SHIELD: Smuggled HEU Interdiction through Enhanced anaLysis and Detectors

Using Statistics to Set Detector Threshold Curves

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Summary

Customs examines hundreds of thousands of cargo containers entering the United States every day as a routine part of international trade. The SHIELD project endeavors to create a screening method to detect radioactive sources being smuggled into the US, which will minimize the cost of crate inspection as well as the risk presented by undetected nuclear devices. This project combines results from stochastic and deterministic models to simulate various sources and cargoes in order to generate synthetic data. This information is then used to develop an adaptive decision algorithm which works with next generation detectors to determine if radiological sources are present in cargo containers.

Background

Traditionally, to screen cargo, crates pass through a set of detectors that are set to trigger if a given count rate threshold is crossed. If this threshold is set too high, then smaller and better shielded nuclear sources will escape detection (a false negative). On the other hand, setting the threshold lower will detect these smaller sources, but will also increase the number of false positives received – ie containers with no source present that still trigger the threshold detector reading – leading to an increased cost of screening as this crate must either be hand searched or otherwise reprocessed.

SHIELD will make use of new detector materials and designs in conjunction with statistics based decision algorithms to minimize the number of such false positives (cost) and negatives (risk) as well as the computational time and resources needed to make such a decision. To develop the decision algorithm, predictions of detector readings are provided by MCNP and deterministic codes. This data is then processed.

Generation of Synthetic Data

Since events such as photon emission and interaction have been described by probabilities in the scientific community for decades, it is natural to use stochastic, or Monte Carlo, methods to model these phenomena. MCNP is a well-developed and supported Monte Carlo code that has been tailored for particle transport problems such as this.

We use MCNP to simulate radiation levels emitted from background sources as well as from cargo containers containing different material and source configurations. To date, we have filled these containers with a mixture of air, cotton, plastic and wood, although this list will be expanded further in the future. As a base case, we model some containers without an HEU source to obtain data about the background radiation. We also simulate the same cargo loads with the addition of a 1kg sphere of HEU that can be surrounded by lead shielding or bare.

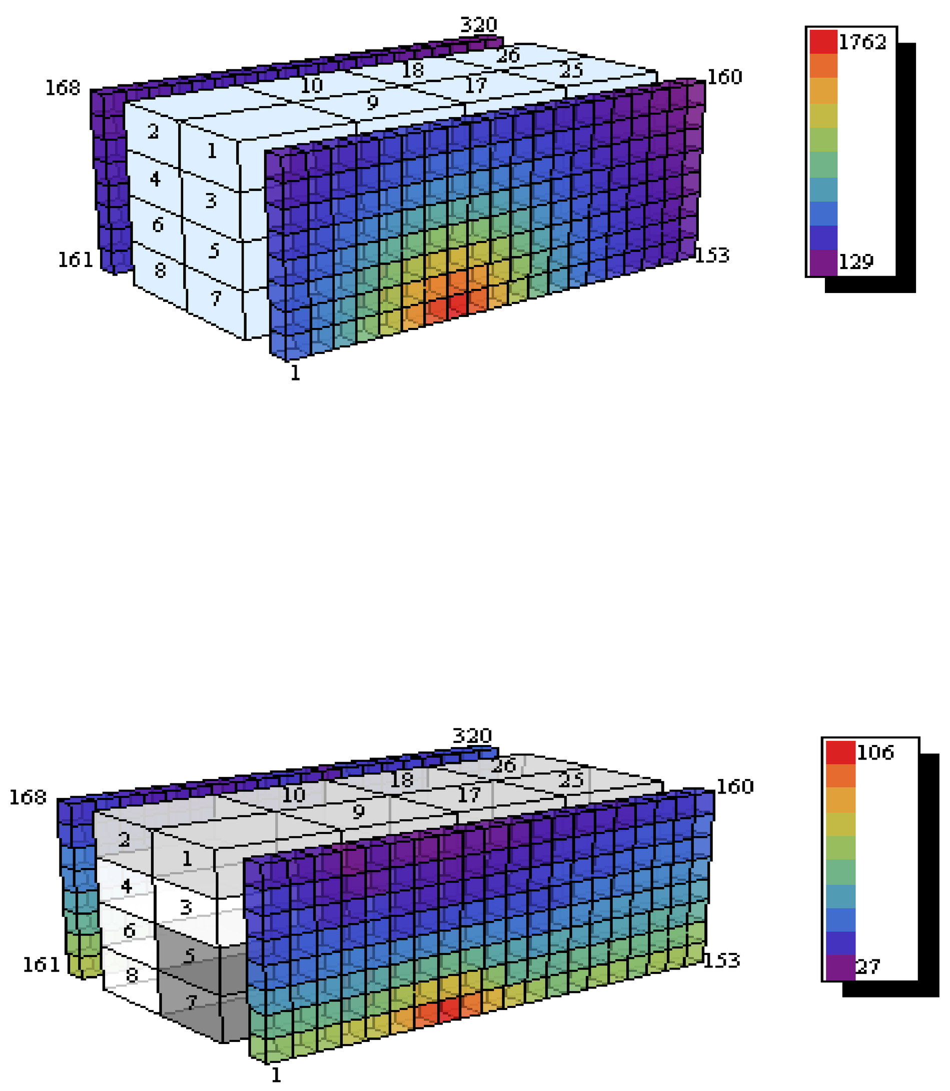

Fig.: *Examples of two container mock-ups consisting of 32 compartments filled with a variety of materials and simulated using MCNP.*

Top: an air filled container with HEU source

Bottom: cargo container filled with a variety of materials and an HEU source. The average density of these materials is depicted by the gray-scale volume rendering.

The color scale shows the 1MeV photon rate seen at the detectors.

(Simulation: S. Chirayath; Visualization: J Webster)

The figure above shows results of computations with two such scenarios out of a very large number that we will simulate to obtain realistic statistics of the performance of detection algorithms. Current work includes modeling many different source and loading scenarios for a more realistic representation of cargoes.

Utilizing Statistical Methods

Photons are produced discretely and independently from other photons, so they can be modeled by a Poisson process. Using the MCNP data as an average number of photons that detectors would see with a given source/load configuration, we can draw from a Poisson distribution to determine what the detectors might actually read if the same configuration passed through the detectors and readings were taken 1000 times. Due to attenuation by the materials filling the cargo container, maximal information content is provided by those detectors with maximum count numbers on either side of the container. Only considering these detectors mitigates false negatives introduced by selecting a fixed number and positioning scheme for the detectors.

The figures at right depict these sample readings generated by the above process. We would like to be able to draw a curve to use as a new threshold setting for the detectors that clearly separates containers with a source from background radiation (source-less containers). One can see that for an empty container, the bare and shielded HEU sources are easily distinguishable from the background radiation.

However, as seen in the close-up, the readings from the loaded container overlap with what we expect from background radiation. This intersection of data sets indicates that additional information is needed to distinguish between loaded cargo containers with sources and background radiation alone.

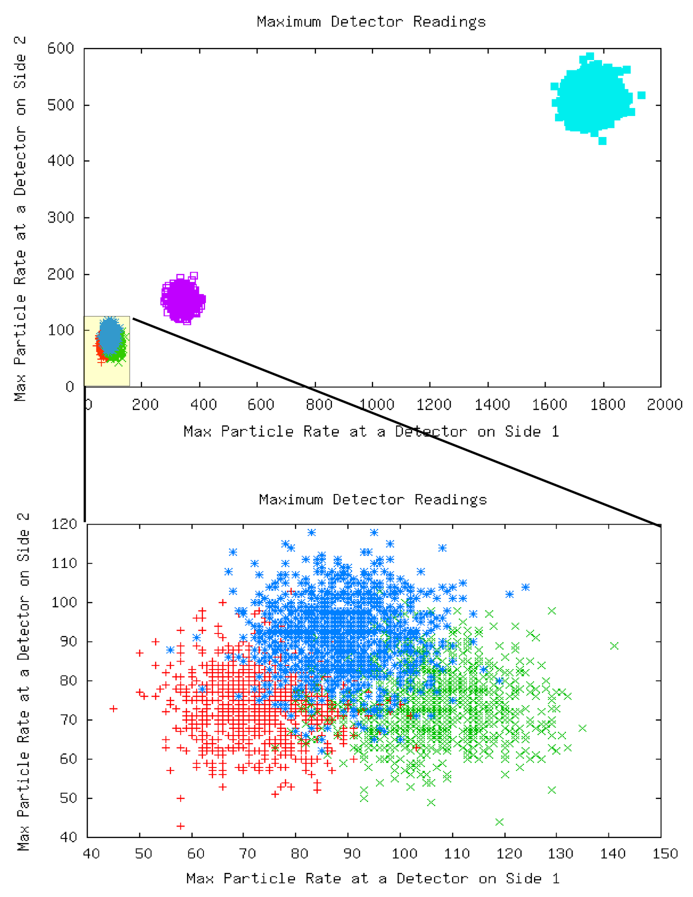

Fig.: *Top: Maximal particle rates at detectors on opposite sides of a cargo container are plotted.*

+ *- loaded container with no HEU*
x *- loaded container with HEU*
* *- empty container with no HEU*
□ *- empty container with lead shielded HEU*
■ *- empty container with HEU*

Bottom: Close Up of the Lower Left Corner of the Top Figure.

(Simulation & Visualization: J Webster)

Advantages of Shielding Background Radiation

For well-shielded or small sources, the radiation from background sources, such as concrete, provides a significant challenge in identifying appropriate threshold levels. To counter this effect, MCNP simulations were re-run with a 2 inch steel shield placed in between the cargo container/detector assembly and the concrete it rests on. This dramatically reduced the influence of background noise on the detectors, as seen in the figure below.

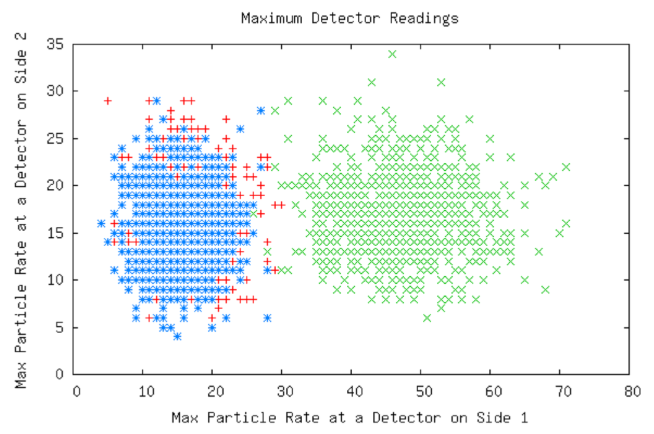

Fig.: *Steel Shield introduced to geometry and maximal particle rates at detectors on opposite sides plotted.*

As before:

+ *- loaded container with no HEU*
* *- empty container with no HEU*
x *- loaded container with HEU*

(Simulation & Visualization: J Webster)

With the introduction of the steel shield, there is a clear distinction between background radiation and the loaded container containing a source, which will allow us to set a threshold curve.

Future Work

- Determining the limits of sensitivity of this method through probabilistic analysis and numerical experiments
- Develop an adaptive algorithm which sets threshold curves for multiple detectors
- Testing the method on more realistic data sets such as the ones obtained from MCNP or PDT