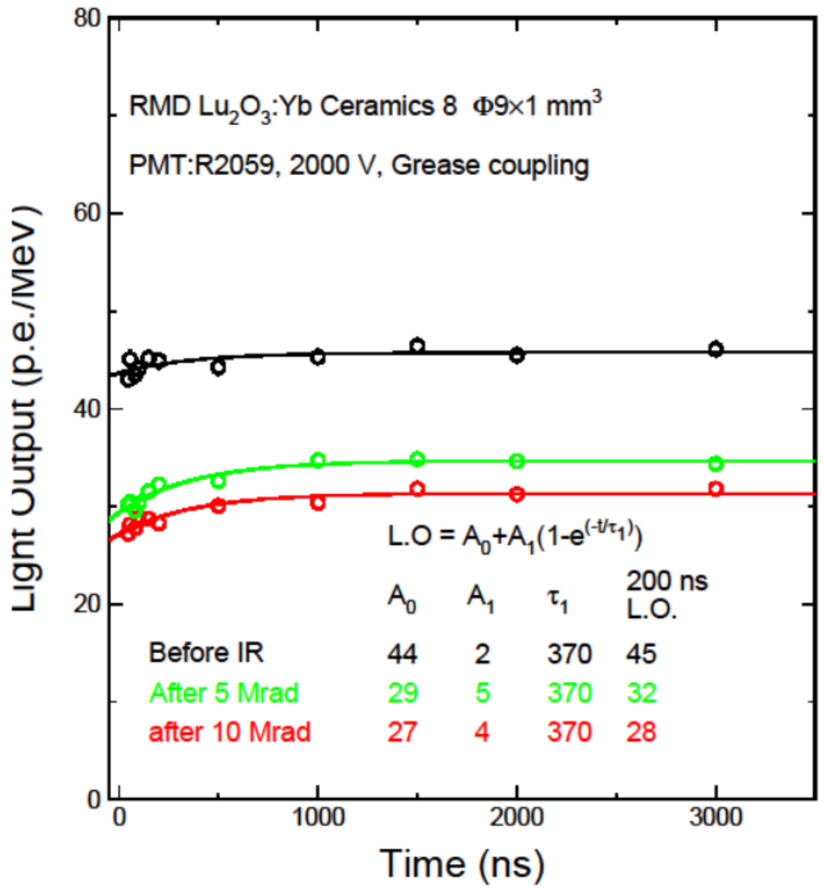


SN4496 Measured up to 10 Mrad

^{22}Na peak measurable after 5 and 10 Mrad, but not 15.3 Mrad
With good transmittance correlation between LO and transmittance observed

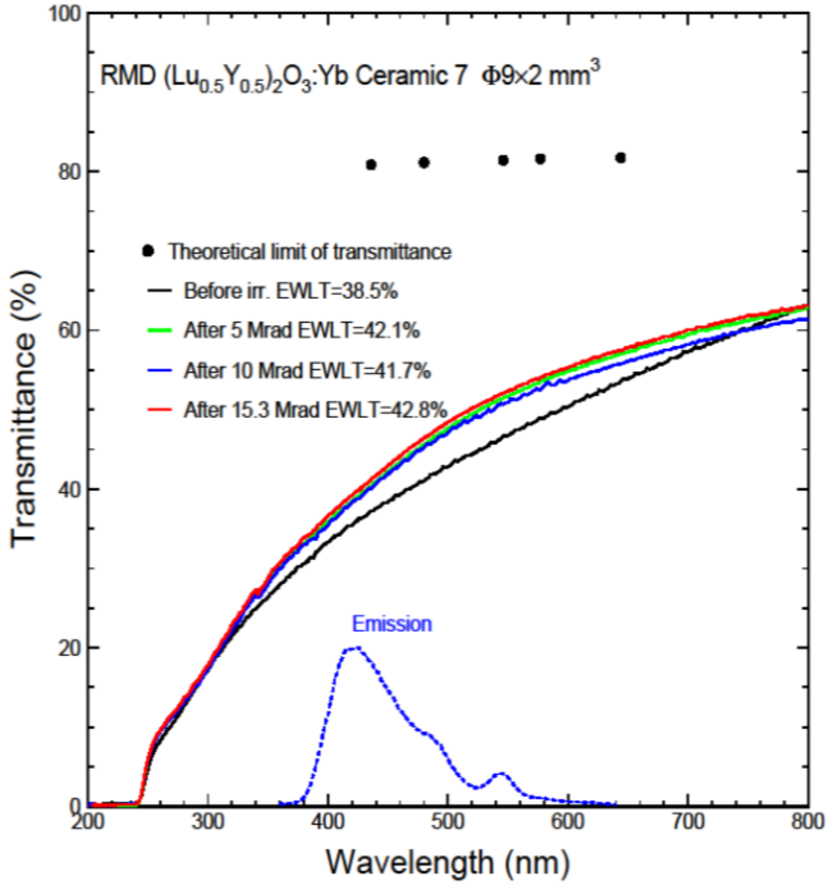


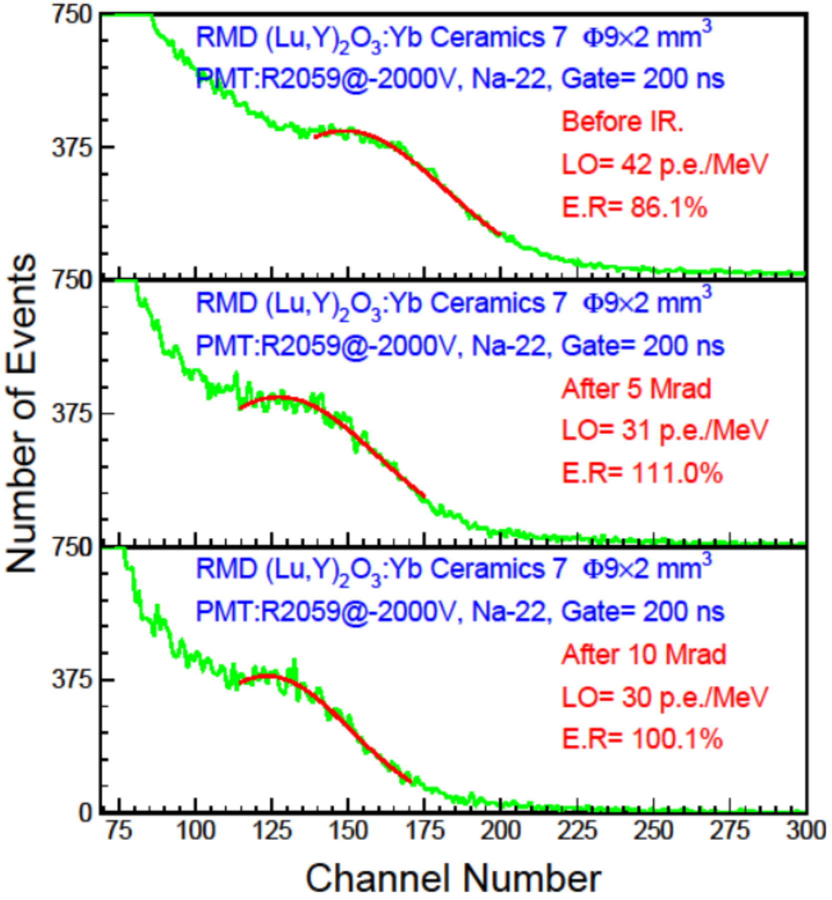


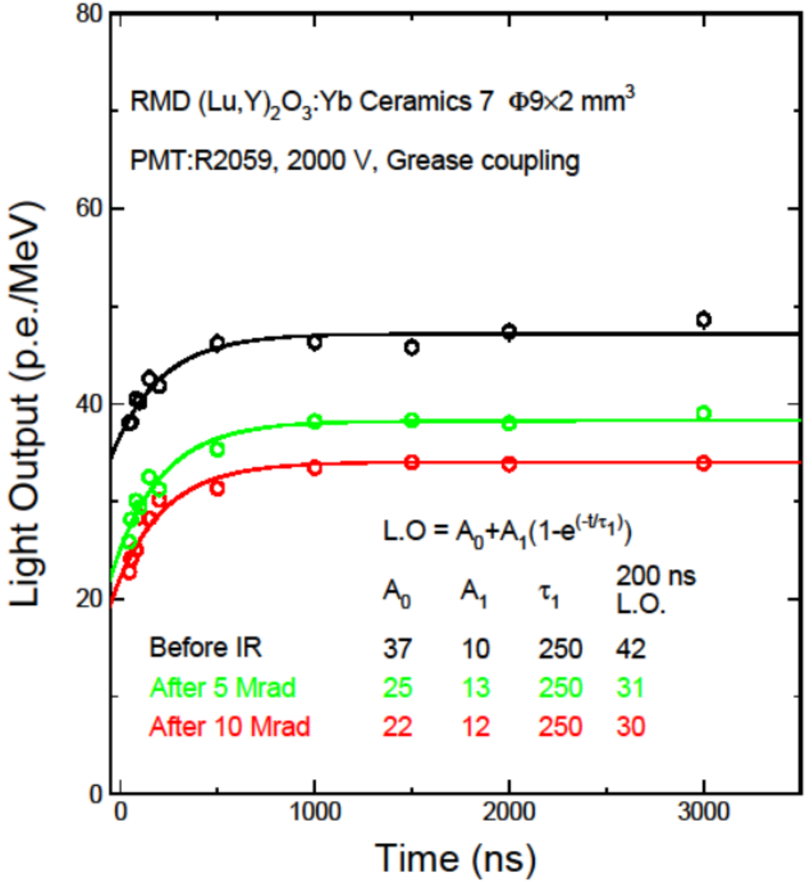


SN4494 Measured up to 10 Mrad

[22]Na peak measurable after 5 and 10 Mrad, but not 15.3 Mrad
Slow component exist in this $(Lu,Y)_2O_3$ sample

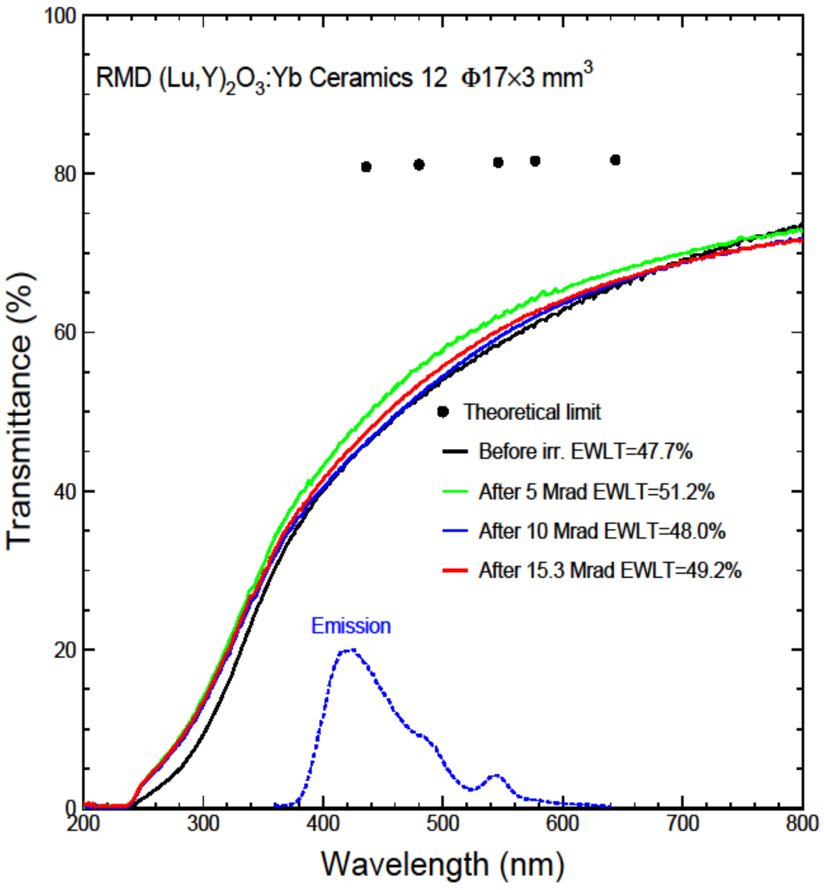


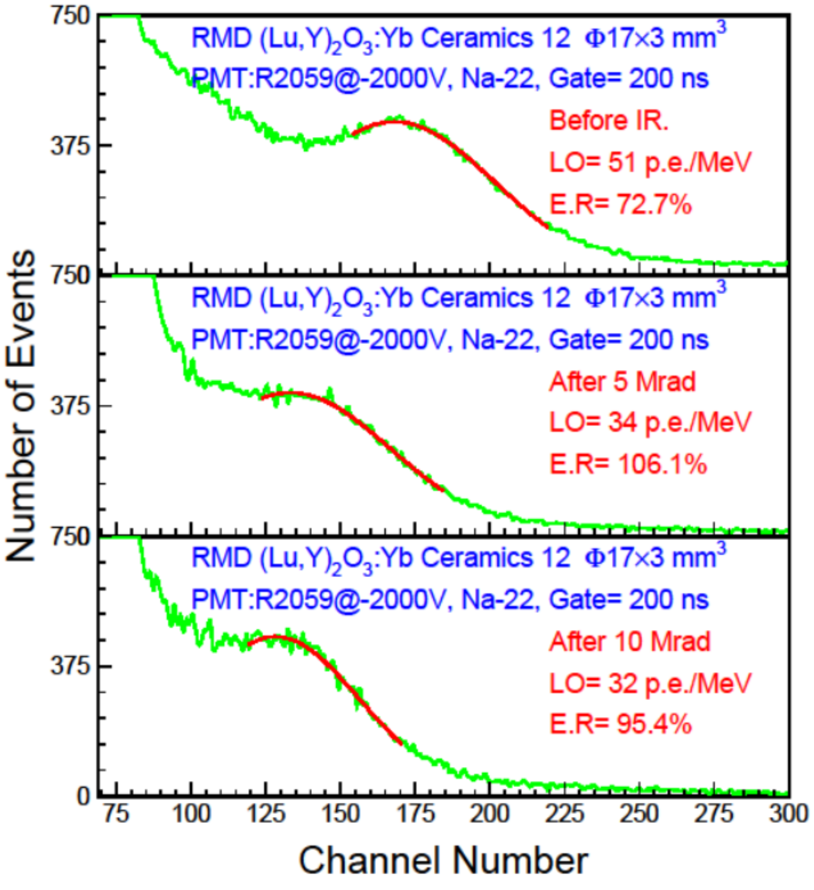


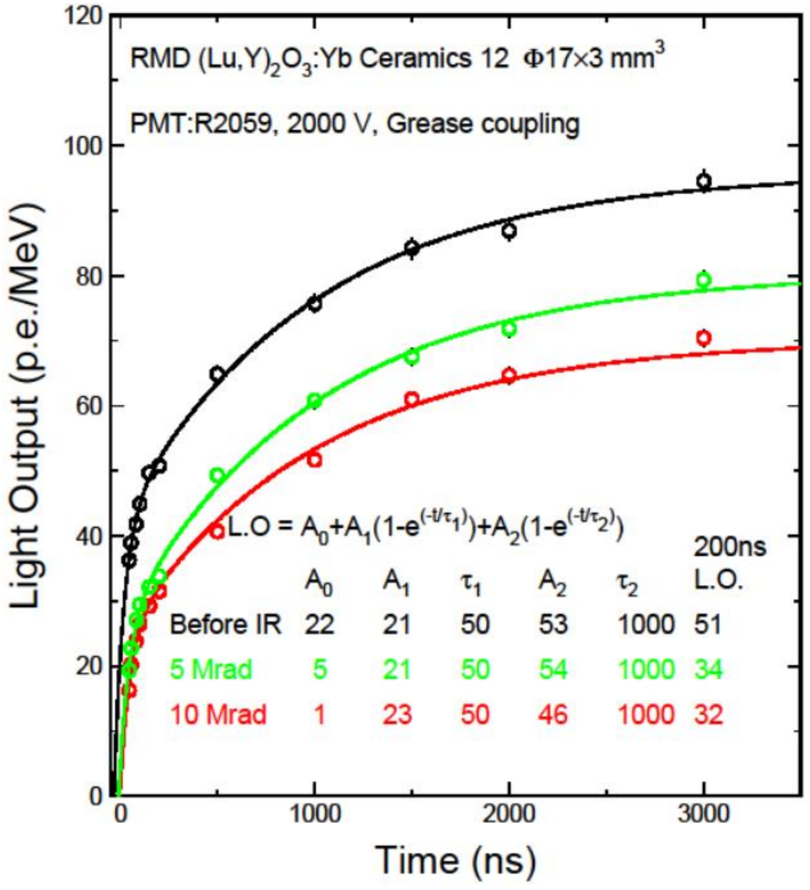


SN4805 Measured up to 10 Mrad

^{22}Na peak measurable after 5 and 10 Mrad, but not 15.3 Mrad
Slow component exist in this $(Lu,Y)_2O_3$ sample

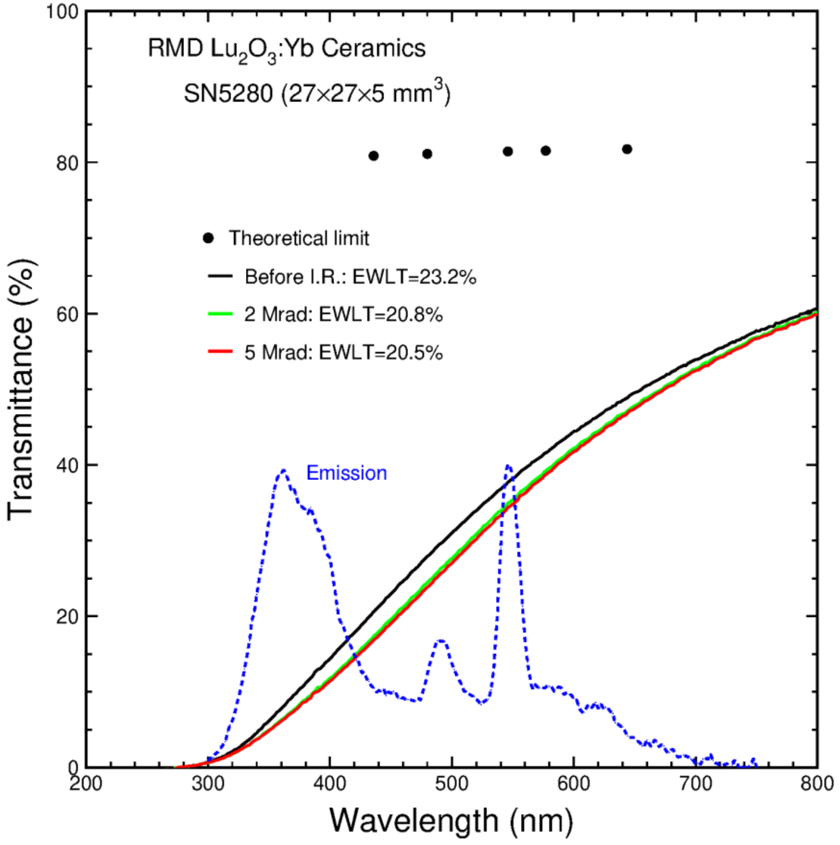


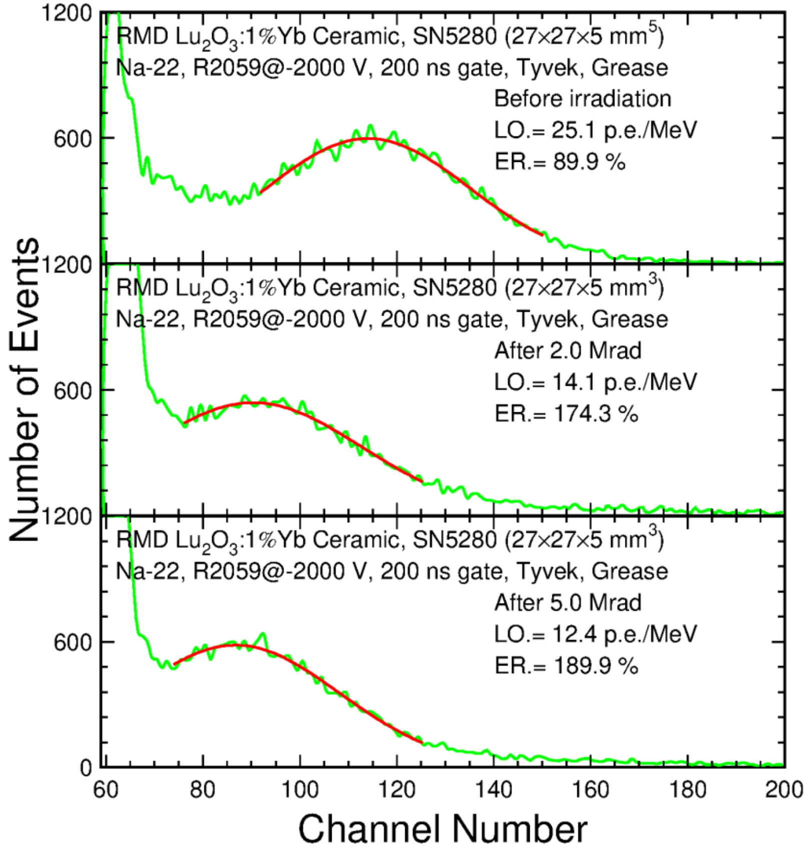


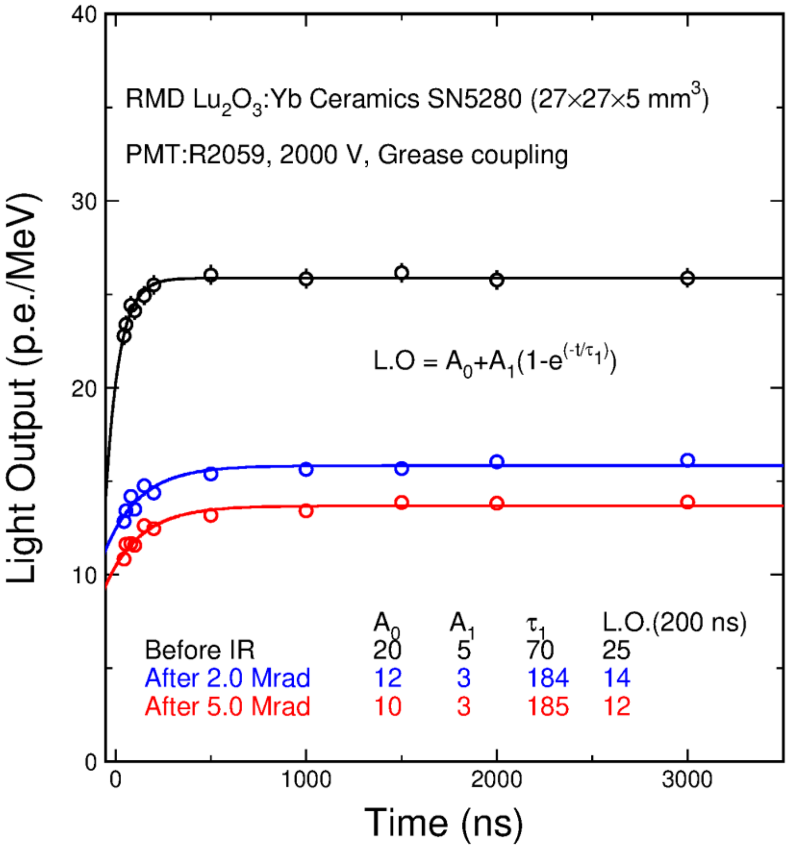


SN5280 Measured up to 5 MRad

^{22}Na peak measurable after 2 and 5 Mrad
Slow component exist in this sample

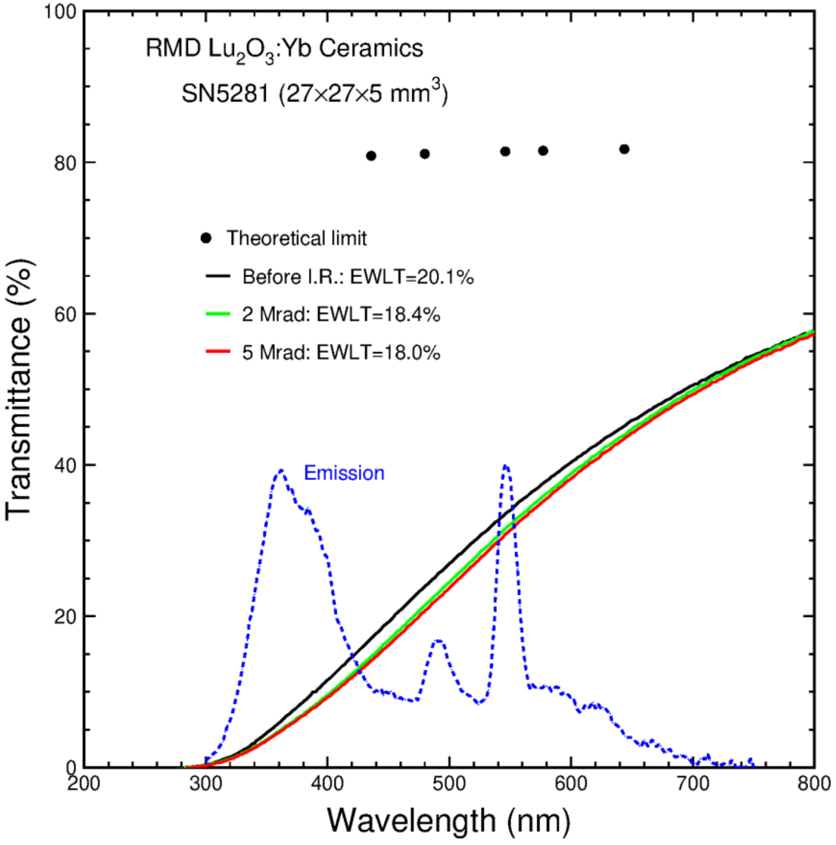


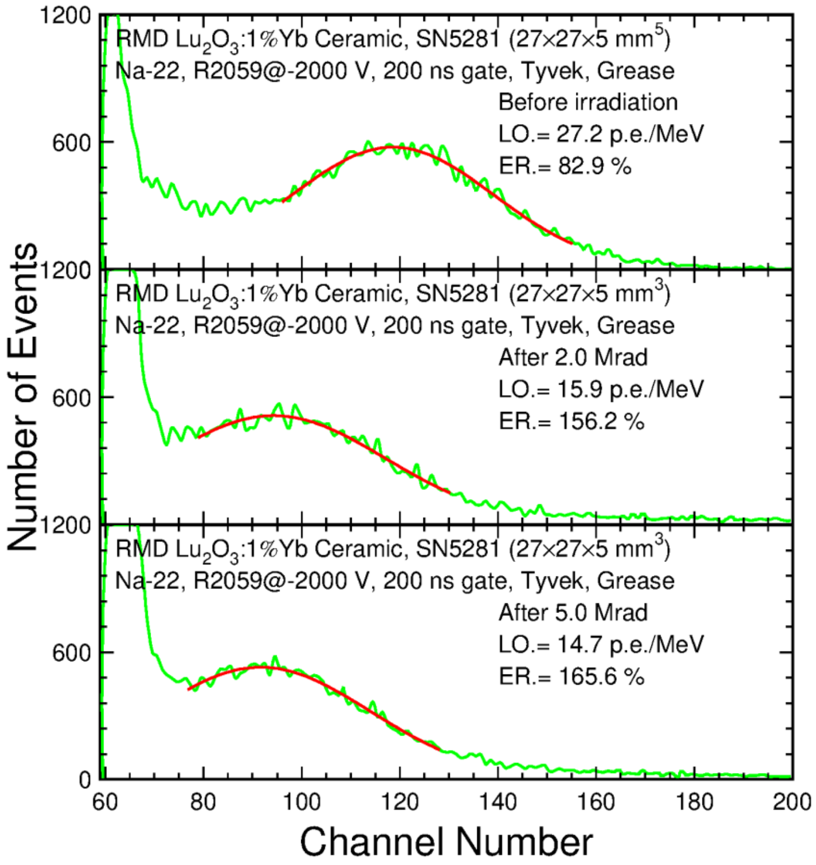


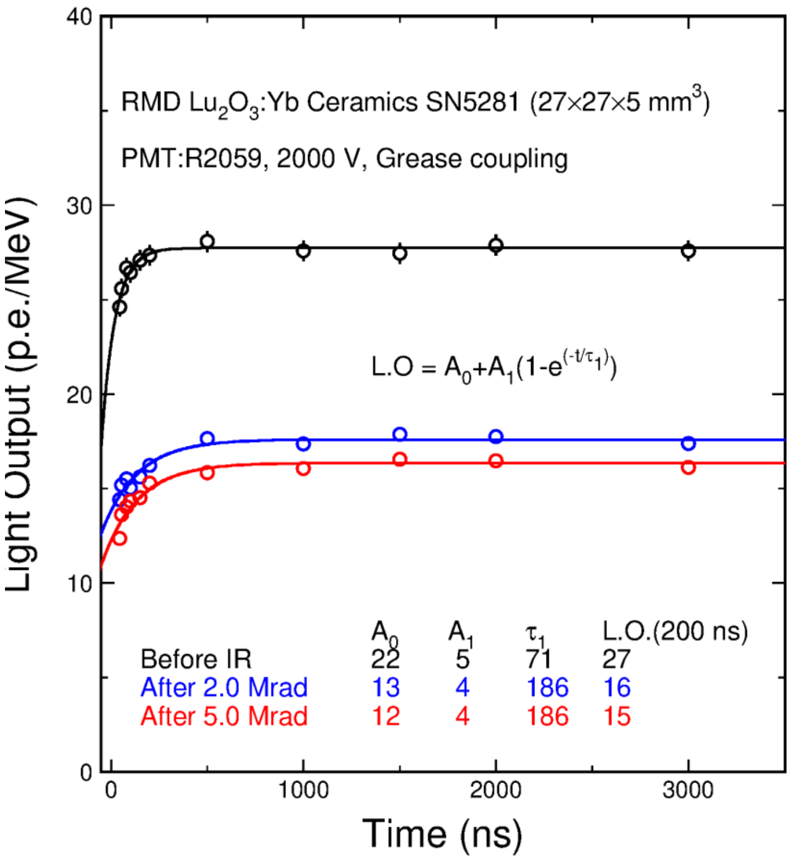


SN5281 Measured up to 5 MRad

^{22}Na peak measurable after 2 and 5 Mrad
Slow component exist in this sample







Summary

- Ultrafast heavy inorganic scintillators with sub-nanosecond decay time is important to break the ps timing barrier for future HEP TOF system and ultrafast calorimetry, as well as GHz hard X-ray imaging.
- Lu_2O_3:Yb samples show XEL emission peaked at ~360, 490 and 545 nm with decay time of 1.1 ns measured by MCP-PMT. Improved transparency observed in 2023 samples of large size.
- Six Lu_2O_3:Yb samples irradiated by γ-rays up to 50 Mrad. No recovery was observed in 22 days after irradiation.
- Sample SN2681 shows excellent radiation hardness up to 50 Mrad. All other five samples show visible ^{22}Na peak up to 10 Mrad.
- With high density, ultrafast decay time and high Ultrafast/Total ratio Lu_2O_3:Yb ceramics are promising for future HEP detector application.

Acknowledgements: DOE HEP Award DE-SC0011925 and SBIR Award DE-SC0021686