SHIELD: Smuggled HEU Interdiction through Enhanced anaLysis and Detectors

Forward and inverse simulation capabilities for detection and imaging

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Summary

Ideally, detection of illicit radioactive materials at border crossings would be based on imaging of containers, cars, and people. Whether passive or active imaging is possible at all depends on the amount of information available from radiation detectors as well as the relationship between signal levels coming from the potential source to those from the background.

We describe our efforts in realistic modeling of radiation levels as well as approaches of passive imaging of containers.

Background

Detection and imaging methods can be developed for a variety of settings, but their ultimate success depends on their ability to operate on realistic data. Acquiring such data in real experiments is not only a costly enterprise, it is also limited by the availability of only the current generation of detectors. As a consequence, potential algorithms can only use what data is available today and can not explore ideas that would require a new generation of detectors.

The SHIELD project is, among other things, concerned with developing next generation detectors both based on newly available detector technology as well as input from what kind of data imaging algorithms may be able to use, or may require to deliver radically better results. In order to develop these new detector concepts, we need the ability to realistically predict radiation levels that can be expected from cargo containers or cars at border crossings.

We develop this capabilities through both stochastic and deterministic forward simulation of the radiative transfer equation. In parallel, we investigate which passive imaging algorithms could work if they had different kinds of data available, such as direction-of-flight information for each particle hitting a detector.

Stochastic simulations of cargo containers

One of the simplest ways to generate data about particles exiting a cargo container is to generate them at random locations inside a source region, using random directions of flight, and trace how they are scattered and absorbed. We can count them if they hit a detector somewhere. By considering a large number (billions) of particles, we can achieve realistic statistics on detector count rates.

The MCNP program is an advanced Monte Carlo code that implements such a stochastic approach. We use MCNP to simulate radiation levels from cargo containers with contents composed of compartments filled with air, cotton, plastic, wood, concrete, iron, or potash (e.g. fertilizer; the potassium in potash is partly radioactive itself). Containers also have 1kg

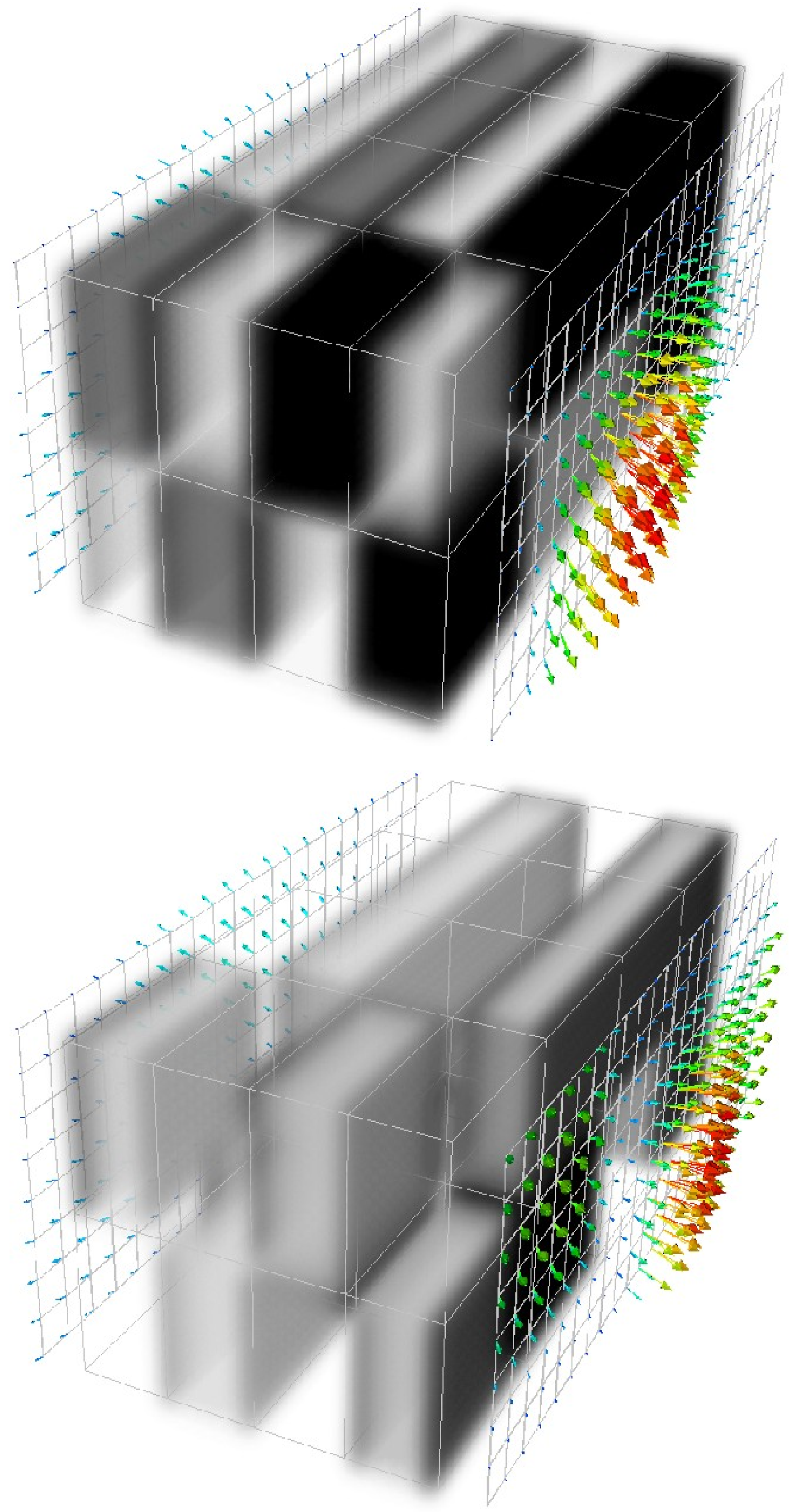

Fig.: *Examples of two container mock-ups consisting of 32 compartments filled with a variety of materials. The average density of the materials in these compartments is depicted by the gray-scale volume rendering. A 1kg HEU source is located in a compartment at the bottom of the container (second row, second compartment from the right).*

Colored arrows indicate the amount of radiation exiting containers on the two shown sides. The effect of the makeup of containers on the spatial variability of detectable radiation is clearly visible.

(Simulation: S. Chirayath; Visualization: J. Webster, W. Bangerth)

of HEU with or without lead shielding.

The figure shows results from 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 the incorporation of realistic background models as well as better binning in angular direction and energy groups.

Deterministic transport simulations

The use of MCNP has three significant drawbacks: (1) MCNP is export controlled and consequently can not be run on most of the compute resources available to us; (2) To get statistically accurate results, a very large number of particles has to be computed, resulting in long compute times for each model; (3) It is hard to gauge the correctness of results without a model to compare with.

We are therefore developing the Parallel Deterministic Transport (PDT) code, a deterministic finite element-based solver for the multigroup radiative transfer equations. PDT is massively parallel and runs on 1,000s of processors to achieve fast simulation times even for complex setups.

Our current focus is the generation of libraries of multigroup photon and neutron cross sections using SCALE. We are also adding first/last collision sources, and the ability to output fluxes in a format that would make it easy to interface with MCNP detector models.

Imaging approaches

One can ask whether we could image the source of radiation inside a cargo container if only we had detectors with angular sensitivity. Such detectors can be built (for example based on the principles of Compton cameras) and it may be that angular sensitivity provides enough information to passively image containers.

We are investigating such imaging approaches based on microlocal analysis. They allow the use of any particle (photon, neutron) and our trials show that they can determine the source of radiation even in situations where the (angularly uniform) background radiation is orders of magnitude larger than the (angularly directed) source radiation.

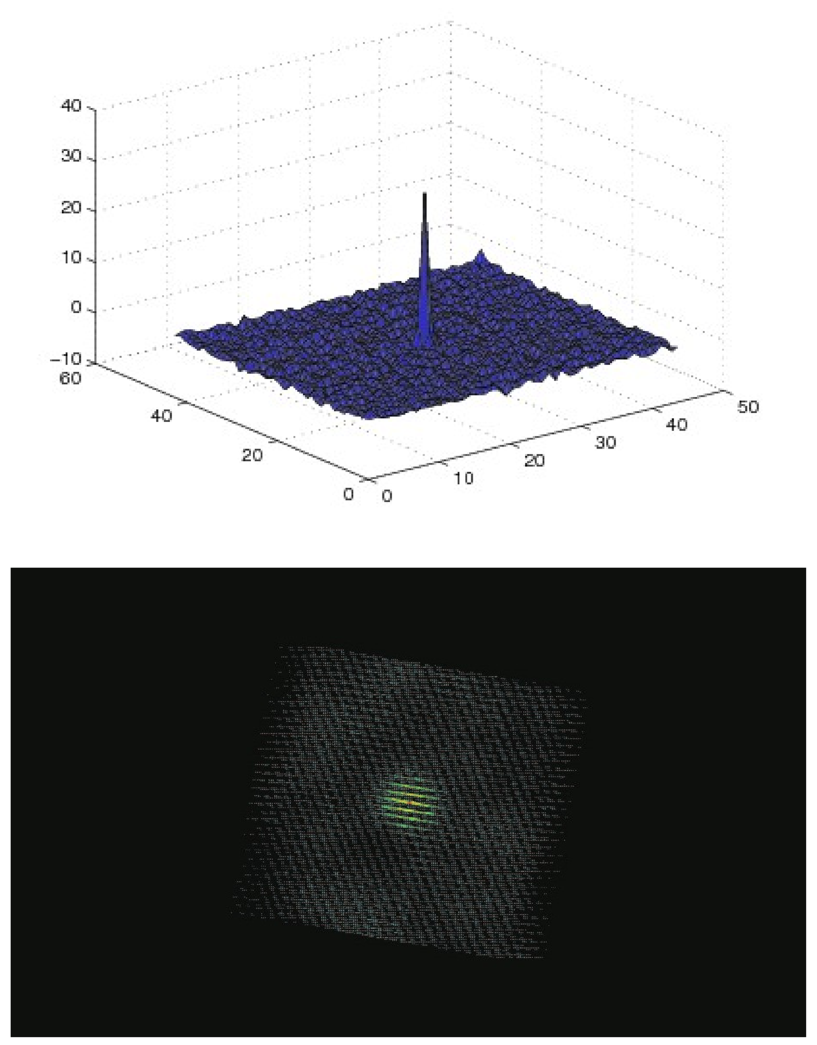

Fig.: *Two and three dimensional source strength reconstructions using detectors with angular sensitivity. The images show reconstructed source strengths for each pixel or voxel for a data that represents a point source plus random background.*

In the top picture, the overall signal to background ratio was 0.018 whereas detector bins in the direction of the source had a ratio of 1.25. For the bottom picture, the overall SNR is 0.0075. As can be seen, sources can be reconstructed even in cases of overwhelmingly large background.

(P. Kuchment, G. Kanschat)

Current research directions on imaging are:

- Determining the limits of sensitivity of these methods through probabilistic analysis and numerical experiments
- Testing the methods on realistic data sets such as the ones obtained from MCNP or PDT
- Developing faster algorithms and adjusting them to realistic geometries such as those available from Compton cameras.