Verifying Contents of Dry Fuel Casks with Multiple Coulomb Scattering of Cosmic Ray Muons

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INTRODUCTION

Multiple coulomb scattering (MCS) muon radiography was developed at Los Alamos National Laboratory (LANL) as a means of using naturally occurring cosmic ray muons as an interrogative probe. The nature of MCS of charged particles makes the technique especially sensative to high Z material, and thus a useful probe for identifying nuclear fuel in a relatively low Z container. The use of this technique for verifying the contents of dry fuel casks has been the subject of several theoretical simulation studies [1–10]. The results of simulation indicate that the technique would be well suited for fuel cask verification. This was verified by a 2015 measurement by the LANL Threat Reduction Team [11], which indicated that spent nuclear fuel could be identified within a dry spent fuel cask. This paper summarizes followup measurements that the LANL Threat Reduction Team performed on a Westinghouse MC-10 dry fuel cask at Idaho National Laboratory (INL) [12].

DESCRIPTION OF WORK

The premise upon which MCS muon radiography works is that the small coulombic scattering which a charged particle undergoes while traversing a medium may be approximated by the gaussian distribution with a width of

$$\sigma = \frac{13.6\ \mathrm{MeV}}{\beta c p}\sqrt{\frac{L}{X_o}} \quad (1)$$

where βc and p are the particle's velocity and momentum, and L/X_o is the number of radiation lengths that the particle traverses [13]. The quantity $1/X_0$ is quadratically dependent upon the Z number of the material, making MCS particularly sensitive to high Z material.

In order to measure the MCS of muons in the MC-10 cask, planar muon detectors (made from planar arrays of drift tubes) where placed on opposite sides of the cask and incoming and outgoing tracks were recorded. The entire data set consisted of 9 positions of the two planar detectors in order to observe all potential loading locations for spent fuel. However, high winds introduced uncorrectable discrepancies in the scattering data for the final 3 positions which were not included in analysis. The actual loading configuration and used detector positions are show in FIG. 1.

The detectors were allowed to collect data in each position for 7-10 days and the data sets consisted of 4×10^4 to 9×10^4 muon tracks. All of the data used in analysis was aligned into a common coordinate system to create single measurement of MCS in the MC-10.

In order to draw conclusions, the measurement data was compared with Geant4 simulation data of a MC-10 cask with full and empty loading configurations. The simulation data was re-weighted to account for differences in solid angle for each measurement position, as well as differences in the counts for each position. The final analysis was performed on all three data sets; actual measurement data, a full Geant4 simulation, and an empty Geant4 simulation.

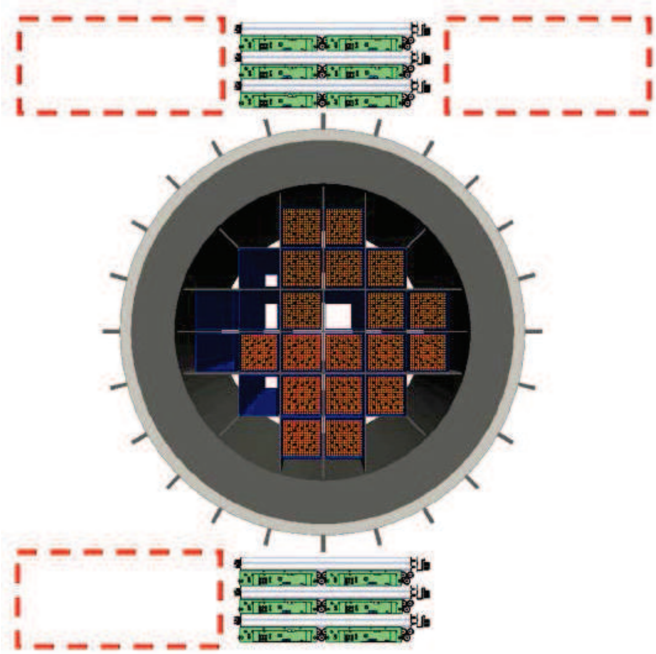

Fig. 1. The loading configuration of the MC-10 and detector positions throughout the measurement. From left to right, the loading in each column is: 0 bundles, 1 bundle, 6 bundles, 5 bundles, 4 bundles, and 2 bundles. The dark gray shell is made from steel for γ shielding and the light gray shell is a neutron absorbing resin.

RESULTS

Analysis of the data required projecting the muon tracks to a vertical plane at the center of the cask. The location of the projected tracks was binned and the weighted scattering angle of the track was added to the bin the neighboring bins. A final histogram of the measurement data and the simulation data is shown in Fig. 2. Comparison of measurement data with the two simulations show that the loading profile of the MC-10 at INL is discrepant with the predicted scattering from a fully loaded or completely empty cask. Analysis of the data show that MCS muon radiography is sensitive (> 5σ) to the removing of several fuel bundles from a fully loaded cask. Additionally, the measurement indicated a sensitivity to the removal of a single fuel bundle at 2.3σ.

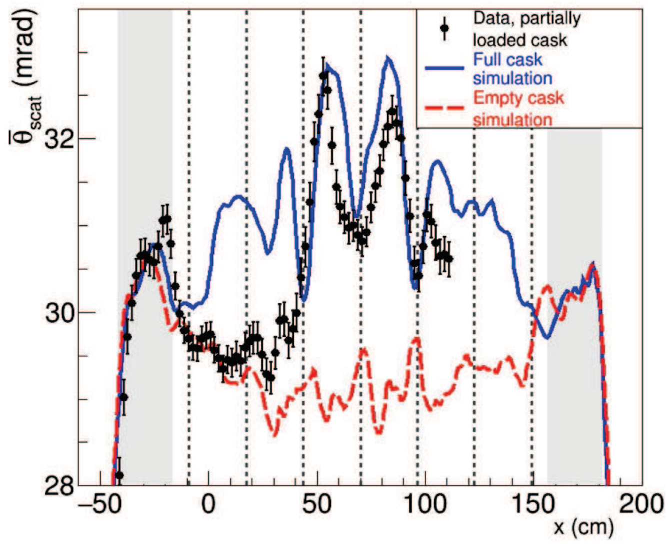

Fig. 2. The average scattering of muon tracks projected to a central plane in the MC-10. Vertical dotted lines indicate the boundaries of fuel bundle loading columns. The gray columns indicate where scattering is increased due to the curving of the steel shielding in the MC-10. The unusable data from the final 3 detector positions would have been used to fill in data points in the final two columns.

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