Forbush decrease of March 2012 detected using a commercially-available muon-tomography cargo scanner

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Abstract—**Muon-tomography (MT) scanners are built and operated to detect the smuggling of contraband in cargo. Simultaneously with cargo scanning, MT systems can be used to measure naturally occurring changes in cosmic radiation. Our commercially-available MT system detected the decrease in muon flux following the 6 March 2012 coronal mass ejection. We discuss the practical implications for cargo scanning posed by variation in background cosmic radiation.**

I. INTRODUCTION

MUON tomography (MT) makes use of background cosmic radiation to scan objects without the need for artificial radiation sources [1]. The basic idea is to track incoming muons, allow them to pass through an object, and then track the same muons leaving the detector. Changes in muon direction and momentum provide information about the object. One commercial application of MT is passive scanning of shipping containers to detect the smuggling of special nuclear material (SNM) and other contraband. Decision Sciences manufactures MT scanners large enough to scan a fully loaded tractor trailer (Fig. 1). Each scanner constantly monitors the background cosmic radiation field.

On 6 March 2012 the Sun launched a coronal mass ejection (CME) in the direction of Earth [2], [3]. The CME arrived at Earth on 8 March 2012, and produced a drop in background cosmic radiation, a phenomenon known as a Forbush decrease [4]. As a result, the number of muons tracked by our scanner decreased, with practical ramifications for MT cargo scanning.

II. METHODS

Our muon-tomography scanner is based on drift tubes. Each drift tube produces a voltage spike upon interaction with an ionizing particle. Modules are made out of many parallel tubes, together with readout electronics. Modules are stacked above each other in alternating orthogonal layers to form a supermodule. Muon direction and momentum can be estimated by coincidence detection of tube hits within a supermodule. By placing supermodules above and below the region of interest, changes in muon direction and momentum due to interaction with the cargo can be measured.

Muon data in this paper were recorded in March 2012 using the MT scanner installed at our Poway, CA lab (32°57'N, 117°1'W, altitude: 260m). While turned on, the system constantly monitors various parameters of interest, in particular the number of muons being tracked. During cargo scans details of each muon track are recorded.

Fig. 1. Loaded tractor trailer inside the muon tracker.

Throughout the period described here a loaded tractor trailer was parked in the scanner (Fig. 1). The shipping containers on the trailer were loaded with a mix of objects simulating high-atomic-number clutter typically found in transit. Simulated contraband was hidden in the containers and moved around at various times during this period.

To put our observations into context we examined a time series of Forbush decreases observed using the neutron monitor at Mt. Washington Observatory (44°18'N, 71°18′W, altitude 1900m), kindly provided by the NOAA National Geophysical Data Center [5]. Neutron detectors are more sensitive to coronal mass ejections than muon detectors [6], and will therefore show a larger decrease in rate than muon detectors. The neutron data thus provides an overestimate of the decrease expected from muon detectors.

III. RESULTS

We plotted muon track rates for the period from 1 March 2012 midnight UTC through 10 March 2012 05:00 UTC (Fig. 2). The baseline rate was about 0.665 muons per square centimeter per minute. The Forbush decrease, a drop in flux of about 5% from baseline, was clearly visible. Over the following days (not shown, due to lack of data) flux slowly returned to baseline.

To understand the historical frequency and magnitude of Forbush decreases, we examined the Mt. Washington data

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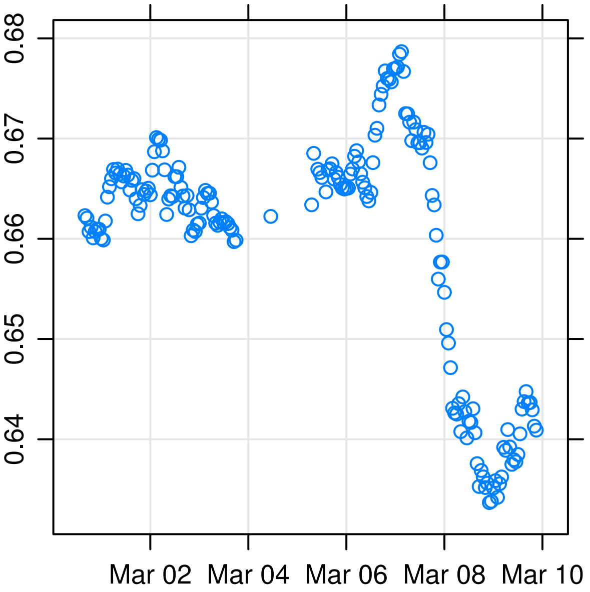

Fig. 2. Hourly average muon detection rates ($\mu/\mathrm{cm}^2/\mathrm{min}$) before and after the coronal mass ejection, recorded in Poway, CA. (Not corrected for barometric pressure, temperature, or scanner sensitivity.)

set. The number of decreases per year ranged from zero to fourteen (Fig. 3). The Mt. Washington data set only considers a decrease to be a Forbush decrease if the drop in neutron rate was at least 2.5%. We also plotted a histogram of the decrease magnitudes (Fig. 4).

Unfortunately Mt. Washington Observatory shut down their neutron monitor in 2006, so we don't know how big a decrease they would have seen. Because the neutron rate varies with altitude and with longitude it is difficult to make a direct comparison with another detector at a different location. Nevertheless, the neutron monitor in Mawson, Antarctica (67°36'S, 62°52'E, altitude: 30m) reported a 9% decrease in neutron rate on 9 March 2012 [7].

IV. DISCUSSION

Muon tomography scan times are a function of several parameters, including: the composition of the scene being scanned, the desired accuracy on the estimate of material density and atomic number Z, and the number of naturally occurring muons. Error bars on the estimate of density and Z depend on the number of tracked muons; the more muons, the lower the uncertainty.

For fixed scene and error bars, the time to scan a scene depends solely on the rate of naturally occurring muons. An $x\%$ decrease in muon flux produces a $\frac{1}{1-x}$ increase in scan times. Therefore a 5% decrease in muon flux, the magnitude we observed, would result in a 5.3% increase in average scan times. A scan which took one minute under normal circumstances would have taken an extra three seconds during the window of maximum decrease.

A hypothetical 20% decrease would increase scan times by 25%. Thus a scan which took one minute under normal circumstances would require an extra fifteen seconds.

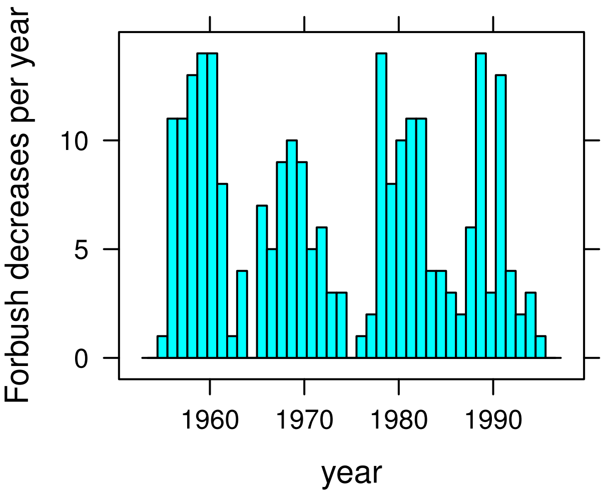

Fig. 3. Number of Forbush decreases per year detected by the neutron monitor at Mt. Washington Observatory, 1955-1995.

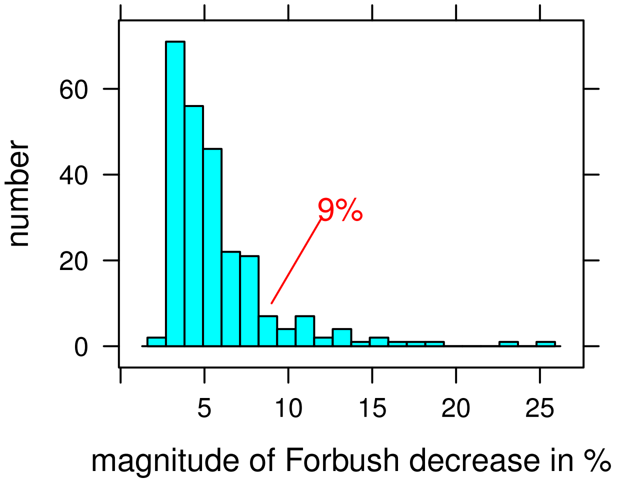

Fig. 4. Intensity of the Forbush decreases detected by the neutron monitor at Mt. Washington Observatory, 1955-1995. Note that neutron monitors show larger decreases than muon monitors, so this is an overestimate of the magnitudes one would see with a muon detector.

The 40-year Mt. Washington dataset has only 28 observations with a neutron decrease of at least 9%, out of a total of 250 observed Forbush decreases. This suggests a muon decrease of at least 5% will only happen once every year or two.

V. CONCLUSIONS

Commercial muon-tomography cargo scanners offer the ability to monitor naturally occurring background rates of cosmic radiation. Changes in the muon rate, for example due to a Forbush decrease, will affect cargo scan times. At the busiest ports, where high-throughput is required, these temporary increases in scan time must be accounted for so as to not interfere with the flow of commerce.

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