A Comparison of Cargo X-Ray Attenuation as Measured by Top-Down versus Side-View Imaging Systems

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Abstract

The primary objective of this project was to determine whether or not the Passport top-down radiographs were less attenuating than Non-Intrusive Inspection (NII) side-view radiographs. First, X-ray images of steel plates were analyzed to obtain a curve of attenuation vs. steel thickness. Both high-resolution and low-resolution Passport radiographs were analyzed and compared. The high-resolution attenuation curve flattened out at around 35 cm, while the low-resolution curve flattened out at around 40 cm. These curves were applied to radiographs of CWMD* cargo constructed to be representative of U.S. imports. As expected, the equivalent steel thickness for CWMD cargos closely tracked bulk density. A general correlation was found between equivalent steel thicknesses from side-view and top-down radiographs of CWMD cargos. For all but one cargo, the top-down and side-view radiographs had similar equivalent steel thickness, thus attenuation.

Introduction

The Department of Homeland Security (DHS) has been tasked to ensure that the United States remains safe from the illicit transportation, development, or procurement of a radiological/nuclear (R/N) device or of Special Nuclear Materials. The Nuclear and Radiological Imaging Platform (NRIP) program within DHS/CWMD aims to develop and characterize the performance of an integrated R/N detection platform and to determine if it performs better than previous screening systems.

Previous studies have shown that threat detection and false alarm rates depend on cargo density and complexity. As part of the NRIP program, a CWMD team collected radiographs from a top-down X-ray inspection system developed by Passport Systems, Inc. and side-view radiographs from an NII system developed by Smiths Detection. This project investigated whether or not the Passport top-down radiographs are less attenuating than Non-Intrusive Inspection (NII) side-view radiographs.

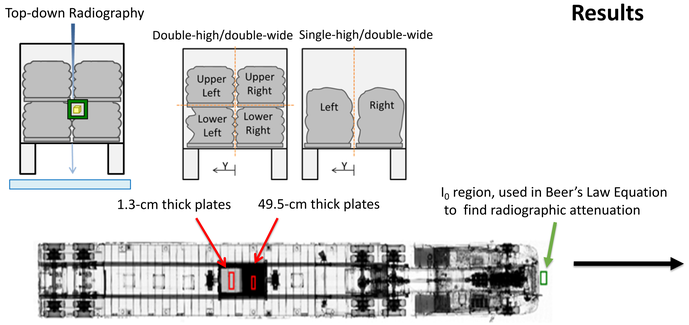
Objectives

- Determine how well the Passport 9-MeV X-ray imaging system penetrates steel
- Characterize CWMD cargos in terms of top-down equivalent steel thickness and compare with known cargo properties
- Determine whether or not the Passport top-down radiographs were less attenuating than a NII side-view radiograph

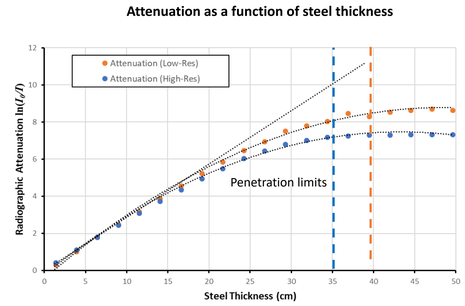
Method

- Developed code to analyze X-ray radiographs of steel plates with thicknesses between 1.3 and 50 cm
- Developed code to analyze X-ray radiographs of CWMD cargos, converting attenuation to equivalent steel thickness radiographs

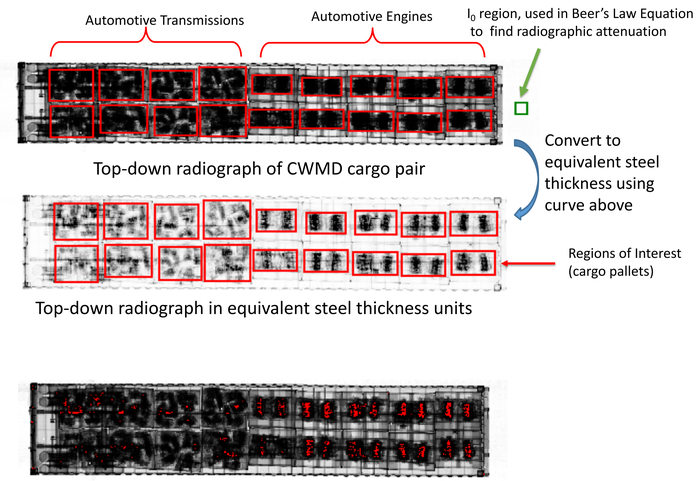
Results



Top-down radiograph (irradiance units) of steel plates

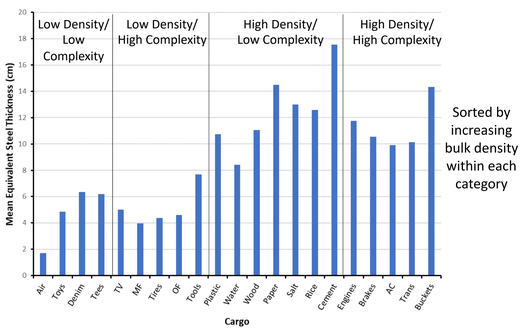


Beer's Law describes X-ray attenuation: $I = I_0 e^{-\mu L}$
Radiographic attenuation is defined as $\ln(I_0/I)$.



Top-down radiograph of CWMD cargo pair

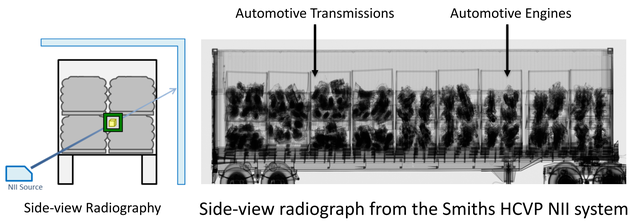
Top-down radiograph in equivalent steel thickness units



Sorted by increasing bulk density within each category

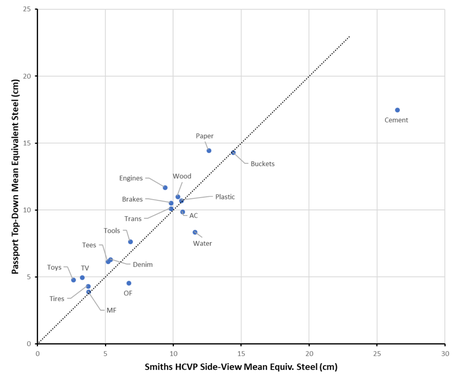
The mean equivalent steel thickness for each CWMD cargo was determined using the radiographic attenuation data.

Red areas added to the radiograph to indicate insufficient information (lack of penetration)



Side-view Radiography

Side-view radiograph from the Smiths HCVP NII system



The top-down Passport equivalent steel thicknesses are compared to those for the HCVP side-view NII system, and all but cement seem to have the same equivalent steel thickness.

Discussion

High- and low-resolution attenuation curves were derived from the top-down Passport radiographs of steel plates.

- High-res curve flattened out at around 35 cm
- Low-res curve flattened out at around 40 cm

The equivalent steel thickness for CWMD cargos bar graph shows higher density cargos have higher equivalent steel thicknesses, as expected.

A comparison of equivalent steel thicknesses from side-view vs top-down radiographs shows that they are correlated and similar for all cargos except cement.

Cement is an outlier due its height being small relative to its width. Cement is single-high and double-wide in order to meet weight constraints.

Conclusions

The low-res curve takes longer to flatten out, so there is more penetration of the steel plates than in the high-res subsystem.

The equivalent steel thickness for CWMD cargos bar graph shows that the densities and the equivalent steel thicknesses cargos of the cargos closely track, as expected.

The mean equivalent steel thicknesses of the cargos in side-view and top-down radiographs are similar. Performance difference should be expected for cement, and other dense, single-high cargos.

More work is needed to determine if top-down radiographs show complexities similar to side-view radiographs.

References

J. Pashby et. al, "Radiation Detection and Dual-Energy X-Ray Imaging for Port Security" (2017), LLNL-POST-735791.

N. Birrer et. al, "Characterizing Density and Complexity of Imported Cargos" (2017), LLNL-POST-735787.

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