Radiation Detection and Dual-Energy X-Ray Imaging for Port Security

J. Pashby, S. Glenn, C. Divin, H. Martz Jr.

Lawrence Livermore National Laboratory

Introduction

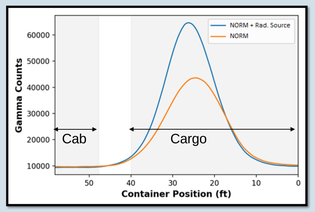
Millions of cargo containers are transported across the United States border annually. The characterization of these containers is important to national security by detecting and preventing the transport of radiological and nuclear materials into the homeland. In addition, being able to validate the contents of the container is vital to verifying the tariff laws are followed. The Department of Homeland Security seeks to tackle these issues. Due to the high traffic across the borders, it is impractical to manually inspect all cargos. Passive and active non-destructive inspection methods are used to secure U.S. ports.

Goals

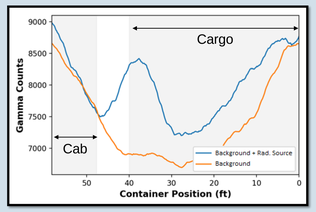
The objective of this study is to (1) analyze the radiation signature for threats within the cargo and (2) determine the material profile of the container.

Passive: Radiation Detection

Some cargo has a unique radiation "fingerprint", due to the presence of naturally occurring radioactive material (NORM). The orange line illustrates that natural radiation profile while the blue line indicates the radiation for the same cargo with an added radioactive source. By subtracting the two plots, we should be able to determine the relative strength of that added source.

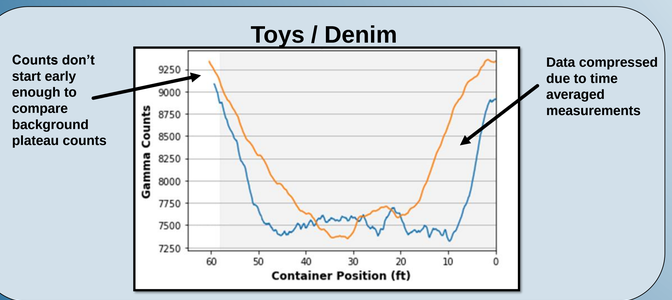


Cargo: Road Salt (KCl)

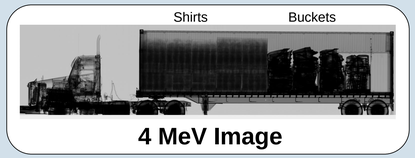


Cargo: Engines & Transmission

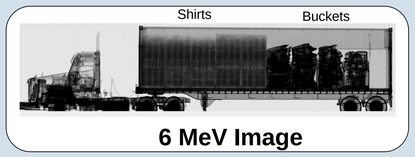
Unlike the previous above two examples, much of the data, e.g. shown below, was not reproducible. The plot below shows two runs with the same cargo and no source. Despite using the same cargo, the passive measured gamma rays deviate up to 25%. Therefore, this data is not useful for the analysis methods previously used and described above.



Active: Dual-Energy X-Ray Material Discrimination



4 MeV Image

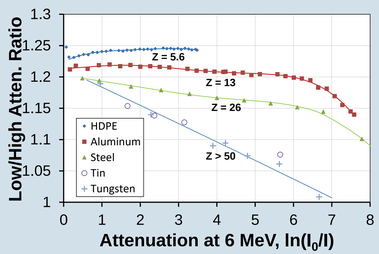


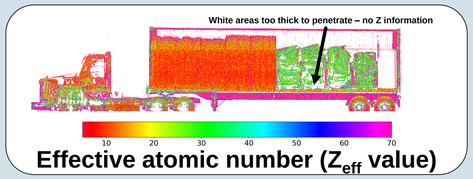
6 MeV Image

Convert the above images to attenuation (μx) values using the equation: $I = I_0\, e^{-\mu x}$

Calculate the low-to-high attenuation ratio. An algorithm was used to select the attenuation values from 0.4 - 7.5

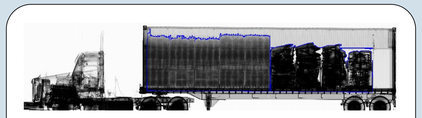
Effective Z_{eff} values were found using the calibration data shown below





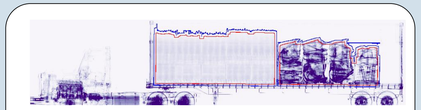
Effective atomic number (Z_{eff} value)

Thresholds were applied to segment the front and back cargo regions



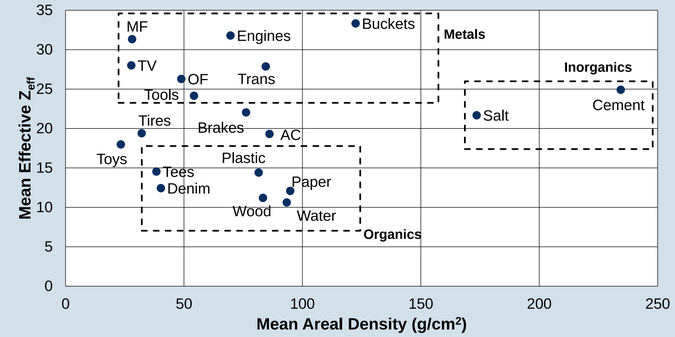
Cargo Segmentation

The attenuation image was used to find the areal density of the cargo

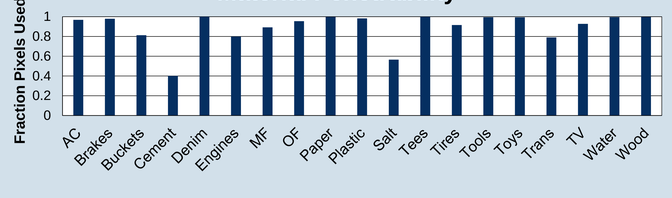


Areal Density

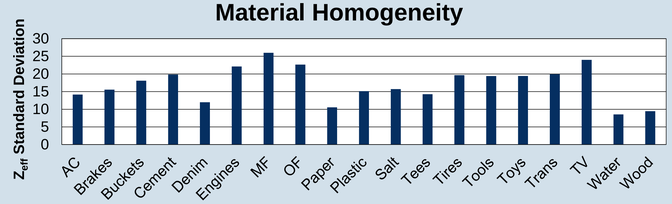
Active Results



Material Penetrability



Material Homogeneity



Contrast was observed between the metals and organics as shown in the scatter plot. The first bar graph illustrates the fraction of useful data, while the second shows the material's uniformity around that specific Z_{eff} value.

- As seen from the calibration data and the scatter plot, it is tough to differentiate among materials with Z_{eff} values < 15, including plastics and organics.
- It is difficult to determine the composition of cargos with high areal density (> 150 g/ cm^2) since X-rays do not penetrate well

Future Work

The next step in this study is to apply the dual-energy analysis to stream-of-commerce cargos and to match common cargos with their respective Z_{eff} values. Another possibility is to combine Z_{eff} with other metrics such as density and complexity to develop an automatic high Z_{eff} threat detection algorithm.

This research was performed under an appointment to the U.S. Department of Homeland Security (DHS) Domestic Nuclear Detection Office (DNDO) Summer Internship Program, administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the U.S. Department of Energy (DOE) and DHS at the Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. ORISE is managed by Oak Ridge Associated Universities (ORAU) under DOE contract number DE-AC05-06OR23100. This work has been supported by the US Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract/IAA HSHQDN-17-X-00003. This support does not constitute an express or implied endorsement on the part of the Government. All opinions expressed in this paper are the author's and do not necessarily reflect the policies and views of DHS, DOE, or ORAU/ORISE.

LLNL-POST-735791