Development of Benchmark Measurements for Capture Gamma Cascades

Progress Report | WANDA 2025 | 13 FEB 2025

Overview & Team:

Objective: Develop the methodology & provide data to benchmark accuracy of neutron capture gamma-ray cascade evaluations

Project Overview:

1. Collect measurement data using the RPI LINAC and the RPI Capture Gamma-Ray Multiplicity Detector.
2. Simulate neutron capture gamma-ray transport using Monte-Carlo codes & cascade generators.
3. Assess quality of neutron capture gamma-ray cascade evaluations by comparing measurements and simulations using evaluated data as cascade generator inputs.

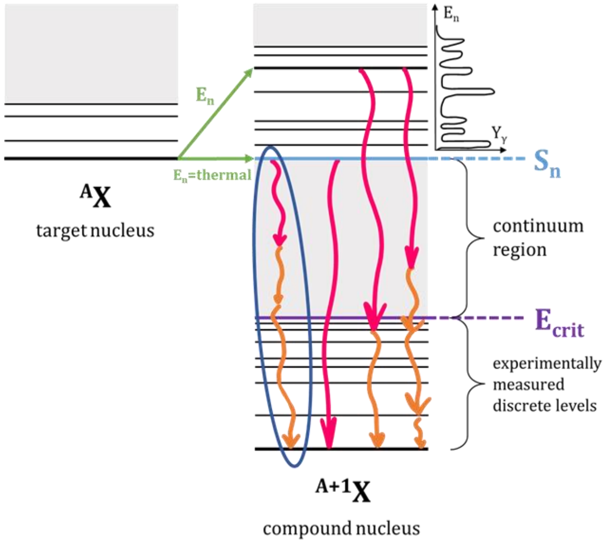
Deliverables:

1. Benchmark methodology including a quantified accuracy assessment.
2. Experimental data collected at RPI and inputs for simulation codes.
3. Simulation methods including an in-line gamma-ray transport code and gamma-ray cascade generator.

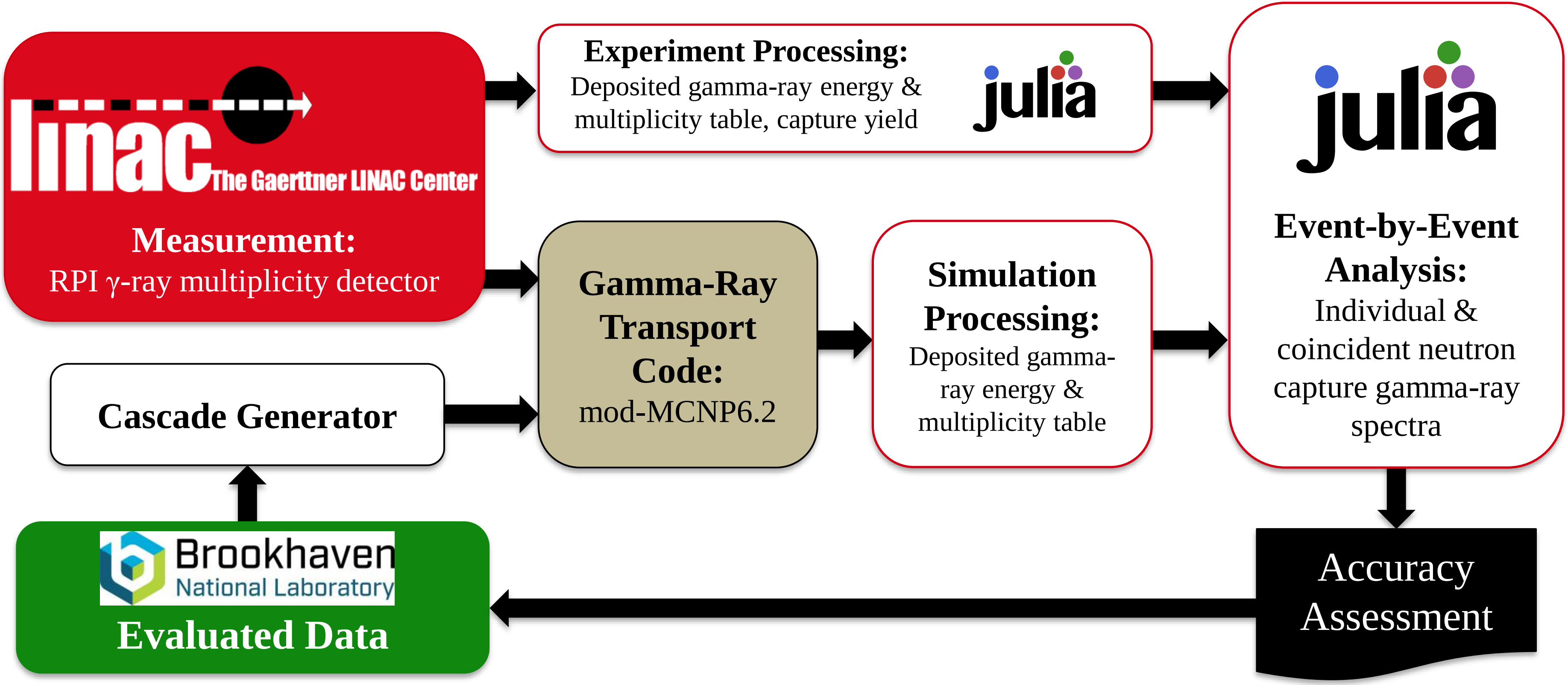
Rensselaer Polytechnic Institute:
Yaron Danon – PI
Katelyn Keparutis – Graduate Student
Ian Parker – Graduate Student
Brookhaven National Laboratory:
David Brown
Emanuel Chimanski
Naval Nuclear Laboratory:
Devin Barry
Amanda Lewis

There is a need for benchmarking neutron capture gamma-ray spectra

- Applications require accurate gamma-ray production data:
  - Including gamma-ray heating in critical systems, active neutron interrogation, and detector response calculations.
  - Both individual detectors and arrays are used, therefore individual and coincident gamma-ray emissions need to be known.
- Traditional simulation methods do not always accurately predict gamma-ray emissions for single detectors and lack capabilities for coincident gamma-rays.
- Limited or no data (primary gamma-rays, intensities, etc.) is available for many isotopes in nuclear databases.
- Lack of validation experiments & methods to assess the data.

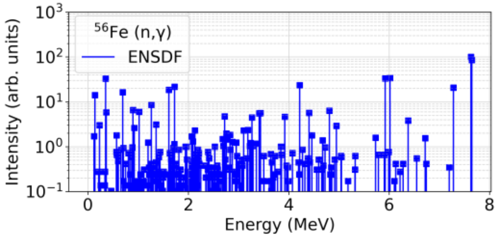


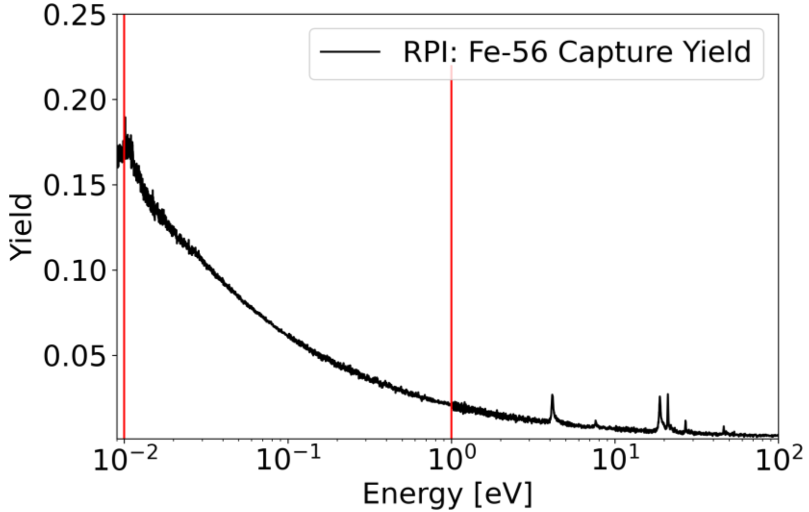
Benchmark Methodology:

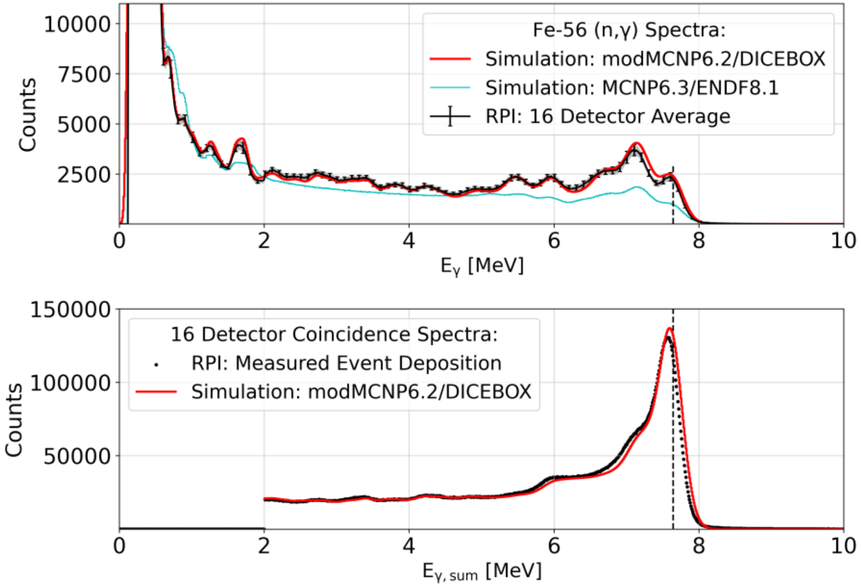


Methodology Verification: Fe-56

- Fe-56 capture primary gamma-ray energies and intensities are well known up to the binding energy.
- Variable experimental capabilities:
  - Spectra for defined incident neutron energies.
  - Gamma-ray spectra for each observed multiplicity and each detector.



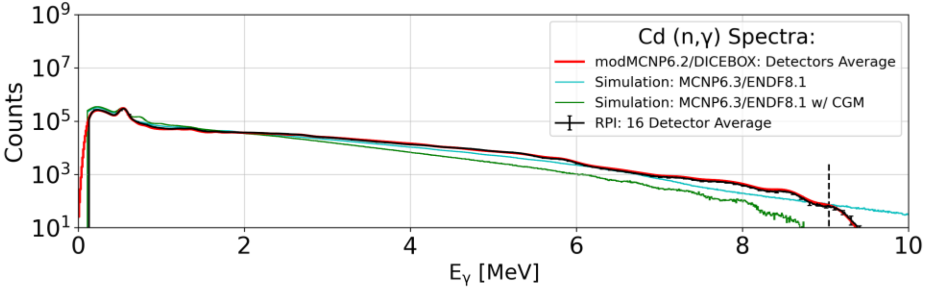


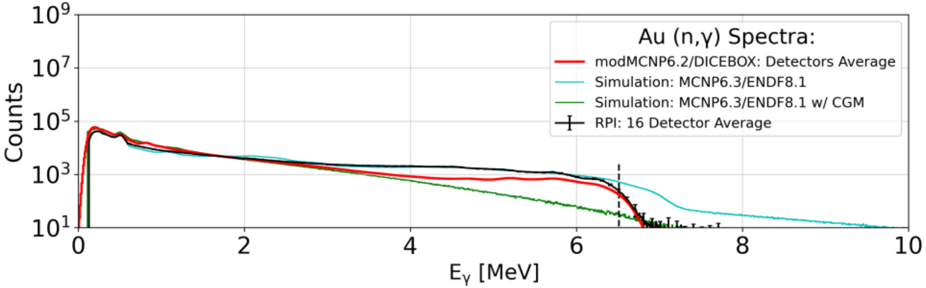


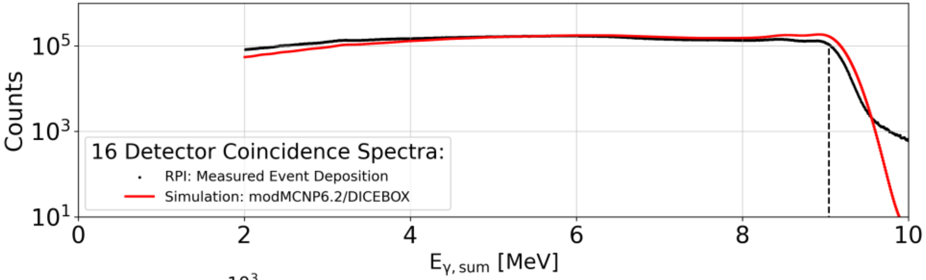
Progress Toward Benchmark: Accomplishments to Date

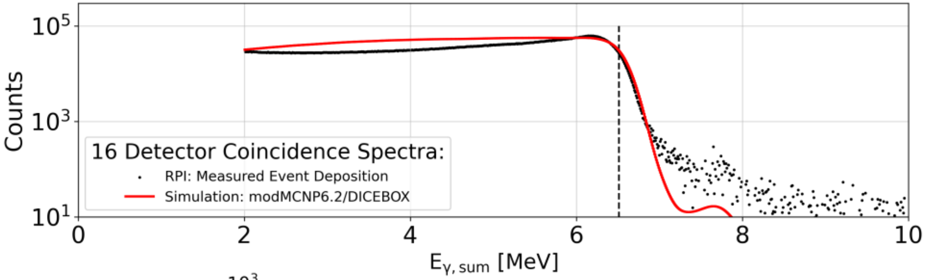
- Implemented new experimental energy calibration and alignment procedures.
- Investigated and utilized GIDI+ & OpenMC as simulation alternatives.
- Identified potential sources of uncertainty within the methods & experimental setup.
- Additional measurements of Cadmium, Indium, and Gold in Spring 24.

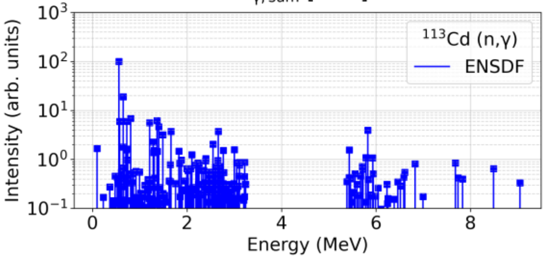
Experiment: Spring 2024 Results

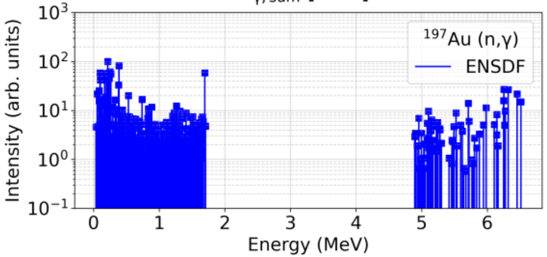




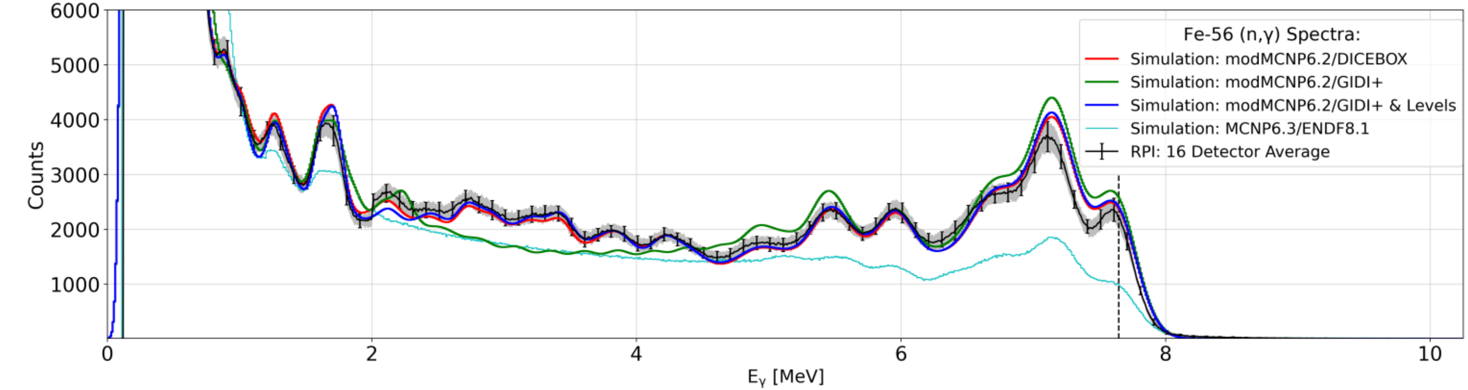


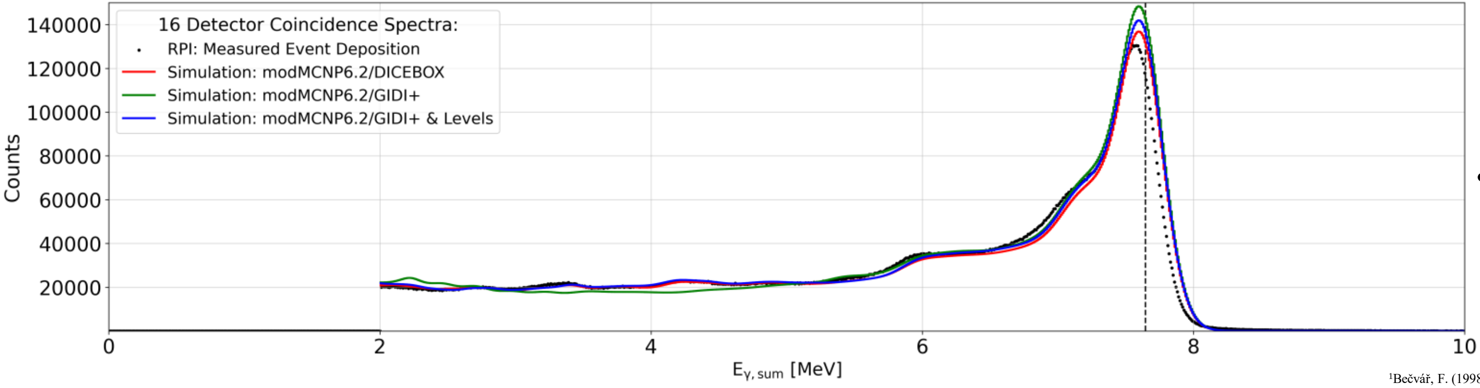






Simulation: mod-MCNP6.2 GIDI+ vs DICEBOX Cascades for Fe-56



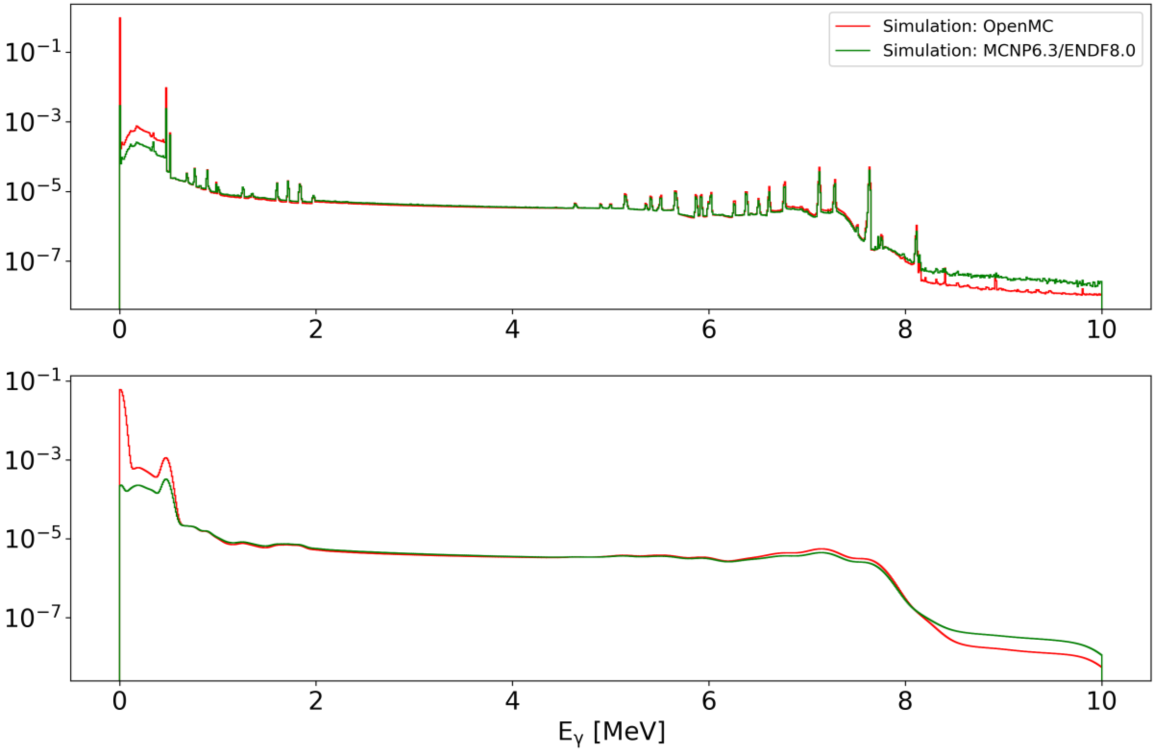


- DICEBOX[1] and GIDI+ (LLNL & GRIN) both create gamma-ray cascades.
- September 2024 collaboration with BNL learning GIDI+ and doing comparison to DICEBOX (cascades & simulation results).
- Using the same input data for the cascade generators, simulated spectra are very similar.

[1]Bečvář, F. (1998). Simulation of γ cascades in complex nuclei with emphasis on assessment of uncertainties of cascade-related quantities. *Nuclear Instruments and Methods in Physics Research Section A*, *417*(2-3), 434-449. https://doi.org/10.1016/S0168-9002(98)00787-6

Simulation: OpenMC vs MCNP6.3 Fe-56 Simulation Results

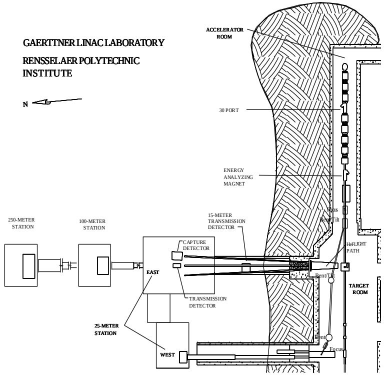
- To make the distribution of the benchmark easier, an open-source code such as OpenMC can be utilized rather than MCNP.
- Preliminary results are generated using distributed nuclear data libraries.
- Requires more work – implementation of the mod-MCNP6.2 abilities to read and transport gamma-ray cascades in OpenMC.



Uncertainty Analysis: Possible Sources of Uncertainty

LINAC:

- Monitor Counts
- Triggers
- Flight Path
- Gamma Flash
- Collimation

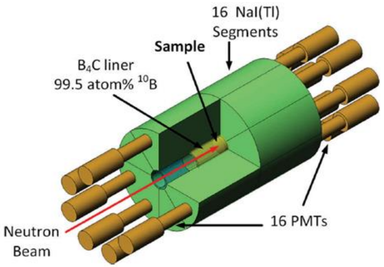


Processing:

- Energy Calibration
- Alignment
- Coincidence Time
- Processing Parameters

System/Detector:

- Background Spectra
- Deadtime/Pileup
- PMT & Hardware Performance



Sample:

- Impurities
- Scattering to Detector Structure
- Activation
- Radioactive Samples

Next Steps

- Investigate discrepancies & unknowns between experimental results & simulations.
- Continue uncertainty analysis & begin error propagation.
- Spring 2025 measurement – Samples TBD.
  - Expand & test capabilities and limitations of benchmark.
- **Begin benchmark qualifications & template.**

Thank you!
Questions/comments/suggestions?
parkei@rpi.edu

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Award Number DE-SC0024679.