Detection Technique Providing Noninvasive Radioisotope Depth Mapping

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A novel technique for localizing radioactive sources using photopeak counts from uncollimated detectors

Summary of technique

Calculation:
- Precompute: detector response as function of source position and medium – build efficiency matrix
- Field analysis: very fast comparison of detector array response with efficiency matrix

Measurements:
- detector count rate from 3 or more positions
- uncollimated = high efficiency
- all can be on single side of the source

Results:
- Localization: Source depth and lateral position within medium e.g. depth of source in soil or distance from array
- Activity: Extract source activity from position, efficiency, and detector readings

Implications: Modeled and experimentally validated with detectors all on one side of source:
- noninvasive measurements
- possibility for standoff detection

Application examples:
1. Where surrounding or penetrating material with detectors not practical, e.g. soil remediation
2. To extract extra information from current detector systems, e.g. to speed secondary inspection from portal monitoring

Abstract

A technique has been developed to extract position and activity information on radioactive sources. No prior knowledge of source activity or position information is needed, only prior information on the attenuating medium and the gamma-ray energy or energies of interest.

Purpose

The original problem addressed with the technique is environmental remediation of contaminated soils, to extract depth information from detector surveys of large area sites as they are already being conducted.

The technique is being investigated for application to extracting position information with portal monitors to speed secondary inspection, **which will allow lower thresholds**. Diffuse sources, multi-source resolution, lead shielding, varied shielding, and other variables are being investigated. Soils are presented here.

For environmental remediation of large area contaminated sites, 2-D surface source mapping is typically performed [1] by moving detectors across the surface. More invasive measures can be used to determine the depth of the contamination in the soils and concrete. Soil/concrete is then removed and the area remapped to confirm that the contamination was removed, or the process is repeated to remove deeper sources.

The same information that is already gathered in the 2-D surface mapping might be used to develop depth maps of the radioisotopes without resorting to active methods or excavation. This can reduce the amount of material removed and disposed of, greatly speeding the process and the cost of remediation.

Methods

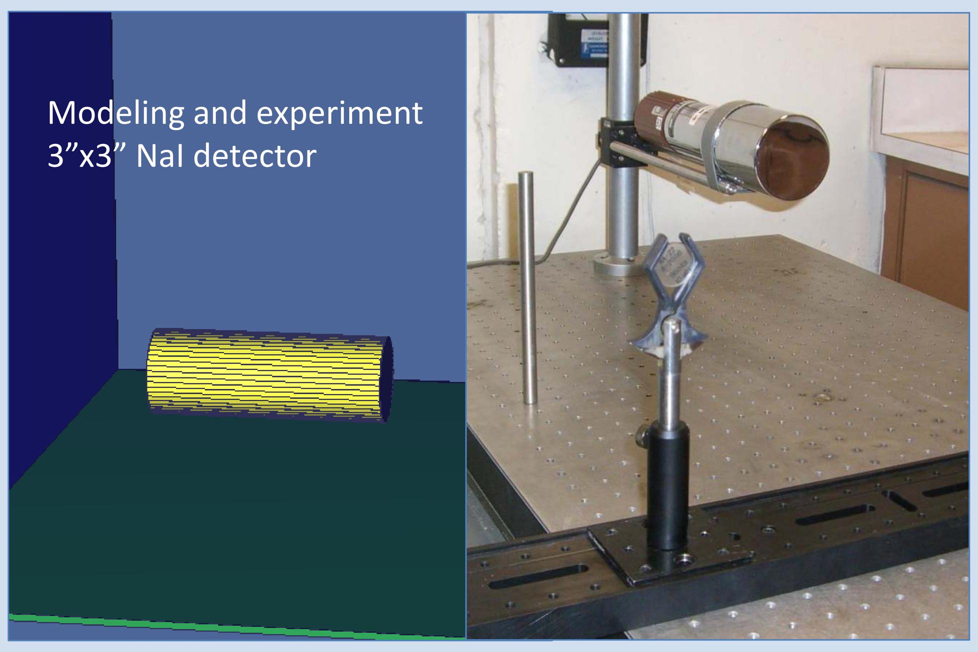
Precomputing - To construct efficiency matrix:

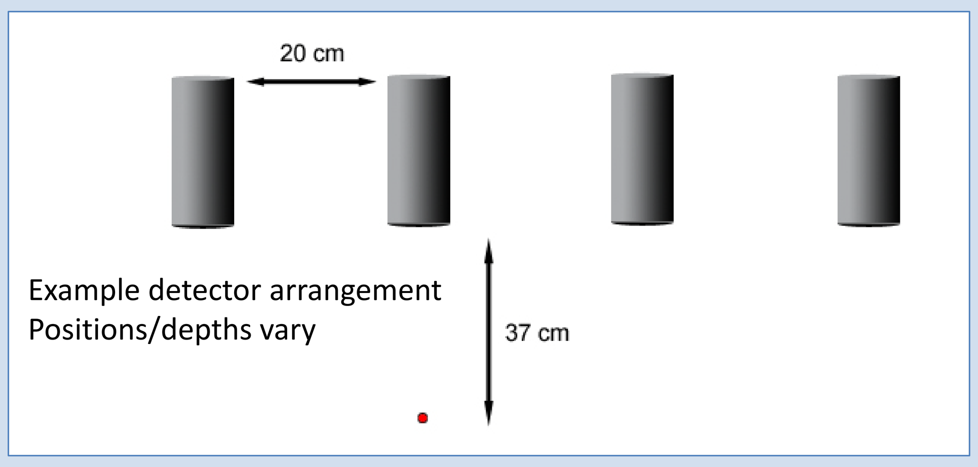
•Simulations performed using MCNPX [2] to find full-peak efficiency of 3”x3” NaI detectors as a function of source position, and with different attenuating media.
•The modeled detector efficiency as a function of position recorded with 1 cm resolution.
•10,000,000 photons emitted isotropically from each source position to determine efficiency.
•To keep error down, at least 100 photons are required per position used, a 10^{-5} efficiency.
•Sources used: ^{137}Cs, ^{60}Co, and also ^{22}Na
  -to allow subsequent experimental validation
  -to have some overlap with isotopes from known contamination sites: ^{137}Cs, ^{60}Co, and ^{90}Sr [3].
•Efficiencies as a function of position/source/and attenuation material were recorded in efficiency matrices, referenced below to compare with detector array measurements.

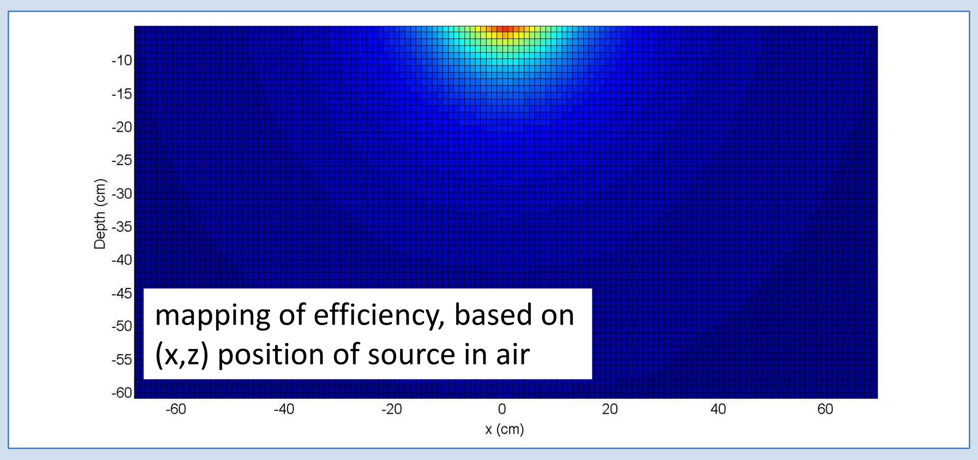
Field measurements and comparison:

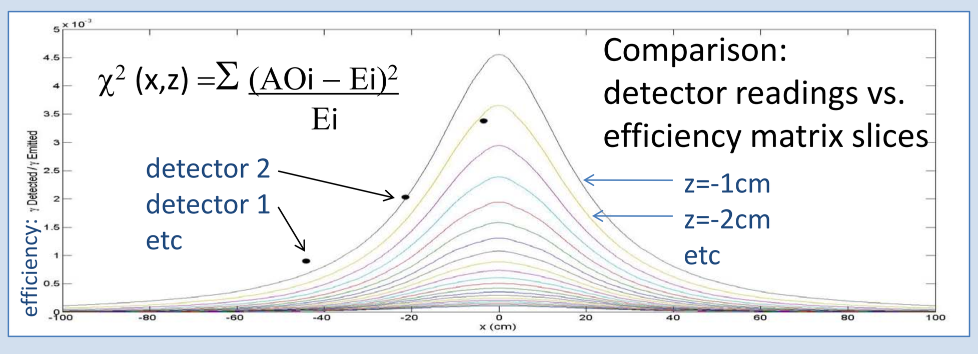
•Detectors at 3 or 4 positions gathered full energy photons.
•The rates and spacing between the detectors were compared for different source positions to the expected response grid.
•The difference in the measured ratio and the expected ratio for each position was subsequently mapped as a χ^2 fit value, with **the minimum χ^2 indicating the source position**.
•The fit used a common free scaling parameter, the source strength does not need to be known.
•The scaling parameter can then be used to extract the source strength.

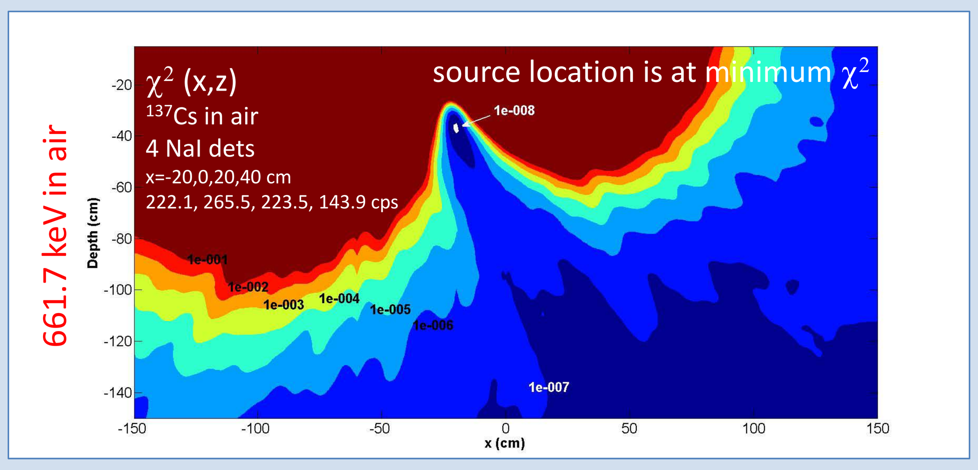
In Air



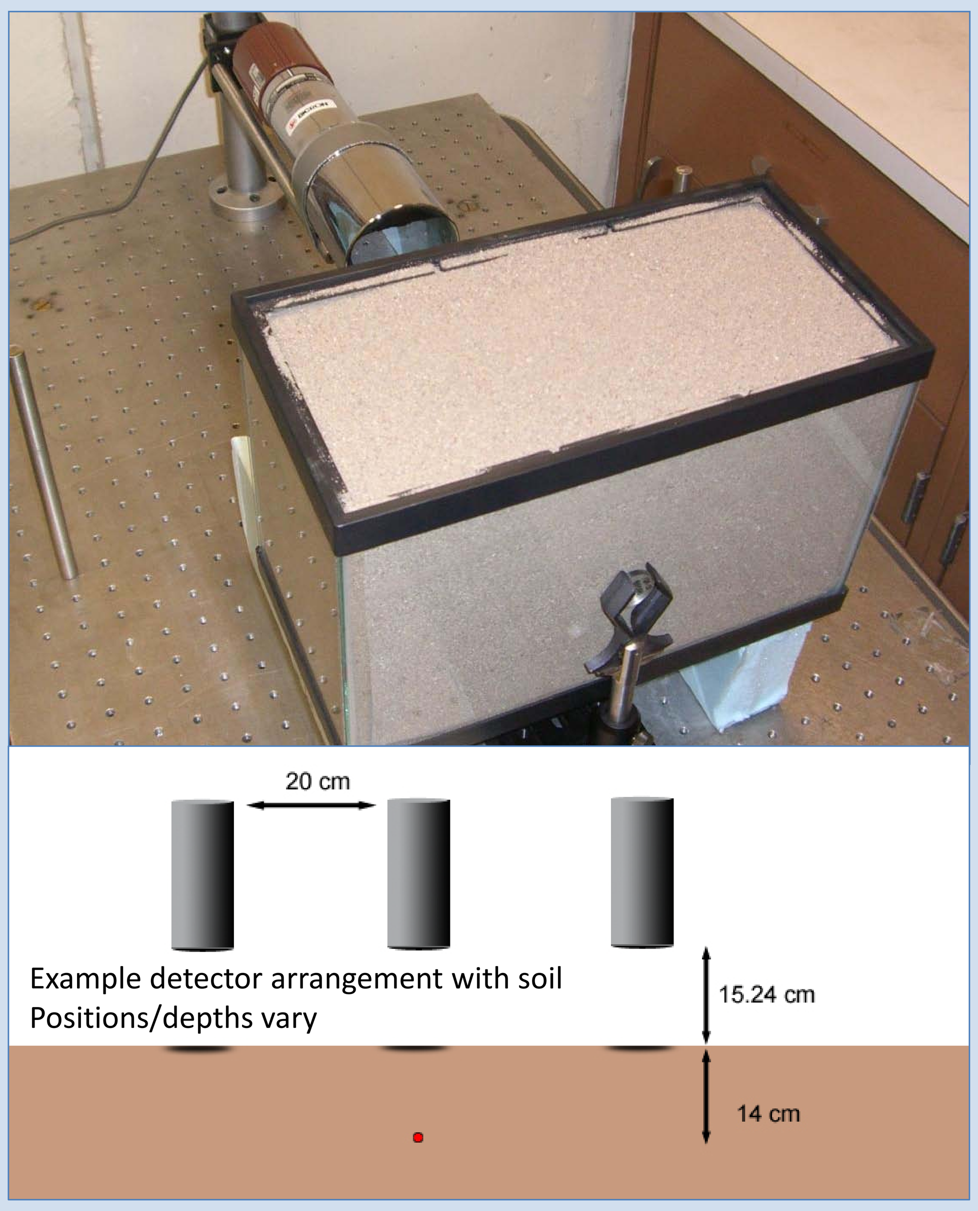


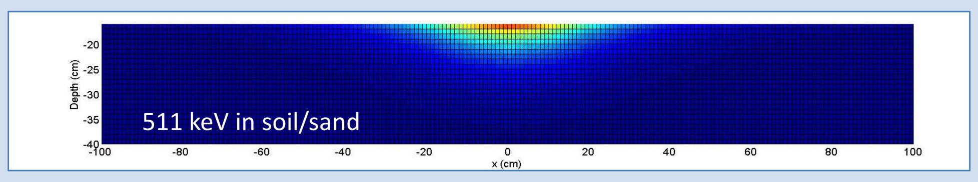




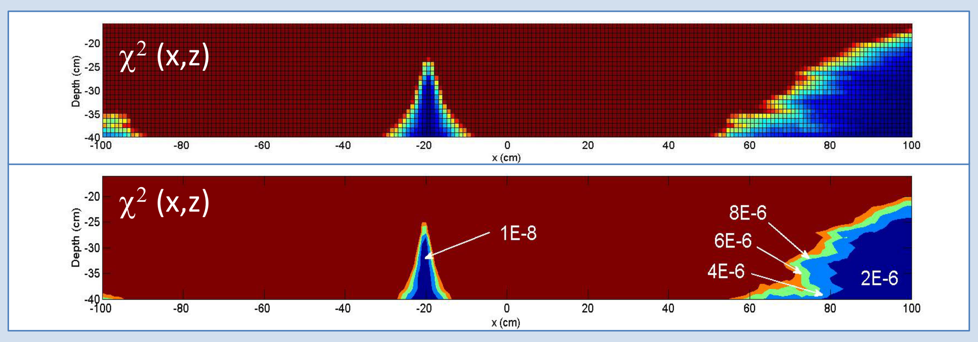


In Soil

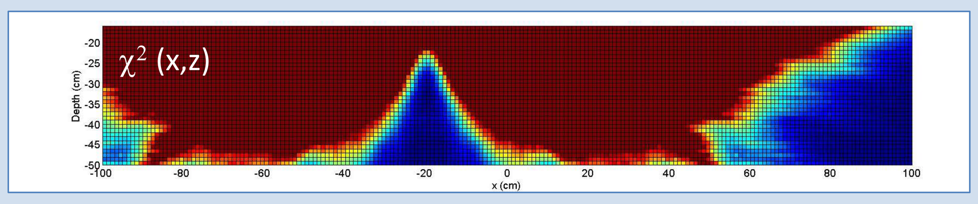




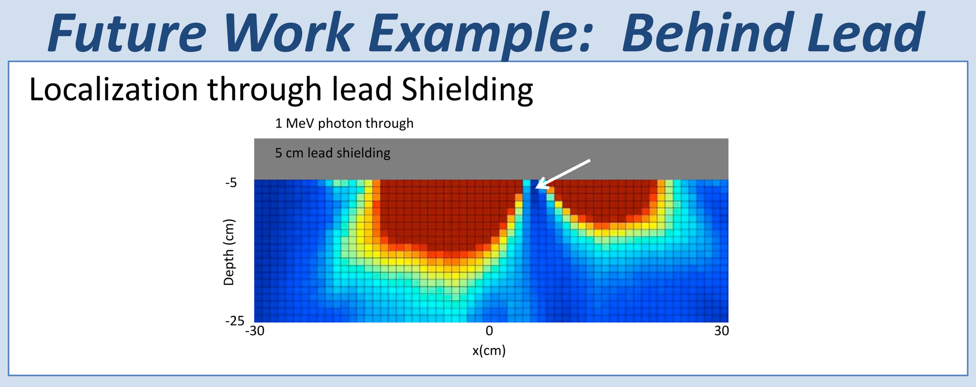
511 keV in sand



1274.5 keV in sand



Future Work Example: Behind Lead



Results

•Simulated and experimental measurements were performed for validation and are presented graphically (χ^2 mappings at different (x,z) positions) and in tables.
•Results are very close to the true source position, with the farthest still closer than even half a single detector size.
•The χ^2 values increase rapidly away from the true source position, indicating a probability sharply peaked at the true source position.

Discussion

Time required:

Precomputing:
Detector response mappings are developed for specific source energies and attenuating materials using Monte Carlo methods. With 10^7 photons tested per location, an efficiency map may take a day.

Field processing:
Field analysis – fitting detector rates to the efficiency map – is performed in a fraction of a second. In real applications, the detector response to common sources and materials may be mapped beforehand and quickly applied in the field.

REFERENCES
[1] ITRC (Interstate Technology Regulatory Council) 2006. *Real-Time Measurements of Radionuclides in Soil: Technology and Case Studies. RAD-4. Washington,* D.C.: ITRC Real-Time Radionuclide Team.
www.itrcweb.org
[2] Pelowitz, D.B., April 2008. MCNPX user’s manual version 2.6, Los Alamos National Laboratory report LACP-07-1473.
[3] Reistad O, Dowdall M, Selnaes ØG, Standring WJ, Hustveit S, Steenhuisen F, Sørlie A, J Environ Radioact. 2008 Jul; 99(7):1045-55. *On-site radioactive soil contamination at the Andreeva Bay shore technical base, Northwest Russia.*

Results

Results for experiments in air

	Actual			Extracted			Difference	
Energy (MeV)	x (cm)	depth (cm)	activity (Bq)	x (cm)	depth (cm)	activity (Bq)	Δ activity %	Δ position cm, %
0.662	-30	50.5	187,353 ±5%	-29	49	185,483	0.1%	1.8, 3%
0.662	-20	36.5	232,325 ±5%	-20	37	234,809	1%	0.5, 1%
0.511	-30	33	142,805 ±5%	-27	32	148,585	4%	3.2, 7%
1.274	-30	33	142,805 ±5%	-28	31	123,891	13%	2.8, 6%

Results for experiments in sand

	Actual			Extracted			Difference	
Energy (MeV)	x (cm)	depth (cm)	activity (Bq)	x (cm)	depth (cm)	activity (Bq)	Δ activity %	Δ position cm, %
0.511	-20	30	142,805 ±5%	-20	31	151,050	5.8%	1, 3%
1.274	-20	30	142,805 ±5%	-20	33	186,362	30.5%	3, 8%

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