Use of Non-Contact and Remote Sensing Methods to Detect Radionuclide Bearing Compounds

Graham Walford, Ph.D
Research Professor, University of Tennessee

Sean Branney, Ph.D
Savannah River National Laboratory
Abstract:

The difficulties of sensing radionuclide bearing deposits at a distance are well known. Critical distances of continuing interest range meters to kilometers. Detection needs range from source material of the order of a few microns thickness deposited from plumes (or suspended in plumes) to shielded or buried objects. For such ranges of needs, it is realistic to expect improvement in probability of detection – not certainty.

However, opportunities offered in remote sensing development efforts allow improved personnel protection by identifying areas of surface or air borne contamination before those personnel become exposed. Optimal Performance Development (OPD) is a multi-step process:

In the first step we examine optimal developments with gamma ray detection systems. In one of these systems, careful configuration of the detector-shield configuration also allows the gamma ray system to exhibit neutron sensitivity. This provides a response in addition to and separately distinguishable from the gamma ray energy spectrum.

In the second and in subsequent steps we use “optical” non-radionuclide bearing technologies. One of these is Laser Induced Breakdown Spectroscopy (LIBS). The resulting optical analysis of light emitted when a laser beam impacts a surface provides detailed surface materials analysis. For example, measurement, enrichment and analysis of uranium content of surface contamination can be made at a distance of several meters to 100 microgram/cm$^2$ in two seconds or less. Also, such a system can identify $^{99}$Tc if present in the same two second time frame. The full atomic number range of materials analysis is available from that laser impact analysis. This is a single point analysis.

To provide area analysis, infrared hyper spectral imaging cameras are available to provide object/area image. Near real time analysis infrared spectroscopic analysis is possible on a per pixel basis. Therefore unique molecules can be identified in an image even where the net plume or deposit thickness is a few wavelengths thick. Such systems enable the sensing of accompanying compounds that may not be radionuclide bearing but indicators of illicit or other operations. Such sensing is possible to several kilometers. Examples are presented.
The use of digitized optical and infrared imaging to sense surface contamination is discussed. None of these techniques replace nuclear based detectors but enable the “steering” of gamma ray and neutron detectors toward targets of significance.
Use of Non-Contact and Remote Sensing Methods to Detect Radionuclide Bearing Compounds

Graham V. Walford\textsuperscript{1,2)}, Debbie B. Browning\textsuperscript{2)}, John E. Patterson\textsuperscript{2,1)}, Sean J. Branney\textsuperscript{3)}, David W Roberts\textsuperscript{3)}, Raymond K. Maynard\textsuperscript{3)} Laurence F. Miller\textsuperscript{1)}, Christoph C. Borel\textsuperscript{4)}, David F. Bunker\textsuperscript{4)}, John N. Dewes\textsuperscript{3)}

1. University of Tennessee,  
2. Strata-G, LLC  
3. Savannah River National Laboratory  
4. Wright Patterson Air Force Base (Air Force Institute of Technology)

The Nuclear and Supporting Measurement Scene

- Cost of equipment
- Current nuclear detection capability profile
- Close Range to Remote
- Neutron
- Hyper Spectral Imaging
  - Other
    - LIBS
    - Optical
    - IR
The Need to Know

- **Radiation** is a part of our daily environment. What you are exposed to depends upon your geographic location and elevation, housing, medical interventions, occupation, personal awareness and behavior and “unexpected” situations you become involved with.
- **Radiation** comprises X and gamma ray fluxes, (cosmic, medical and natural terrestrial sources) alpha particles (i.e. from radon), beta particle fluxes (from radioactive decay) neutrons (fissile or atmospheric interactions)
- **Hopefully** our need to know derives from normal environmental control efforts and monitoring of normal operations of medical, industrial, the nuclear power and enrichment cycle usages and control

Some Hazards to Prepare For:

- **“Radiation”** sources in the natural environment and in industrial settings are generally accessible in daily operations and subject to normal assessment-control and remediation
- **“Unnatural Radiation”** sources may include, dirty bombs, explosives placed in a medical center and prior to detonation, fissile based weapons, accidents, or dealing with post detonation conditions. In the first case the sources are physically small and possibly shielded. In the second case, the hazard is probably classified as large area contamination
- **Measurement Targets of Interest** include gamma radiation for both cases from small objects and also larger areas for contamination and particulates, both airborne and deposited. Particulates comprise dust containing various radioisotopes in a variety of chemical forms
“Geographic” and Spatial Issues

- We must sense source material in all locations and where geographic/geologic structures and building structures cause significant variances in background fluxes over very short distances (i.e. sometimes a few meters)
- Measured gamma radiation will comprise natural and known placements of radionuclides (U, Th, 40K, medical) AND a large scatter fraction.
- THEREFORE we must fully analyze this radiation signal to help identify unnatural source distribution
- AND use additional means including optical and imaging methods to support analyses – the difficult and the detectable
- Can we predict or anticipate the location of source material in a small localized environment?

Objectives of this Effort

- Optimize current radionuclide detectors through the intertwined parameters of maximized detection efficiency and understanding and mitigating background radiation effects (i.e. signal/noise ratio)
- Using the above approach, maximize detector dynamic range
- Use optical techniques to provide additional information for radionuclide location and identification
- Use optical techniques for predictive background radiation scenes
- Use optical techniques to identify target material conditions
Radiation Detection

- So let us look initially at radionuclide measurement
- Non contact non invasive measurement
- Means couple of feet to infinity
- What do we have to detect? – SNM gases, plumes, surface contaminants buried objects
- Non contact means keeping people safer

Background Radiation

- Baseline background radiation is seldom known
  - May change depending on surroundings and human activity
  - Detection of low-level source requires knowledge of natural/baseline background levels
  - Data on background radiation and materials is generally simplistic and limited
  - USGS produced background radiation maps from aerial radiological data but ended program in 1993
  - EPA has national radiation monitoring system
    - Few monitoring sites (only 2 within 100 miles of Dayton)
    - US only
The Measurement Problem

- **Gamma ray flux** is the more penetrating radiation that can also be directional.
- **However** detection systems are limited, slow responding and atmospheric absorption restricts long range detection.
- **To Overcome** these limitations and enhance the detection process we must:
  - Enhance the Nuclear Radiation Detector performance
  - Through the use of additional sensors and analysis, provide improved “insight” and measurement cross referencing
- **Gamma Ray Detector Performance** is optimized by maximizing detection efficiency while minimizing and understanding interfering background radiation.
- “Optical” Sensors define the field of view, chemical information, define anticipated natural isotopes, ground cover, suspicious items

---

The Gamma Ray Directional Detector Approach

Collimator Concept – One Example:

- Dimensions Control Line Width
- Detector
Collimator Concept – One Example:

- Tungsten or Lead Plates
- Low Density/Low Atomic Number (Z) Expanded Polystyrene

Dimensions Control Field of View

Creating a “Line” Field of View
Some Detector Field of View Options

Wide Beam Parallel Plate
- Parallel Plate/Honeycomb – wider FOV/range system
- Divergence defined by plate separation/collimator length ratio
- Detector should be rectangular

High Resolution Parallel Plate
- Parallel Plate/Honeycomb – longer range system
- Divergence defined by plate separation/collimator length ratio
- Detector should be rectangular

"Focused" Collimator Plate
- Plane-source is focused in plane of defined distance in front of assembly front face, i.e. 10 cm

Figure 6785: Comparison of Ge Eu152 plastic block with and without collimator
Measurement of 152Eu Through Block With Ge Detector With and Without Collimator

Low Level Geologic Fault
3. Low Level Geologic “Fault”

Scatter and Direct Source Radiation Can be Used
Assessment made as:

a) solid source,
b) source distributed over area $a \text{ m}^2$

Assessments made at $h$ ranging: 2, 10, 50, 100, 300 meters

Assessments made at $d$ ranging: 0 to 1.0 kM

---

Measured from center of Point Source source
Measured from center of distributed source

- **Point Source**
  - $h = 2.0$ Meters
  - $h = 10.0$ Meters

- **Area Source**
  - $h = 2.0$ Meters
  - $h = 10.0$ Meters

**Graphs:**
- **Graph 1:** Peak Count Rate (cps) vs. Distance from Center of Source (Meters)
- **Graph 2:** Peak Standard Deviation % vs. Distance, Meters
Create an image as low a cost as possible

- Efficiency
- Bgrd and bgrd complexity – optical is big helper
- Energy resolution
- Controlled field of view – first presentation speaks to parallel plate approach
- However – scatter fractions become defined which is highly useful
- Several pixels each as stand alone and then working together

Modeling Problem

- Estimate of background radiation needed to distinguish baseline background from elevated levels caused by incident
- Not practical to measure baseline levels across entire country
- Need ability to model background levels based on terrain and natural/manmade features
Estimation of Radiation Levels

- Nuclear transport codes used to estimate expected radiological intensity from sources
  - Numerous codes available from Radiation Safety Information Computational Center at ORNL
  - Cannot account for natural or baseline levels
  - Require background information, physical & thermal properties of objects between source and area of interest to accurately model detection scenarios

USGS Radiation Atlas, 1993

- Potassium Concentrations
- Uranium Concentrations
- Thorium Concentrations
- Terrestrial Gamma-Ray Exposure at 1m above ground
Extended radiosity method is able to rapidly compute emitted, scattered and attenuated radiation in complex 3-D geometries and is faster than Monte Carlo methods, e.g. MCNP.

**Note:** Photon mapping is also a method to predict and render emissive scenes.

**ASPECT Flight**
Flight Path with 1 second data points

Contour of Total Counts per Second
Application of Leaf Area Index

- Water in vegetation absorbs γ-rays & nuclear particles
  - Leaf area index can be determined from spectral band ratio techniques
    - Essentially a measure of amount of water in vegetation coverage
  - If leaf area index is known, vegetation layers can be estimated and resulting water content used in nuclear transport codes

### Table: % Attenuation Due to Vegetation

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>K</th>
<th>Th</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine Forest</td>
<td>20.0</td>
<td>14.0</td>
<td>13.5</td>
</tr>
<tr>
<td>Native Forest</td>
<td>21.9</td>
<td>14.1</td>
<td>16.4</td>
</tr>
</tbody>
</table>
Neutron Sensitivity in Gamma Detectors

Sean to present

Layout of Detector for Control Rod Scan
Measurement near concrete casks sep 14 with 5 inch detector

1: no shield
2: lead
3: lead + side coll.
4: lead + narrow coll.
5: lead + plastic coll.

spectrum of 5" detector with differing geometries for CFS52

1 = background
2 = source in front
3 = source 12 ft away
4 = source to one side

26 cpm
29 cpm
511 keV
1460 keV

0.64 cpm
Data Acquisition and Processing

Element Gamma Ray Fields of View

Incoming Gamma Ray Paths

Incoming Neutron Flux

In Summary – Neutron Development is a Work In Progress

- Has promise
- Provides additional detection capability without hindrance of Gamma Ray detection part
However, For All Detection:

• We are playing a game of probabilities and cannot solve all problems
• Therefore do the best we can to improve the odds
• Not every application is about naughty people
• Radionuclides have a chemical form
• So line of sight can exist

Other Ways to Skin the Cat

• Source Buried or not?
• Source Distribution?
• Line of Sight?
  – Hyper Spectral Imaging
  – Optical
  – Laser Induced Background Spectroscopy (LIBS)
  – Infrared
• Does One Technique Help Steer the Other?
Hyperspectral Imaging

• Radionuclides exist in Chemical Form
• Use IR spectroscopy to identify compounds

Air transmission

![Graph showing transmission vs. wavelength](image.png)
Hyper-Spectral Imaging Spectroradiometer

- Imaging Spectroradiometer
- Boresight video
- Fourier Transform Technology
  - LWIR: 8-12 \(\mu\)m
  - MWIR: 3-5 \(\mu\)m
  - MWIR-E: 1.5-5.5 \(\mu\)m
- Cooled Focal Plane Array 320x256
- IFOV of 0.35 mrad
- Adjustable spectral resolution
  - 0.25 – 150 cm\(^{-1}\)
- Real time FFT and calibration
- Internal calibration blackbodies
- Portable, small, lightweight

An IR spectrum is acquired for each pixel in the 320x256 array
Performance vs Distance

- As long as pixel is filled, increase surface of observation compensates for aperture solid angle loss
- Atmospheric attenuation may be a factor in some cases

Camera Concept

- Blackbody
- Interferometer
- Scene
- Window
- Lens Assembly
- Motorized Focus
- Focal Plane Array
- Retro-Reflector
- Beamsplitter
Advantages of FT-IR Imaging Over Dispersive Systems

- No raster image artifacts from line scanning
- Simple “Stigmatic” imaging
  - Better imaging
- Number of spectral channels not limited by FPA size
  - The spectral resolution is defined by maximum optical path difference (time)
- Very high spectral resolution (0.25 cm⁻¹)
  - Corresponds to 0.025 nm @ 1 µm or 2.5 nm @ 10 µm
  - Corresponds to 1,600 channels for the 8-12 µm band
- Multiplex approach (advantage or disadvantage)
  - Neutral if photon-noise limited
  - Advantage if detector noise-limited
Optical Forensics

- Chemical composition and size are key HE characteristics
- Standard forensic analysis difficult in theater given high risk to personnel
- Understand IR signature to enable optical forensics

Field of view –
Use of telescopes

- 0.25x Telescope 20×24 deg
- 3.5x Telescope 1.5×1.8 deg
- No Telescope 5.1×6.4 deg
To Compare Chemical and Nuclear Detection Systems:

- Example of small physical source
- Using Gamma Ray Detector measure this source with differing distance and altitudes
- Distribute the source over an area spreading to 10 microns thickness or so
- Using FTIR Hyper Spectral Camera, re-measure this source with the two above conditions
Primary Comment

- Gamma ray emissions detectable from surface and internal contents of package
- Infrared analysis is made on wavelengths transmitted through plume
  - Analysis also made on surface coatings on structures, particulates and other items
  - Coating may range 5-10 microns thickness

Optical Analysis
a) Marked location of trench
b) Unprocessed image of trenching location cut 20 months prior
c) Simple contrasting to show reflectance difference

Laser Induced Breakdown Spectroscopy (LIBS)
Laser Induced Breakdown Spectroscopy

- Simple and robust analytical method based on laser-induced atomic emission spectroscopy
- Rapid detection (single-shot analysis); no sample preparation - aim and fire to obtain results
- Provides in-situ and standoff analysis
- Quantitative analysis possible through calibration
- Good sensitivity – down to several nano grams for some elements
- Simultaneous detection of all elements (low and high Z)
- Versatile method for all material forms - gases, liquids, solids – conducting and non-conducting
- Hundreds of analytical lines/element plus use of chemometrics provide positive identification for CBRNE threats
- Readily combined with orthogonal methods to increase capabilities (i.e. improve detection, decrease false alarms)

Thermal Infrared Imaging
Unwarranted Thermal Activity in a Building Supposedly Unused
Studying Surface Contaminants with Thermal Technologies

Object

High Speed Thermal Camera

a) Prior to thermal Flash

b) Loose deposits identified with 0.5 sec thermal flash
Faster Detection Approach?

Combine differing instruments

LIBS
Gamma Radiation detector
Infrared Camera

Thank You