Detecting Small Low Emission Radiating Sources

M. Allmaras, W. Charlton, D. Darrow, Y. Hristova, G. Kanschat, P. Kuchment, J. Ragusa, G. Spence
Mathematics and Nuclear Engineering Departments, Texas A&M University

**Issues**
- Manual searches expensive and time-consuming
- Low emission from source, typically within a much larger background

**Idea**
- Prevent smuggling of highly enriched nuclear material through border
- Can we use passive detector gates to classify containers into suspicious/non-suspicious?
- Only search suspicious freight manually

**Goal**
- SPECT (Single photon emission computer tomography) imaging
  - Low emission from source, typically within a much larger background
  - Severe time constraints for detection
  - Manual searches expensive and time-consuming

**Problem**
- Small sources are geometrically singular, can this be used in detection?
  - Direction insensitive measurements are not sufficient for detection as they cannot distinguish between source and background particles.

**Assumptions**
- Source is geometrically small compared to detection region
- Background radiation is random
- Source and background particles are indistinguishable
- Some directional information about incoming particles is available

**Backprojection**
- Assume we know the number of particles \( g(\omega, s) \) that were detected at position \( s \) coming from direction \( \omega \). Then
  \[
  T^\# g(x) = \oint_{|\omega| = 1} g(\omega, x \cdot \omega) \, d\omega
  \]
- At point \( x \), \( \tau \) integrates over all lines passing through \( x \)
- Reveals areas of unusually high concentration of lines
- Allows estimation of confidence of detection

**Setting**
- Detect \( \gamma \)-photons, neutrons exiting cargo
- Sources are expected to be weak and shielded
- Background radiation may be orders of magnitude stronger than source (SNR \( \approx \)0.1%)

**References**
- Detecting small low emission radiating sources, M. Allmaras, D. Darrow, Y. Hristova, G. Kanschat, P. Kuchment (preprint, arXiv:1012.3373v1)

**Compton measurements**
- In practice, detectors cannot determine the direction a particle came from without discarding most of the signal through collimation.
- Direction data is therefore not obtainable for low-emission sources with short count times.
- However, Compton camera detectors can determine a cone of possible directions for each detected particle without collimation.

**2D results (using a detector array gate)**
- 2D backprojection from Compton measurements along three sides
- \( > 91.97\% \)
- After subtraction of local means
- After thresholding detection confidence \( > 91.97\% \)

**3D results**
- 3D backprojection from Compton measurements along eight sides of a cube
- \( > 99.99\% \)
- After subtraction of local means
- After thresholding detection confidence \( > 99.99\% \)

**3D backprojection from x-ray measurements along eight sides of a cube**
- \( > 91.97\% \)
- After subtraction of local means
- After thresholding detection confidence \( > 91.97\% \)

**Backprojection**
- \( T^\# \) integrates over all lines passing through \( x \)
- \( g(\omega, x \cdot \omega) \) is attenuated Radon transform
- Lines are parametrized by normal \( \omega \) and signed distance \( s \) to origin

**SPECT (Single photon emission computer tomography) imaging**
- Let \( f \) be unknown source distribution, \( \mu \) attenuation
- Measurements are integrals over lines \( L \):
  \[
  T^\# f(L) = \int_L f(x) e^{-\int_x^\omega \mu(y) \, dy} \, dx
  \]
- \( T^\# \) is attenuated Radon transform
- Lines are parametrized by normal \( \omega \) and signed distance \( s \) to origin

**Problem**
- Collimation is required, which would eliminate the weak signal
- Reconstruction schemes cannot handle strong noise in signal

**2D backprojection from x-ray measurements along three detector arrays**
- \( > 91.97\% \)
- 2D backprojection from x-ray measurements along 3 detector arrays
- \( > 91.97\% \)
- 10^6 background particles, SNR \( \approx \)0.1%