Organic Glass Scintillators for Nuclear Physics Experiments

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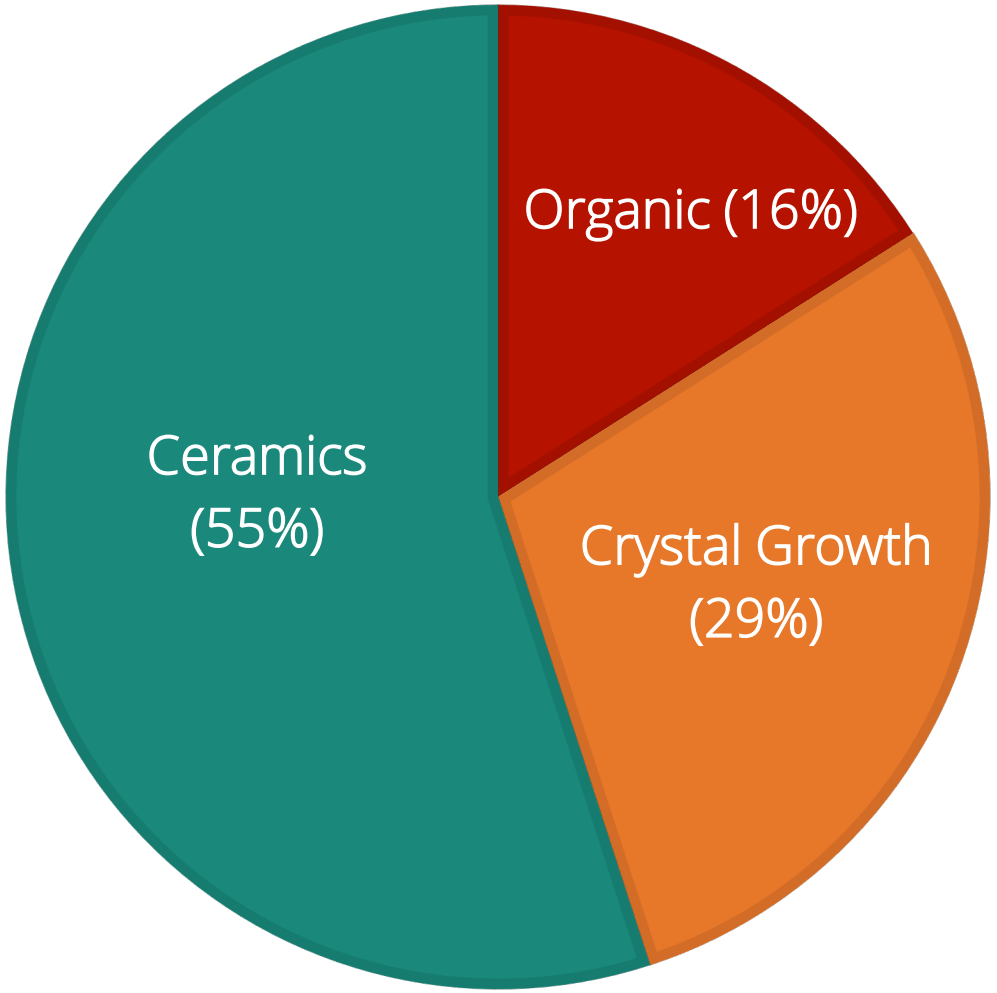
This work has been supported by the U.S. Department of Energy contract # DE-SC0021545. This support does not constitute an express or implied endorsement on the part of the Government. Distribution A. Approved for public release, distribution is unlimited.

Radiation Monitoring Devices, Inc. (RMD)

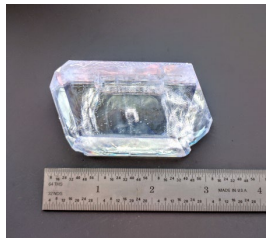
- **Mission**
  - Perform world class research
  - Develop exceptional commercial products
- **Overview**
  - Founded 1974
  - R&D and commercial products
  - Acquired by Dynasil in 2008
  - 65 employees
- **Research Expertise**
  - Semiconductors
  - Scintillators
  - Instruments & Systems
  - Imaging
  - Coatings

Scintillator Research at RMD

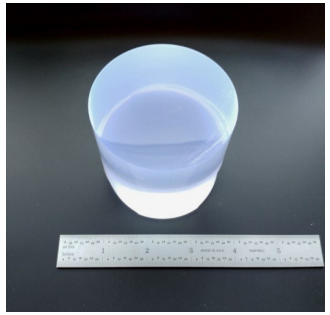


Organic Scintillator Research at RMD

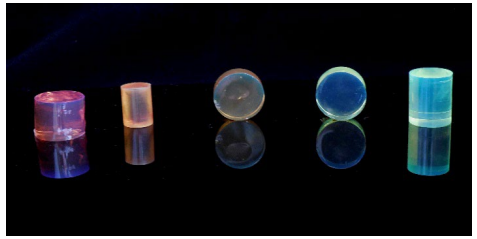
2011-2017
Research into Organic Single Crystals
Collaboration with Lawrence Livermore National Laboratory

2012-2016
Research into metal-loaded plastic scintillators
Collaboration with Sandia National Laboratory



2013-2015
Triplet-harvesting plastic scintillators
Collaboration with Sandia National Laboratories



2015-2021
Large area plastic scintillators
Collaboration with Sandia National Laboratories

Organic Scintillator Research at RMD

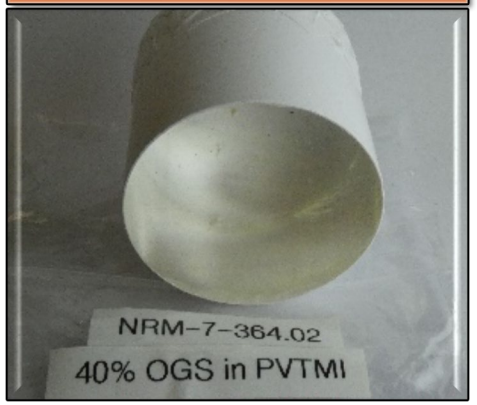
2020-

Research into Organic Glass Scintillators

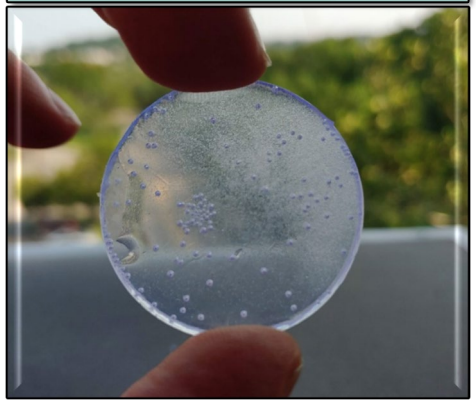
Collaboration with Sandia National Laboratories

Standard

Polymer (POGS)



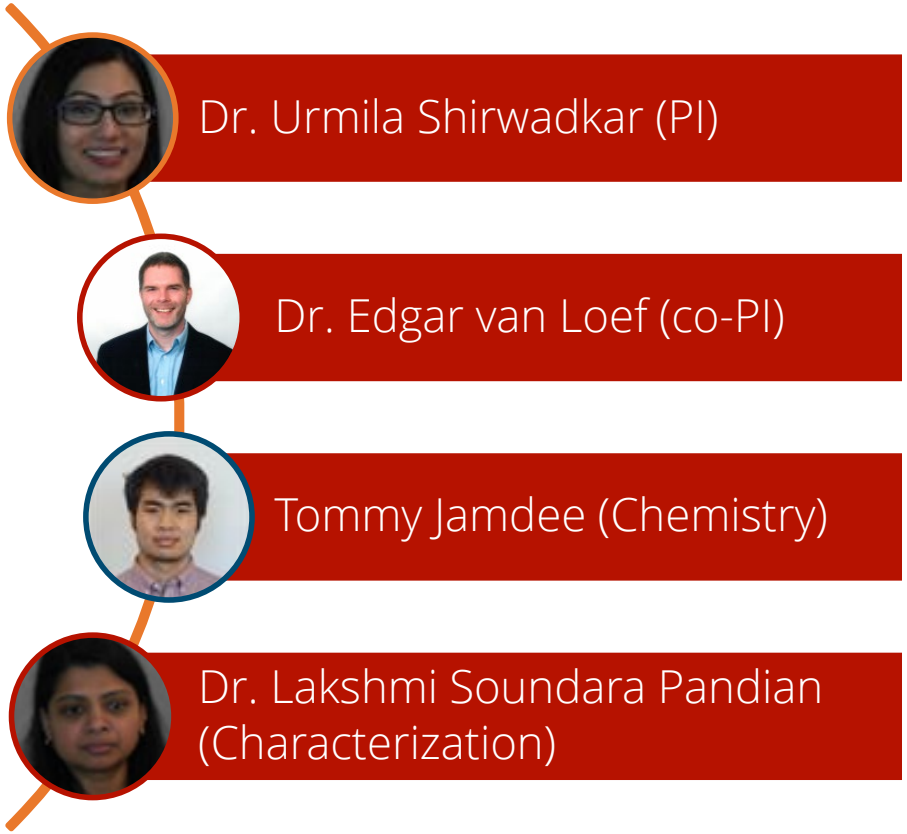
B Loaded



Sn Loaded

Organic Glass Scintillators for Nuclear Physics Experiments

- RMD team
  - Urmila Shirwadkar, PI
  - Edgar van Loef, co-Pi
  - Tawan (Tommy) Jamdee, Chemist
  - Lakshmi Soundara Pandian, Characterization
- Sandia National Laboratories team
  - Patrick L. Feng, co-PI
  - Annabelle Benin, Chemistry
  - Ryan Witzke, Chemistry
- Michigan State University team
  - Remco T. Zegers, Professor of Physics
  - Jorge Pereira, Staff Physicist
  - Cavan Maher, Graduate Assistant



Executive Overview

Organic Glass Scintillators for Nuclear Physics Experiments

❖ Objective

- Develop polymer-blended Organic Glass Scintillators (OGS) with high light yields, fast scintillation decay, and PSD capabilities similar or better than those of Stilbene and liquid scintillators.
- Nuclear physics experiments will benefit due to the higher light yield and better PSD of OGS compared to the currently used plastic scintillators.
- Fabricate several LENDA-sized OGS bars, to be evaluated at MSU.
- Compare OGS bars to plastic LENDA bars.

Organic Glass Scintillators for Nuclear Physics Experiments

❖ Scope

- Phase II: Two-year project with three main goals:
  1. Optimization of the polymer content in polymer-blended OGS
  2. Scale-up of OGS to LENDA Bar sizes (12″ x 2″ x 1″)
  3. Evaluation scintillation properties, light attenuation, thermal stability, and accelerated environmental aging of OGS bars

❖ Teams

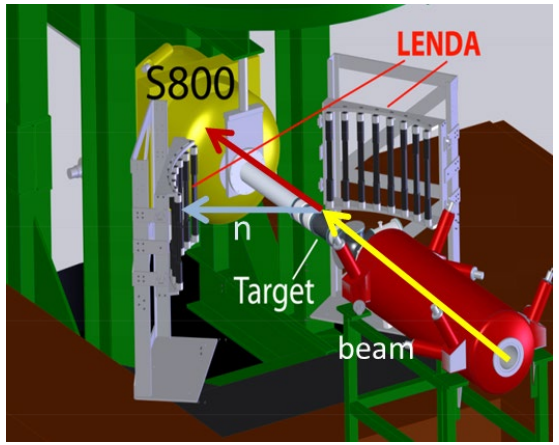
- RMD: Fabrication of OGS bars, characterization of scintillation properties
- Sandia: Fabrication of OGS bars, thermal stability and accelerated aging studies
- MSU: Evaluation of OGS bars in LENDA Array

Background

Neutron detectors at FRIB

❖ Background

- The Low Energy Neutron Detector Array (LENDA)* is a neutron time-of-flight spectrometer developed for inverse kinematics (p,n) charge-exchange experiments in which low energy neutrons (~150 keV to 10 MeV) are detected.
- LENDA consists of 24 BC-408 plastic scintillator bars with, each coupled to a Hamamatsu H6410 PMT.
- The current LENDA array is unable to differentiate between neutrons and gamma rays, complicating background subtraction.



* G. Perdikakis et. al., "*LENDA: A low energy neutron detector array for experiments with radioactive beams in inverse kinematics*", NIMA, Volume 686, 2012, pp. 117-124.

Neutron detectors at FRIB

❖ Ideal detector requirements

- Separation between neutrons and photons by pulse-shape discrimination (PSD)
- Low neutron-detection threshold (<200 keV)
- Good timing resolution (< 1 ns)
- Position resolution (≤ 5 cm)
- Cover large are cost-effectively

Limited number of options available, development of new detector materials warranted

Neutron detector solutions

❖ Organic Glass Scintillators (OGS)

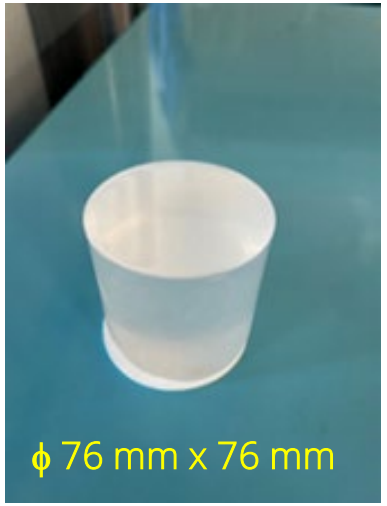
- Ability to set low energy thresholds due to high light yield of OGS
- Ability to provide PSD between gamma-rays and neutrons
- Ability to scale up to large sizes, near net shapes
- Ability to provide fast timing due to fast response of OGS

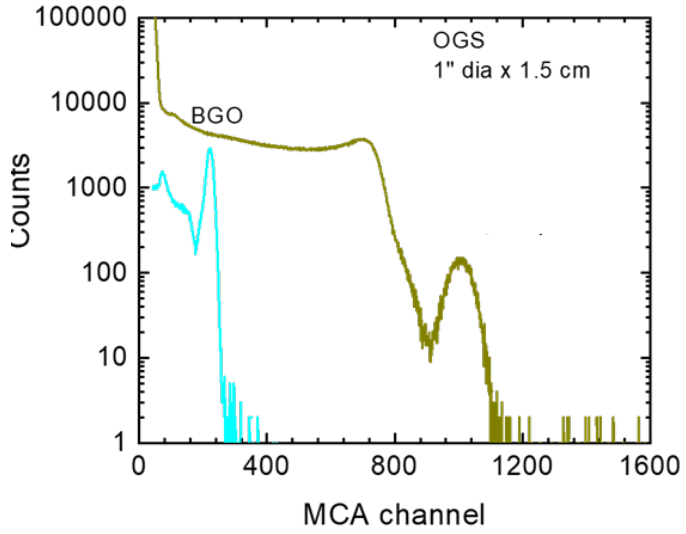
Scintillator	Emission (nm)	Light Yield (Ph/MeV)	Decay (ns)	PSD (FOM)
Stilbene	390	16,000	2.4-4.5	> 3
BC-408	425	9,000	1.8	No
EJ-301	425	12,000	3.0	Yes
Organic Glass Scintillator	440	18,000	1.5	> 3

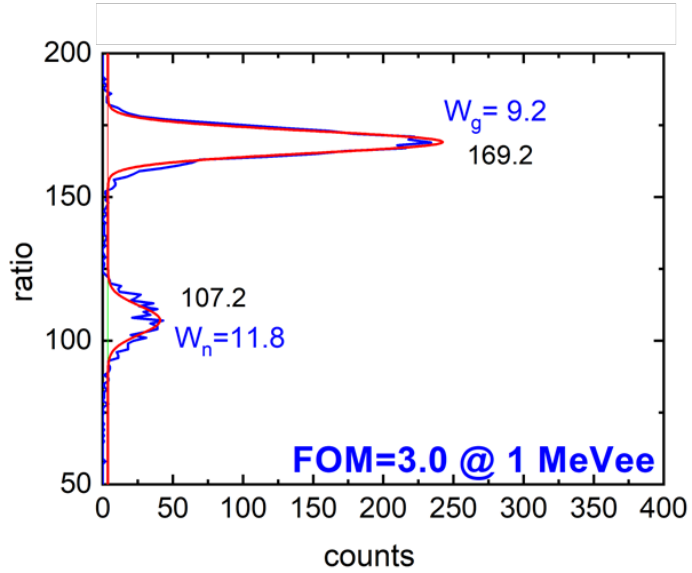
Premium option: Gamma spectroscopy

❖ Tin-loaded Organic Glass Scintillators

- Increased gamma-ray sensitivity, spectroscopic capabilities
- Several reaction channels in one experiment, optimization of scientific output of complex and high-cost FRIB runs (Facility for Rare Isotope Beams)
- No compromise on the neutron detector solid angle to measure simultaneous gamma rays







R&D of Organic Glass Scintillators at RMD

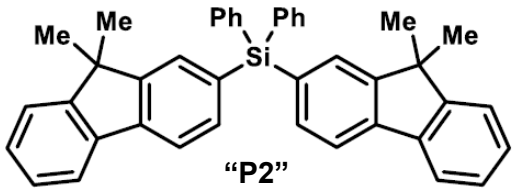
Development of OGS bars for the LENDA Array

- Polymer-blended OGS
  - Standard OGS too brittle for high aspect ratio detectors (30 x 4.5 x 2.5 cm^3)
  - Polymer blending of OGS can significantly enhance the mechanical properties of OGS *
  - The core technology is an OGS-polymer mixture that comprises OGS and a small amount of polystyrene (PS), polyvinyltoluene (PVT), or polycarbonate (PC)
  - This polymer-blended OGS composition can be scaled-up while maintaining the high-performance of standard OGS

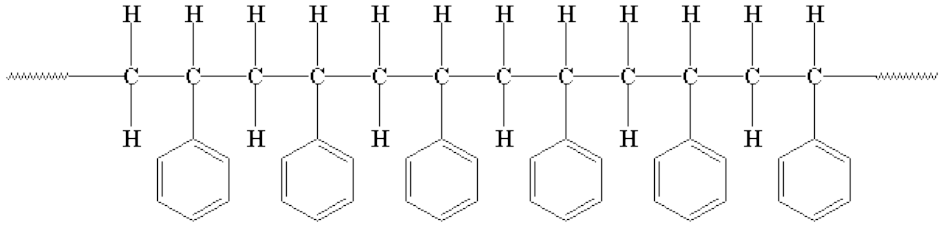
** Nicholas R. Myllenbeck et. al. "Nano-segmented optical fibers containing molecular organic glass scintillator for fast neutron imaging", Proc. SPIE 11838, Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XXIII, 118380R (1 September 2021); https://doi.org/10.1117/12.2596532*

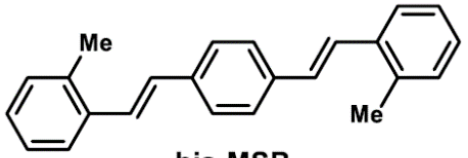
Development of OGS bars for the LENDA Array

- Starting Materials
  - OGS base material: *Bis(9,9'-dimethylfluoren-2-yl)diphenylsilane* (aka "P2")
  - Polymer: PS or PVT
  - Wavelength shifter: bis-MSB



"P2"


Polystyrene

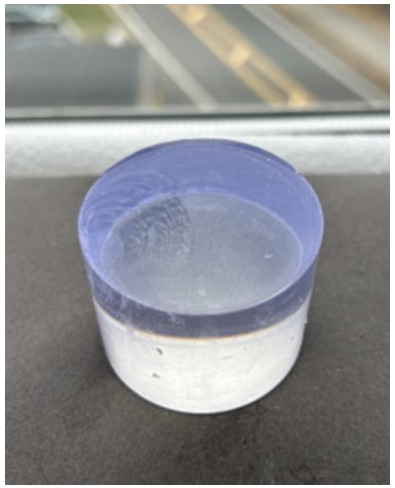


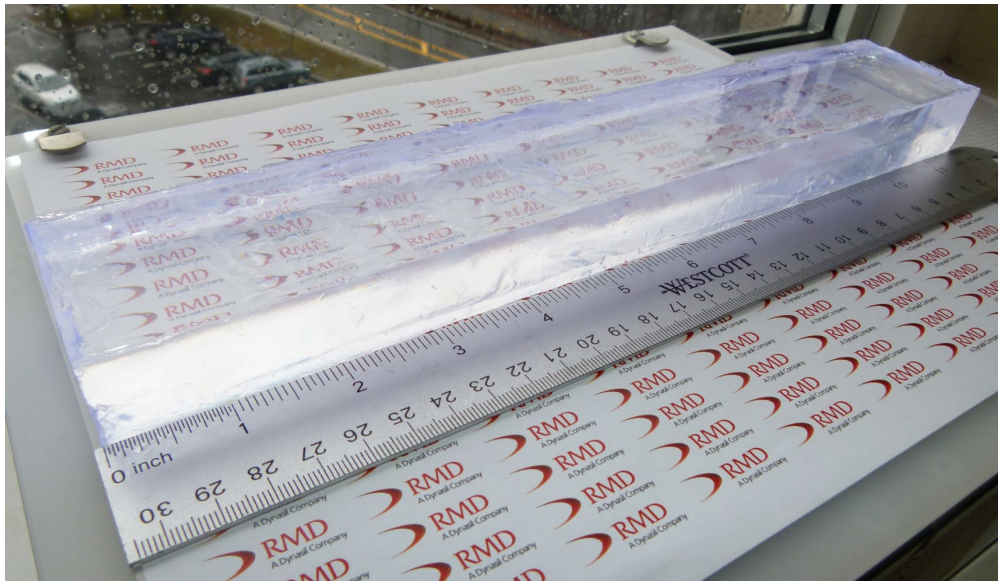
bis-MSB

* Nicholas R. Myllenbeck et. al. "Nano-segmented optical fibers containing molecular organic glass scintillator for fast neutron imaging", Proc. SPIE 11838, Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XXIII, 118380R (1 September 2021); https://doi.org/10.1117/12.2596532

Development of OGS bars for the LENDA Array

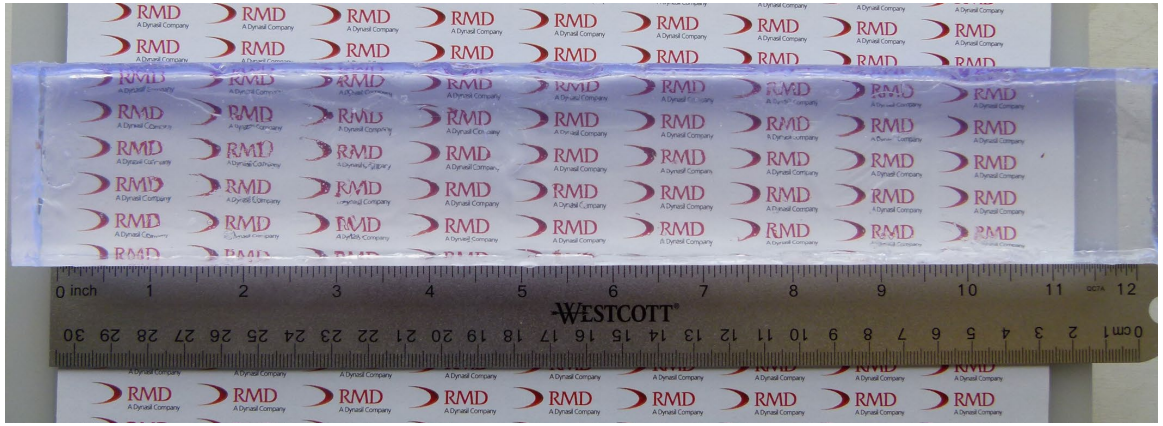
- Fabrication of OGS
  - Purify starting materials as necessary
  - Melt mixture of P2, polymer, and wavelength shifter
  - Cast melt into mold and cool down to room temperature
  - Remove mold and cut/polish OGS





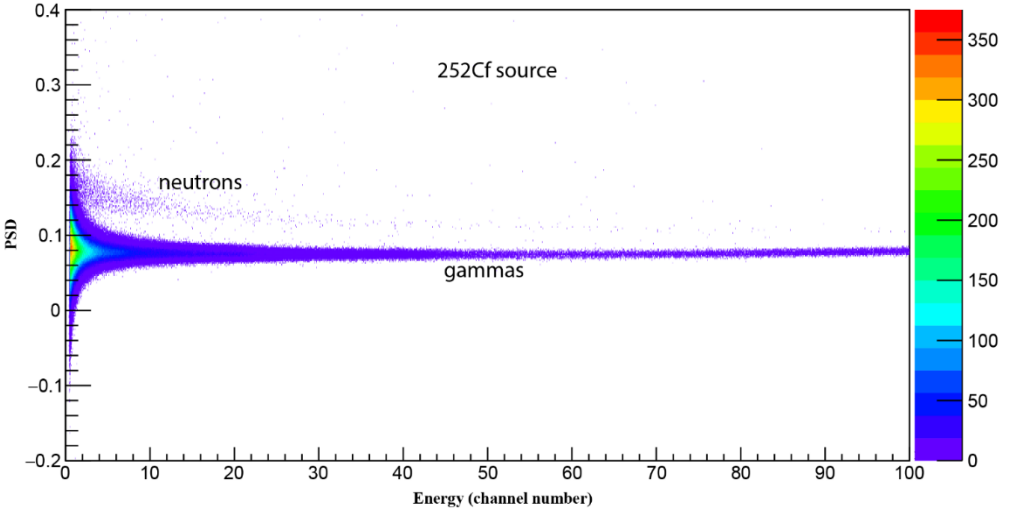
Development of OGS bars for the LENDA Array

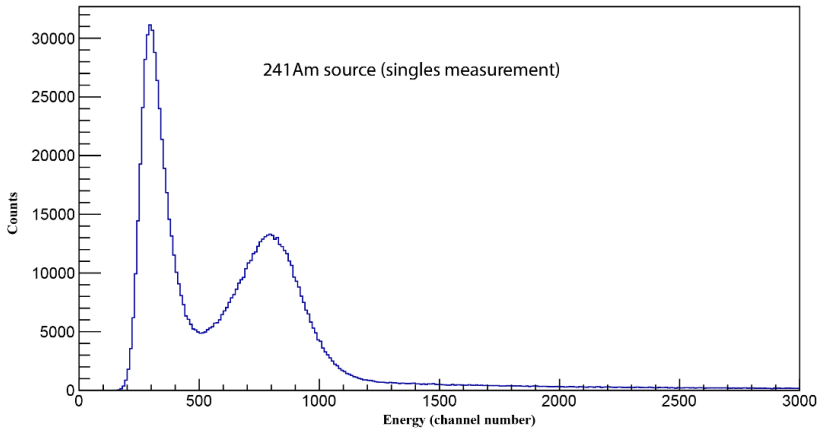
- LENDA Bar module
  - OGS bar (12″ x 2″ x 1″)
  - Two PMTs
  - Electronics

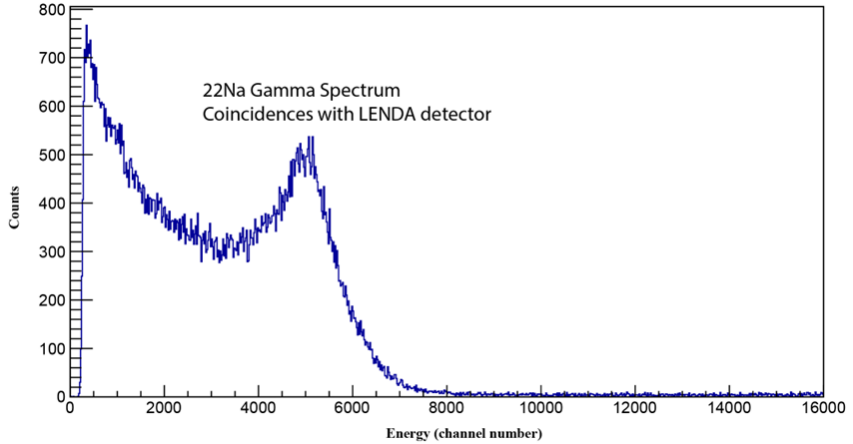


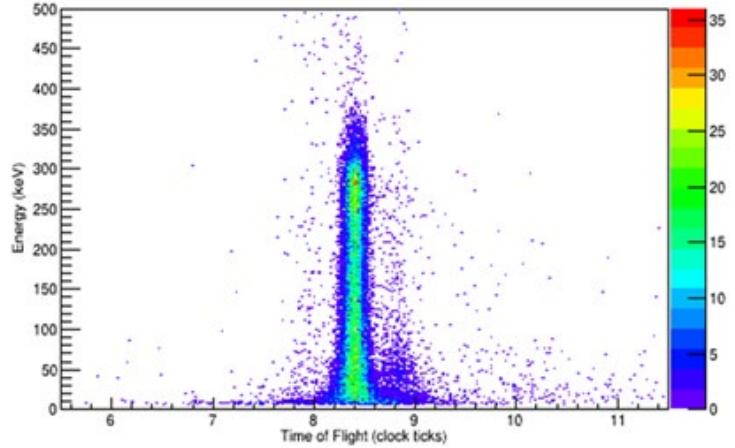
Development of OGS bars for the LENDA Array

- Measurements at MSU
  - Minimum measurable energy-loss signal (threshold)
  - Pulse-shape discrimination capabilities
  - Timing resolution
  - Neutron efficiency
  - Compare results with plastic LENDA bars









Development of OGS bars for the LENDA Array

❖ Results

- Neutron energy threshold: < 20 keV
- Pulse-shape discrimination capabilities: Yes
- Energy resolution at 59.6 keV (^{241}Am): 20 keV
- Timing resolution: 500 ps

Examples of successful commercial products originating from research

CLYC

CLYC is used in many ThermoFisher Scientific's products

CLLBC

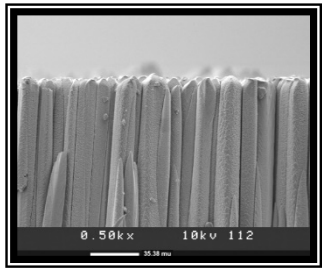
CLLBC - 2019 R&D 100 Award Winner

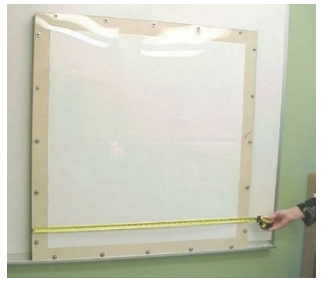
Kromek D5 RIID (2020)

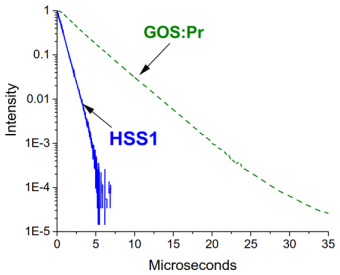
FLIR's R440 RIID (2020)

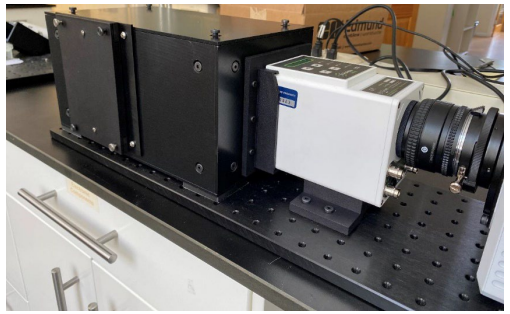
ANSTO's G-N Imaging Instrument CORIS360™ (2020)

Cs:Tl Films









Commercialization of Organic Glass Scintillators

- Potential Applications
  - Neutron scattering
  - RPMs
  - Fusion energy
  - Space, etc.
- Recent OGS sales
  - Atomic Weapons Establishment, UK
  - Georgia Tech
  - Michigan State University
  - NASA
  - Navy Research Laboratory
  - University of Michigan

Commercialization of Organic Glass Scintillators

- For more information
  - Technical exhibitor talk at IEEE (Tampa, FL) on OGS products
  - RMD/Hilger booth at the IEEE

Acknowledgement

This work has been supported by the US Department of Energy under contract # DE-SC0021545.
This support does not constitute an express or implied endorsement on the part of the Government.

Thank you for your attention!