A Novel Application of Cosmic Rays for Spent Nuclear Fuel Monitoring

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Introduction

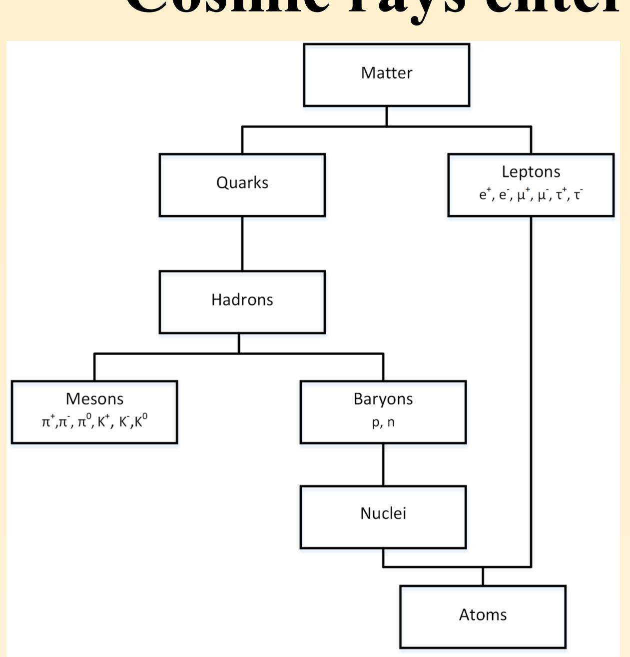
Monitoring nuclear waste and controlling spent nuclear fuel at its source is one of the main strategies to minimize the risks of nuclear proliferation and reduce potential homeland threats. Storage of high level waste from a fission reactor typically involves placing spent fuel in sealed dry casks. After the spent nuclear fuel has been placed inside the dry cask, the cask is welded, not allowing for visual inspection. Conventional methods for examining the interior of materials e.g., X-rays, are limited by the fact that they cannot penetrate very dense well-shielded objects. Instead, cosmic ray muons have the potential to allow for assessment of spent nuclear fuel stored within sealed dense dry casks.

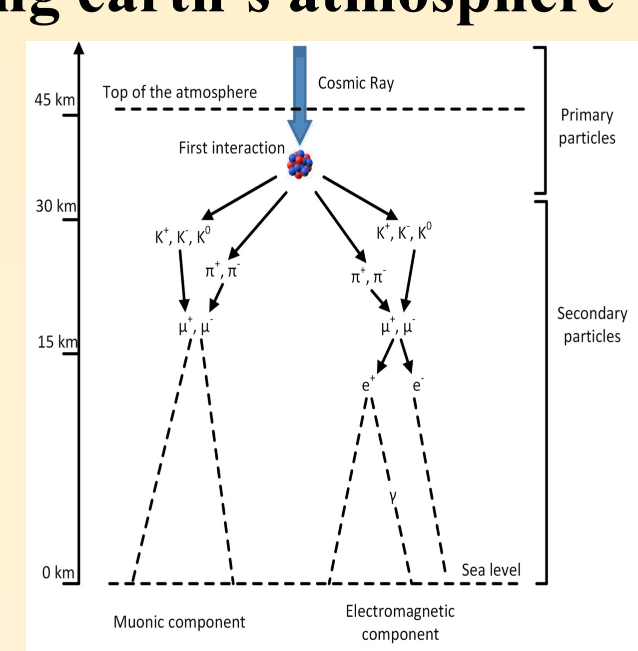
Objectives

1. Exploit the ability of cosmic ray muons to penetrate high density materials allowing the distribution of materials within the object to be inferred from the muon tracks.

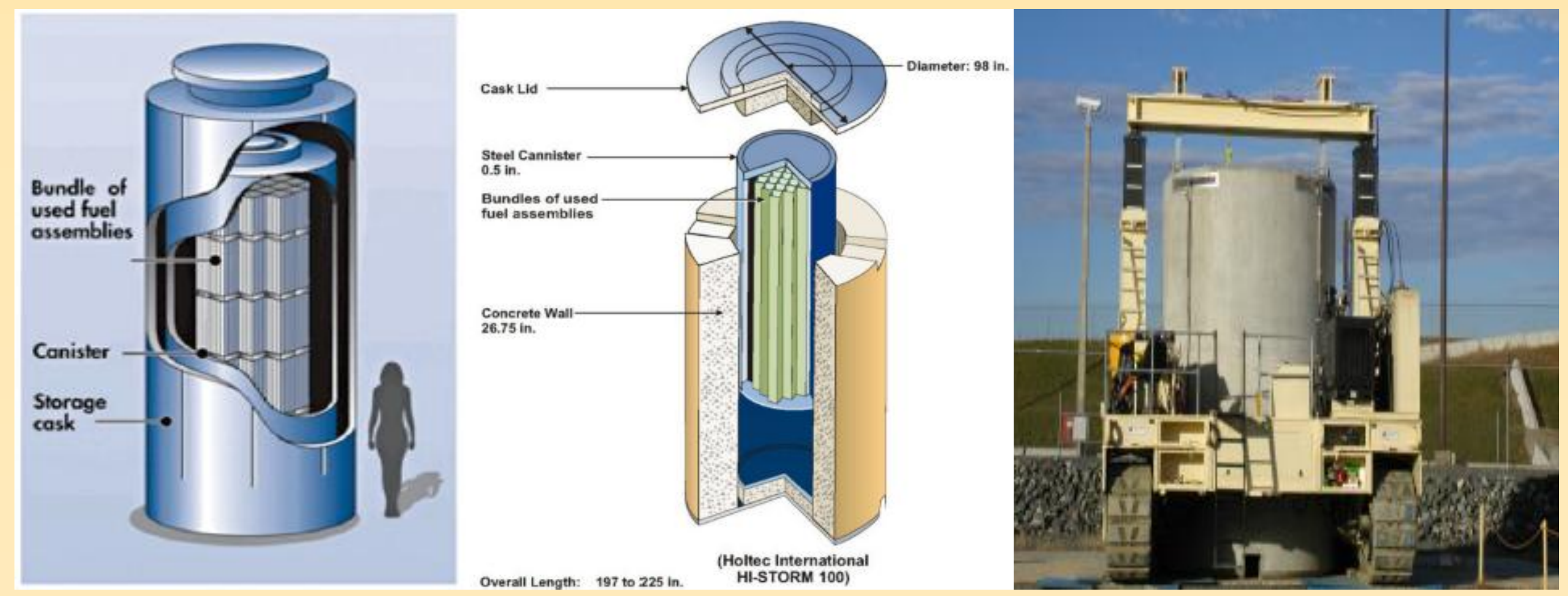
2. Develop a monitoring system that tracks the path of cosmic ray muons, including their deflection and attenuation, to identify the contents of a closed dry cask

Cosmic rays entering earth's atmosphere

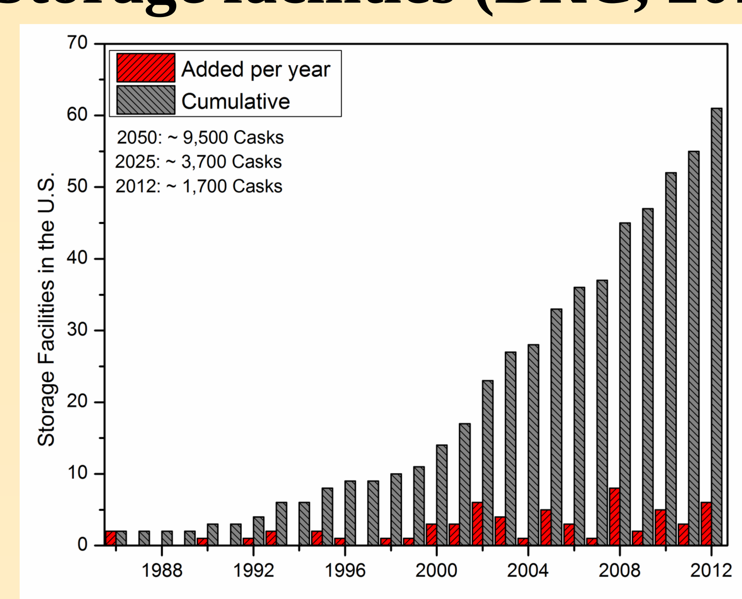




Examples of dry cask storage (USNRC, 2011)



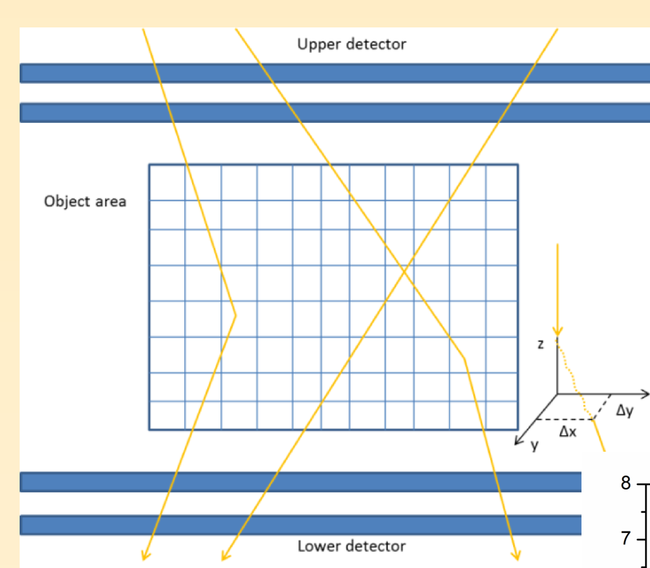
Storage facilities (BRC, 2012) - Muon scattering (Bethe, 1953)



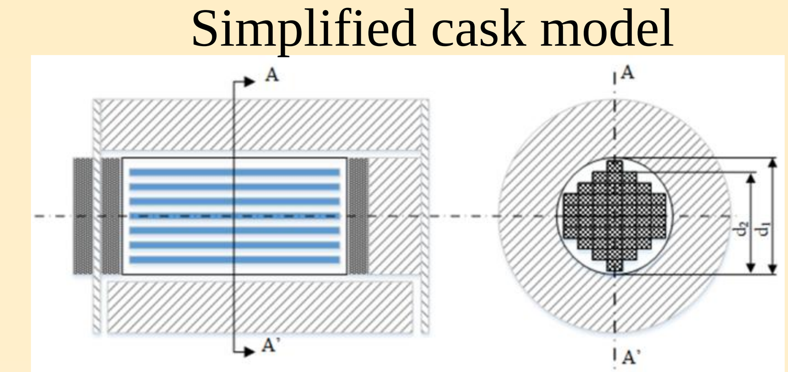
$$\sigma_\theta = \frac{13.6MeV}{\beta pc}\sqrt{\frac{x}{X_0}}\left(1 + 0.038\log\frac{x}{X_0}\right)$$

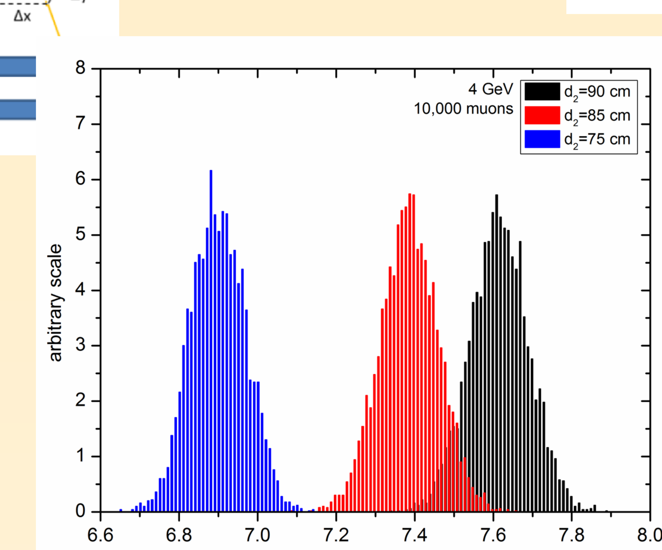
$$X_0 = \frac{716.4\left(\frac{g}{cm^2}\right)}{\rho}\,\frac{A}{Z(Z+1)\log\frac{287}{\sqrt{Z}}}$$

Muon scattering distributions through multiple materials

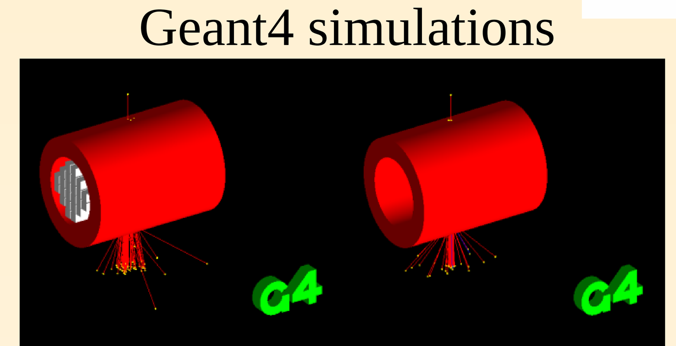


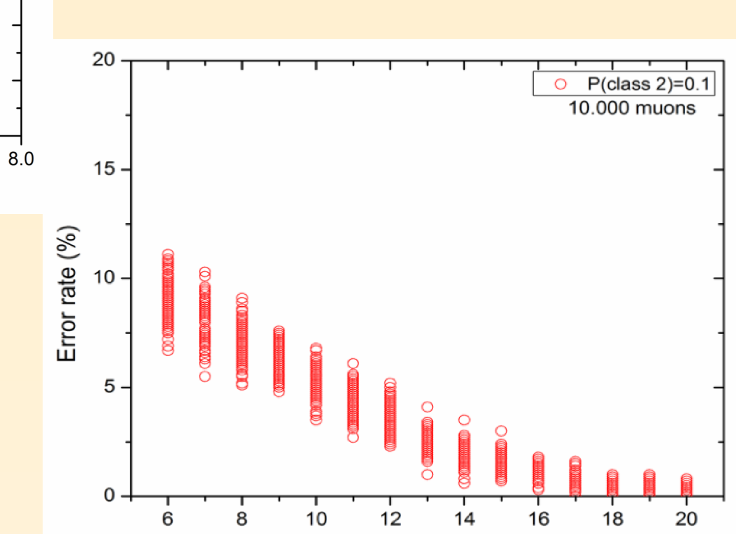
Simplified cask model





Geant4 simulations





Methods

- Monte-Carlo simulations using Geant4
- Bayesian decision theory for signal classification
- Wavelet analysis for noise cancellation
- Chaotic Neural Networks for signal encryption

Results

1. Preliminary statistical analysis proved that the method is feasible and has the ability to identify the presence of spent nuclear fuel in a dry cask

2. Using monoenergetic muons, a dry cask with one fuel assembly missing can be correctly identified with error rate <1%

Broader merit

Once completed, the proposed project for cosmic ray muon transport will enable a new and potentially transformative approach towards efficient, inexpensive and remote cosmic ray muon applications in archaeology, medicine and safeguarding of nuclear materials.

Collaborations

- Argonne National Laboratory (Dr. A. Raptis, Dr. A. Heifetz)
- Los Alamos National Laboratory (Dr. M. Durham, Dr. E. Guardincerri)

Acknowledgements

Research supported by DOE Office of Nuclear Energy, Award Number: DE-NE0000695

Applied Intelligent Systems Laboratory

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