A Very Fast and Robust BaF_2 Calorimeter for Future HEP/NP Experiments

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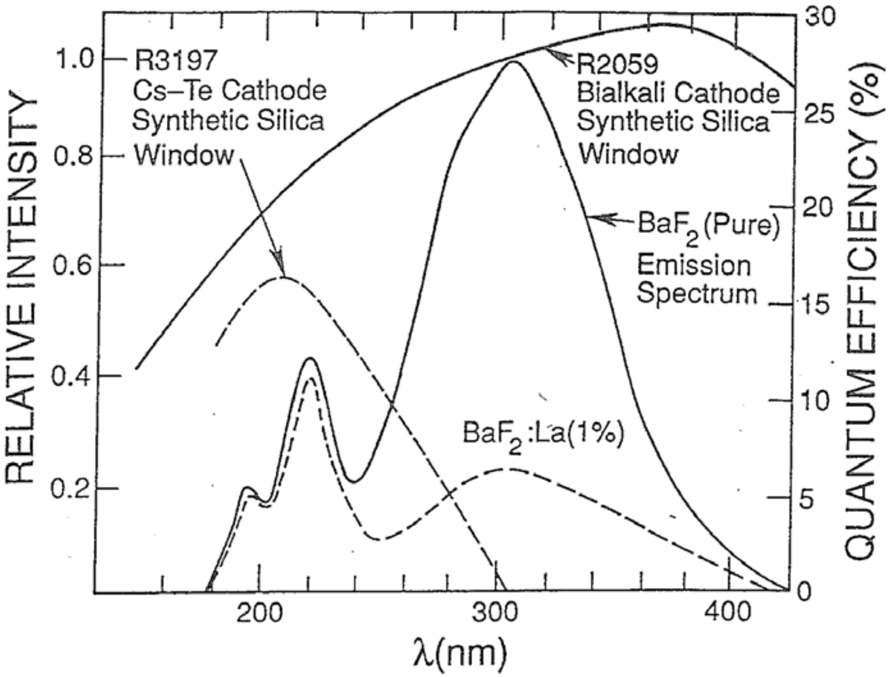
Introduction

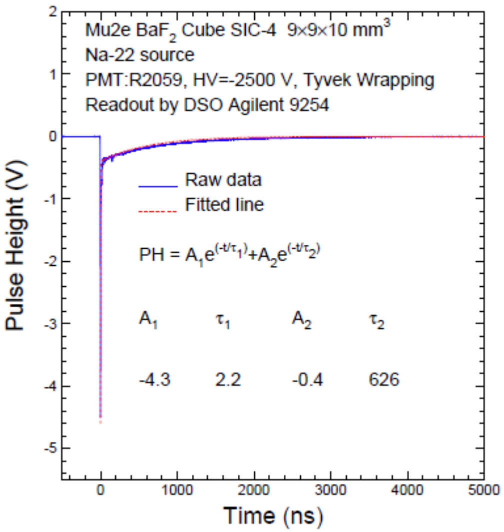
- Fermilab is building a undoped CsI calorimeter for the Mu2e-I detector, which is featured with 30 ns scintillation and surviving ionization dose up to 100 krad. A radiation level exceeding 100 krad is expected by the proposed Mu2e-II, so BaF_2 is being considered.
- With sub-ns fast scintillation and excellent radiation hardness beyond 100 Mrad, BaF_2 promises a very fast and robust calorimeter.
- There are several approaches to handle 600 ns slow scintillation in BaF_2: solar blind photodetector and selective doping in crystal.
- Effective suppression of the slow component has been achieved in Yttrium doped BaF_2 crystals.
- Mass production capability of BaF_2 exists in industry:
  - BGRI (China), Incrom (Russia) and SICCAS (China);
  - Hellma (Germany).

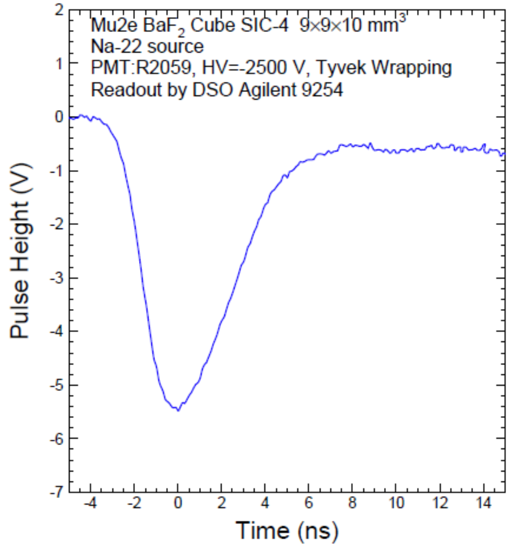
Fast and Slow Signal from BaF_2

The amount of light in the fast component of BaF_2 at 220 nm with sub-ns decay time is similar to undoped CsI.

Spectroscopic selection of fast component may be realized by solar blind photocathode and/or selective doping.



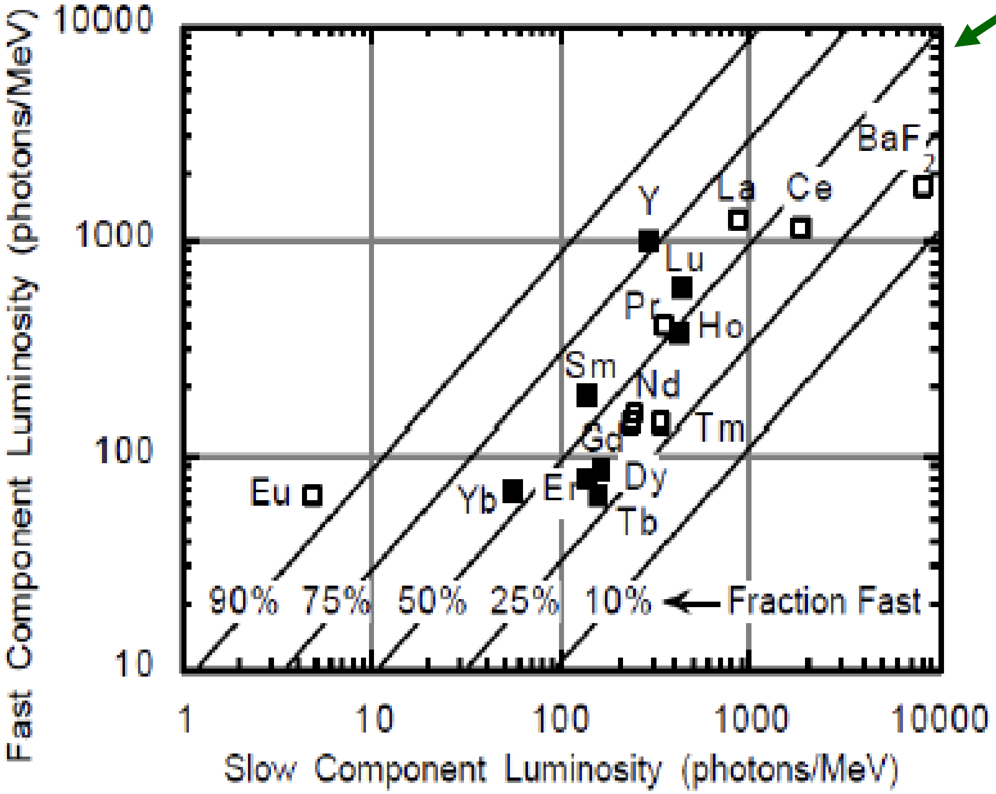


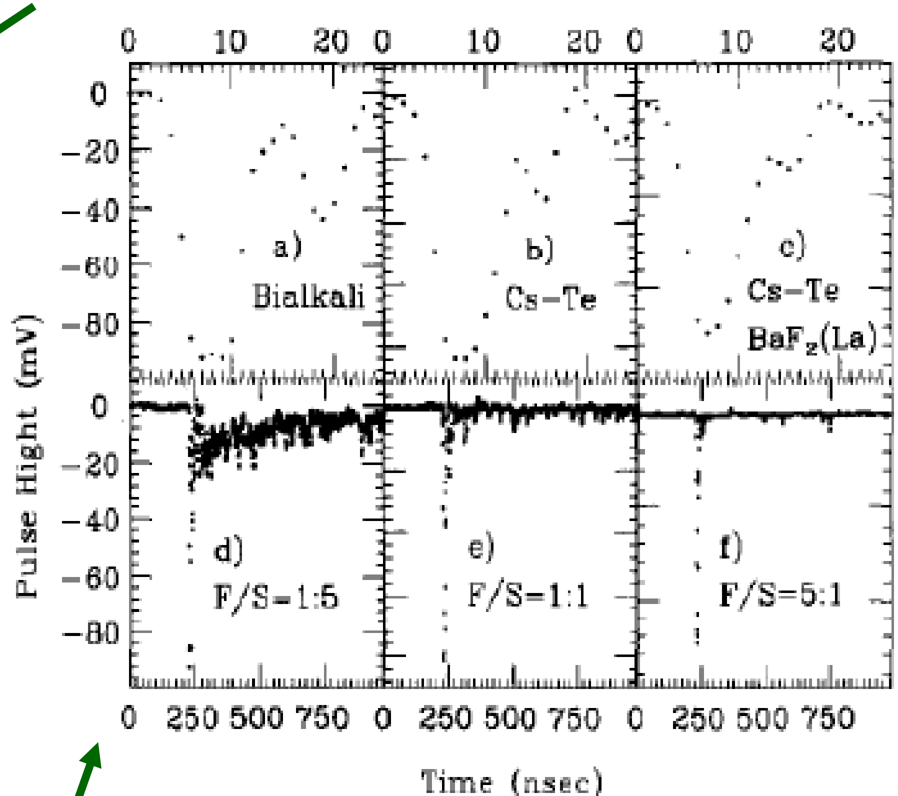


Slow Suppression: Doping & Readout

Slow component may be suppressed by RE doping: Y, La and Ce

B.P. SOBOLEV et al., "SUPPRESSION OF BaF2 SLOW COMPONENT OF X-RAY LUMINESCENCE IN NON-STOICHIOMETRIC Ba0.9R0.1F2 CRYSTALS (R=RARE EARTH ELEMENT)," *Proceedings of The Material Research Society: Scintillator and Phosphor Materials*, pp. 277-283, 1994.

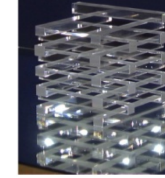




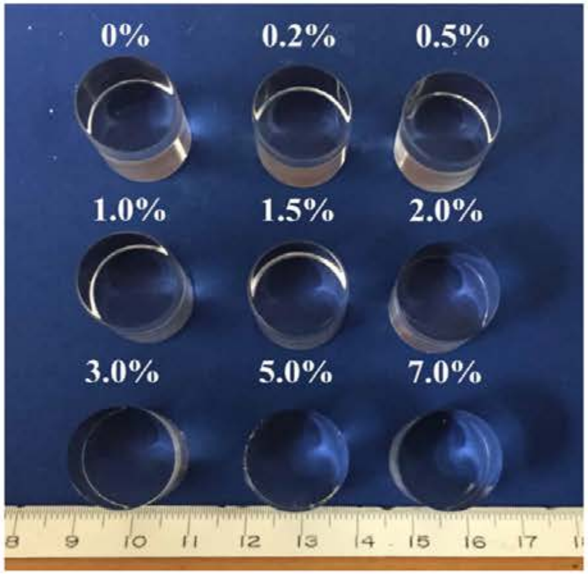
Solar-blind cathode (Cs-Te) + La doping achieved F/S = 5/1

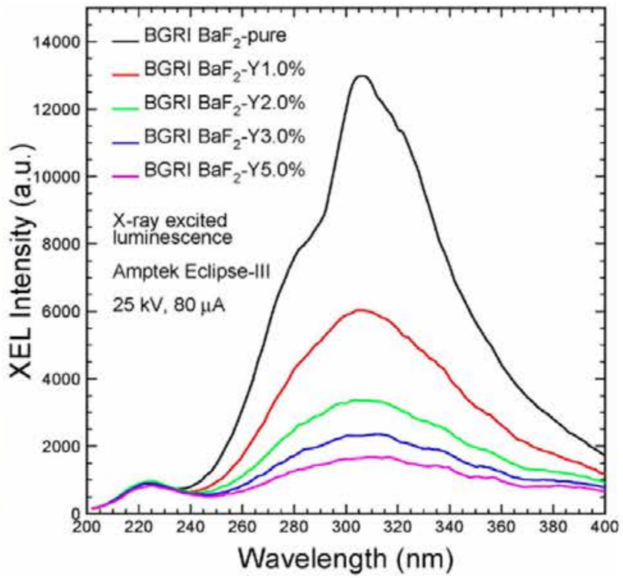
Z. Y. Wei, R. Y. Zhu, H. Newman, and Z. W. Yin, "Light Yield and Surface-Treatment of Barium Fluoride-Crystals," *Nucl Instrum Meth B*, vol. 61, pp. 61-66, Jul 1991.

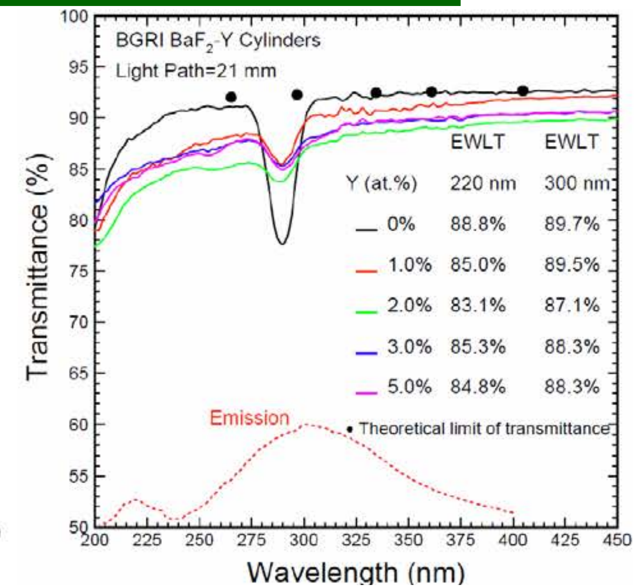
Yttrium Doped BaF_2

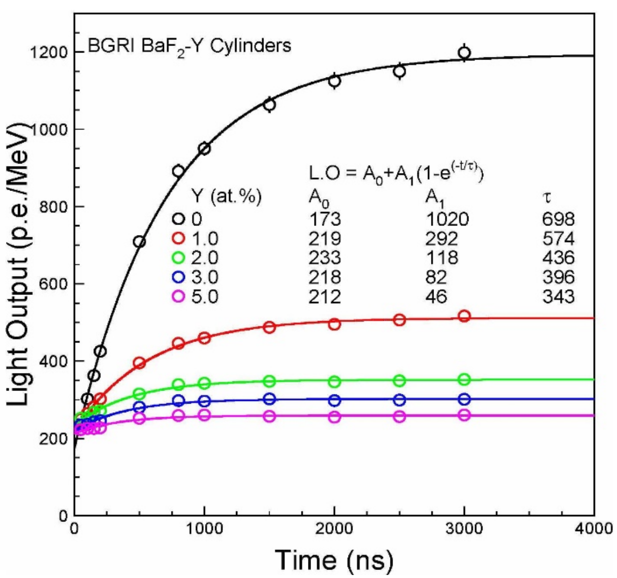


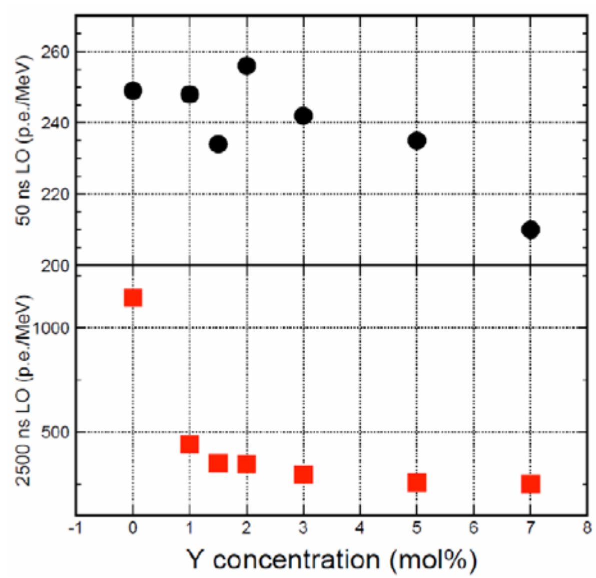
F/S ratio from 1/5 to 5/1: very effective slow suppression

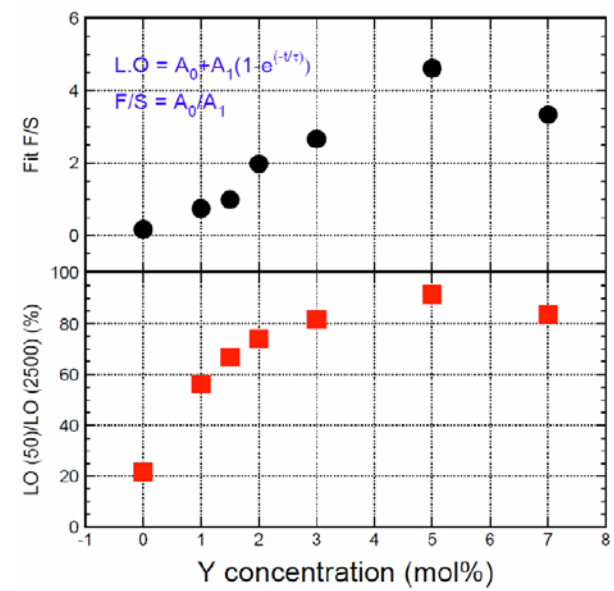










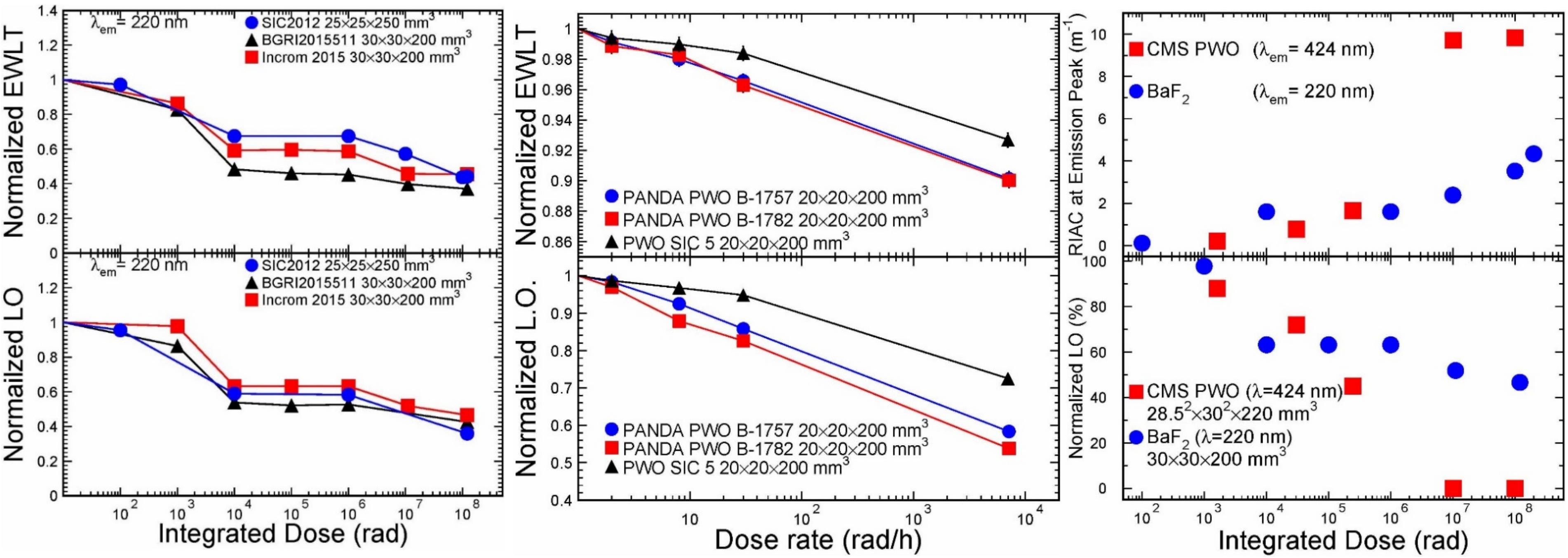


BGRI/Incrom/SIC BaF_2 Samples

ID	Vendor	Dimension (mm³)	Polishing
SIC 1-20	SICCAS	30x30x250	Six faces
BGRI-2015 D, E, 511	BGRI	30x30x200	Six faces
Russo 2, 3	Incrom	30x30x200	Six faces

Ionization Damage in BaF_2 & PWO

Dose rate dependent damage in PWO
Good radiation hardness in BaF_2 up to 100 Mrad

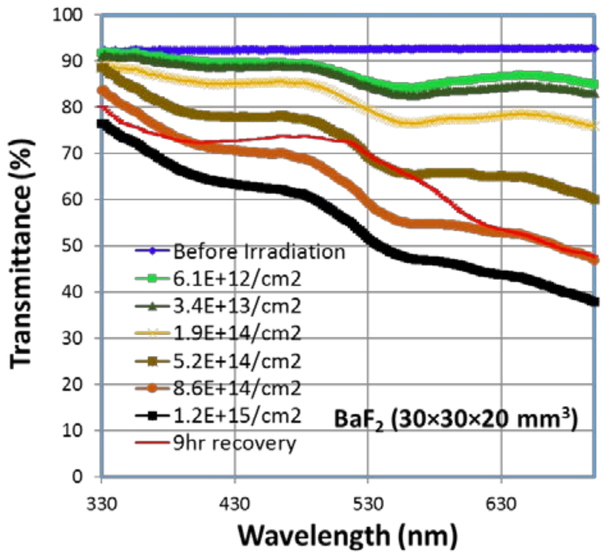


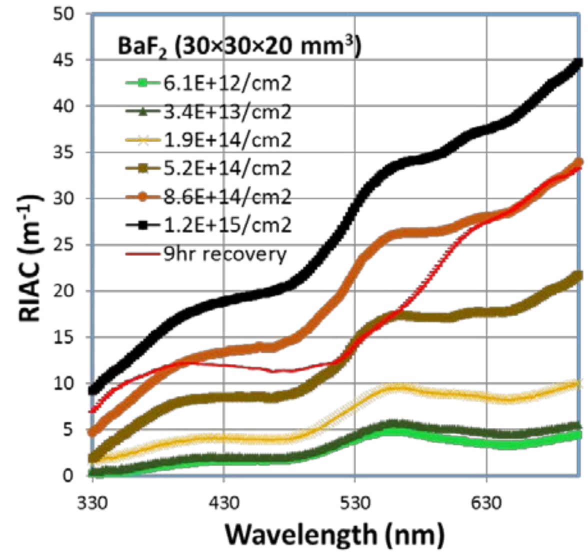
Fan Yang, et al. IEEE Trans. Nucl. Sci., 2017, 64: 665-672.

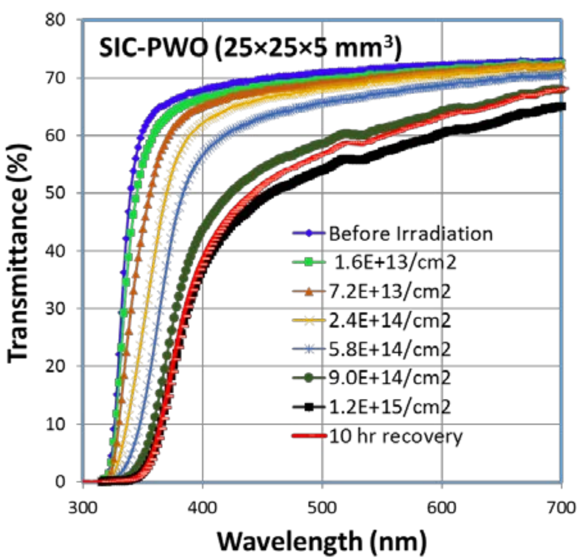
40% fast scintillation light remains after 120 Mrad ionization dose

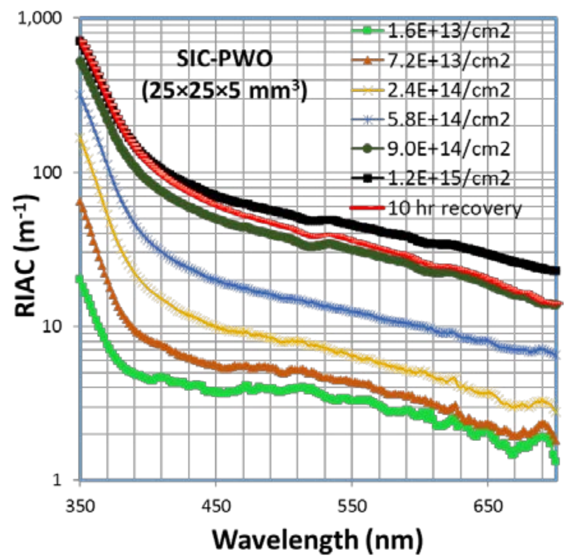
800 MeV Proton Damage in BaF_2 & PWO

A Hellma BaF_2 of 2 cm was irradiated from 6.1×10^{12} to 1.2×10^{15} p/cm^2 in six steps with transmittance (330-650 nm) measured *in-situ*. The sample will be measured at Caltech for 200 – 650 nm.







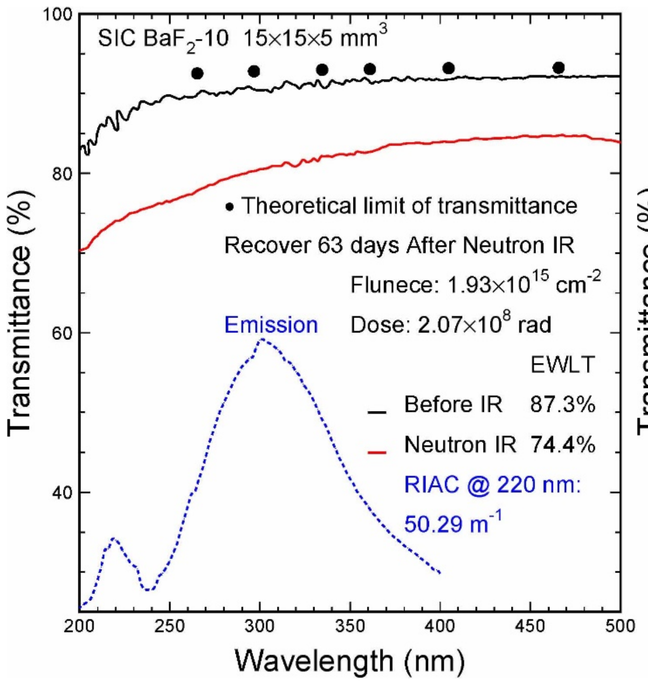


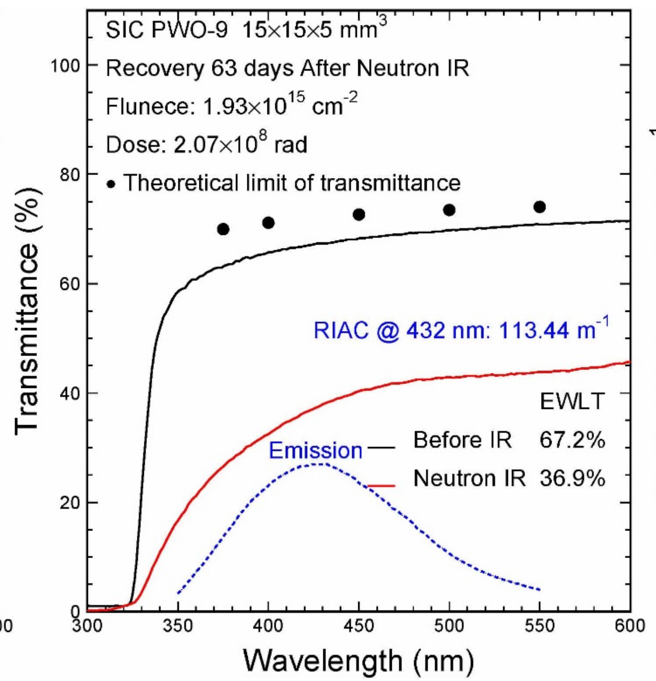
A 5 mm thick SIC PWO plate was irradiated from 1.6×10^{13} to 1.2×10^{15} p/cm^2 with transmittance (300-700 nm) measured *in-situ*. The RIAC at 420 nm was measured to be 13.1 / 92.2 cm^{-1} after 2.4×10^{14} / 1.2×10^{15} p/cm^2.

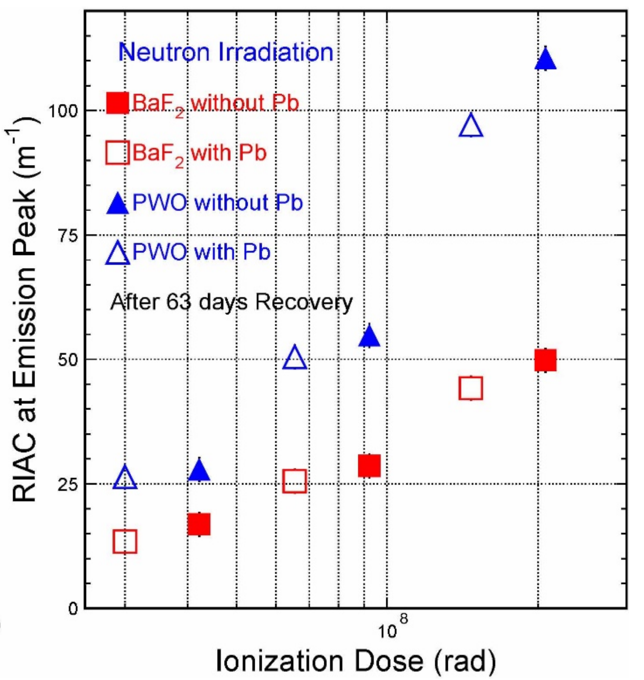
R.-Y. Zhu, "Preliminary Report on the Experiment 7324 with 800 MeV Protons at Los Alamos," http://www.hep.caltech.edu/~zhu/talks/ryz_1601207_LANL.pdf

Neutron + Ionization Dose in BaF_2 & PWO

Samples in three groups irradiated at the East Port of LANSCE







Results consist with ionization dose induced damage showing no neutron specific damage in BaF_2 and PWO

Summary

- Commercially available BaF_2 crystals provide sufficient fast light with sub-ns decay time and excellent radiation hardness beyond 100 Mrad. They promise a very fast and robust calorimeter in a severe radiation environment.
- Work on yttrium doping in BaF_2 crystals has increased the F/S ratio from 1/5 to 5/1 without using selected readout. The slow contamination at this level is already less than commercially available undoped CsI.
- To be investigated is photodetector with DUV response, e.g. a diamond photo-detector, and radiation hardness of yttrium doped BaF_2 crystals.
- It would be a joint effort with the HEP community if the EIC group will choose to pursue this novel crystal calorimeter.