^{12}C Inelastic Scattering Cross Sections using GENSIS Organic Scintillators

2nd Lieutenant Brayden Buckley
Air Force Institute of Technology
Lawrence Berkeley National Laboratory

NSSC Fall Workshop and Advisory Board Review
October 17-18, 2023

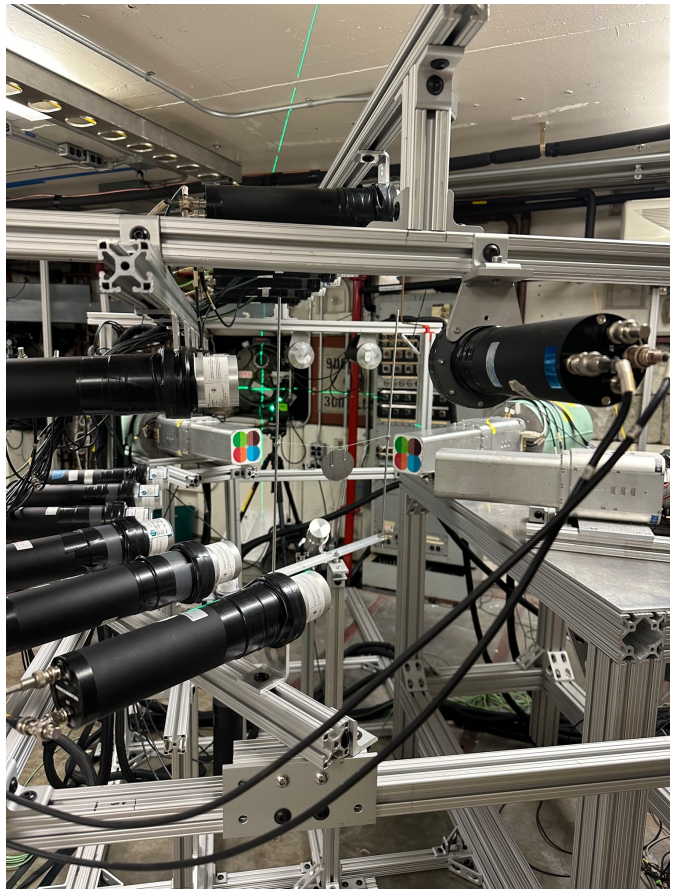
Introduction

University
Air Force Institute of Technology
Dept. of Nuclear Engineering

Advisor
Dr. Juan Manfredi

Partner Lab
Lawrence Berkeley National Laboratory

Mentor
Dr. Thibault Laplace



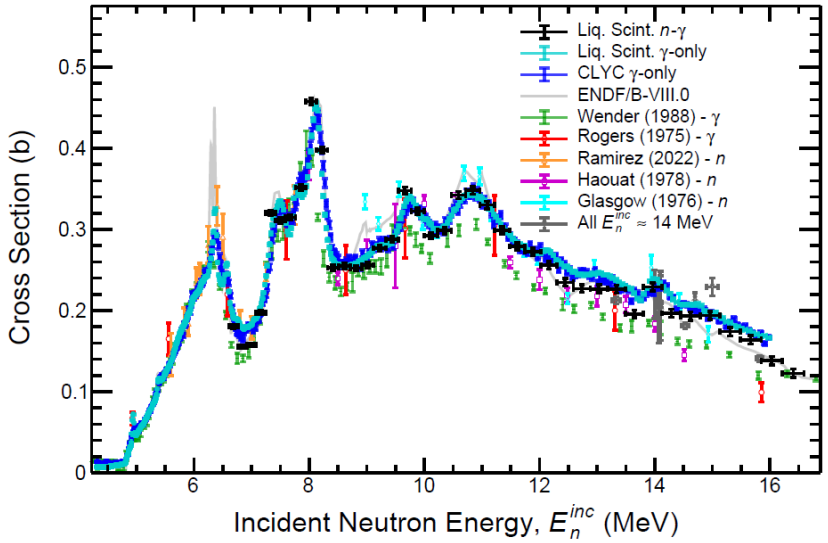
Research Focus:
Neutron Inelastic Scattering Cross Sections

Mission Relevance:
Accuracy of high priority cross sections

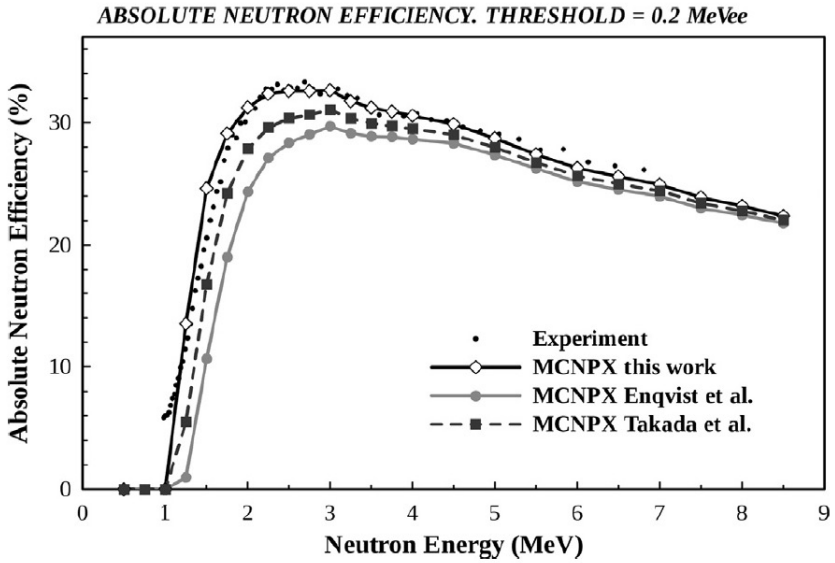
Objectives – $^{12}C(n,n'\gamma)$

Overall Goal:
Create an accurate energy dependent inelastic scattering cross section of ^{12}C using only EJ-309 organic scintillators

Secondary Deliverables:
EJ-309 neutron and gamma ray detection efficiencies



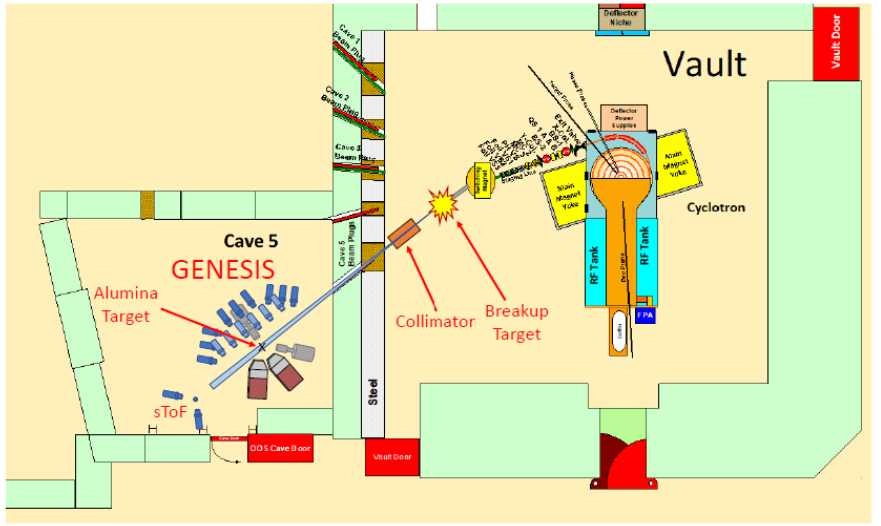
^{12}C cross sections measured by LANL, but no efficiency data (Kelly et al.)

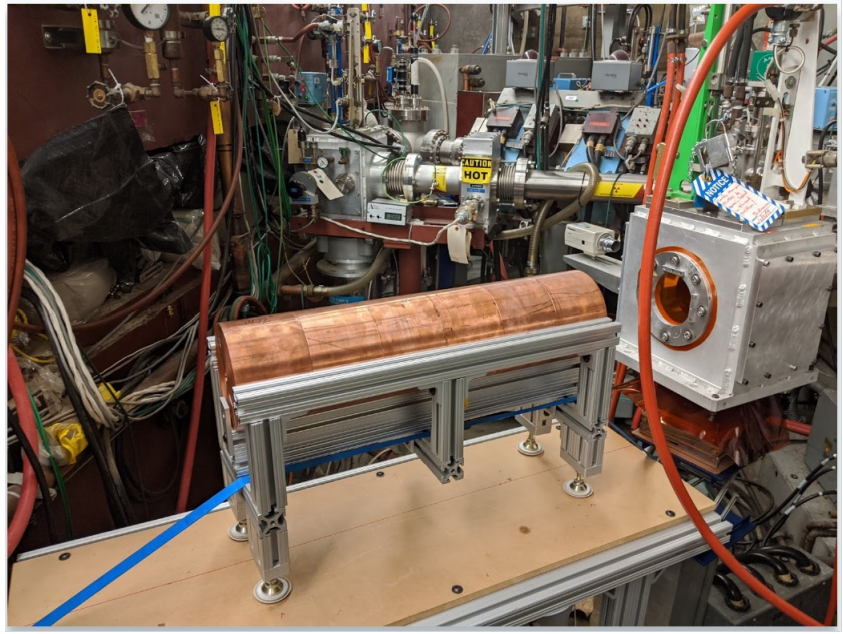


Organic scintillator neutron efficiencies modeled by Pino et al.

GENESIS Overview

- **G**amma **E**nergy **N**eutron **E**nergy **S**pectrometer for **I**nelastic **S**catter
- Array is housed in Cave 5 located at the 88-Inch Cyclotron
  - d breakup, broad spectrum n beam
- Array of 26 organic scintillators and 3 clover HPGe's
- Scatter time-of-flight (sToF) array used to measure beam characteristics





GENESIS Measurement with Scintillators

New Analysis Approach w/ GENESIS:

- Organic scintillator only measurements create new method of validation of cross section measurements with comparison between scintillator-only and scintillator + HPGe values

- Measure cross section using n-γ coincidences in EJ-309 scintillators
  - Due to the isolated 4.4 MeV excited state gamma ray, cross section can also be measured with γ data only

Pros and cons of using only organic scintillators to measure γ production cross sections

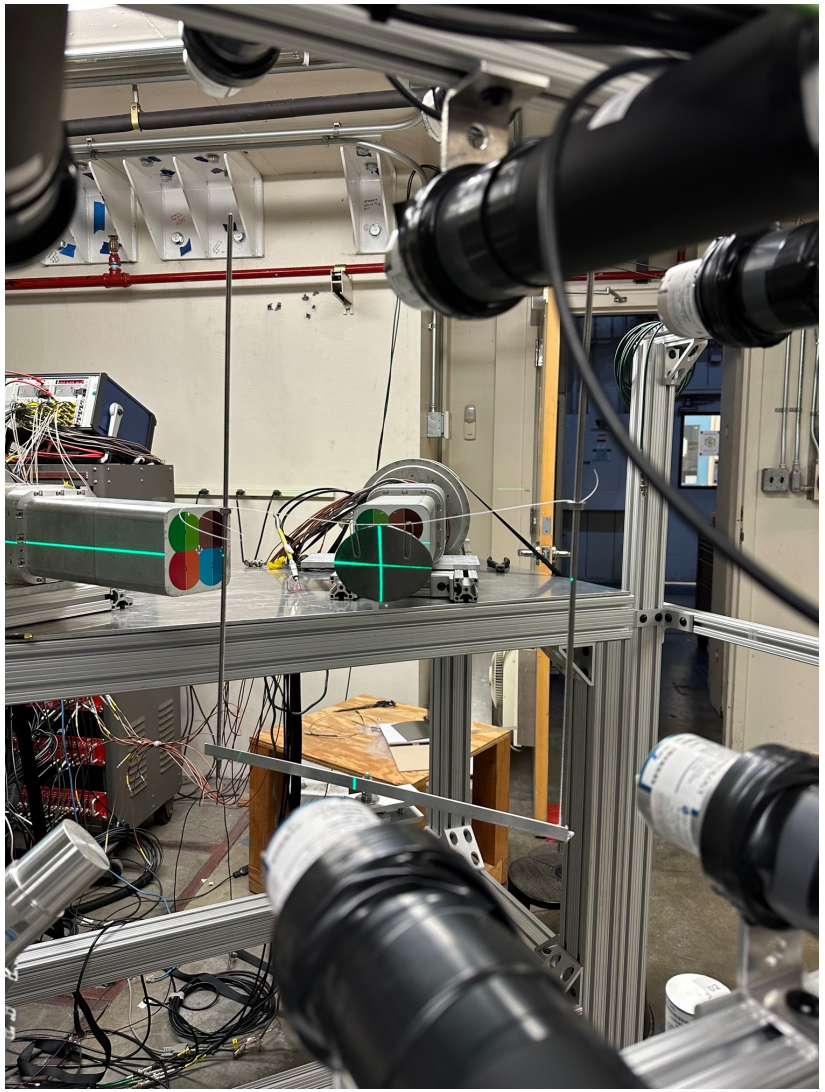
Better timing resolution, (neutron energy)	Poorer pulse amplitude resolution, (γ energy)
Greater angular coverage with less cost + care	High density gamma environment creates Compton overlap

First 3 excited states of ^{12}C

Energy Level (keV)	J^{π}	E (γ)	IT (%)	Final Level (keV)	Final Level (J^{π})
0	0+				
4439.82	2+	4438.94	100	0	0+
7654.07	0+	3213.79	4.26×10^{-2}	4439.82	2+
9641	3-	9637	4.1×10^{-5}	0	0+

^{12}C GENESIS Experiment

- ^{12}C experiment conducted, February 2023
- 25 MeV deuterons on carbon *breakup* target
- A carbon *reaction* target was placed in the center of the GENESIS detector array
- Approximately 90 hours of beam time recorded on target, 20 hours of blank data
- Beam flux was monitored using a scatter time-of-flight array and activation foils
- Parallel HPGe + scintillator analysis in progress

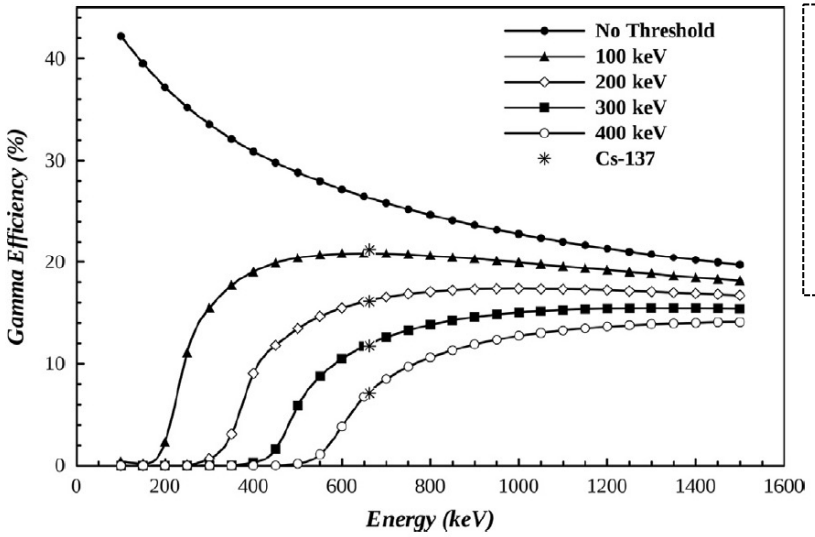


Technical Challenges – Gamma Efficiency

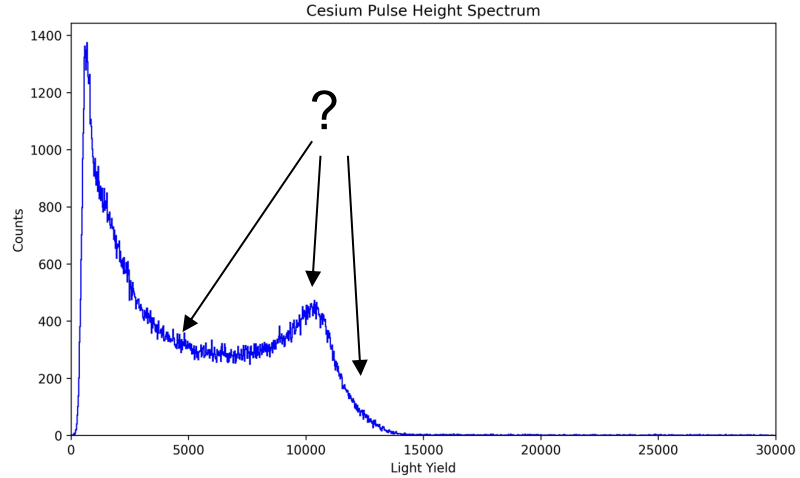
- Measuring $^{12}C(n,n'\gamma)$ cross section with organic scintillators depends on EJ-309 efficiency at 4.4 MeV

- Organic scintillator gamma efficiencies can be difficult to measure, sparse in literature
  - No photopeak
  - Compton edge + continuum

- Even more difficult at higher energies
  - Few gamma ray sources emit single gamma rays at ~4 MeV

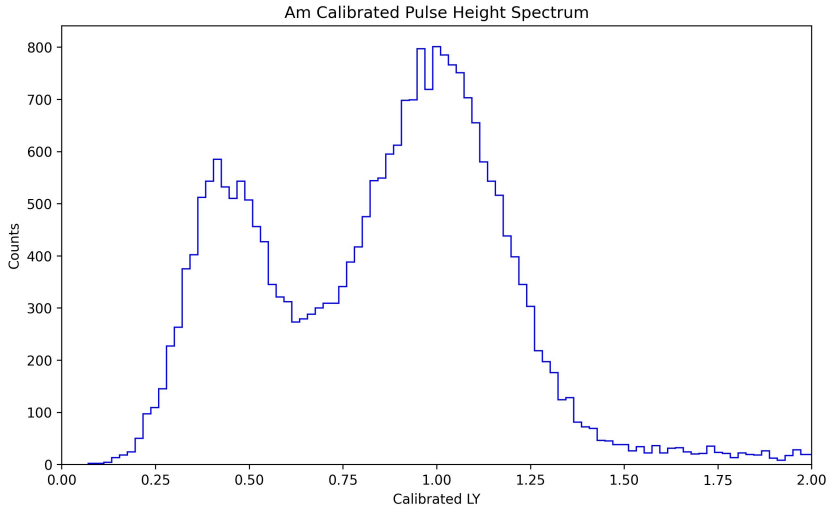


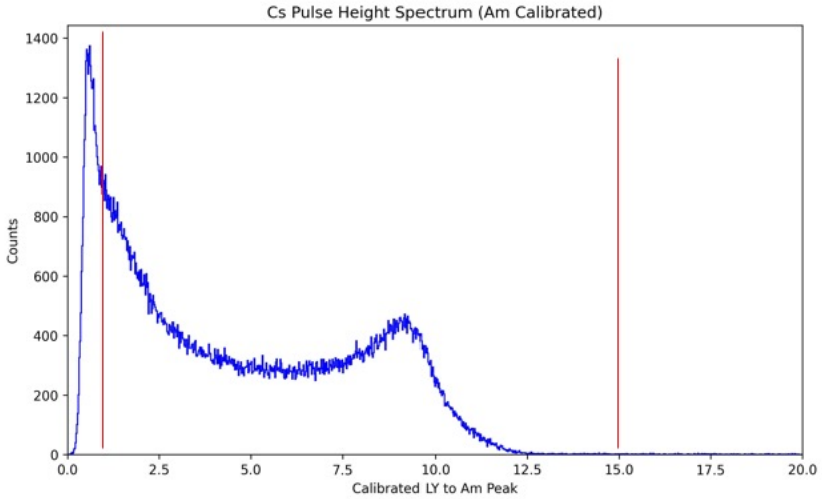
Organic scintillator gamma ray efficiencies modeled by Pino et al.



Gamma Ray Efficiency Measurements

- Experimentally measured Am-241, Cs-137, Na-22, and AmBe to determine efficiency values
- Set threshold at 60 keV using Am-241 photopeak
- Calculated efficiencies of all spectra using set 60 keV threshold based on Am-241 calibration



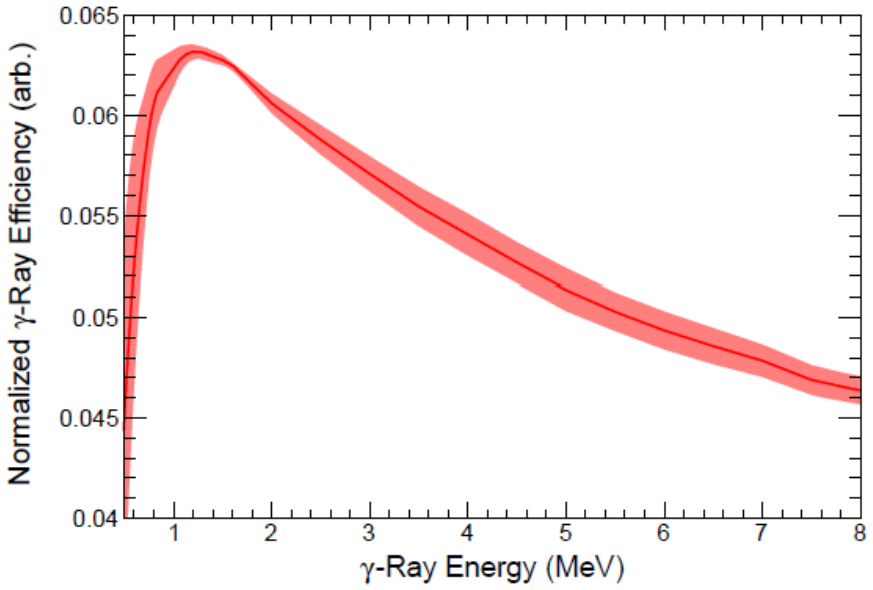


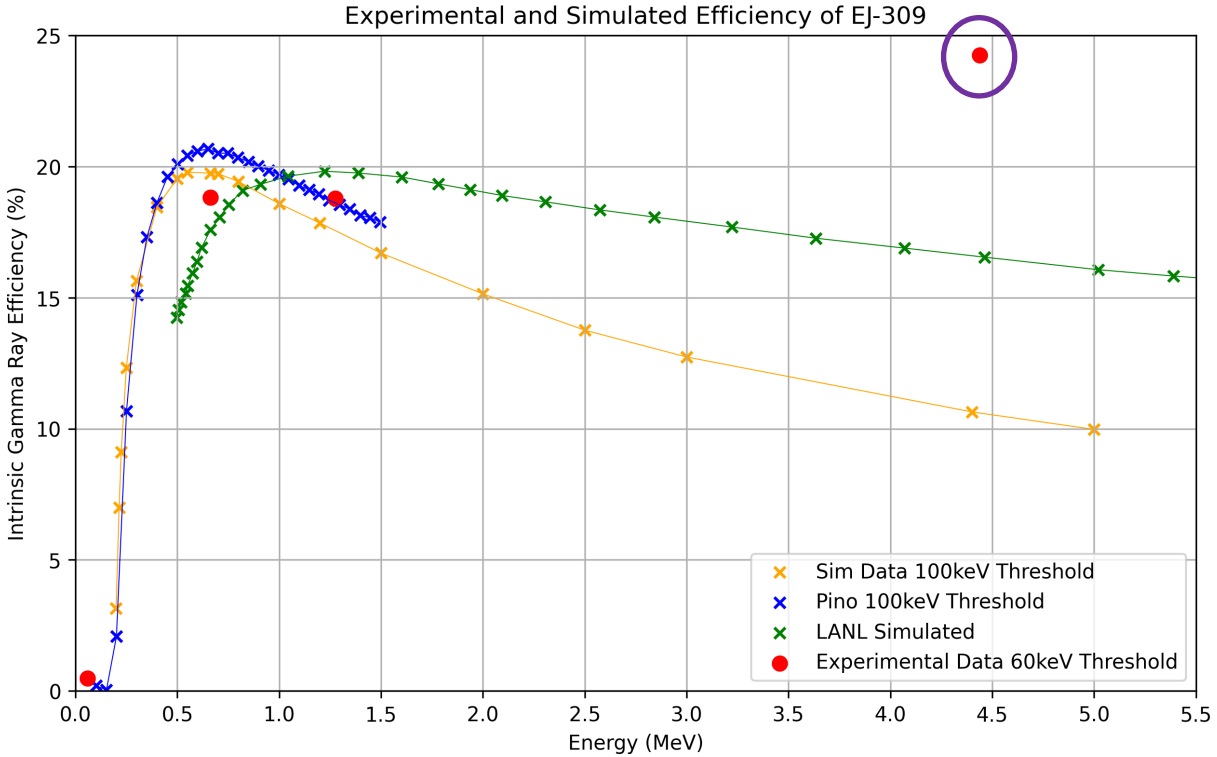
Gamma Ray Efficiency Results

- Conducted measurements of Am-241, Cs-137, Na-22, and AmBe to experimentally determine efficiency values at several energies
- Created Geant4 simulations of similar environment to compare experimental and simulated efficiency values

AmBe source poorly characterized!

Arbitrary magnitude simulated EJ-309 gamma ray efficiency curve by LANL



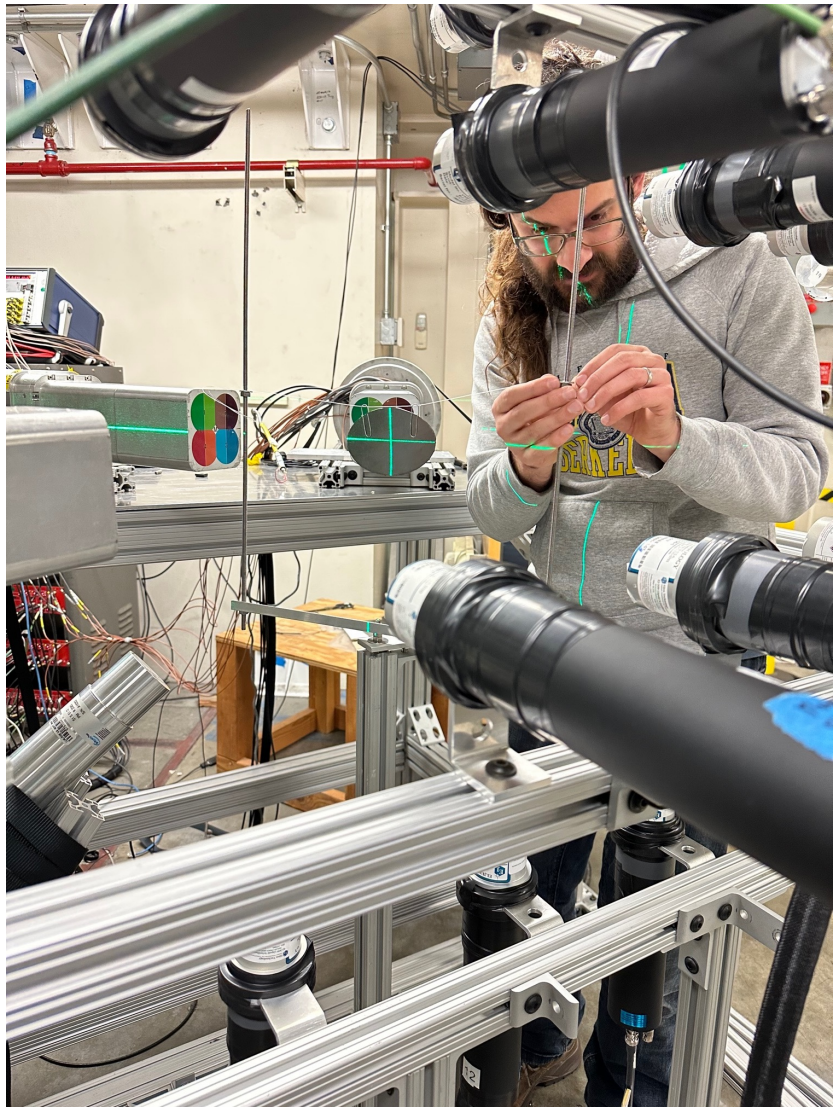


Future Work

- Remeasure gamma ray efficiency at 4.4 MeV using a different method (i.e., α-beam on Be, well-characterized AmBe)
- Determine neutron efficiency of the organic scintillators in the array using ^{252}Cf measurements and simulation
- Calculate angle and energy dependent cross sections of ^{12}C using the positions and efficiencies of the organic scintillators

NSSC Experience

- Research collaboration with LBNL, LLNL
- Upcoming dedicated research trip to LBNL
- Academic advisor (Dr. Juan Manfredi) is an NSSC alum
- Experimental and analysis work with mentor at LBNL



Acknowledgements

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number **DE-NA0003996.**