Analysis of Radiographic Images to Improve Radiological/Nuclear Threat Detection in Commercial Cargo

and Experiences Working with DHS/CBP

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LABORATORY FOR NUCLEAR SECURITY AND POLICY

SWWC

1. Space: Nuclear/radiological detection (SNM and RDDs) in commercial cargo
2. Problems: High cost of effective systems, poor overlap with other CBP missions, high false alarm rates
3. Solution: Better utilization of general purpose radiography systems in conjunction with passive detection by leveraging existing radiography data to characterize cargo streams
4. Results: Data analysis shows very high probability of detection of large class of nuclear/radiological threats at false positive rates of $\sim$2%
5. DoD TRL: Analysis/technique at TRL 2, but utilizes TRL 8/9 hardware
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Current Approaches to Nuclear Cargo Security

- **Passive techniques**
  - Simple, low-cost
  - Specific to nuclear material

Image Source: NNSA, Nevada Site Office Photo Library

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  - Simple, low-cost
  - Specific to nuclear material
- **Bremsstrahlung radiography**
  - More expensive in both time and money
  - Much more general

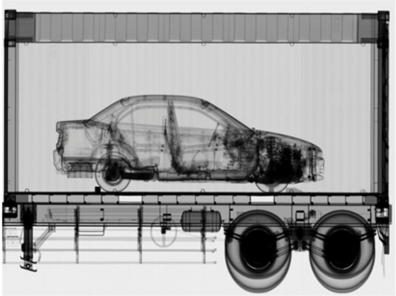


Image Source: Varian Medical Systems

Current Approaches to Nuclear Cargo Security

- **Passive techniques**
  - Simple, low-cost
  - Specific to nuclear material
- **Bremsstrahlung radiography**
  - More expensive in both time and money
  - Much more general
- **Active interrogation**
  - Typically specific to nuclear material, very high cost
  - Remains very much "on the drawing board"

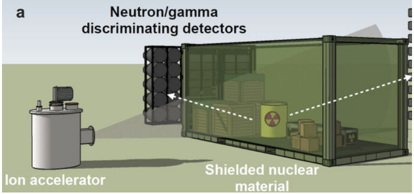


Image Source: P.B. Rose, *et al.*, Scientific Reports 6, 24388 (2016)

What is the ideal solution?

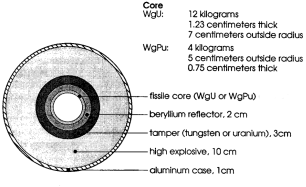
- **Speed:** Must process a container in $\lesssim$1 minute
- **Material sensitivity:** In some way, must be sensitive to nuclear and radiological material
- **Low false alarm rate:** False positives are a key complaint of port operators
- **Easy Operation:** System must be reliable, have a small footprint, and produce easy-to-understand alarms
- **Ideally overlaps with other missions:** Contraband/tax evasion detection, stowaways (both detection and dose safety)

Essential Approach

- This is the first analysis of a significant set of radiographic images of cargo containers to assess the frequency of objects appearing similar to shielded nuclear/radiological threats
- Utilizes a set of 120,000 images of 20 and 40 foot container images taken with a Rapiscan Eagle 6 MeV bremsstrahlung rail scanner at the Port of Rotterdam
- Essential approach:
  - Model the appearance of relevant nuclear/radiological threats in radiographs, characterized by their apparent size/areal density
  - Determine the frequency of objects of the relevant sizes/densities in the container stream (which amounts to a false alarm rate using this technique in isolation)

Consider the effective radius at thickness greater than 25 cm steel equivalent of a few example objects

- Bare U critical mass — $\sim$7.5 cm
- Assembled fission weapon — $\sim$12 cm
- U pit shielded with 3 cm Pb on all sides — $\sim$10 cm
- Pu pit fully shielded against neutron detection — $\gtrsim$40 cm



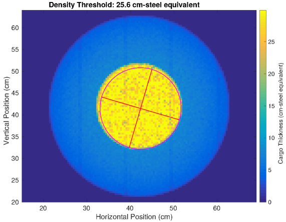
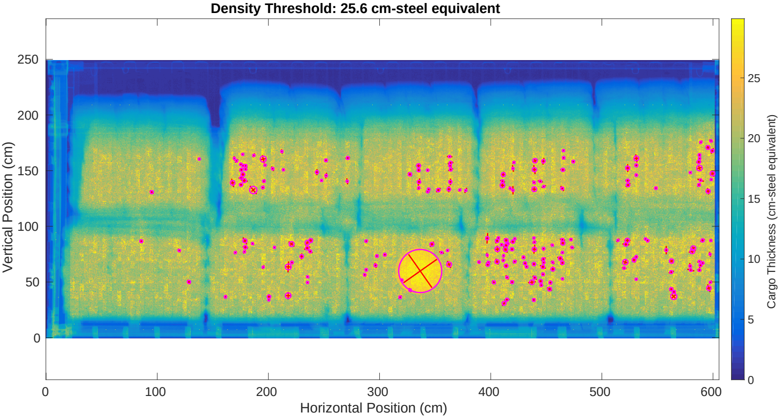
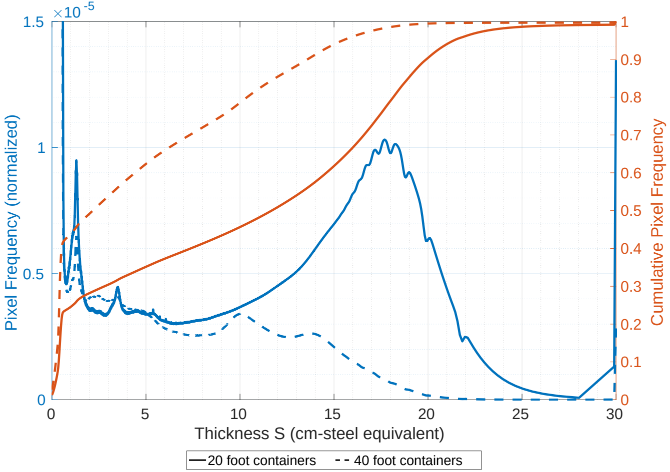


Image Source: Fetter, *et al.*, Science & Global Security 1, 225 (1990) (TOP)

Simulated Pu Device in a Container Image

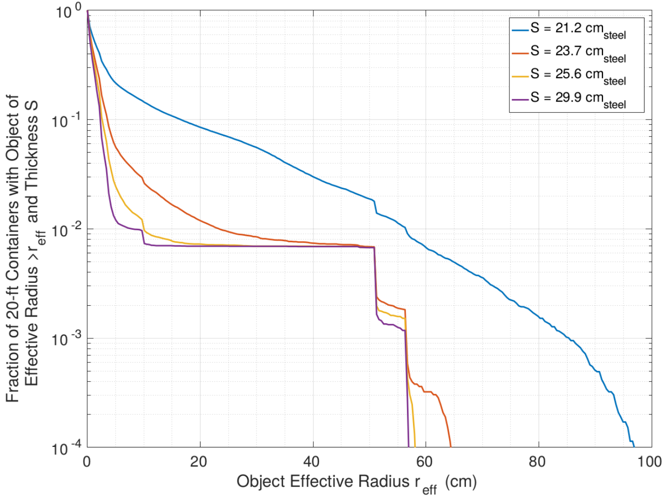


Density Distribution of Cargo



Characterization of cargo stream properties at fine scale

Largest Object (by Radius) per 20-ft Container



Effective false positive rate using this technique in isolation

Image Analysis Conclusions

- This analysis shows that objects that appear like nuclear weapons occur in $\lesssim$2% of containers, several percent for other threat classes
- There is much to be learned by digging into this data and there may be a significant opportunity to improve nuclear/radiological threat detection and inform other missions
- Analysis of other data streams is critical, along with fusion of multiple data sources for containers
- **CBP/DHS should seek to promote analyses of large data sets, and facilitate fusion of multiple sources. Much can be gained with little or no development of novel technology/hardware**

For More Information and Similar Approaches

Upcoming Publication of This Work

Henderson, B. S. “Analysis of the Frequency and Detectability of Objects Resembling Nuclear/Radiological Threats in Commercial Cargo”, **In press**. (*Science and Global Security*) (2018). Pre-print: `arXiv:1901.03753`.

Unless otherwise noted on the slide, all images in this presentation are from this work.

Related Machine-Learning Work Using Same Data for Other Customs/Security Goals

N. Jaccard, T. W. Rogers, and L. D. Griffin, in *2014 11th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS)* (2014) pp. 387–392.

Extra Slides

The 9/11 Commission Act Mandate (2007)

§1701. Container Scanning and Seals

IN GENERAL.—A container that was loaded on a vessel in a foreign port shall not enter the United States (either directly or via a foreign port) unless the container was scanned by nonintrusive imaging equipment and radiation detection equipment at a foreign port before it was loaded on a vessel.

Mandated for implementation in 2012, delayed 4 times since then, and no plan exists for meeting the next deadline in 2020

Current Procedure at US Ports

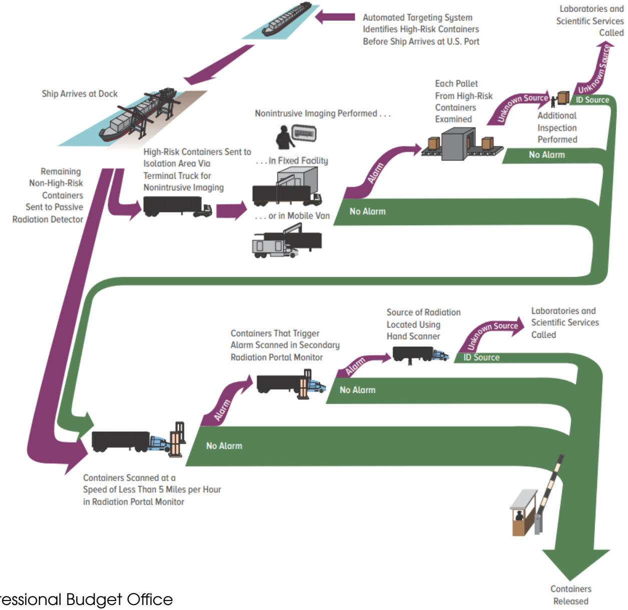


Image Source: Congressional Budget Office

Previous Data on Cargo Density

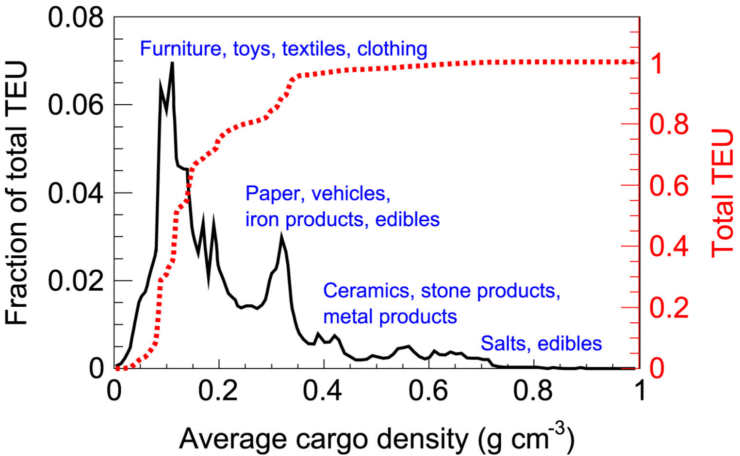


Image Source: Descalle, *et al. Analysis of Recent Manifests for Goods Imported through US Ports*, UCRL-TR-225708.

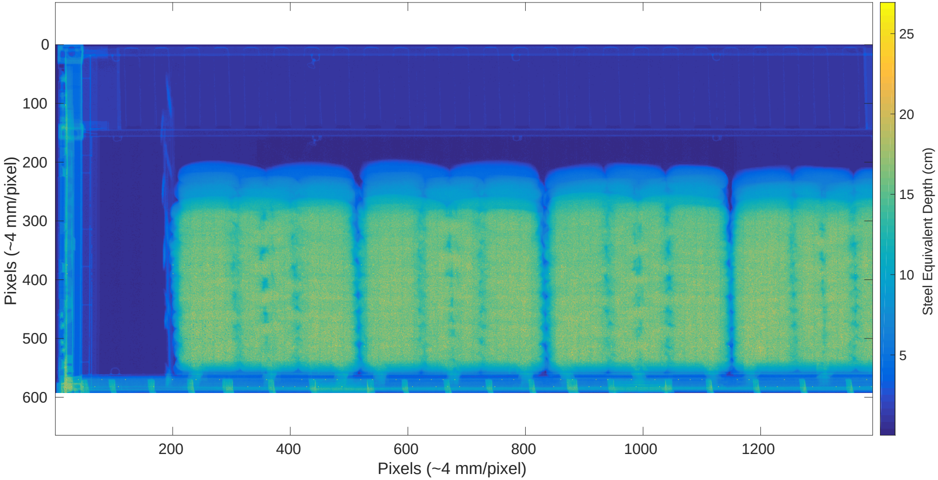
Image Data Set Parameters

- $\sim$120,000 images of 20 and 40 ft containers
- Dual energy 4 and 6 MeV bremsstrahlung beam
- 4×4 mm pixel size
- Penetration up to 30 cm steel equivalent
- 16-bit integrated transmittance measurement per pixel
- $\sim$20% empty containers

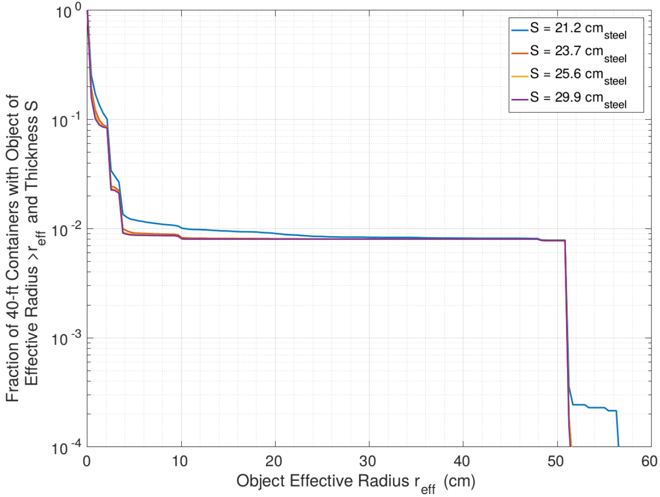
The Rapiscan R60 Rail Scanner in Rotterdam

Image Source: Rapiscan Systems

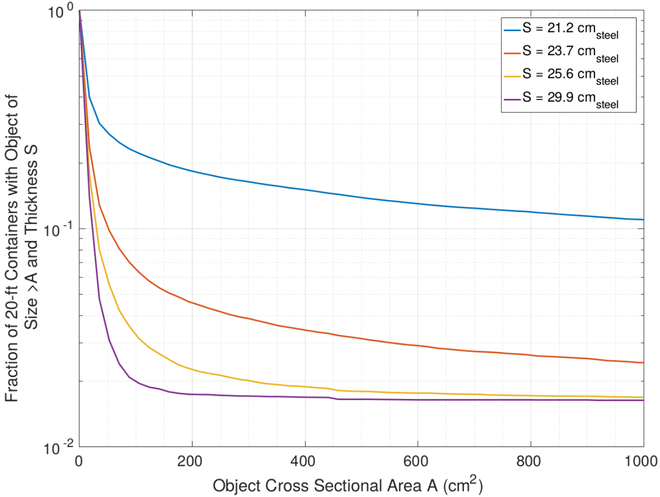
Typical Container Image



Largest Object (by Radius) per 40-ft Container



Largest Object (by Area) per 20-ft Container



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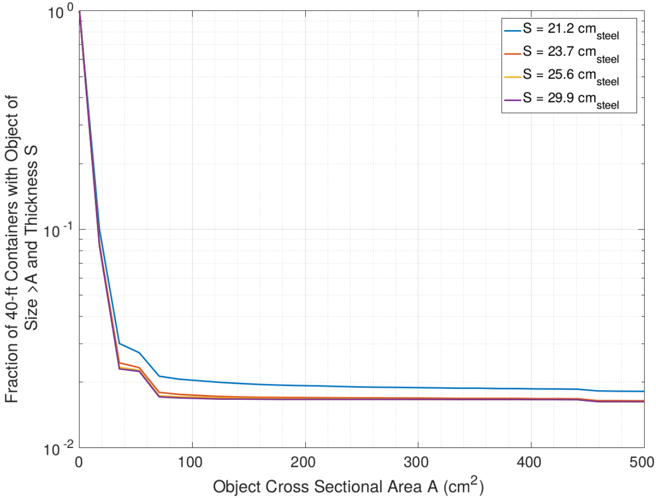
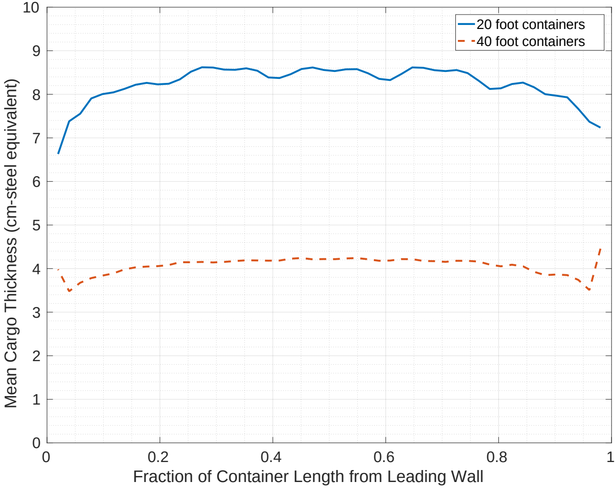
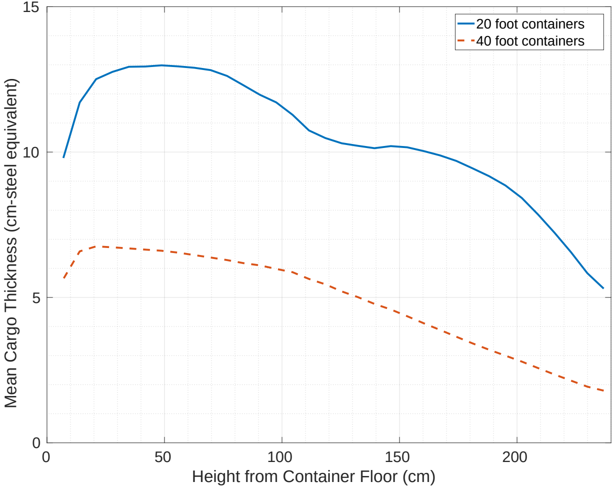


Mean Cargo Thickness Along Container Length



Mean Cargo Thickness Along Container Height



Data-Driven Single Pixel Uncertainty Estimate