Dry Cask Storage Verification Using Muon Imaging

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Introduction

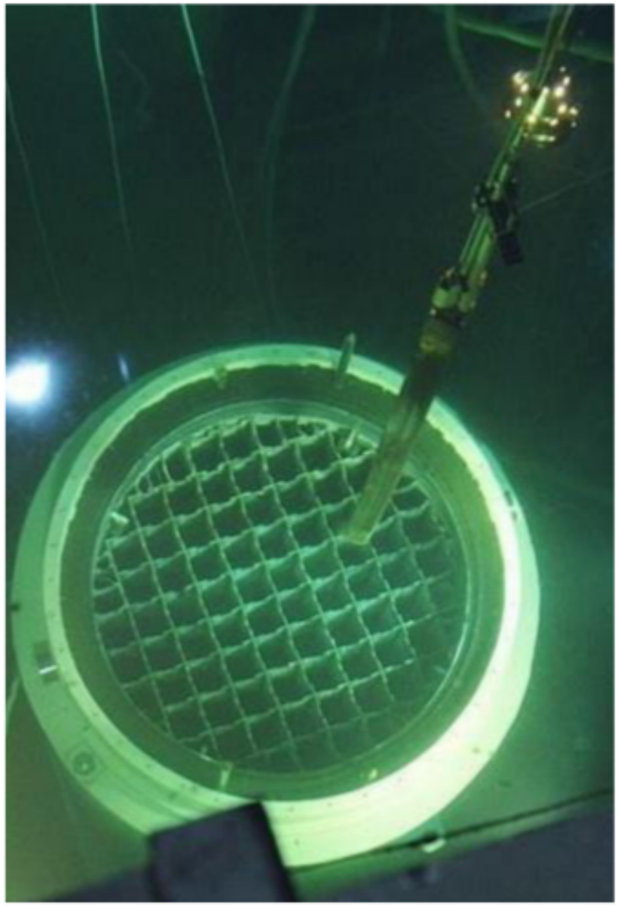
Dry Storage Casks:

Trust paperwork, or…

Measure what is inside

Thick walls, can't x-ray…

Dry cask storage containers must be returned to spent fuel pools for verification



Loading spent fuel cask under water. Holtec 2017

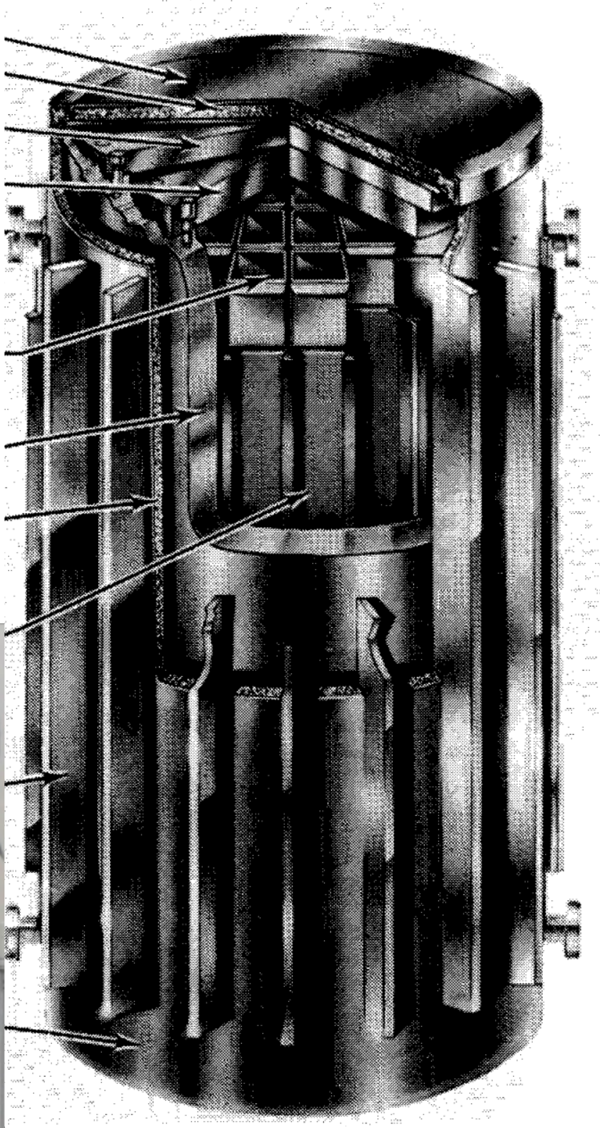
Motivation

Current methods of dry cask storage verification are time and labor intensive.

- Passive measurements of decay products are difficult due to large amount of shielding present
- Current verification methods require moving entire cask into spent fuel pool

Muon imaging will allow for in situ inventory verification

- Natural background muons
- Detect the diversion of used fuel



Mission Relevance

Muon imaging techniques can be used to

- Ensure all of a facilities declared nuclear material is accounted for
- identify if nuclear material has been removed from storage containers

In line with NNSA Mission

- *Website:* https://www.energy.gov/nnsa/missions/nonproliferation

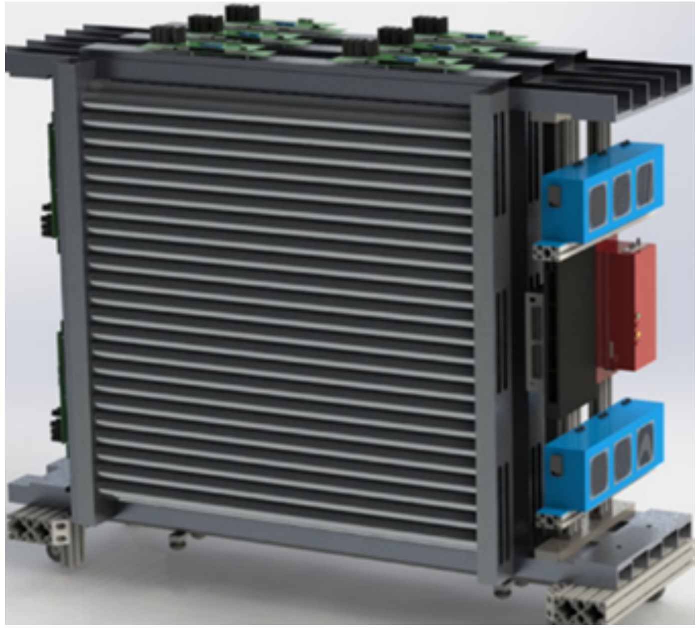
Preventing nuclear weapons proliferation and reducing the threat of nuclear and radiological terrorism around the world are key U.S national security strategic objectives that require constant vigilance.

NNSA's Office of Defense Nuclear Nonproliferation works globally to prevent state and non-state actors from developing nuclear weapons or acquiring weapons-usable nuclear or radiological materials, equipment, technology, and expertise.

Technical Approach

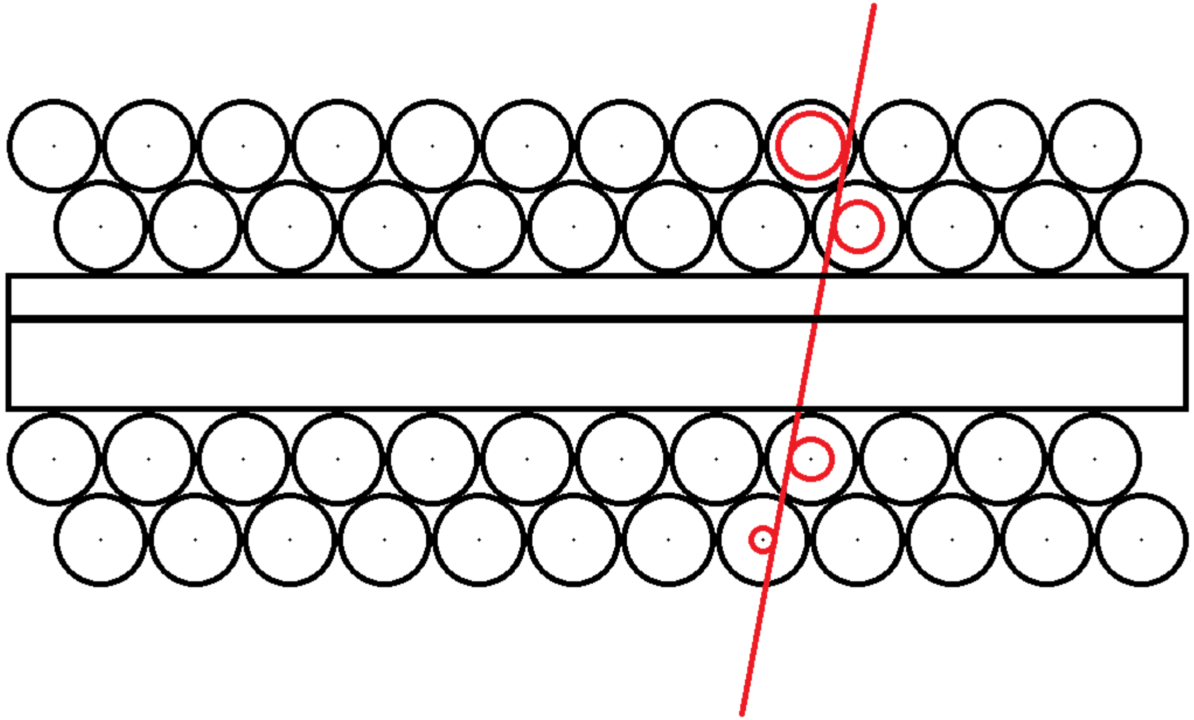
Using muon detectors developed by Los Alamos National Laboratories

- Demonstrate imaging, up to tomographic reconstruction, of dry cask storage containers using measured scatter data
  - Use mock-ups to develop reconstruction algorithm
  - Test algorithm performance on an actual storage container contained spent fuel



Durham, J. M. et. Al (2018). Physics Review Applied.

Leverage existing infrastructure



Pictured above: High level schematic of muon detection

Pictured left:
Drift tube array
designed by LANL

Research Goals

- Detailed simulations of cosmic-ray muons passing through fuel casks and other geometries will be performed.
  - Several simulations will be performed to provide useful data for development of analysis algorithms, focusing on improving spatial resolution and lowering acquisition times.
  - Additional simulations will be used as benchmarks against preliminary data taken with the LANL muon trackers.
- Become familiar with running 1.2mx1.2m module LANL array and analysis software
- Create a mockup fuel cask, new data
  - This expanded data set will be used for experimental tomog11raphic reconstruction
- Test and run larger LANL array: 1.8mx1.8m and 1.8mx2.4m modules
- Test with casks –INL? MTV Collaborators?

Simulation Results

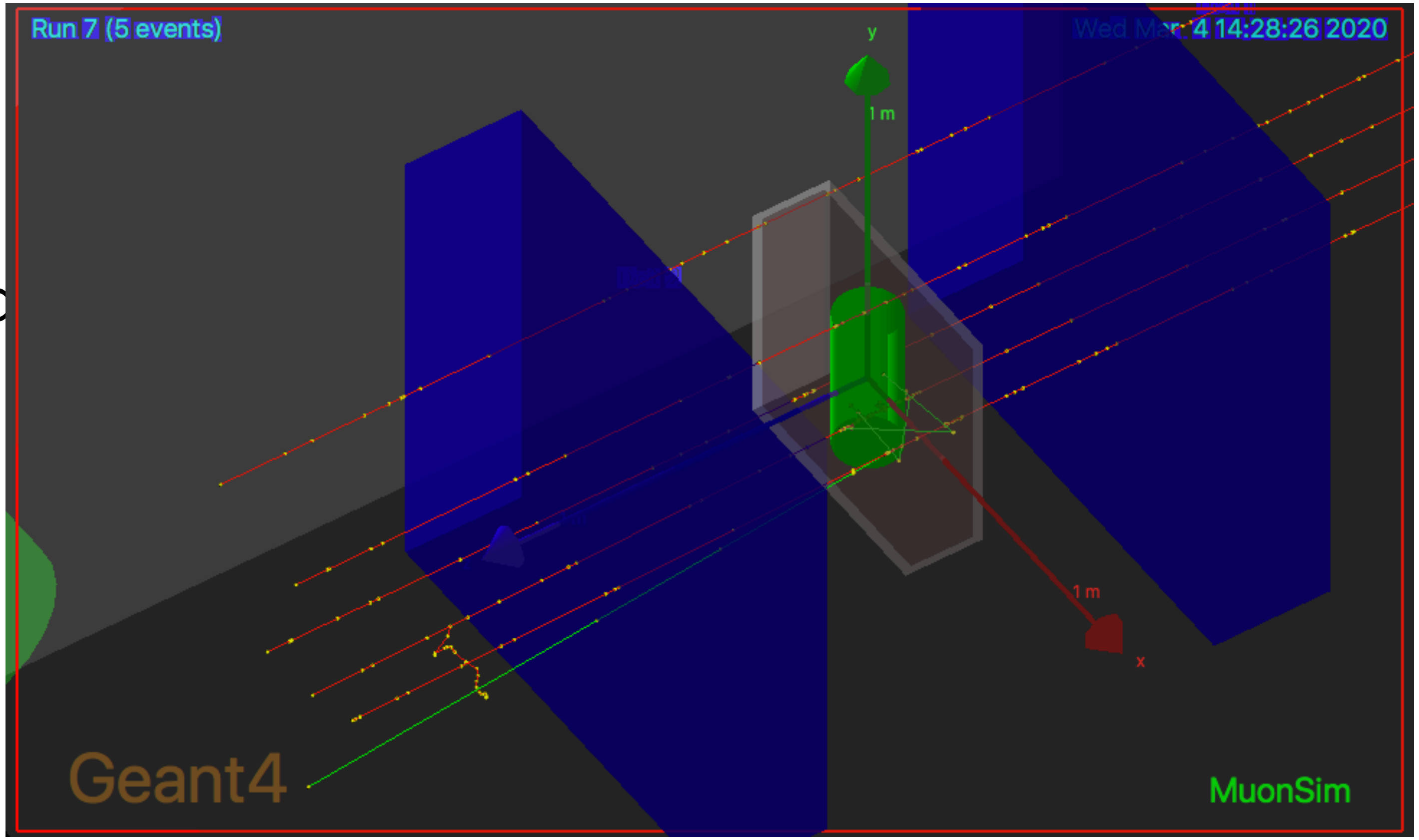
SOW Year 1 Goals:

Have cosmic-ray muon simulations of spent fuel casks and simulated benchmark data

Geant4

Muon detectors are modeled as rectangular prisms

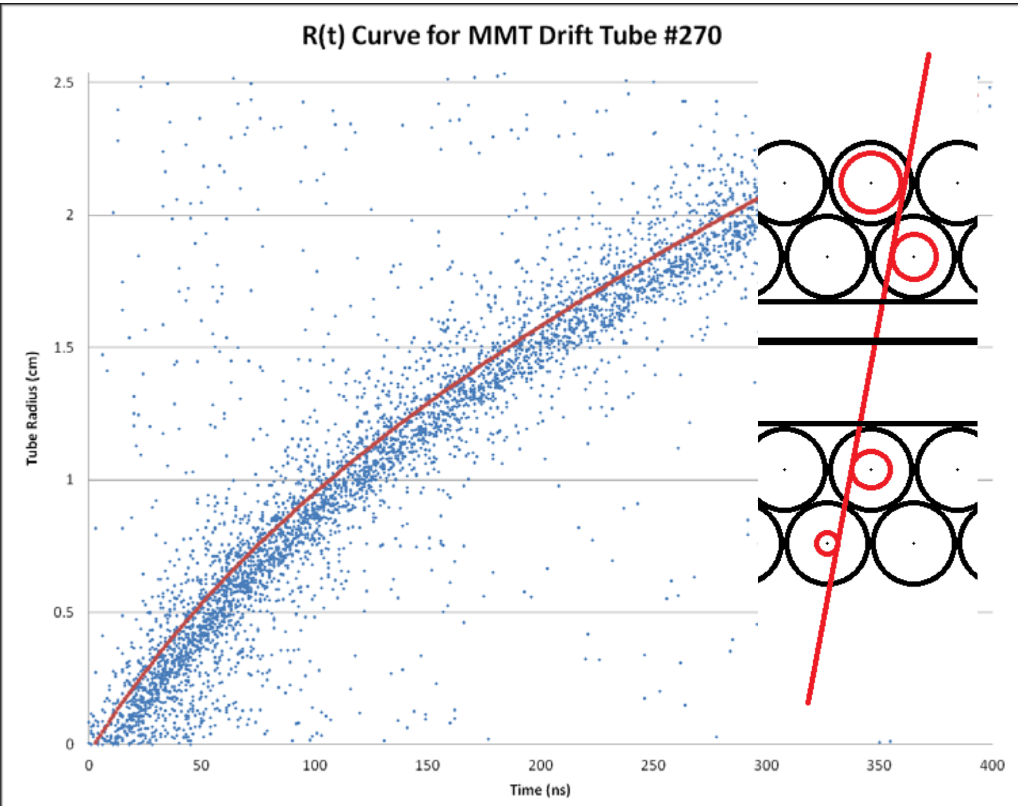
- Muon position at entrance and exit of detector are saved
- Four resulting points are used to create initial and final trajectory of muon
- Trajectories approximate scatter in object of interest

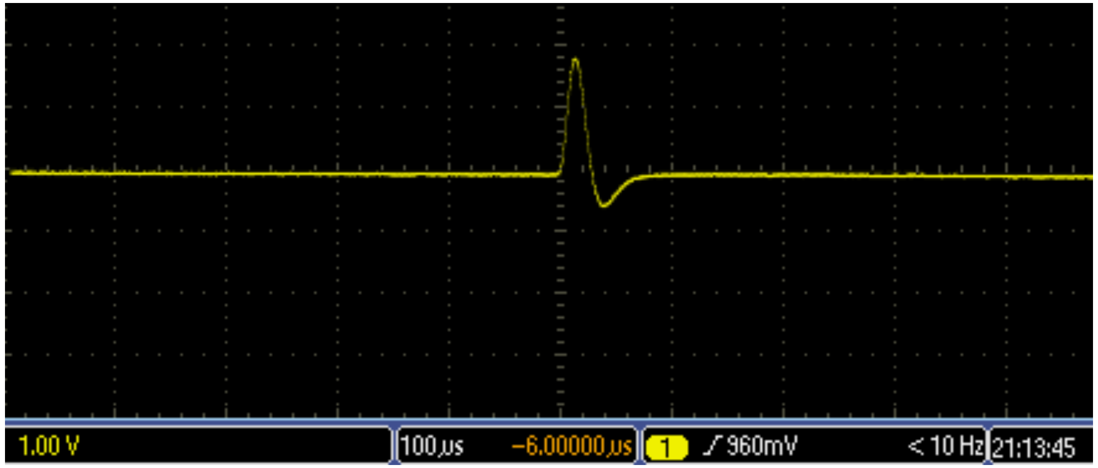


Experimental Work

Borrowed drift tubes from LANL

- Determine drift tube response
  - Pulse shape, timing, etc.





Expected Impact

- Prevent/detect the diversion of nuclear fuel
- Allow for greater material accountability

MTV Impact

Major need for project is access to a dry cask storage facility

- Past measurements performed at Idaho National Laboratories.
- Leverage potential MTV connections to access different facilities or container models

MTV discussions towards access to storage casks

Potentially pair muon tomography system with neutrino detection projects

- Potentially Virginia Tech group? LLNL.

Conclusion

Current progress will enable us to begin with core project objectives

- Focus on using simulation data to create image reconstruction algorithms
  - Eventually apply algorithms to real data for actual image reconstructions.
- Experience with drift tube response will allow us to apply tomography algorithms to real data.

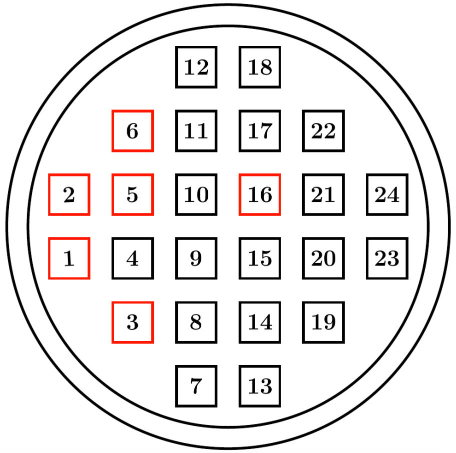
This work directly supports the NNSA Nuclear Nonproliferation mission by

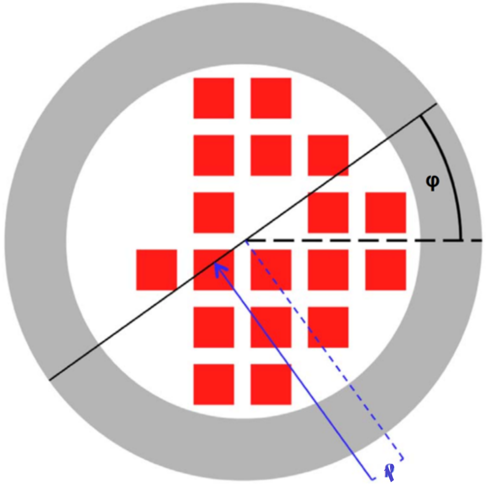
- Enabling the detection of spent nuclear fuel diversion
- Allowing for passive verification of dry cask storage containers

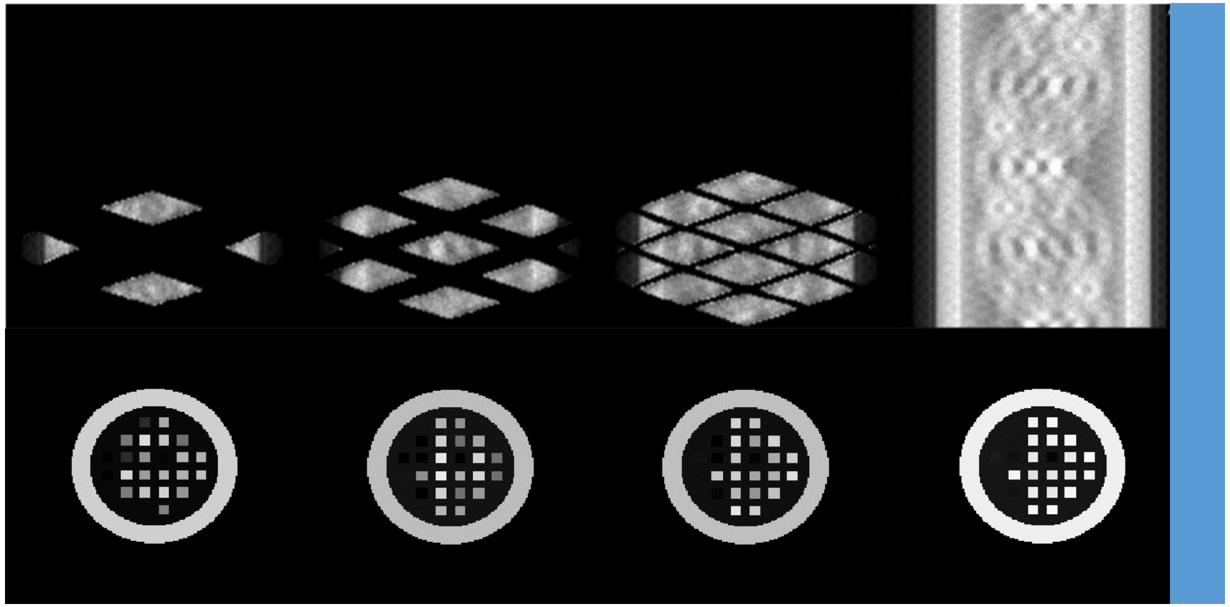
Next Steps

- Current focus will be using data produced in Geant4 to
  - Simulate data produced by the LANL developed muon detection system
  - Determine maximum likelihood of scatter angles
  - Use this data to create reconstruction algorithms
- Work on drift tubes at UNM
- Travel to Los Alamos to take measurements during this upcoming summer

Partial View CT Reconstruction







Densities (Z^2/A) obtained from the partial and full data sets
n = 2,3,4, and full data

Fingerprinting: What materials present

14 d fresh missing lead steel

Acknowledgements

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National Nuclear Security Administration