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.

Results

### Results for experiments in air

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Actual depth (cm)</th>
<th>Actual activity (Bq)</th>
<th>Extracted depth (cm)</th>
<th>Extracted activity (Bq)</th>
<th>Difference depth</th>
<th>Activity</th>
<th>Activity Error %</th>
<th>Activity Position Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.662</td>
<td>30</td>
<td>203,353</td>
<td>29</td>
<td>185,483</td>
<td>1</td>
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### Results for experiments in sand

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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: 137Cs, 60Co, and also 99mTc
- To have some overlap with isotopes from known contamination sites: 137Cs, 60Co, and 99mTc [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 χ² fit value, with the minimum χ² 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.

Discussion

Time required:
- Precomputing: Detector response maps are developed for specific source energies and attenuating materials using Monte Carlo methods.
- For 10³ 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.

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