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Standoff detection of trace level explosive residue using passive LWIR hyperspectral imaging

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Outline

- Program Overview
- Strategic Framework
- Technical Approach
- Technology Overview
- Summary of Test Results
- Next Steps, Challenges

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Program Overview

- **Ultimate goal: Develop sensor to attack terrorist networks**
  - Covert & Passive standoff detection of explosive residues on surfaces
- **Goal of S&T efforts: Assess and demonstrate the capability to detect trace level explosive residue on surfaces using passive LWIR hyperspectral imaging**
- **Technical Objectives:**
  - **Library signature development as a function of environmental conditions**
  - **Demonstrate wide area detection from true standoff ranges (10 - 100m)**
  - **Demonstrate detection and identification of explosives (RDX, TNT, PETN, TATP, UN, AN, C4, dynamite) present at low surface densities**
  - **Conduct sensor performance evaluation as a function of contamination loading, range, environmental conditions, surface types, interferents, vehicle speed**

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Strategic Framework for Standoff Explosive Detection

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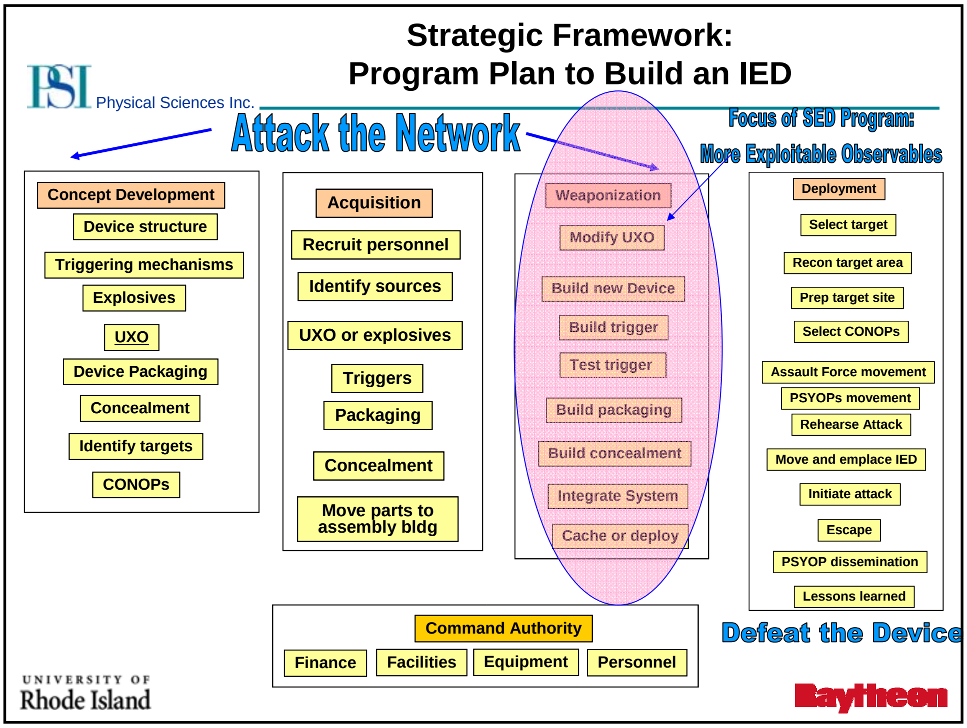
Strategic Framework:
Program Plan to Build an IED
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Attack the Network
Focus of SED Program:
More Exploitable Observables
Concept Development
Device structure
Triggering mechanisms
Explosives
UXO
Device Packaging
Concealment
Identify targets
CONOPs
Acquisition
Recruit personnel
Identify sources
UXO or explosives
Triggers
Packaging
Concealment
Move parts to assembly bldg
Weaponization
Modify UXO
Build new Device
Build trigger
Test trigger
Build packaging
Build concealment
Integrate System
Cache or deploy
Deployment
Select target
Recon target area
Prep target site
Select CONOPs
Assault Force movement
PSYOPs movement
Rehearse Attack
Move and emplace IED
Initiate attack
Escape
PSYOP dissemination
Lessons learned
Command Authority
Finance
Facilities
Equipment
Personnel
Defeat the Device
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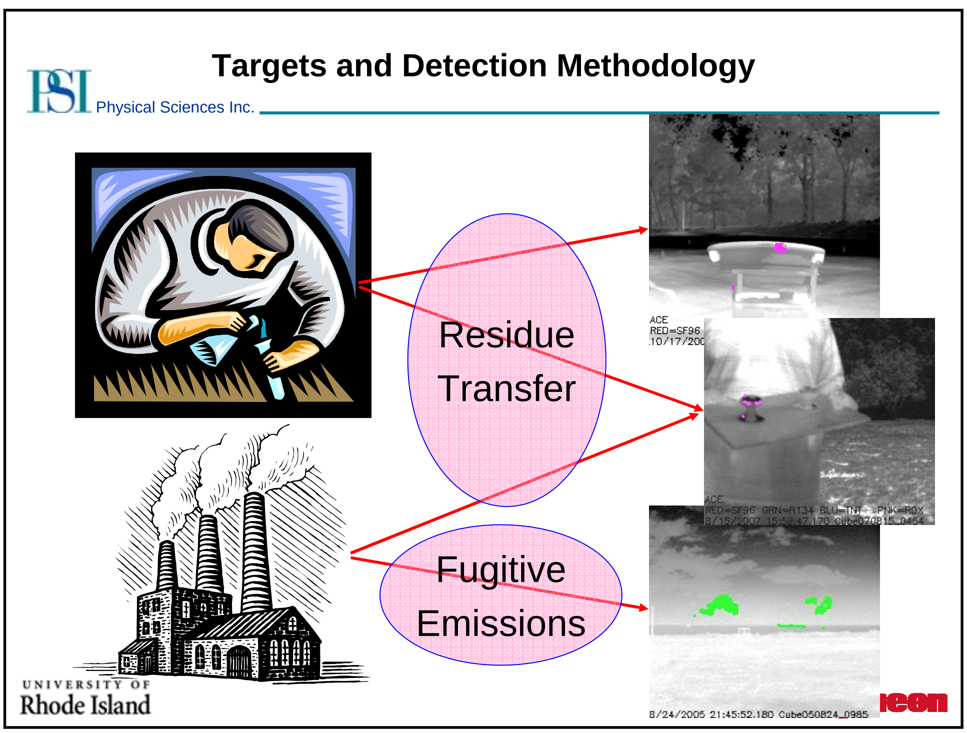
Targets and Detection Methodology
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Residue Transfer
Fugitive Emissions
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Strategic Framework: How Low (Sensitivity) Do You Need To Go?

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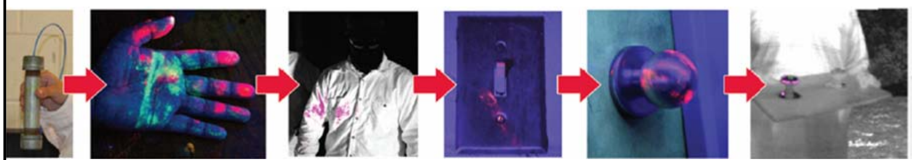

- **Fabricating an IED contaminates its maker, who spreads detectable residues – the trail to finding them**
- **High resolution imaging provides a richer target set**
  - Spatial discrimination & awareness of residues
- **Fluorescent dye studies indicate spot concentrations that are exploitable with a passive LWIR hyperspectral imager**

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Technology Overview

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Technical Approach - Explosive Identification

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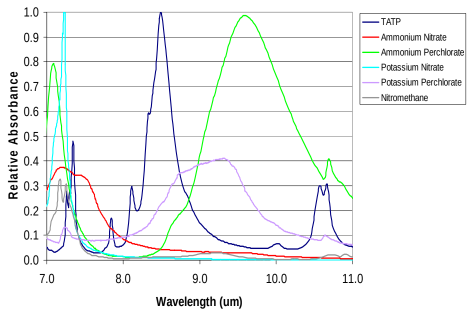
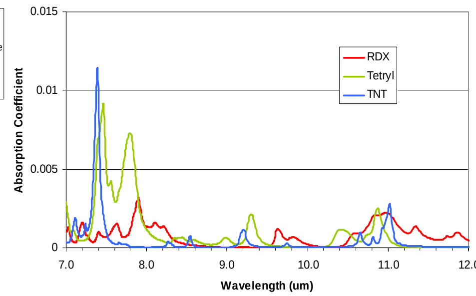
- **Detection & Identification Basis**
  - Molecular absorption spectroscopy
    - Detect changes in reflectance of IR radiation from surfaces due to presence of explosive residue
  - Characteristic explosive spectral “finger prints” in LWIR region (7 – 12 µm)





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Simplified Surface Reflection Model

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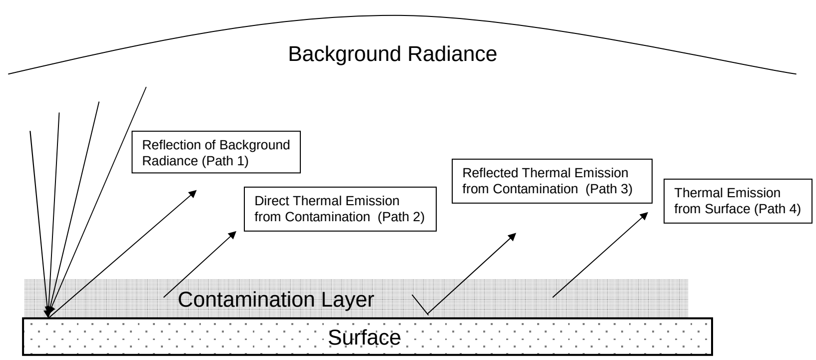

- **Contamination detected as differential change in reflectance due to reflection/absorbance of background thermal radiation**
- **Model sensor signal as linear combination of radiances from each path**

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Combined Path Radiances

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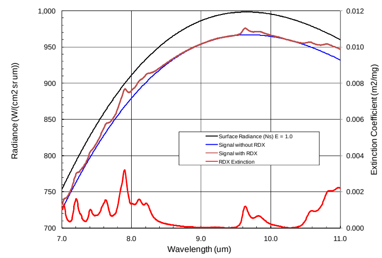
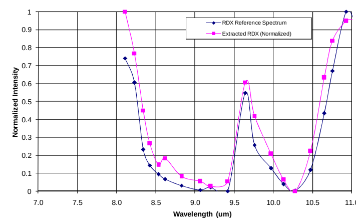
- **Contaminant layer in thermodynamic equilibrium with surface ($N_S = N_C$)**

$$N_D = N_S \varepsilon_S + N_B (1-\varepsilon_S) + 2\alpha\rho(N_S - N_B)(1-\varepsilon_S)$$

Surface Radiance	Background Radiance Reflected from Surface	Background Radiance Modulated by Contaminant Layer and Reflected from Surface
"Background"		"Target Differential Radiance"





- **Does not consider impact of atmospheric transmission**

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The SED System
Adaptive Infrared Imaging Spectroradiometer (AIRIS)

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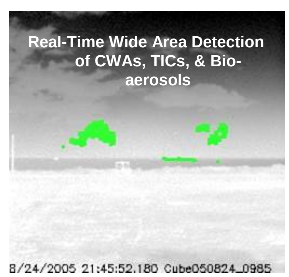

- **Leverages standoff system developed for chemical weapon agents and toxic industrial chemicals**
  - Fabry-Perot Interferometer provides rapid sequential sampling of pre-programmed discrete spectra
  - FPGA-based real time processor provides spatial-spectral detection
  - Integrated advanced algorithms for "on the move" detection of chemical releases without a priori knowledge of background
  - Simultaneously detects up to 4 materials using 20 spectral bands in 200ms
  - Larger explosive databases possible in 10 - 30 seconds

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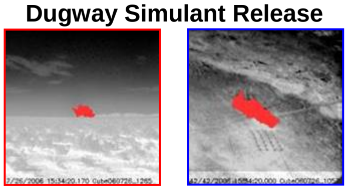
AIRIS-WAD Technology Overview

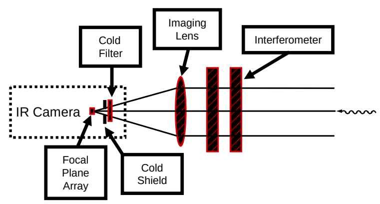
- High speed tunable bandpass filter coupled to infrared focal plane array
- Detection of nerve and blister agents
- Intended deployment on vehicles, rotorcraft, and aircraft
- Built to be qualified to MIL-STD-810F for Shock, Vibration, Drop, and Temperature and MIL-STD-461/462 for EMI

Dugway Simulant Release



Ground **Airborne**

- **32º x 32º FOV direct imaging**
- **Detections overlaid on thermal infrared image of scene using a *real-time processor***
- **Color coded target identification**
- **Data acquired and processed at 5 per second**
- **10 meter spatial resolution at 5 km range for smaller release detection**
- **Archival data storage**



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Summary of Experimental Program

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Detection on Non-Porous Real World Surfaces – Feasibility Assessment

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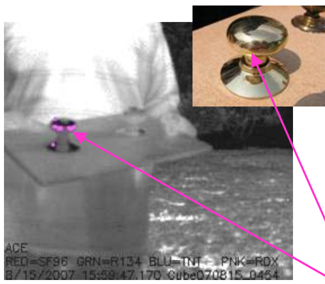
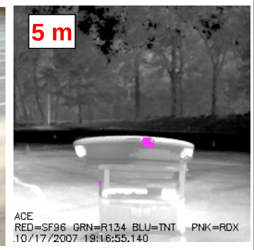
- **Detection on a variety of non-porous metal surfaces demonstrated**
  - Semi-quantitative approach
- **Inability to detect on exterior glass surfaces not yet understood**
  - Could be related to IR coatings used on auto glass

RDX



SF-96
R134a
TNT
RDX



Thumb Smudge of Comp B

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Detection Capability as a Function of Range

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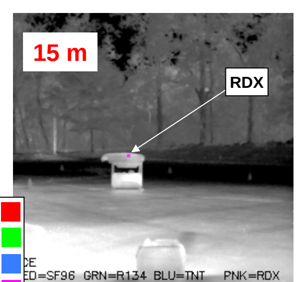
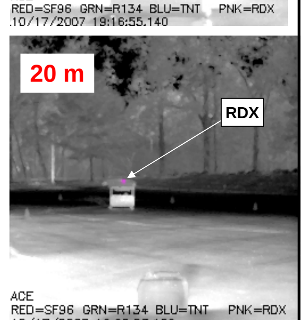
- **Detection demonstrated to 20 meters using RDX**
- **Ranges to 100 meters possible depending on humidity and concentration levels**
- **Optics optimization required to align spatial resolution with CONOPS**
- **At 20 meters detected RDX spot is only 2x2 pixels**
  - ATR could flag operators
  - Zoom lens needed

SF-96
R134a
TNT
RDX





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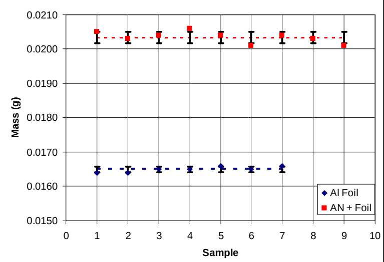
Quantitative Performance Assessment
Sample Preparation: Technical Approach

- **Explosive material is dissolved in a solvent (methanol) and injected into a Sono-Tek Accumist ultrasonic nozzle via syringe pump**
- **Nozzle is stationary and motion of the deposition target (substrate) is actuated via a computer-controlled x-y stage (NEAT 300)**
- **Compressed air injected into the diffuser area of the nozzle**
  - Aids in evaporation of solvent
  - Carries the droplets to the substrate surface
- **Gravimetric analysis to determine efficiency and accuracy of method**
  - **Results indicate a coating uniformity of 2.2%**
- **Conclusion: Method yields accurate and uniform explosive deposits**



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RDX Detection Sensitivity Measurements:
Data acquired with AIRIS-WAD (8 – 11 μm coverage)

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RDX on controlled Al surfaces: Black Anodized and Polished Al
Range = 5 m

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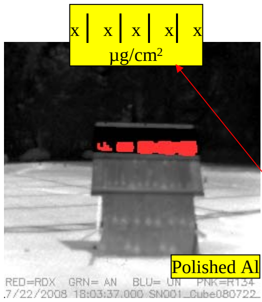

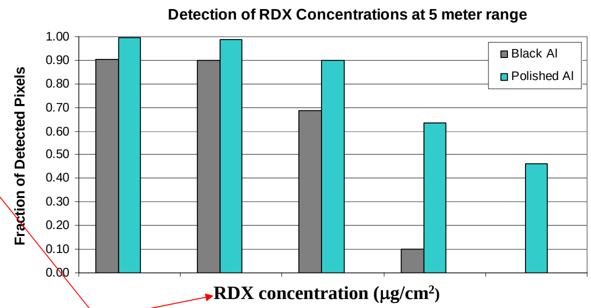

- **Conclusions:**
  – RDX detection demonstrated in complex scenes at 5 m range
  – RDX observed at low concentrations on polished Al surface
  – High probability of detection (P_d > 90%) for low surface densities
  – No false alarm pixels

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RDX on controlled Al surfaces: Black, Polished Al, and Painted Steel
Range = 10 m

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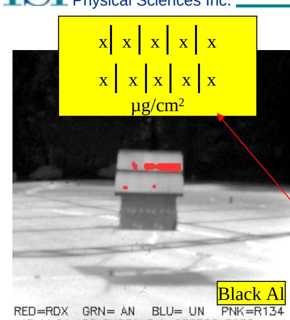

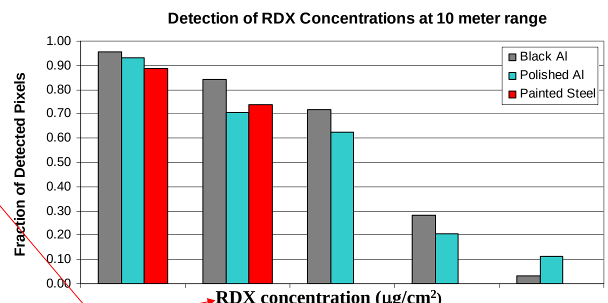

- **Conclusions:**
  – RDX detection demonstrated in complex scenes at 10 m range on surfaces with a range of emissivities
  – No false alarm pixels

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RDX on controlled Al surfaces: Black, Polished Al, and Painted Steel
Range = 20 m

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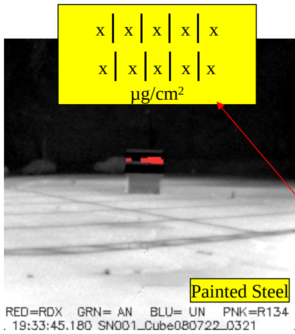

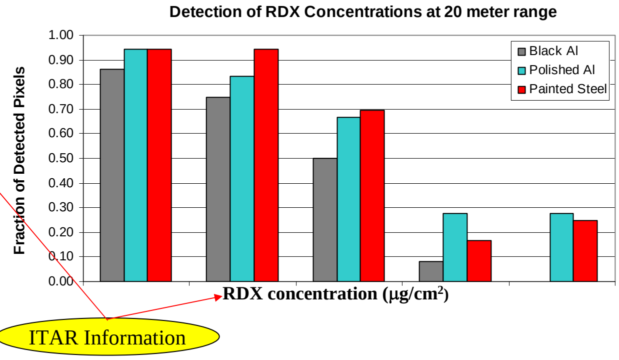

- **Conclusions:**
  - Detection demonstrated in complex scenes at 20 meters range
  - RDX observed at low concentrations on various emissivity surfaces

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Extended Range Detection – 37 meters

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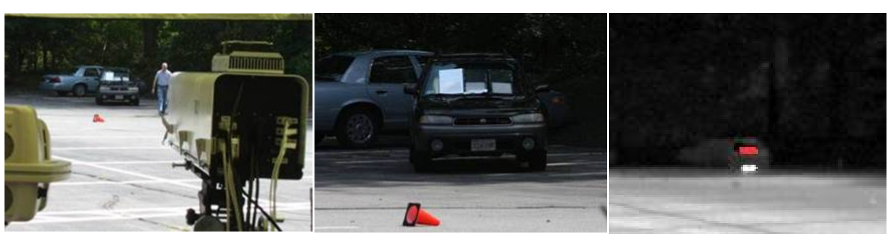
- **RDX Detection**
  - Car with Aluminum plates at 37 m standoff
  - 3 surface loadings on polished Aluminum



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7.5 – 10.5 μm vs. 8 – 11 μm Spectral Coverage

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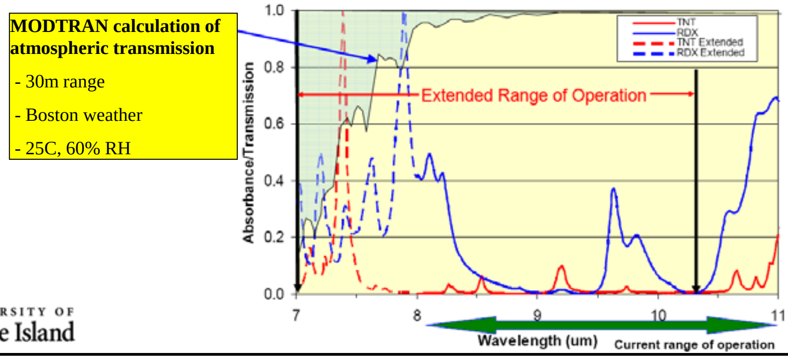
- **Enables use of stronger absorption features**
- **Additional spectral bands allow multi-band correlation using Automated Target Recognition Algorithm**
- **Conclusion:**
  - Expect 3x – 4x improvement in detection sensitivity with a system capable of 7.5 – 10.5 micron spectral coverage
  - In addition, the system would be capable of detecting HMEs



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HME Detections using early generation PAIRIS (7.5 – 10.5 micron spectral coverage)

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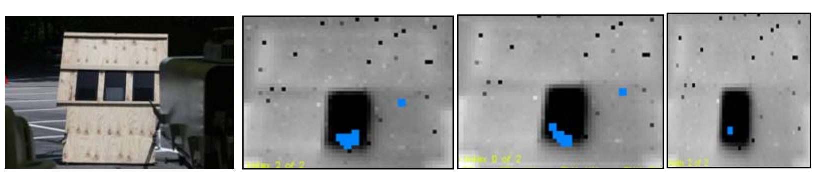
- **HME Detection - Urea Nitrate**
  - UN primary IR signature below 8 microns
    - Employ PAIRIS (lower performance than AIRIS-WAD, easier to modify)
  - Polished Aluminum Test Plates
  - 3 contamination loadings



- **Conclusion:**
  - Successfully demonstrated detection on all 3 concentration levels at 5 m standoff range

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Challenges and Next Steps

- **Library signature generation as a function of environmental conditions – signature robustness**
- **Development of next generation detection algorithms for improved sensitivity and detection statistics (P_d and P_{fa})**
- **Evaluation of sensor performance (ROC curves) as a function of contamination loading, range, environmental conditions, surface types, interferents, vehicle speed, etc.**
  - Impact on signal from surface emissivity, extent of cloud cover, and sky obscuration
  - Variation in sensitivity due to surface porosity, chemical permeability, and roughness
- **Engineering development to align sensor with CONOPs**
  - Adjustable FOV for increased spatial resolution at long standoff ranges
  - Integration with other sensors for a system of systems approach

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