Evaluating Sensitivity Trends for Mobile Antineutrino-Based Safeguards

2023 MTV Workshop

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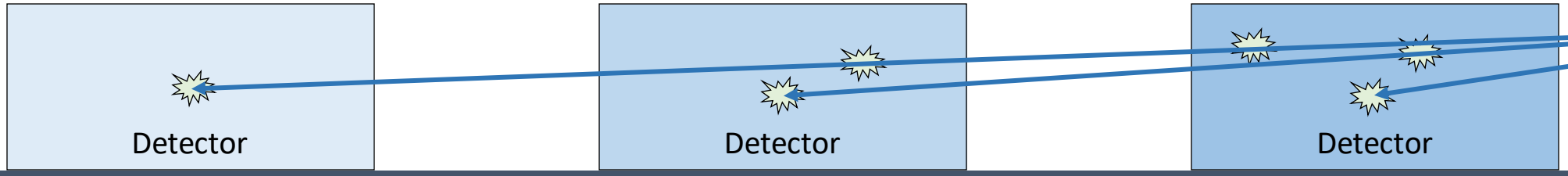
Introduction and Motivation

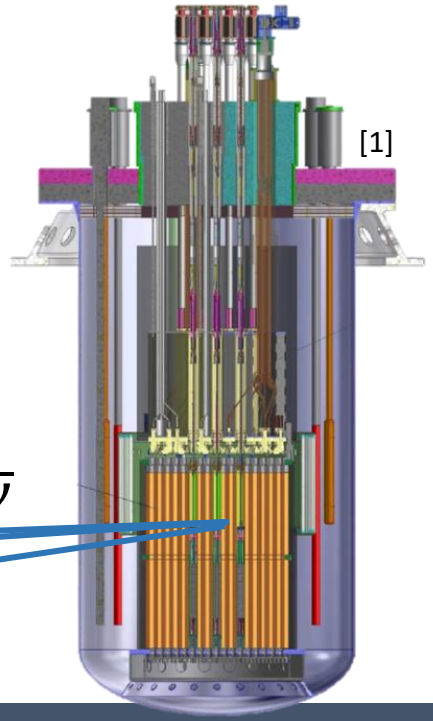
- Antineutrino detection systems may provide unique capabilities to safeguard the next generation of nuclear reactors [Nu Tools Report]
- Requires a careful consideration of system sensitivity and limitations to understand potential utility

On/Off Verification

Power Verification

Inventory Verification





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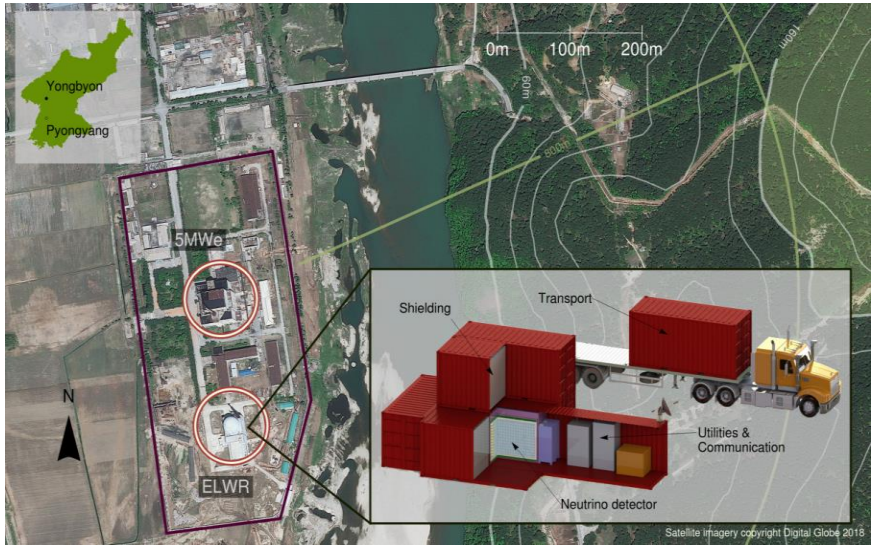
Mission Relevance

- System limitations go beyond technical capabilities
- Mobile antineutrino detection systems are flexible for implementation
  - Can be brought onto a facility after construction
  - Can safeguard multiple facilities and cores with strategic collection periods



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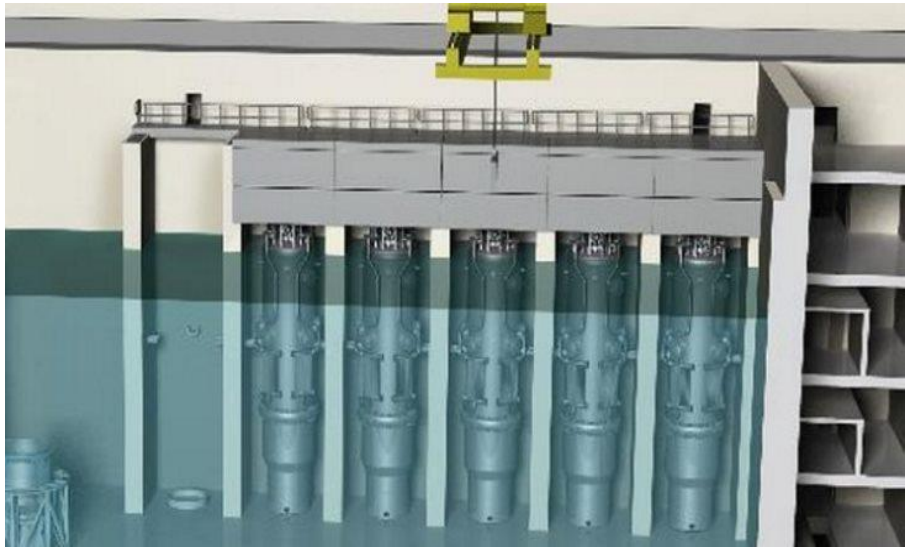

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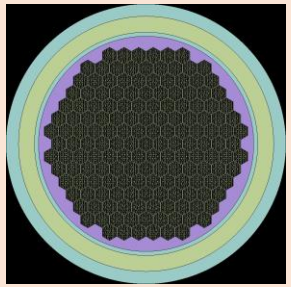
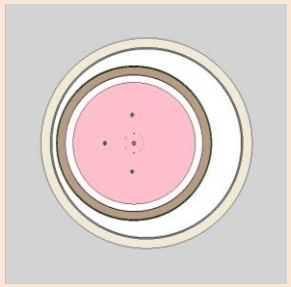
Technical Approach

The Reactor Evaluation Through Inspection of Near-Field Antineutrinos (RETINA) System

New Reactor Designs

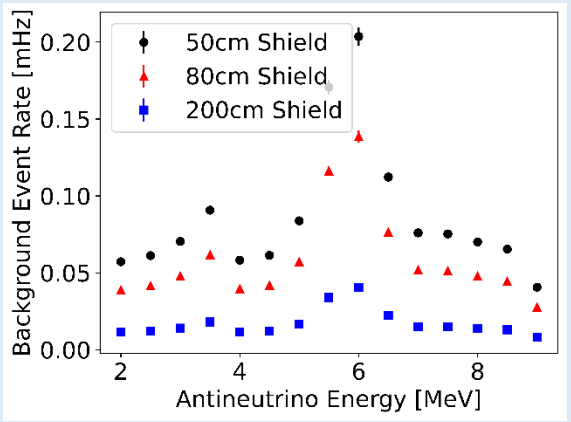


VVER-1000

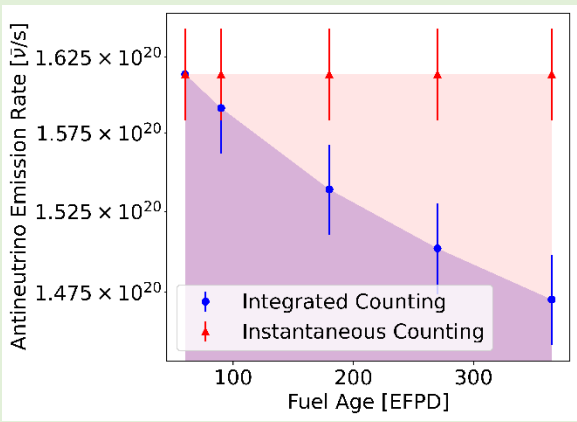


MSRR

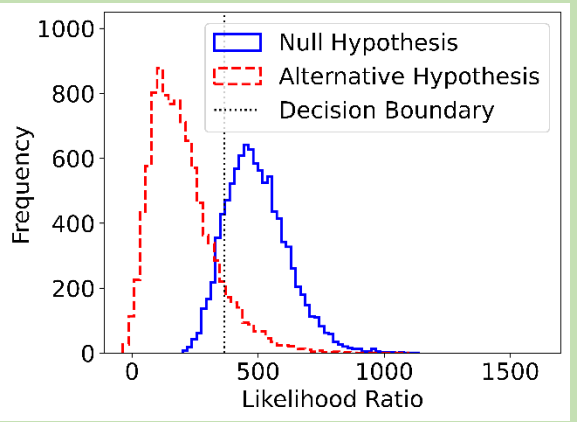
Updated Libraries



Higher-Fidelity Scenario Simulations



Robust Sensitivity Processing Technique



Exploring a Case Study

Advanced Fast Reactor-100

- Design
  - 250 MWth reactor power
  - 30 effective full power year (EFPY) fuel lifetime
- Scenario
  - Full power
  - 1 EFPY

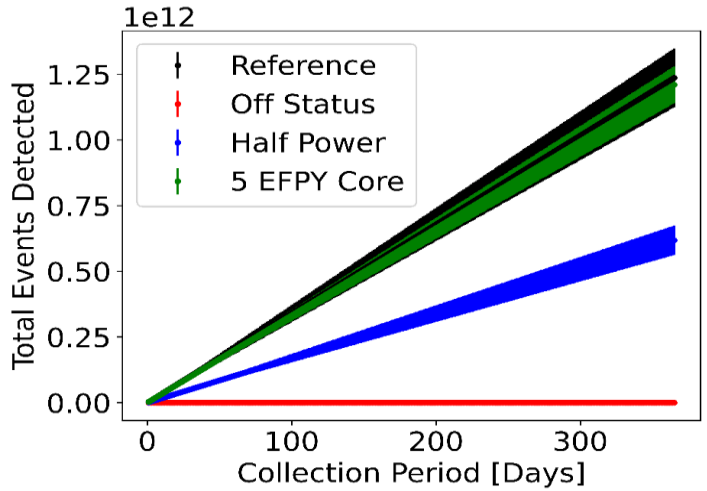
Detection System

- Design
  - Based on the PROSPECT experiment at the High-Flux Isotope Reactor (HFIR)
- Scenario
  - Varying sizes, shielding, and background confidence
  - 25 meter standoff distance

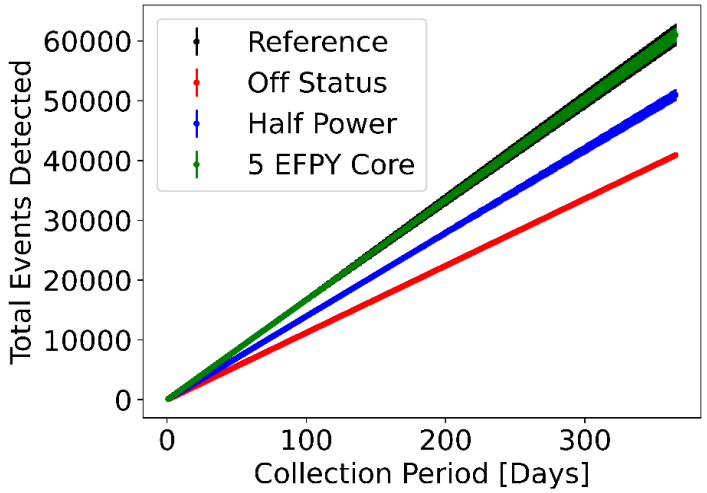
RETINA System Verification Capabilities

- Design
  - On/Off Status
  - Thermal Power
  - Fuel Burnup
  - Isotopic Composition
- Scenario
  - On/Off Status
  - 0.05 False Positive Rate
  - 0.1 False Negative Rate

Detection Spectra for Simulated Models

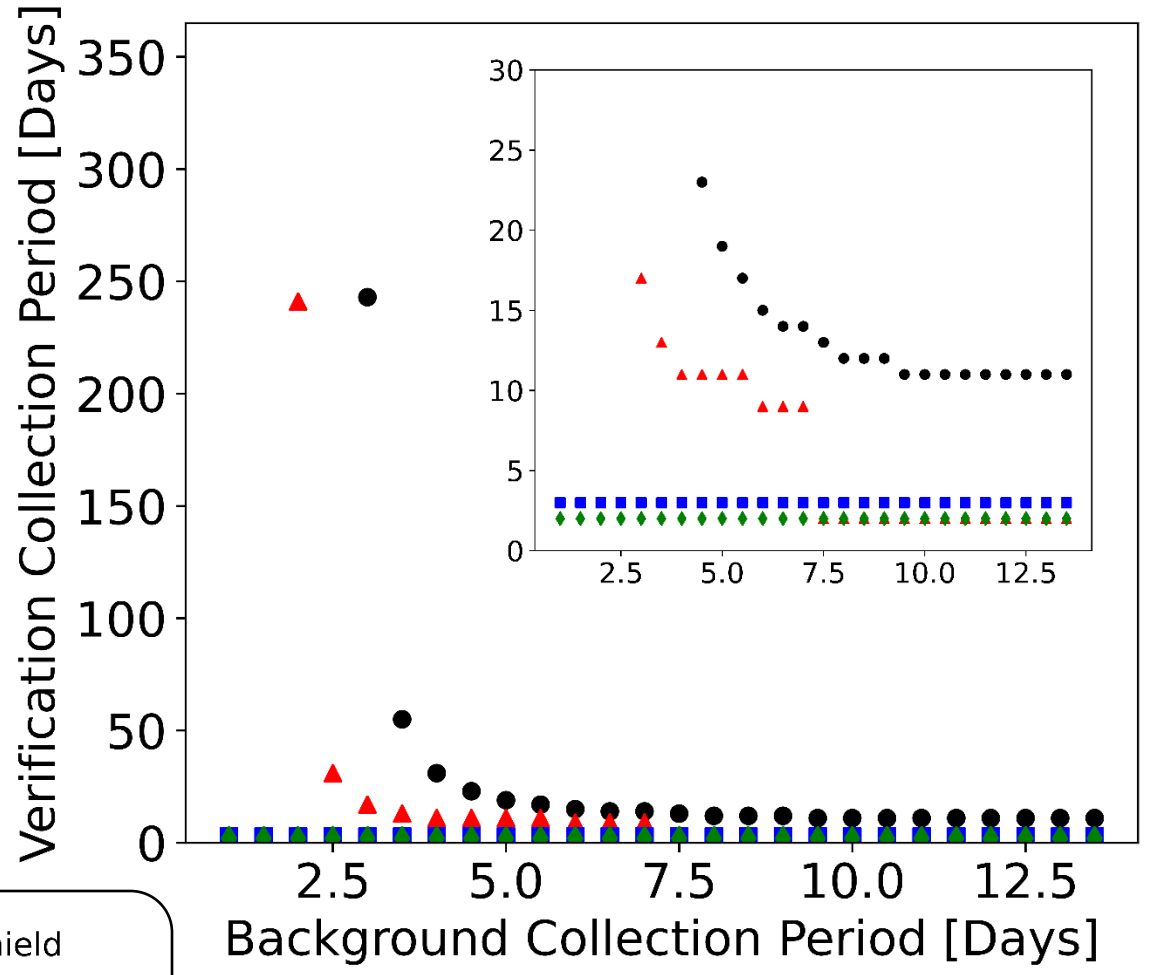


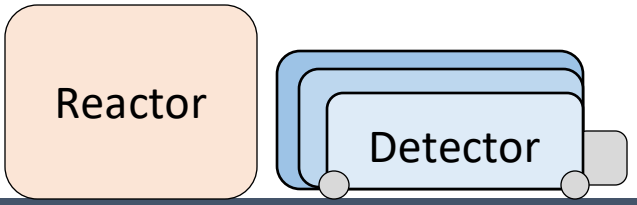
Detection Spectra for PROSPECT-matched Models



Developing Background Knowledge

- Background event rate during a reactor outage
  - Requires reactor outage for a reasonable measurement
  - Does not take long, regardless of the detector mass and shielding
  - Without a reasonable measurement, there is no realistic verification collection period to deduce that the reactor is on





- 1 Ton Mass, 50 cm Shield
- 1 Ton Mass, 80 cm Shield
- 1 Ton Mass, 200 cm Shield
- 2.5 Ton Mass, 200 cm Shield

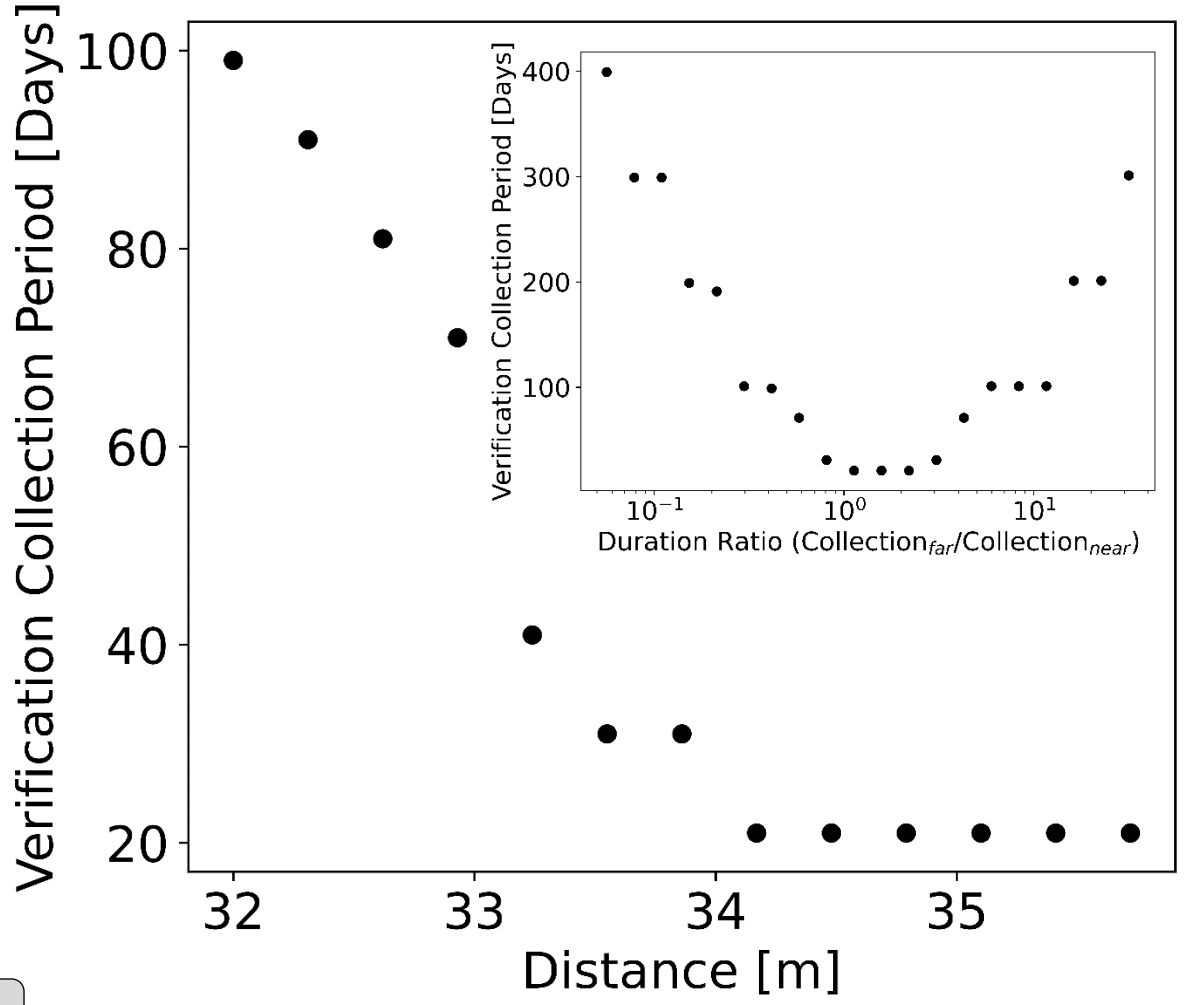
National Nuclear Security Administration

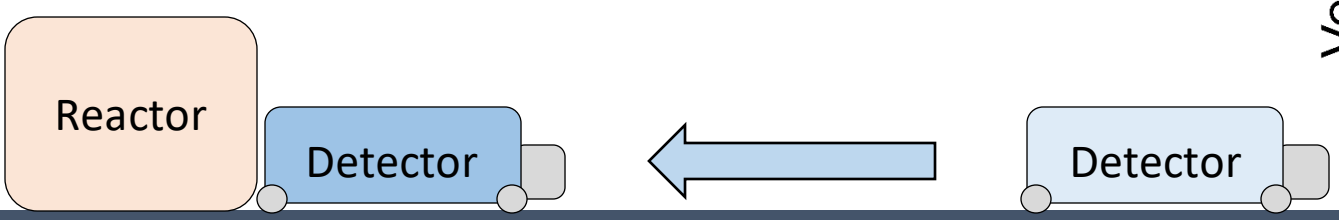
Georgia Tech

LANNS

Developing Flexible Background Knowledge

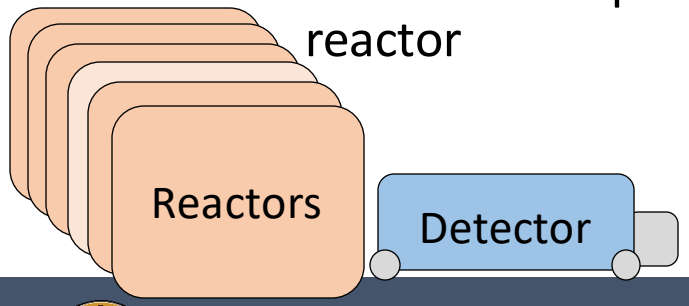
- Background event rate estimated using inverse square law
  - Can implement without a reactor outage
  - Must be far enough to significantly lower the geometric efficiency but close enough for a consistent background event rate
  - Can optimize the total time at the facility

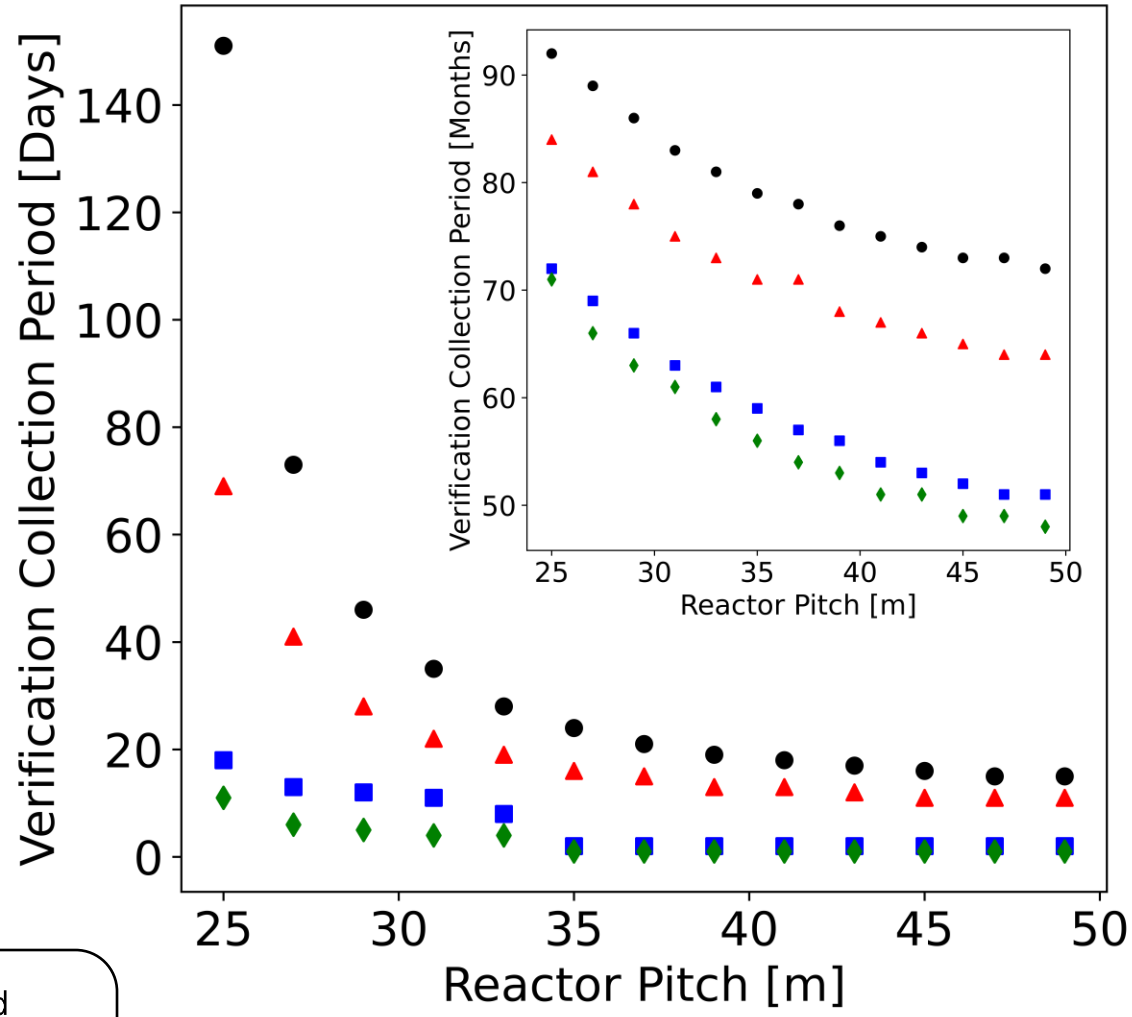




Monitor Multiple Cores

- Can move to safeguard specific cores in reactor halls
  - Assuming a six-core reactor hall, a detector 25 meters parallel to the reactor hall, and a 14 day background collection period during a reactor outage
  - Inverse square law plays a significant role
    - Reactor status can be verified within days if the detector is inline with the core of interest
    - Reactor status verification requires months of collection if equidistant from a full power reactor





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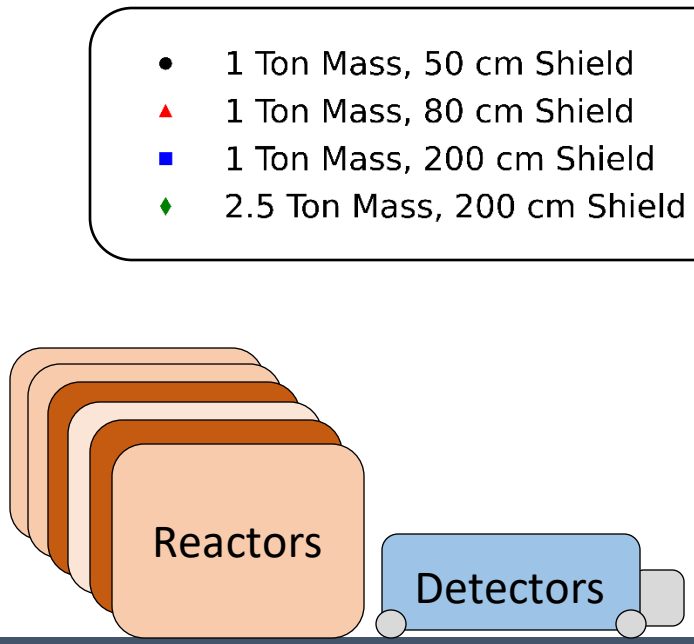
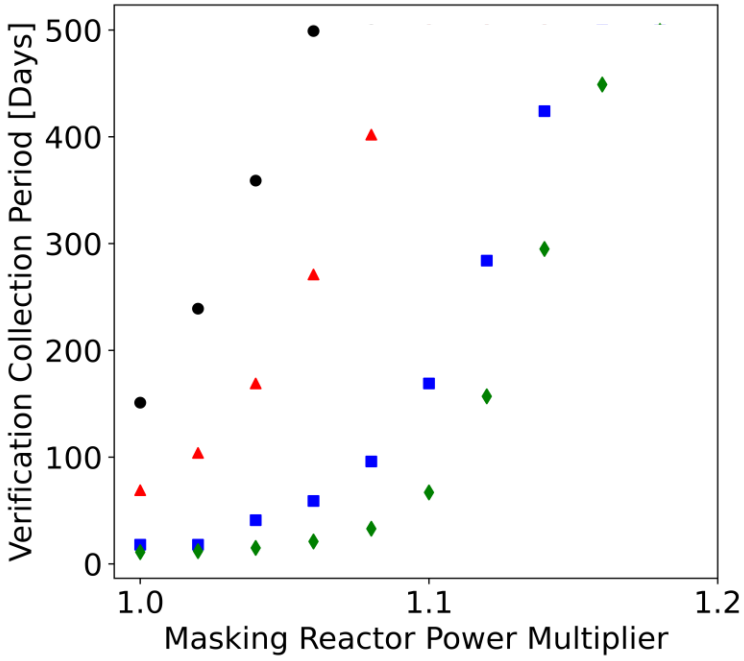
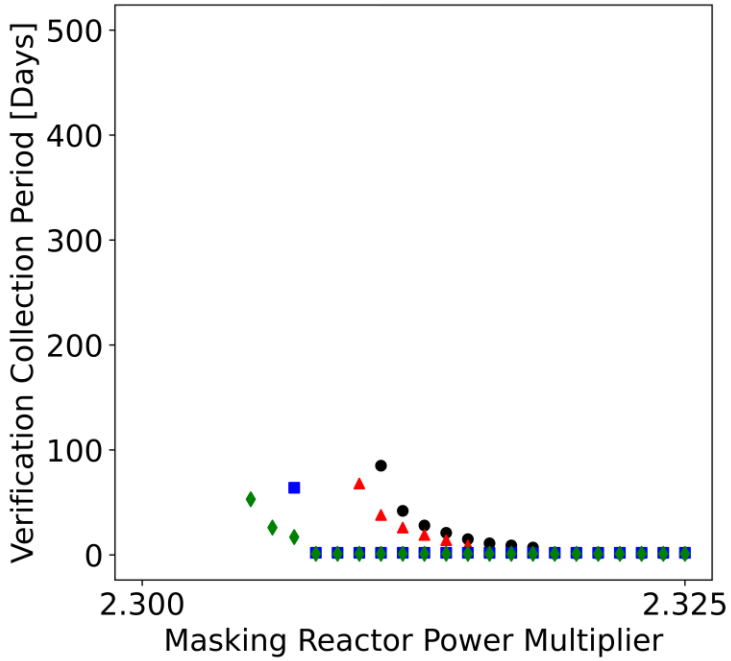
Monitor Multiple Cores – Misuse Masking

- Nearby reactors can increase in thermal power to mask the reactor outage
  - A slight power increase can delay the required verification collection period drastically
  - The power increase will eventually cause a quick misuse detection from overcompensating for the lower antineutrino event rate



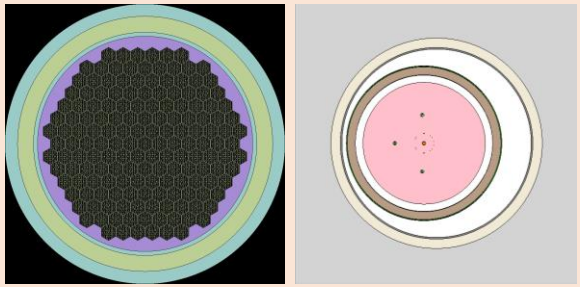




Expected Impact

- Through the newly designed RETINA system, we can generate quick, high-fidelity antineutrino spectra and process the spectra to develop realistic verification timelines
- Can provide guidance for development of systems like mobile antineutrino detectors and assess potential use cases

New Reactor Designs



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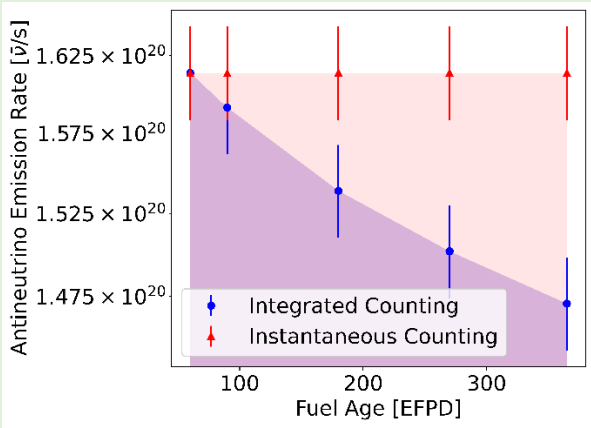
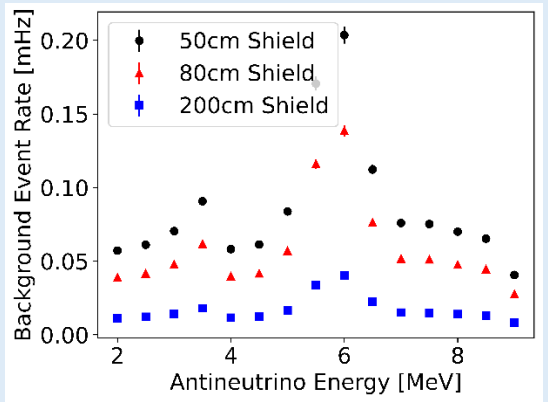


MTV Impact

- Mobile Antineutrino Demonstrator (MAD) Project
  - Collaboration with many universities and national laboratories
  - Led by Lawrence Livermore National Laboratory
  - Demonstrate high sensitivity, applications appropriate antineutrino systems can be implemented in relevant environments

Updated Libraries



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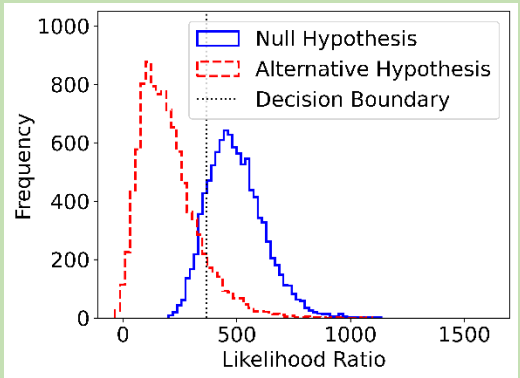
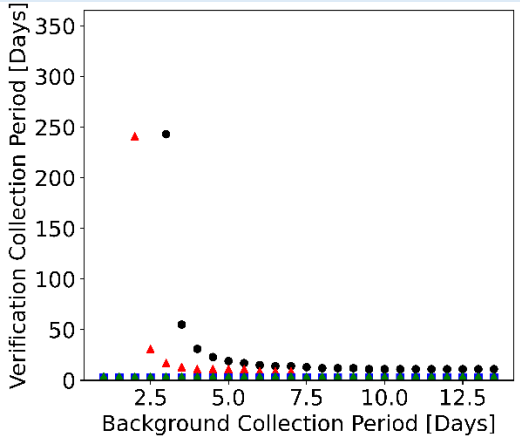
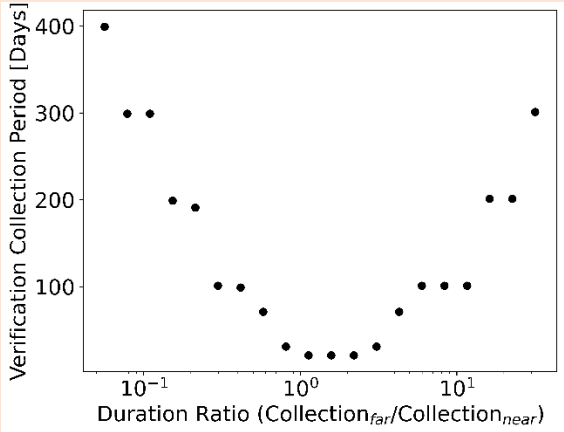


Conclusions

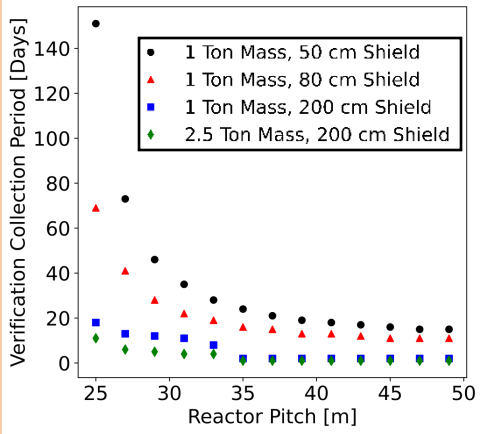
Background Knowledge



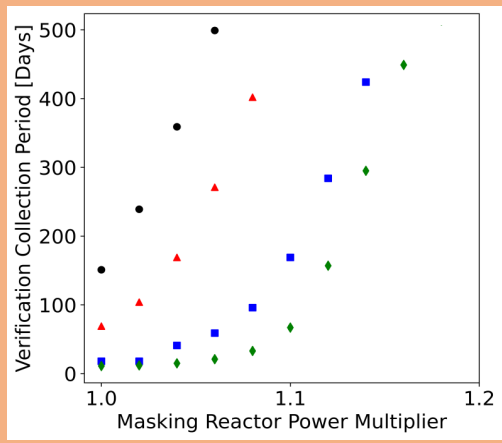
Flexible Background Knowledge



Multiple Cores



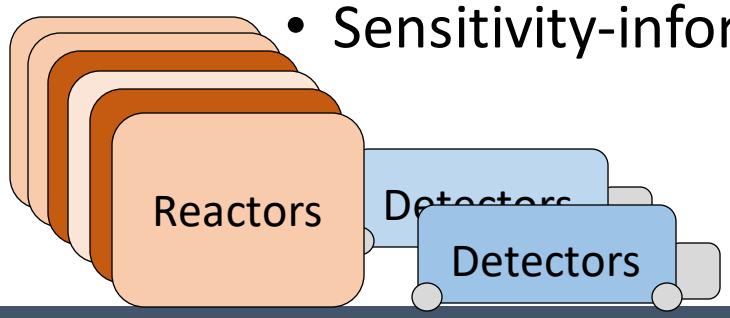
Multiple Cores Masked

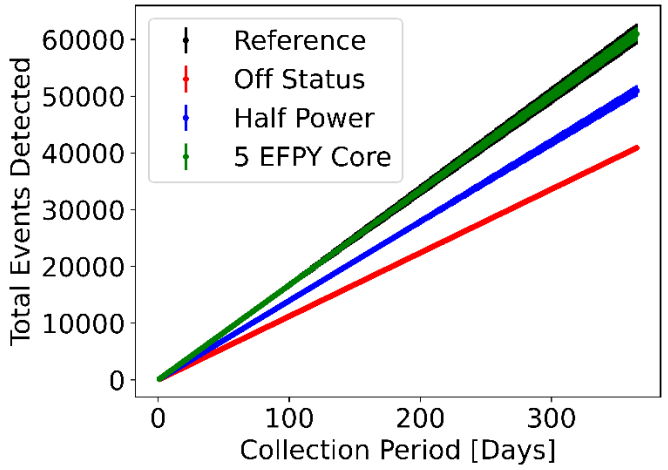


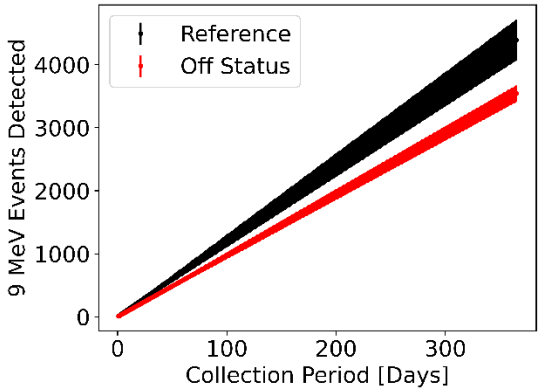
Mobile antineutrino detectors show potential as a flexible, independent tool to effectively safeguard future nuclear facilities

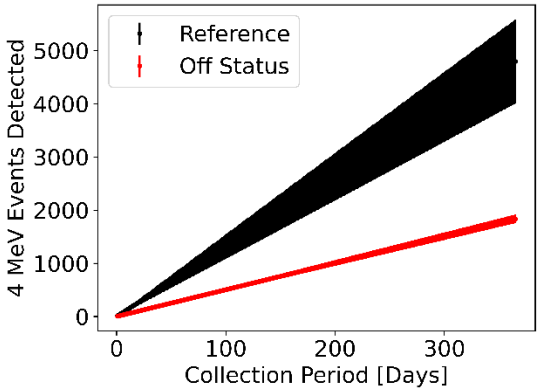
Next Steps

- Continue to explore different scenarios for RETINA system capability limitations
  - Implement multiple detectors
  - Temporal difference learning to prepare system for scenario patterns
- Update detector response with MAD collaboration
  - Other forms of estimating background
  - Sensitivity-informed detector response









Acknowledgements

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2. Carr, Rachel, et al. “Neutrino-Based Tools for Nuclear Verification and Diplomacy in North Korea.” *Science & Global Security*, vol. 27, no. 1, 2019, pp. 15–28., https://doi.org/10.1080/08929882.2019.1603007.
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Nu Tools Report: https://nutools.ornl.gov/