Validating Thermal Neutron Capture γ-Ray Data using the RPI Gaerttner LINAC Center

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Meeting of the International Network of Nuclear Structure and Decay Data (NSDD) Evaluators [virtual presentation]
April 15-19, 2024

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Project Overview

1 Develop **experimental methods** to measure γ-ray cascades produced by thermal neutron capture reactions

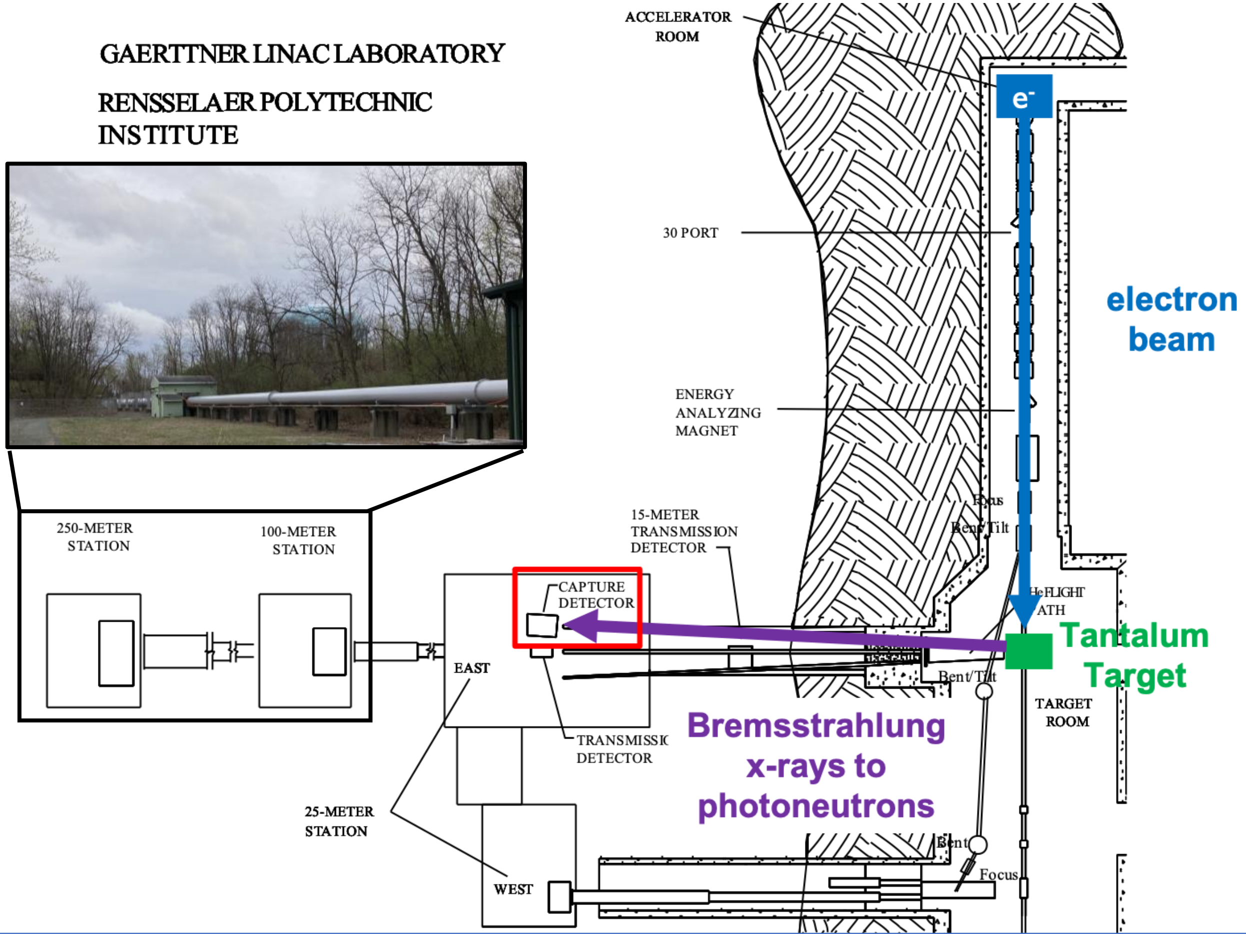
2 Update **simulation methods** to:

1. Accurately model γ-ray cascades emitted during compound nucleus de-excitation [DICEBOX]
2. Simulate γ-ray cascades travelling through detection systems [Monte-Carlo code(s)]

3 Compare the results of both methods to **assess the accuracy of thermal neutron capture induced γ-ray data & evaluations** stored in nuclear data libraries

Experimental Methods

RPI Gaerttner Linear Accelerator (LINAC) Center

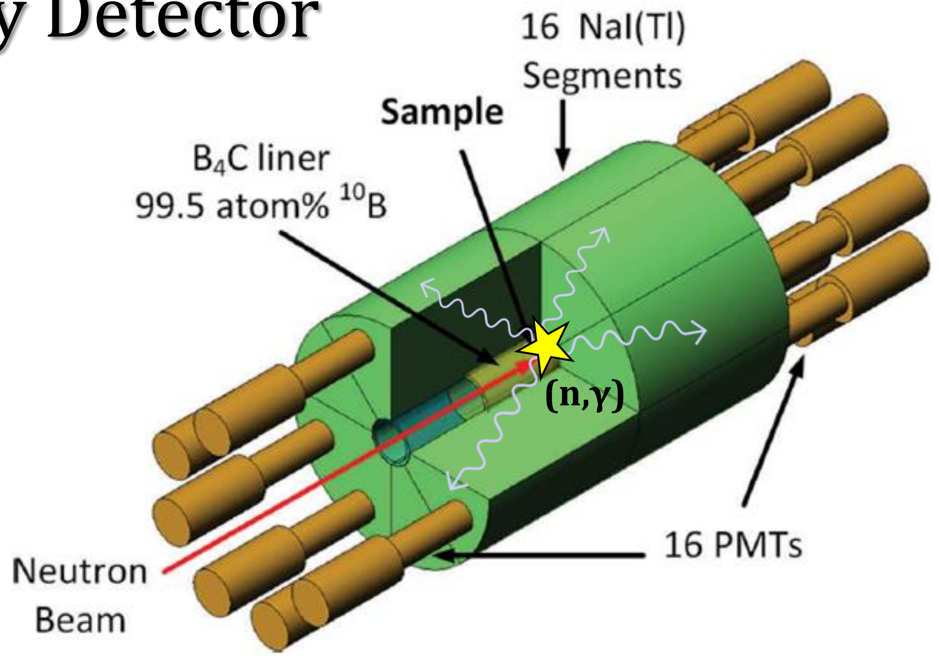


Experimental Methods

RPI Capture γ-Ray Multiplicity Detector

- **16 segment NaI(Tl) capture γ-ray multiplicity detector**
  - 20 L of NaI(Tl) surrounding the sample
  - A 1 cm thick B_4C ceramic sleeve (enriched to 99.5 atom% in ^{10}B) is used inside the detector to absorb neutrons scattering from the sample
  - Up to 96% efficiency for detecting γ-ray cascades
  - Located 25 m from the neutron-producing target
  - Time-of-flight (TOF) method used to determine incident neutron energy

- **Used for neutron capture yield and γ-ray spectra measurements**
  - Incident neutron energies: 0.001 eV – 3 keV



Simulation Methods

Step 1: Model Neutron Capture γ-Ray Cascades using DICEBOX

DICEBOX/ENSDF (+Firestone)

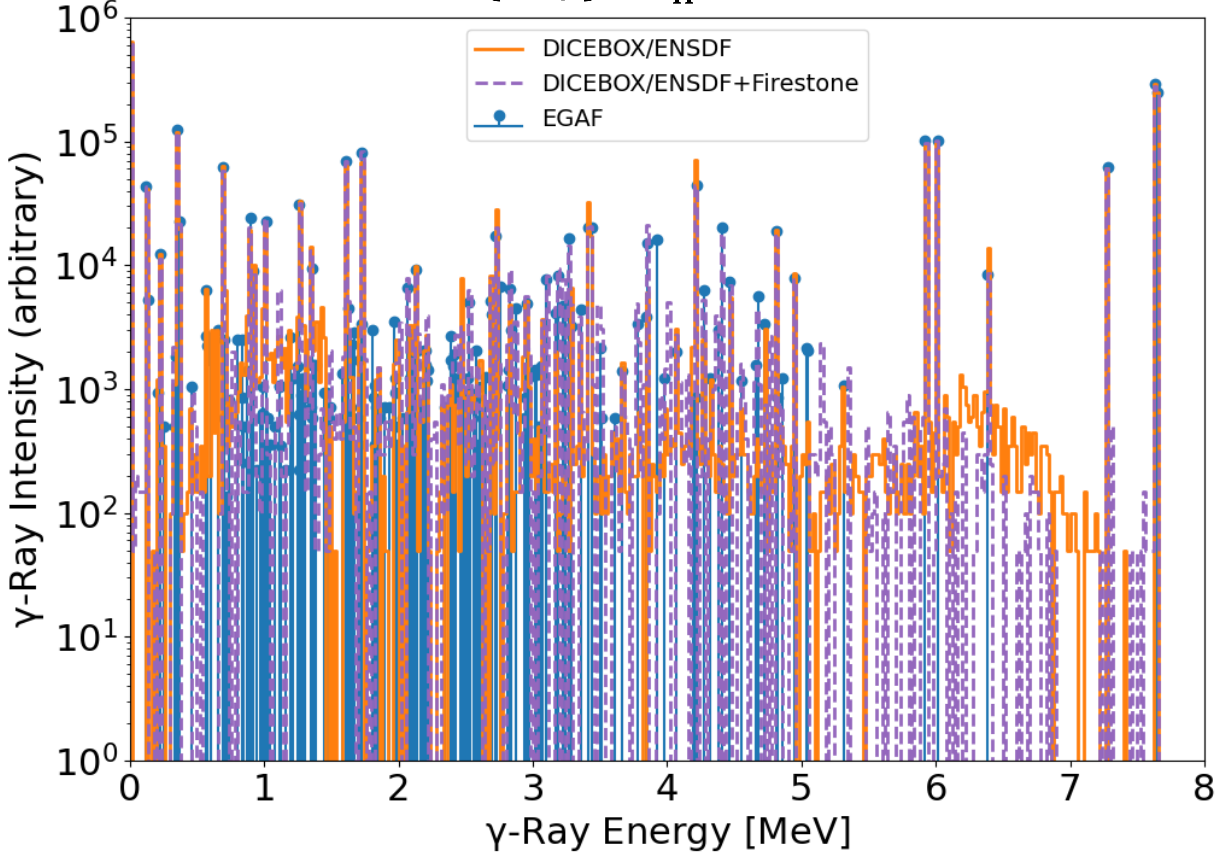
Models full γ-ray cascades using evaluated nuclear data (ENSDF + RIPL-3)

Input tuned to R. B. Firestone et. al., Phys. Rev. C **95**, 014328 (2017)

EGAF

Shows experimentally measured primary γ-ray lines (does not necessarily represent the full cascade)

$^{56}Fe(n,\gamma)$, E_n = thermal



Simulation Methods

Step 2: Transport γ-ray cascades through the RPI Capture Detector

MCNP-6.2/ACE

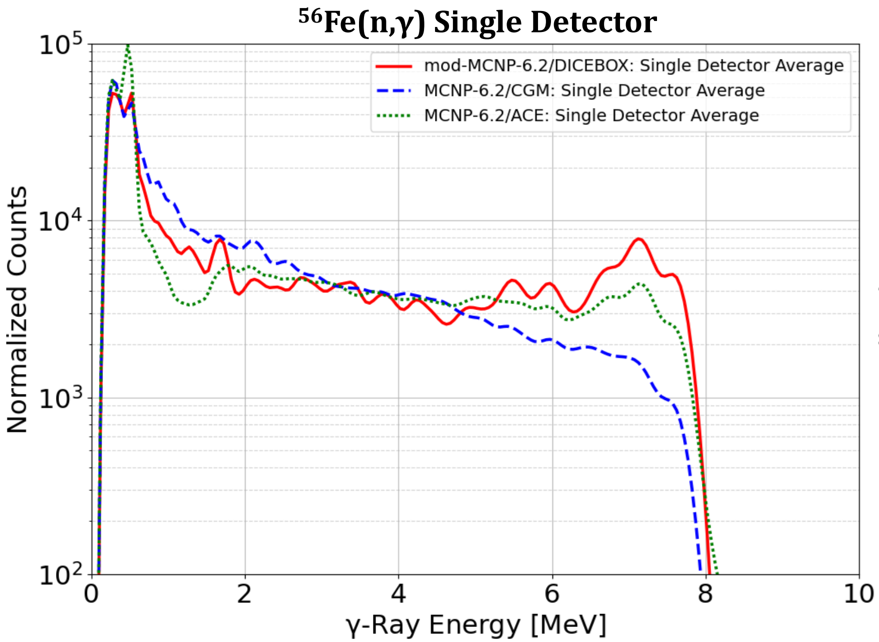
- Extracts γ-ray data from ACE files (ENDF/B-VIII.0)
- Total energy deposition spectra is *expected to disagree* with experimental data because the simulation does not include coincidence

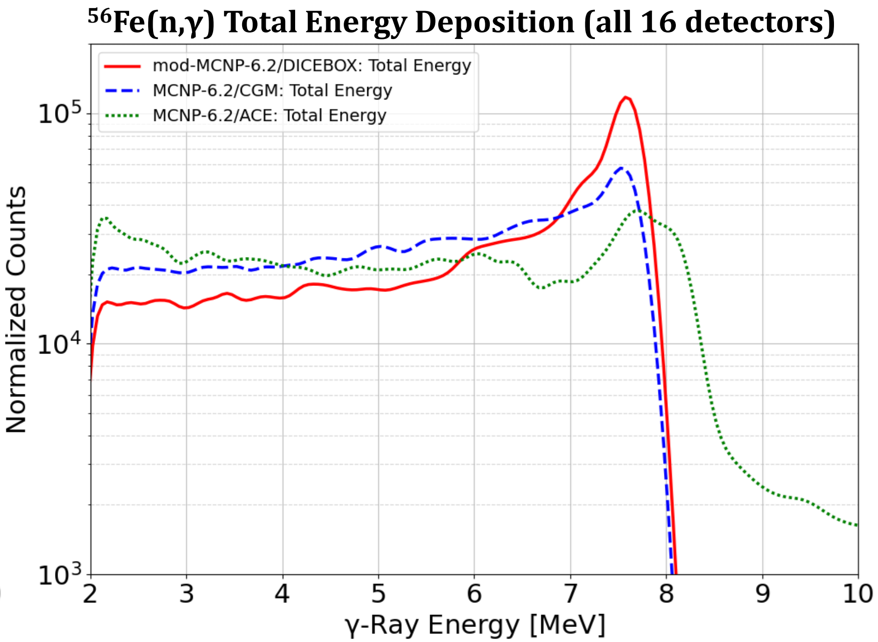
MCNP-6.2/CGM

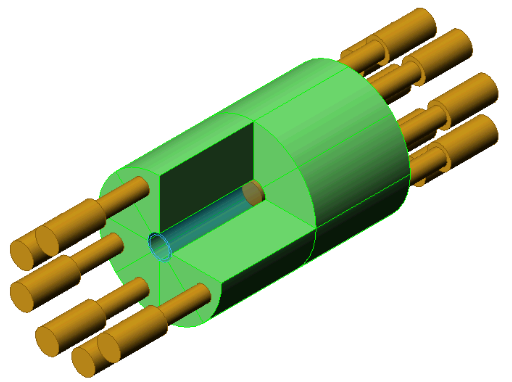
- **C**ascading **γ**-Ray **M**ultiplicity
- Produces correlated secondary γ-ray emissions (cascades)
- Transported through the detector geometry using MCNP-6.2

mod-MCNP-6.2/DICEBOX

- Cascades generated using DICEBOX + primary intensities from ENSDF
- Transported through the detector geometry using a modified version of MCNP-6.2 (mod-MCNP-6.2)
- Tally γ-ray energy deposition in detector segments (enables event-by-event analysis including coincidence)



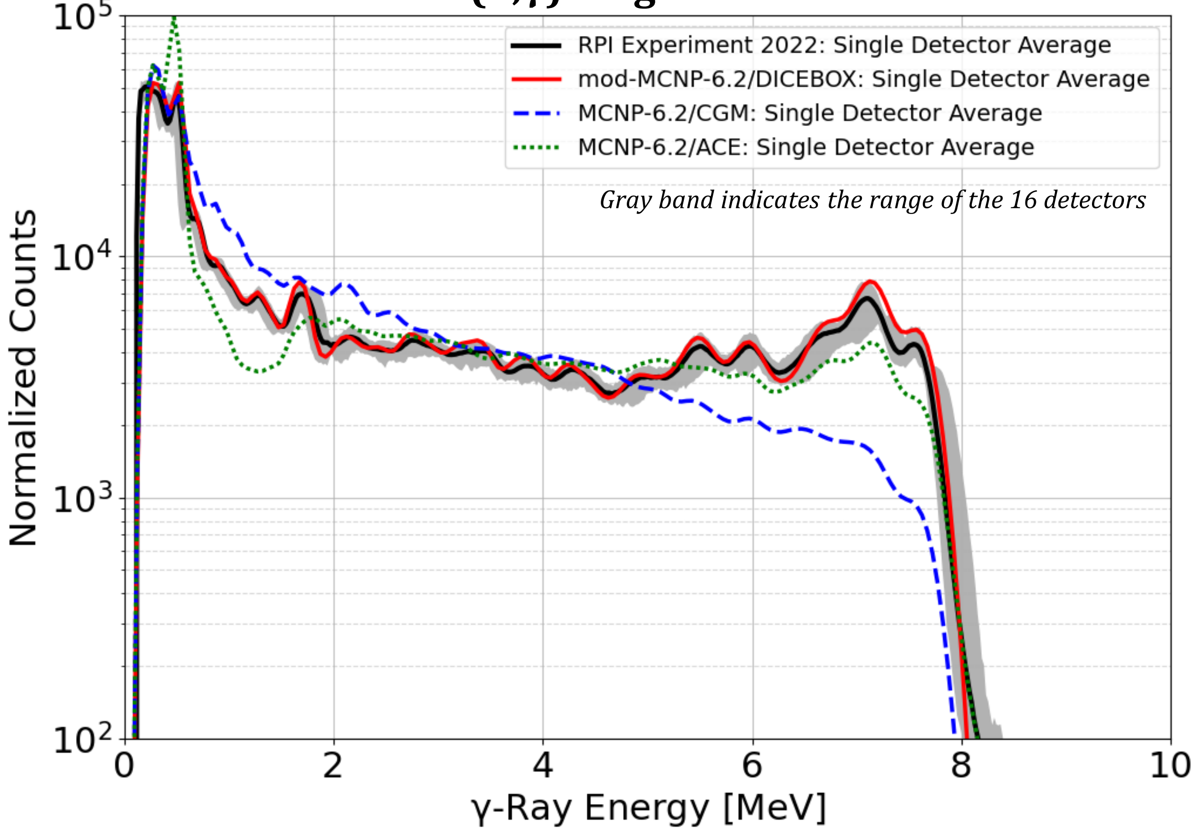




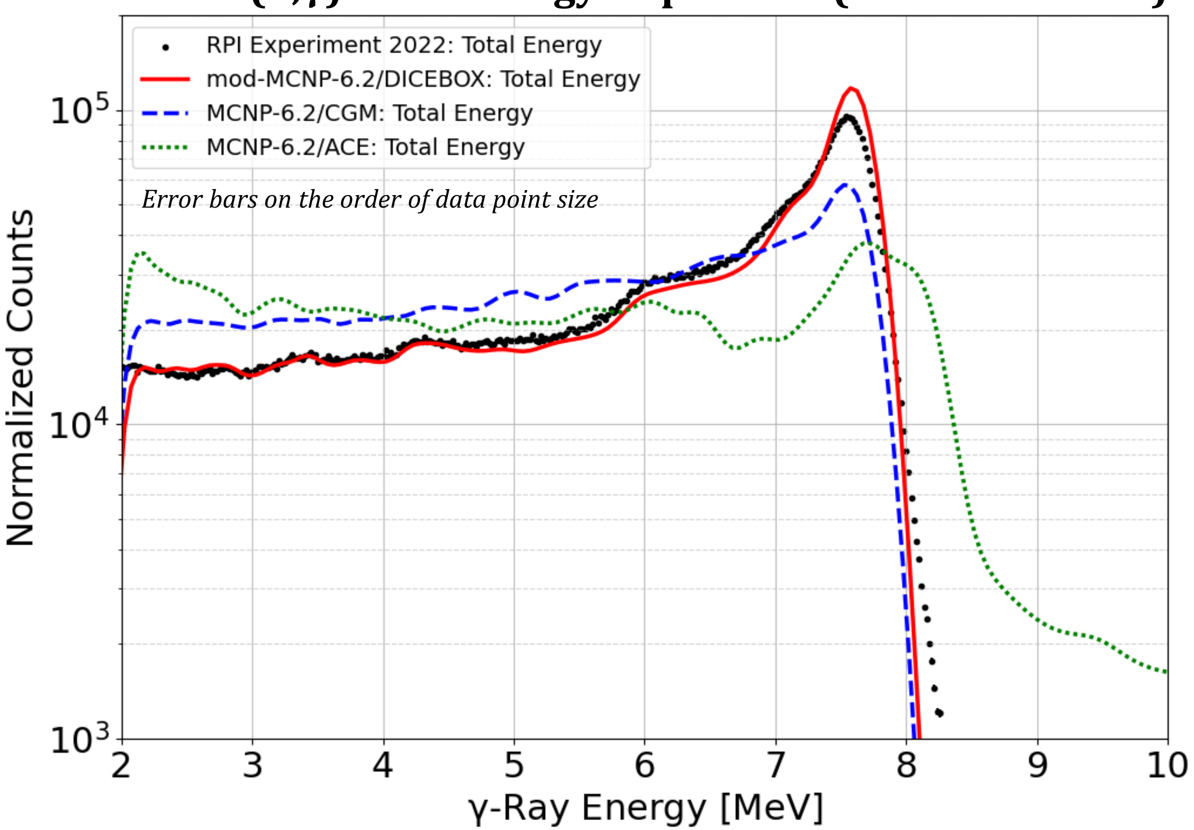
Validating the Experimental & Simulation Methods

^{56}Fe Thermal Neutron Capture

$^{56}Fe(n,\gamma)$ Single Detector

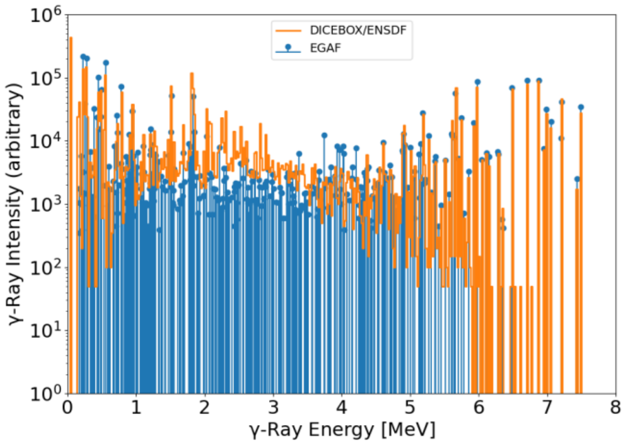


$^{56}Fe(n,\gamma)$ Total Energy Deposition (all 16 detectors)

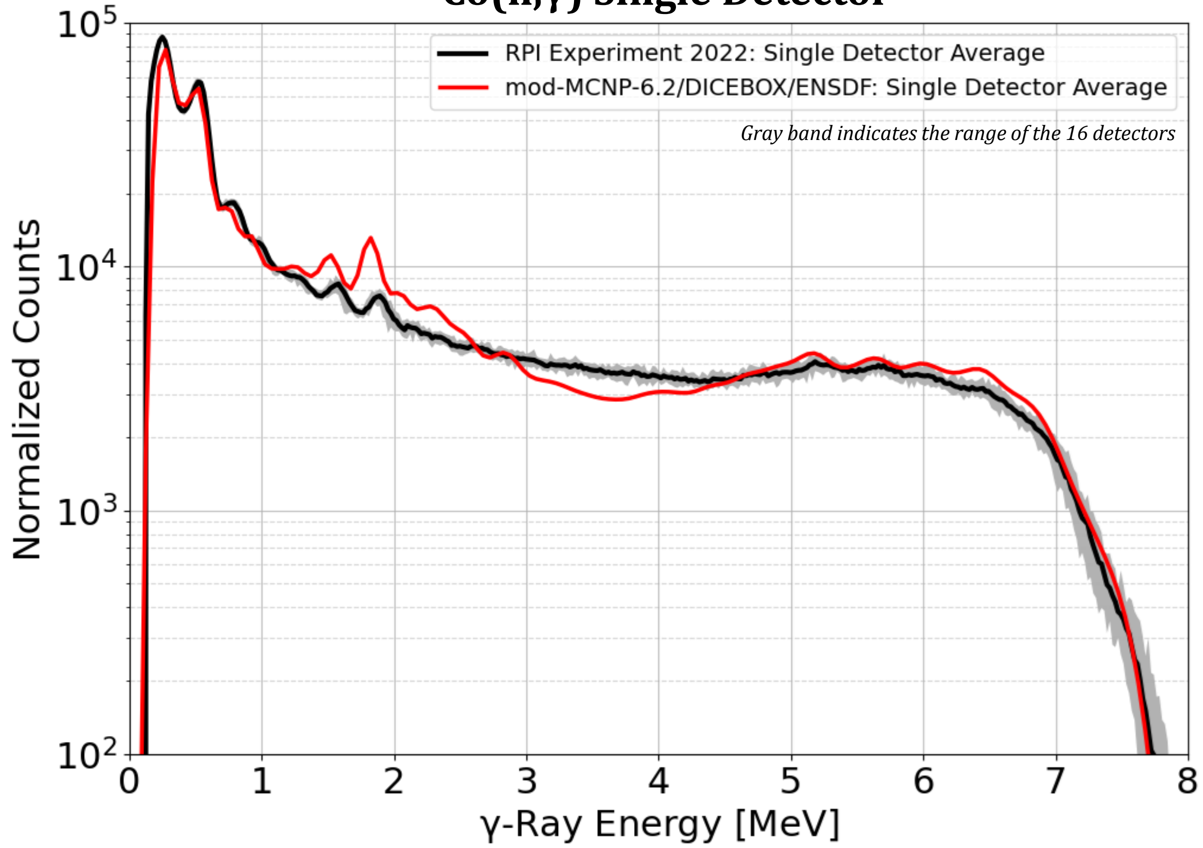


Analysis of Other Isotopes

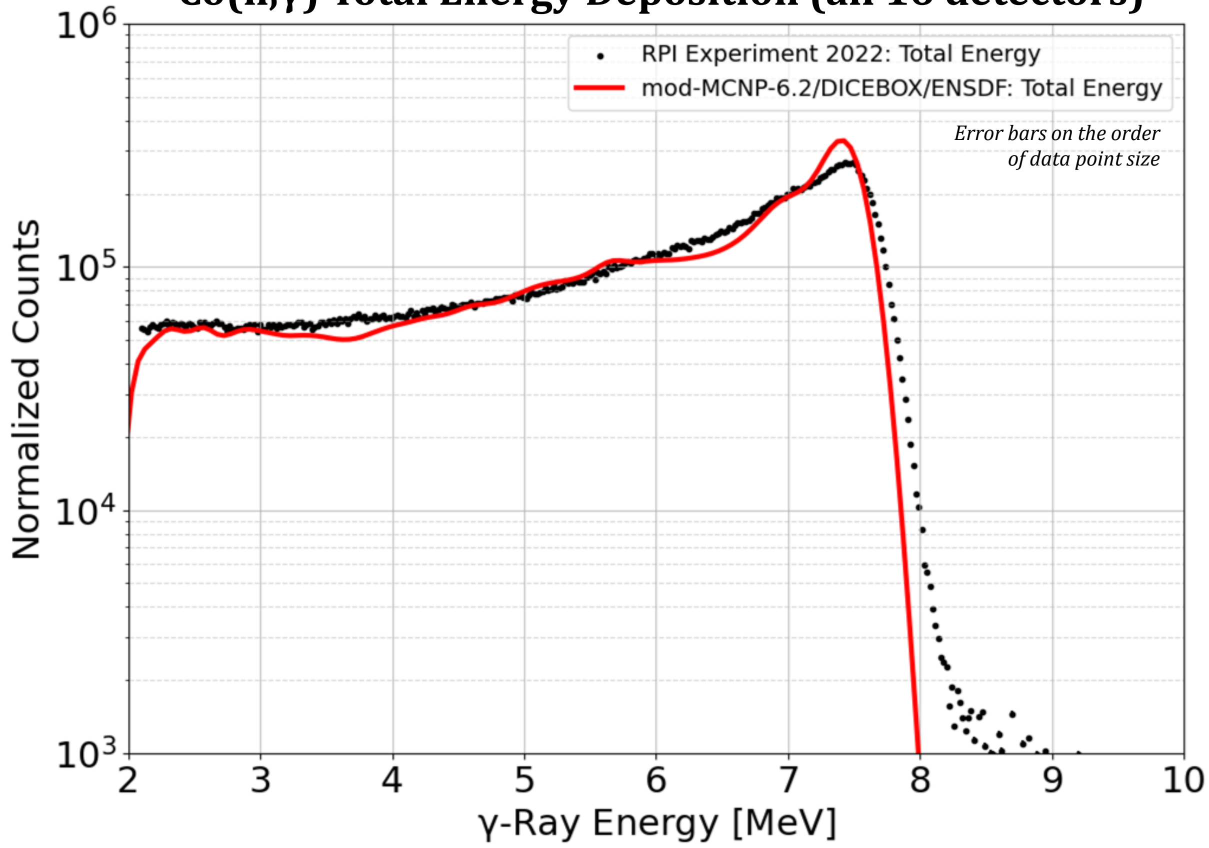
^{59}Co Thermal Neutron Capture



^{59}Co(n,γ) Single Detector



^{59}Co(n,γ) Total Energy Deposition (all 16 detectors)



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Improving DICEBOX Cascades

^{55}Mn Thermal Neutron Capture

DICEBOX/ENSDF

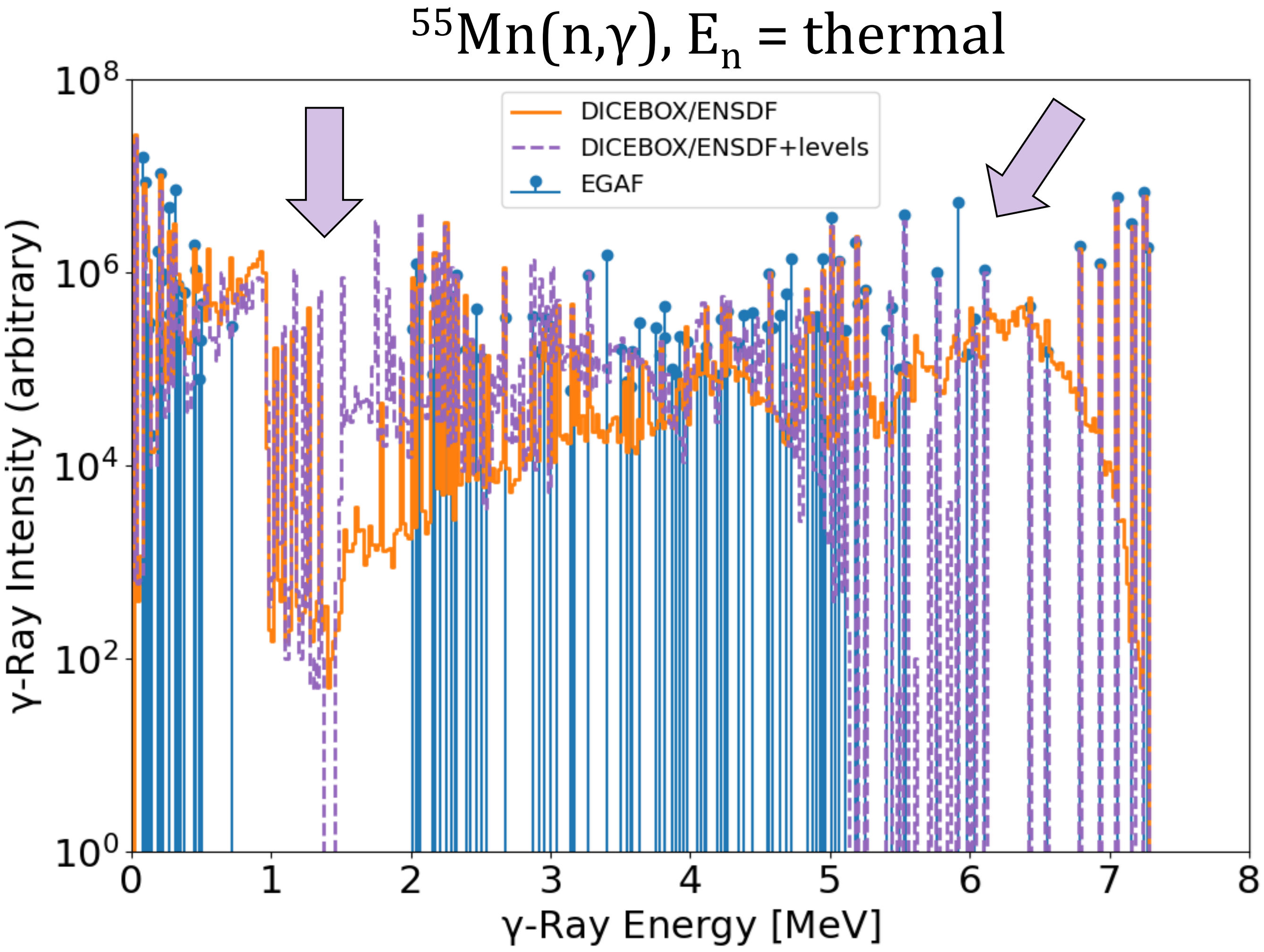
Models full γ-ray cascades using evaluated nuclear data

DICEBOX/ENSDF+levels

Models full γ-ray cascades using evaluated nuclear data **+ additional levels that DICEBOX previously excluded**

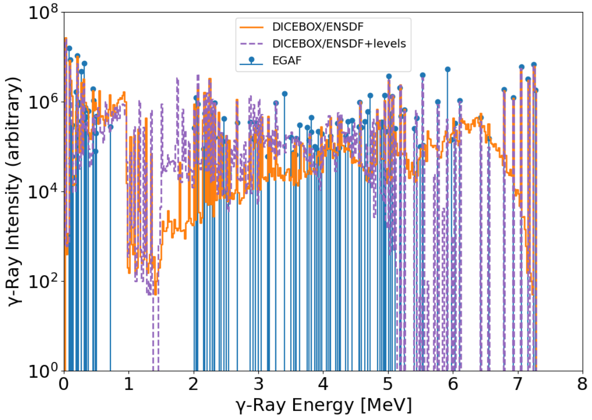
EGAF

Experimentally measured γ-ray intensities

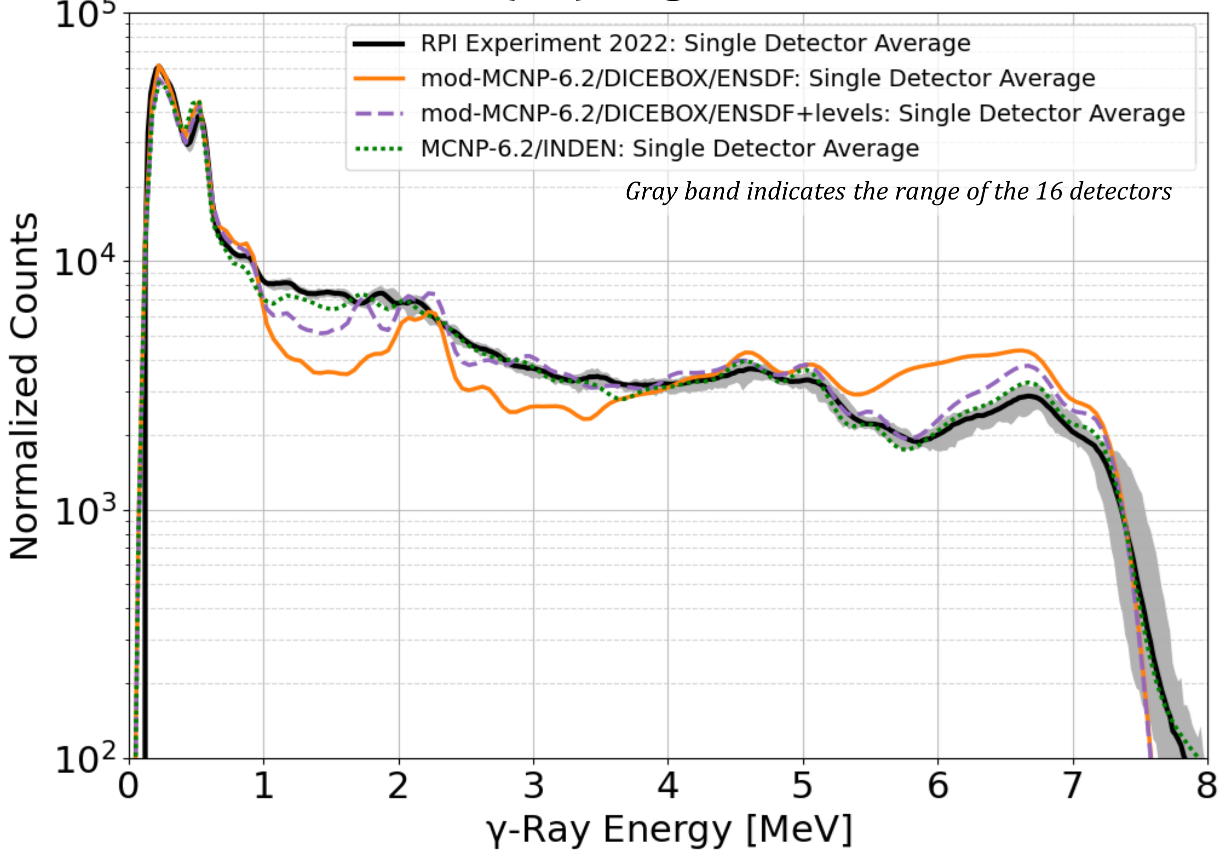


Improving DICEBOX Cascades

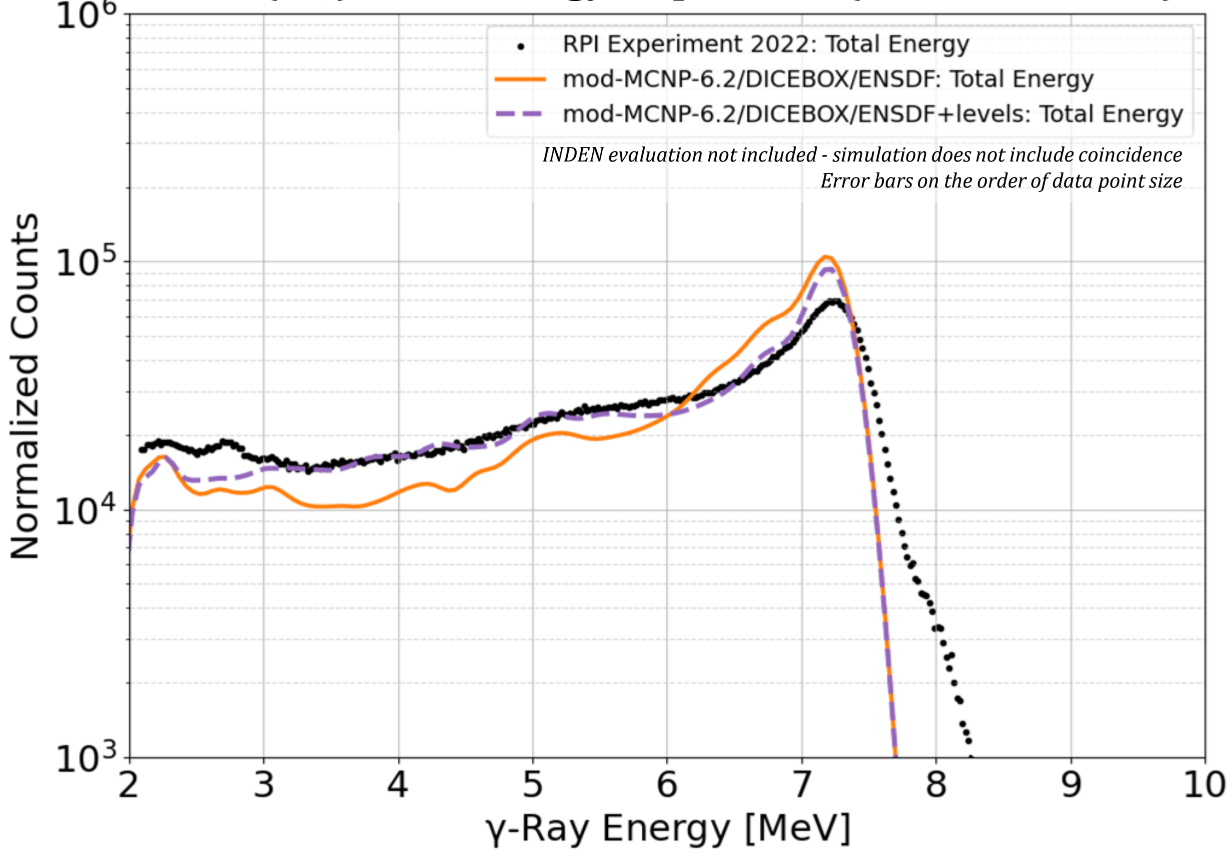
^{55}Mn Thermal Neutron Capture



^{55}Mn(n,γ) Single Detector



^{55}Mn(n,γ) Total Energy Deposition (all 16 detectors)



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Conclusions

- The experimental and simulation methods have been developed to test the accuracy of thermal neutron capture γ-ray data in nuclear data libraries.

- Measuring capture γ-ray spectra with the RPI Capture γ-Ray Multiplicity Detector system has been validated using the ^{56}Fe(n,γ) measurement.
  - **When the neutron capture γ-ray cascade data is well-known, the experimental γ-ray energy spectra can be accurately simulated using mod-MCNP-6.2/DICEBOX.**

- Validation of the system has been extended with ^{55}Mn and ^{59}Co thermal neutron capture measurements

Future Work

Complete the analysis of experimental capture γ-ray spectra for $^{\mathbf{nat,235}}$**U** and compare to **mod-MCNP-6.2/DICEBOX** simulations

- Challenge: separate fission-induced γ rays from capture γ rays

Dr. Robert Block at RPI Gaerttner LINAC Center (1971)

Thank you!
Questions?

This research was performed under appointment to the Rickover Fellowship Program in Nuclear Engineering sponsored by Naval Reactors (NR) Division of the National Nuclear Security Administration (NNSA).

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