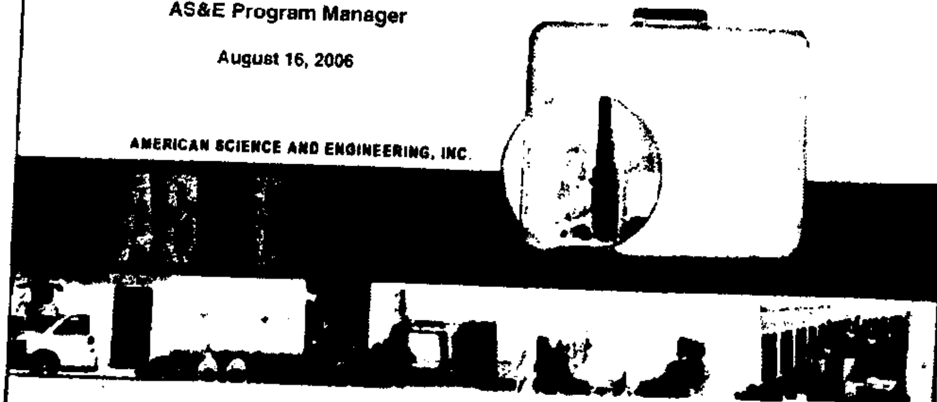
BomDetec

Kick-off Meeting

Mike Winer
AS&E Program Manager

August 16, 2006

AMERICAN SCIENCE AND ENGINEERING, INC.



Team

- Mike Winer – Program Management
- Peter Rothschild – Science (Principle Investigator)
- Rajen Sud – Systems Engineer (EE)
- John Handy – Software Engineer
- TBD – Mechanical Engineer
- Brian Sullivan – Finance
- Rich Wronski – Product Management

Task Detail

3.1 **Develop System Hardware Design**
- Work with partners to gather information
  - Mechanical Design
  - Electrical Design (Power, Control, Signal)
  - Thermal Design
  - Software Design (Control Software integration, Data Acquisition, Data Analysis and Fusion)

3.2 **Develop X-ray Sensor Evaluation Criteria**

3.3 **Evaluate X-ray Sensor Data**

3.4 **Develop System Configuration Concept**

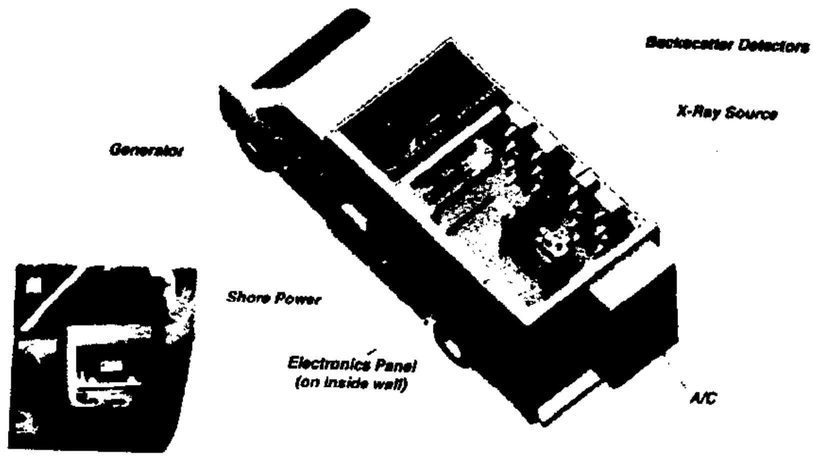
3.5 **Preliminary Design Review (PDR)**
- X-ray sensor and hardware integration

3.6 **Write Phase 1 Final Report**
- X-ray sensor and hardware integration

3.7 **Program Management**
- Technical (planning, tracking, managing)
- Financial (planning, tracking, managing)
- Schedule (Gantt, deliverables, milestones)
- Communication (weekly meeting, monthly technical / cost progress reports, reviews, final report)
- Program Support (travel, meetings, contract)
- System Configuration Concept
- Preliminary Design Review Coordination
- Phase 1 Final Report Coordination

ZBV

Major Components



Needed Sensor Information

- Power Requirement
  - Voltage
  - Current
  - Peak
  - Continuous
- Size
  - Footprint
  - Volume
- Placement
  - Particular orientation of components
  - Arrangement order
  - Line of site

Needed Sensor Information

- Mechanical interface
  - Mounting holes
  - Couplings
- Motion
  - Any concerns with vibration
- Electrical Interface
  - Power connectors
  - Control I/O connections
  - Communication method and connections
- Grounding
  - Any special grounding needs
  - EMI/RFI
    - Emission issues
    - Susceptibility issues

Needed Sensor Information

- Environmental
  - Maximum/minimum operating temperature and humidity
  - Maximum/minimum storage temperature and humidity
  - Cooling Requirements
    - Airflow
- Safety
  - Compliance Requirements
- Theory of Operation
  - Few pages describing how the sensor works
  - Do's and Don'ts

X-Ray Backscatter Imaging

Presentation to Congress
Peter Rothschild
August [illegible]6, 2006

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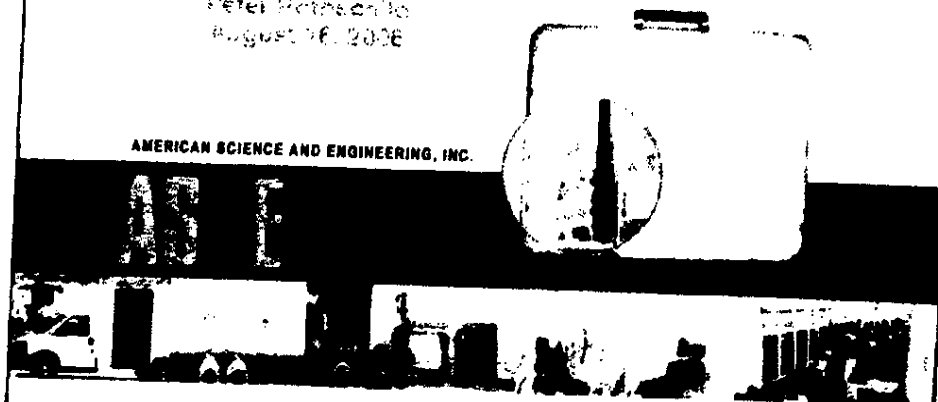
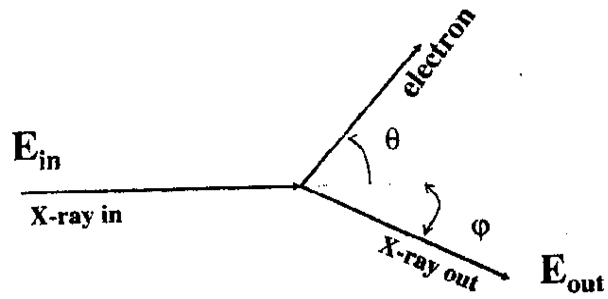


Outline

- Physics of Compton Scatter of X-Rays
- How Is a Backscatter Image Formed?
- Material discrimination with X-Ray backscatter
- AS&E's Z Backscatter Van (ZBV)
- Long Distance Imaging of Suicide Bombers
- Radiation Safety

Compton Scattering

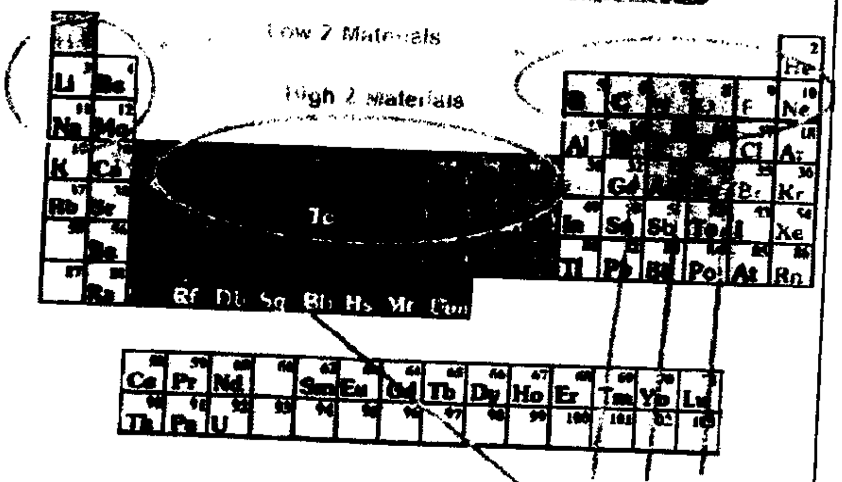


Use energy and momentum conservation to find that:

$$E_{out} / E_{in} = 1 / (1 + \alpha (1 - \cos\varphi))$$

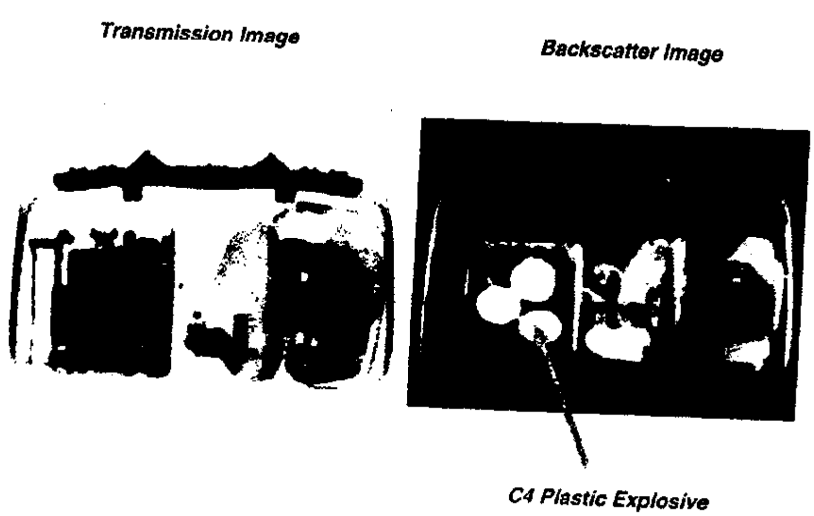
$$\text{where } \alpha = E_{in} / m_e c^2$$

Backscatter Imaging with a Flying Spot

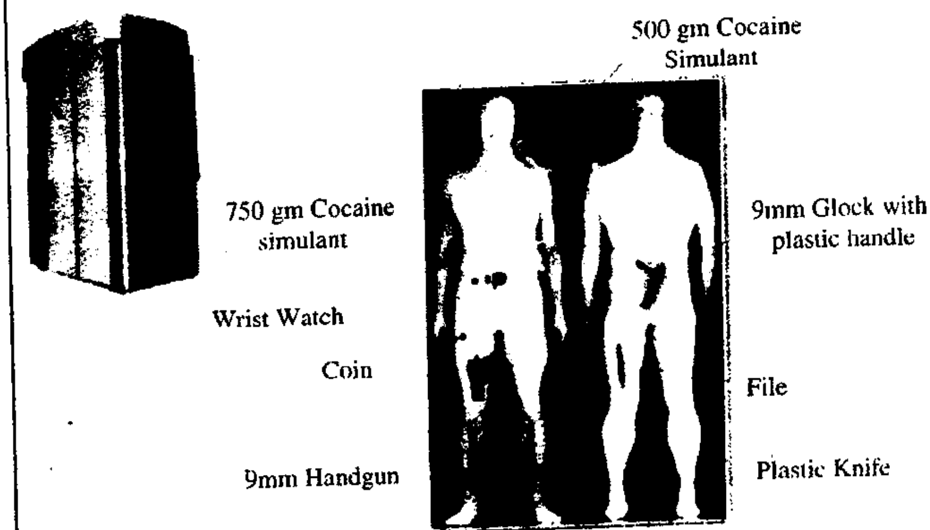


Drugs, Explosives contain H, C, N, O etc
Objects Containing These Low Atomic Number Elements Appear Brightly in a Backscatter Image

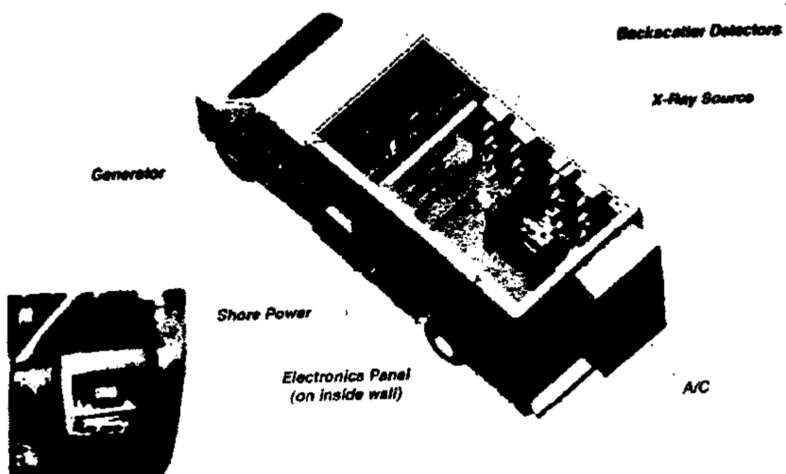
Backscatter Highlights Low Z Materials



BodySearch Reveals Both Metallic and Non-Metallic Objects



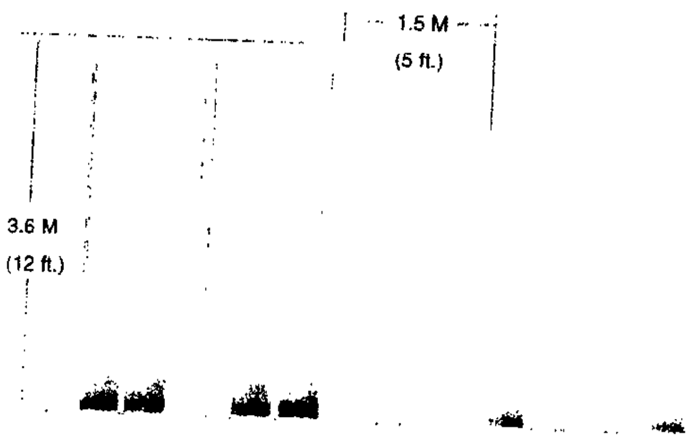
Schematic of the Z Backscatter Van (ZBV)



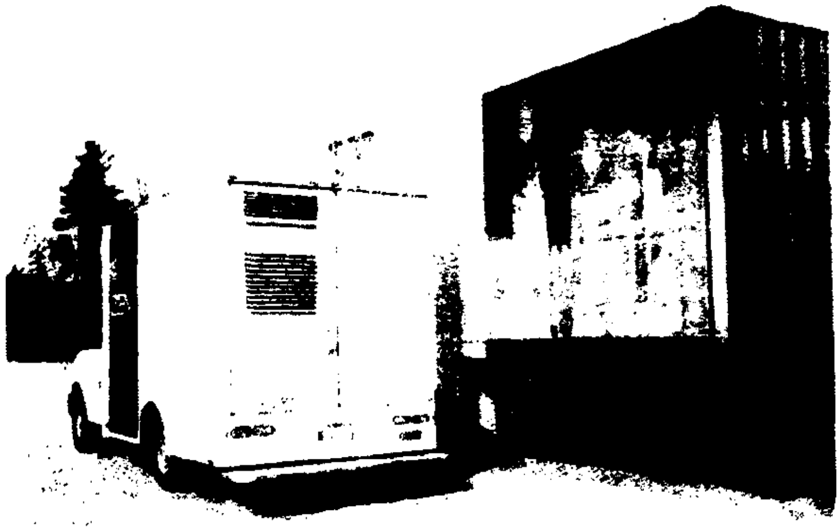
[illegible]

- Single-Sided Inspection
  - Side set at Factory
- Backscatter Only
  - 225 KeV
- Vehicle Offering
  - Mercedes Sprinter (Diesel)
- 1 or 2 Operators
- Multiple Speeds
  - 0.5, 1.5, 5 & 10 kph
  - 0.3, 1, 3, & 7 mph
- RTD Option

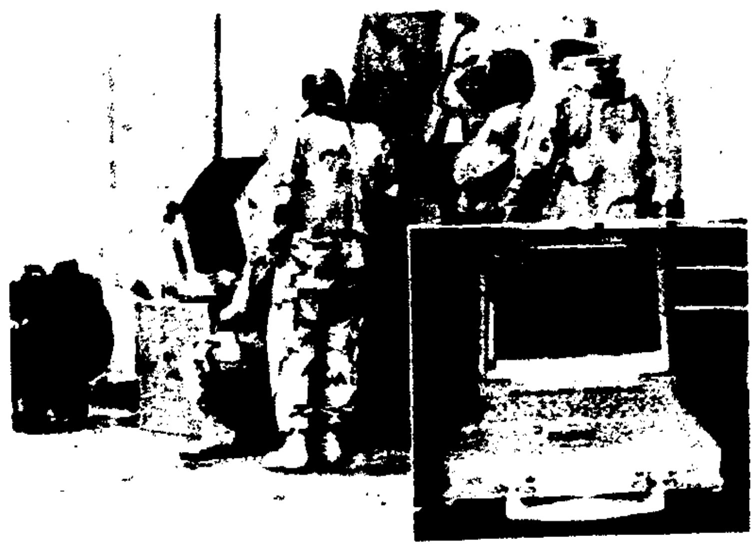
ZBV System Field of View



The Effect of ZBV

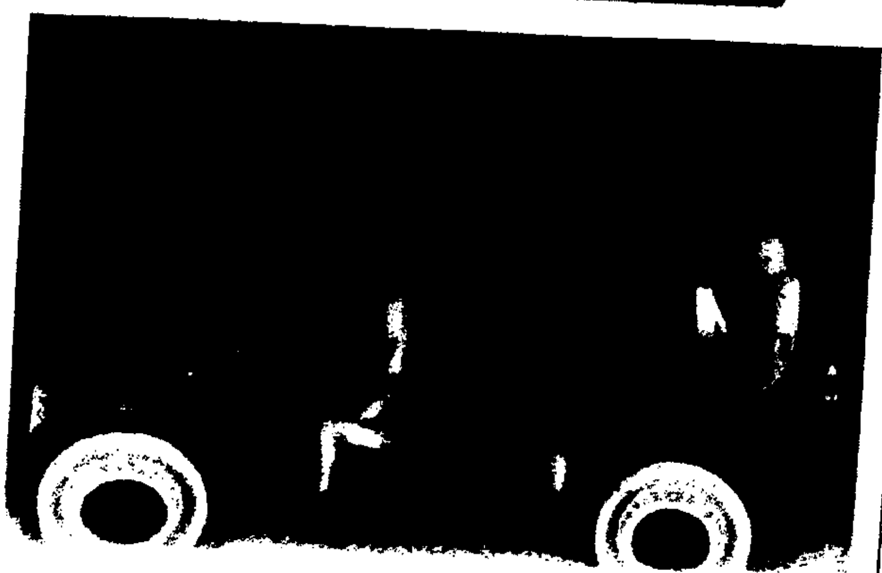


ZBV Deployment with Remote Operation



ZBV Image

ZBV: 2 kg of C4 in vehicle

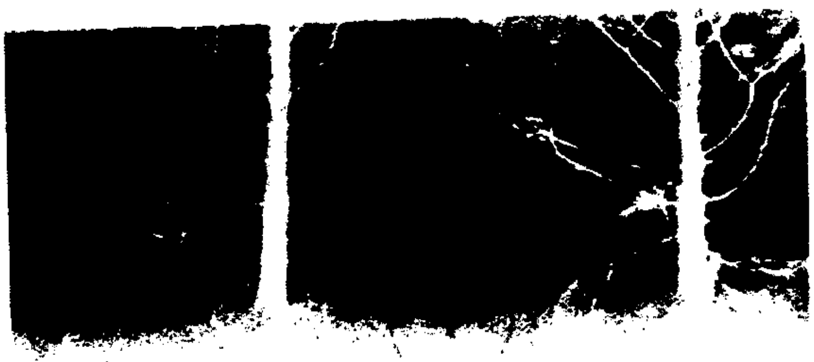


A Quick Way to Examine Large Objects

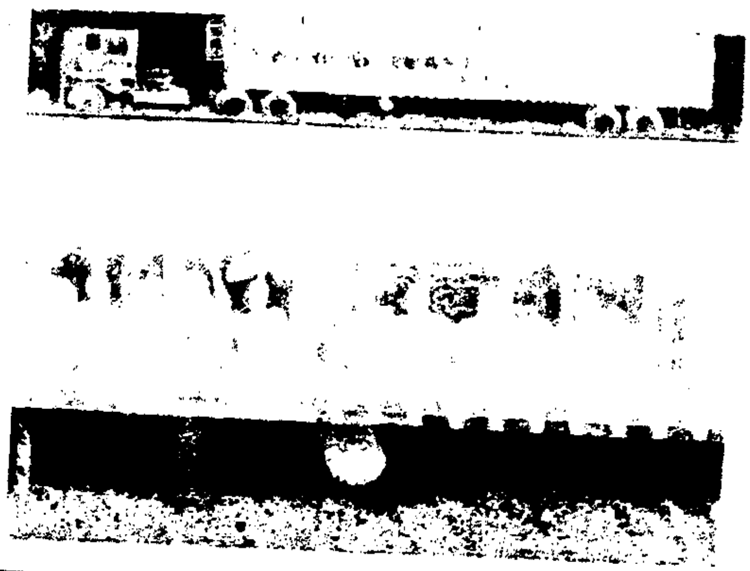
One-sided Imaging Allows for Simple Inspections

Helicopter

X-ray Backscatter Strips Foliage



Scatter Image of Illegal Immigrants



Challenges with Long-Distance Imaging

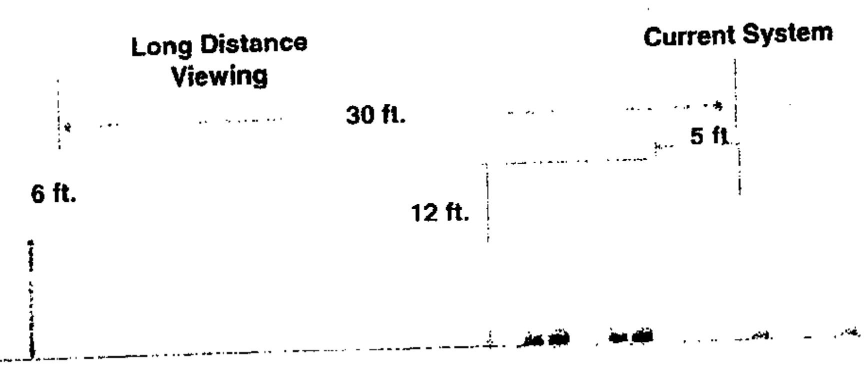
- X-ray beam is diverging so resolution of image decreases rapidly with distance
- Backscatter signal decreases by the square of the distance due to geometry (going from 5 feet to 30 feet reduces the detected signal by 1/36)
- Air scatter further reduces the detected backscatter signal and creates a background "fog"

Solutions

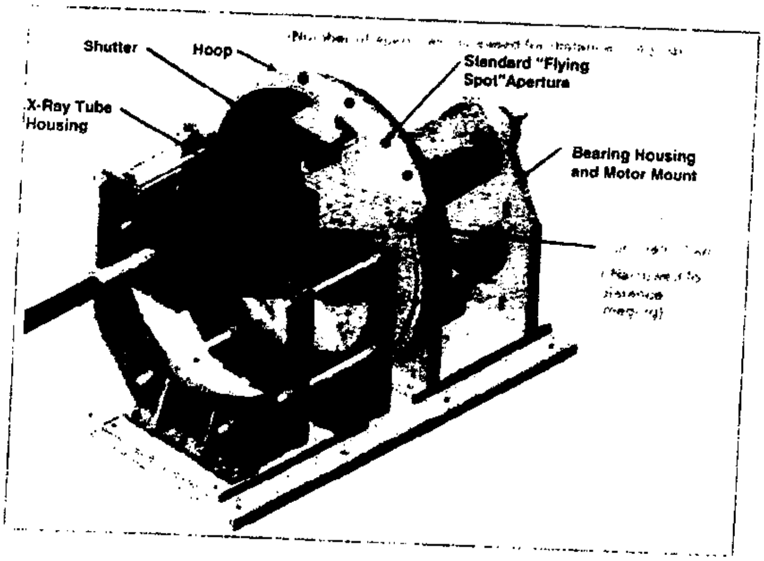
- High power x-ray source with a small focal spot (powerful beam with low divergence)
- Collimate primary beam to prevent air scatter into detectors
- Collimate detectors so that they cannot see the air scatter
- Used pulsed x-ray sources to reduce contribution of detector noise to the backscatter signal

Long Distance Viewing (LDV) – 30 feet

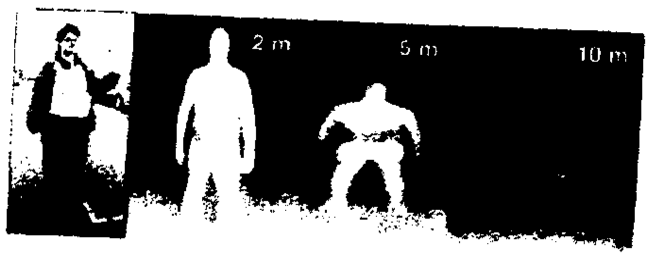
- Increased range – Requires more X-ray flux
  - Can be achieved with a smaller FoV



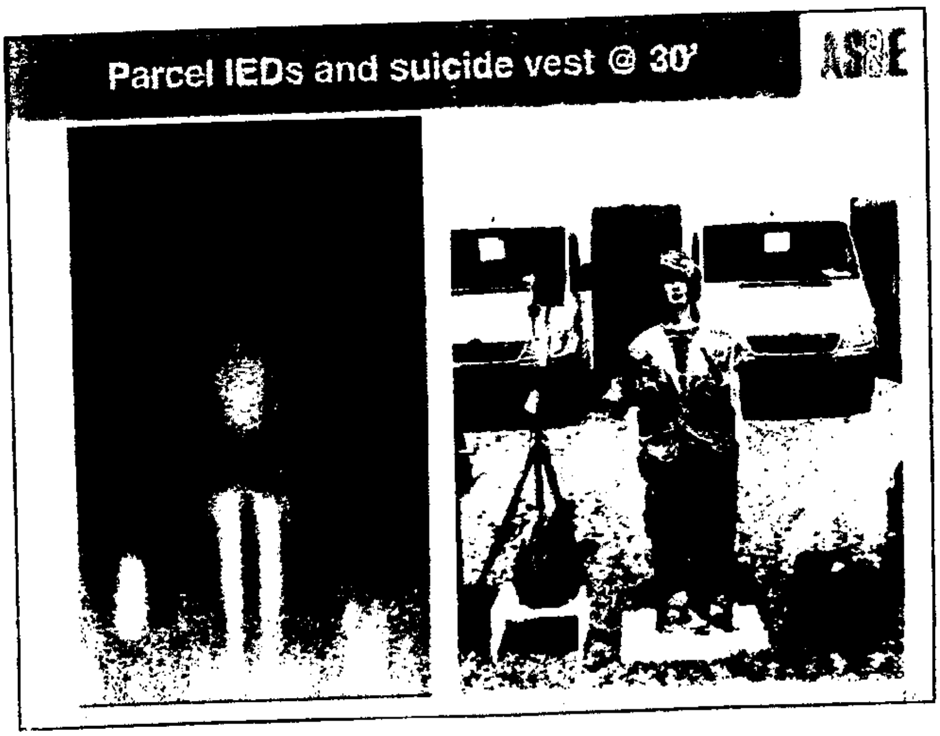
X-Ray Source Assembly



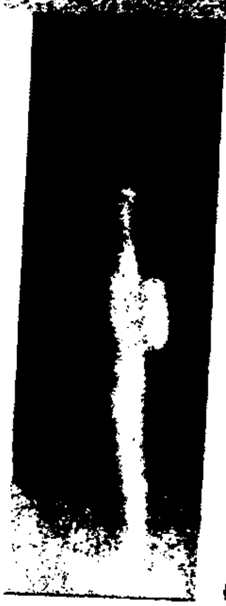
Suicide Bomber at Various Distances




Parcel IEDs and suicide vest
1" diameter pipe bombs in vest
Packs of ¼-20 nuts for shrapnel
5 kg explosive simulant in backpack
10 kg explosive simulant in parcel


Parcel IEDs and suicide vest @ 30'

Backpack IED @



5 kg explosive simulant in backpack

Typical Radiation Doses

- 1 SmartCheck Inspection — 0.05 μSv
- 1 ZBV Inspection (at 1.5 km/hr) — 0.07 μSv
- 1 LDV Inspection — 0.25 μSv
- Airplane Flight (10,000 km) — 50 μSv
- Chest X-ray — 50 - 100 μSv

Note 10 μSv = 1 mrem; 1 μSv=100 μrem

Background radiation ≅ 8 to 10 μSv/day

DISCLAIMER ABOUT SCANNING PEOPLE

- **RADIATION DOSE IS EXTREMELY LOW**
  - Radiation dose from the LDV is measured in tens of micro-R.
  - People who are scanned by the LDV will not be harmed
- **LDV is not, and will not be, a "certified people scanner"**
  - Dose is too high to comply with N43.17, which requires dose per scan ≤ 10 micro-R
  - ANSI N43.17 is the only standard which addresses the issue of irradiating people for security applications
  - This standard was designed for applications such as BodySearch
  - This standard is neither a law nor a regulation. Neither ANSI nor CDRH certifies that equipment complies with the standard.
  - ANSI N43.17 requires many additional safety features which would be difficult or unfeasible to implement in the LDV system
  - ANSI N43.17 requires that people give consent to be scanned. Therefore it is not applicable to covert operations

Center for Subsurface Sensing and Imaging Systems

BomDetec Program
Phase I Kick-Off Meeting
August 16, 2006

HSARPA - Sponsor

Northeastern University (Lead)
- Siemens CR&D
- Raytheon
- AS&E
- RPI
- PPT

Kick – Off Meeting Agenda

- Opening Remarks & Introduction
- Program Overview
- Operational Overview
- BomDetec Sensors
  - Intelligent Video
  - Millimeter Wave Radar
  - X-ray Backscatter
  - Terahertz
- Integration of Software and Hardware
- Programmatic Discussion

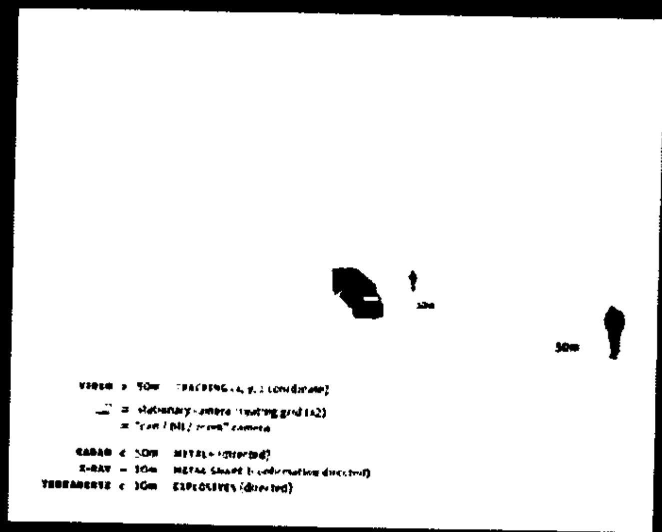
Program Strategy

- Suicide Bomber Detection
  - Person
  - Metal
  - Explosive
- There is No Silver Bullet
- A Flexible Platform or "Mainframe"
  - Capable of Adapting to Future Technological Advances

Program Overview

- A Flexible Mainframe
  - Software
    - Coordinate System (X. Y. Z)
    - Tracking System for People in the FOV
    - GUI
    - Data Analysis. Fusion
    - Database
  - Hardware
    - VAN
      - Power
      - Thermal Regulation
      - Mechanical Support
    - Sensors
    - (Intelligent Video. Radar. X-ray. Terahertz. Other)

Program Overview



Program Overview, Contract Issues

- Final revision to Proposal sent by NU to DHS in late June.
- Notice to Proceed Letter Dated 7/10/06 received from DHS Contracting Officer. Stipulates reimbursement contingent on contract execution.
- Northeastern Letters of Authorization sent to four Phase 1 Subcontractors on 7/24/06.
- Ongoing discussion among all Collaborators to ensure appropriate NDA'S are in place for duration of project.
- Request for additional cost detail received from DHS on 8/11 and forwarded to Collaborators on 8/14.
- Potential Contracting Issues that could be stumbling have been discussed with DHS. Appears to be potential resolution.
- Once Contract in place with Northeastern plan is to lift restriction on Subcontractors.

Programmatic Discussion

- Monthly Reports
  - Title Page (1 pg.)
  - Gantt Chart (1 pg.)
  - Hardware Software Status (1 pg.)
  - Funding Profile ($/month, actual & forecast) (1 pg. – graph)
  - Notable Accomplishments & Events (1 pg.)
  - Program Issues and Concerns (1 pg.)
- Measurement Tools
  - Gantt Chart and % Complete by SOW
  - Financial Numbers (expenses) by SOW

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Concealed Explosives Detection Using Active Millimeter Wave Radar

Carey Rappaport, Northeastern University
John Firda, Raytheon, Inc.

BomDetect Kick-off Meeting August 16, 2006

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Presentations

- Radar and antenna phenomenology background
  - Carey Rappaport, Northeastern University
- Suicide bomber detection, Personal Protection Technologies, Inc.
  - Carey Rappaport
- Radar hardware and testing
  - John Firda, Raytheon, Inc.

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Goals for Millimeter Wave Radar Approach for BomDetect

- Long range indicator of potential threat
- Real time operation
- Threat declaration algorithms based on prior work.
  - Bomber with explosive vest has higher radar cross-section than normal subject
  - Bomber indication is polarization sensitive and provides a discriminator
- Validation and performance metrics for explosive target detection/discrimination
- Handover of hardware specifications and data format to systems integrator

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Polarimetric MMW Radar Discrimination of Hazardous Body-Worn Targets

Carey Rappaport, NEU

BomDetect Kick-off Meeting August 16, 2006

Raytheon Integrated Defense Systems

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Outline

- Basics and tradeoffs of radar explosives detection
- Antenna analysis for best discrimination
- Microwave characteristics of media in scene
- Modeling wave interaction with target/body shapes
- Advantages of polarization feature detection

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Basics and Tradeoffs of Radar Detection

- Transmitter sends waves in a beam to objects, which scatter waves back to receiver
- Scattering varies as size/shape/reflectivity of object
- Higher frequency allows for greater resolution/ discrimination with range and across field of view
- Bigger antennas form narrower beams which more selectively illuminate specific objects
- Scattering is proportional to the *cross section* of scatterer, which is usually comparable to projected area

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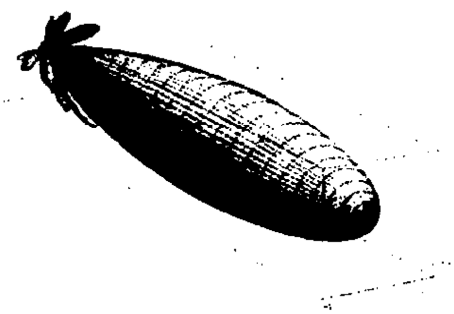
Antenna Analysis

- Antenna beamwidth is inversely proportional to aperture
  - Separation distance between extreme points *D* of array
  - $BW_{3dB} = \lambda/D$
- Sidelobes generate clutter signal



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Required Beamwidth for Chest Spot

- At 50m, a 0.5m wide chest subtends 1/100 radian (0.6 deg.)
- The aperture required to produce this beam, ½ power at the edges of the chest is $D = 100\ \lambda$
- At 77 GHz, $\lambda = 3.9$ mm, so the best aperture width is about 40 cm

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Microwave Characteristics of Media

- Metal reflects 100% of incident waves
- Clothing (cotton, polyester, wool fabric) are relatively transparent to microwaves
- Human skin and muscle tissue at 77 GHz is very conductive, with $\sigma = 60$ S/m, and dielectric constant $\varepsilon' = 12$
  - Reflection Coefficient $\Gamma = 0.65$
- TNT and other explosives are insulators with a dielectric constant of about 3

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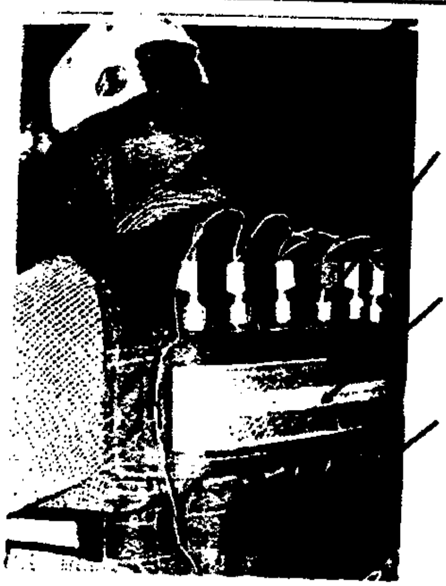
Suicide Bomber IED Mock-Up



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Contrasts / Features of IEDs

- Metal casing is common
  - –Nails/h ardware increases shrapnel yield
  - –Metal is easiest to detect with electromagnetic waves
- Tubes / pipes are typical
  - –Eas y geometry for packing explosive
  - –Fit on bod y effectively

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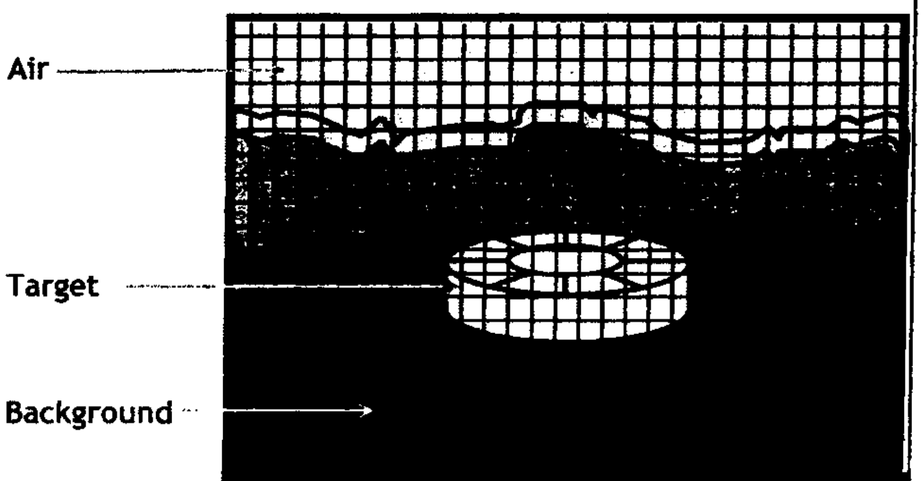
Finite Difference Modeling



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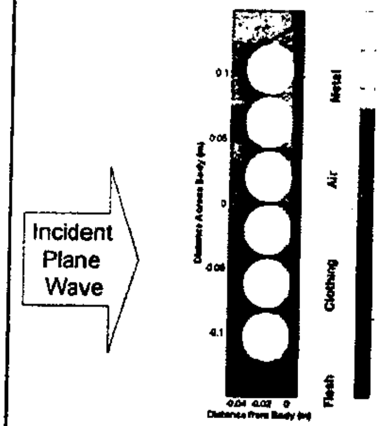
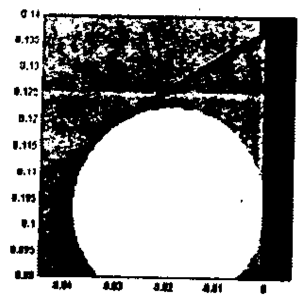
2D Discretization Geometry





Metal Cylinder with Clothing Detail

View from Above

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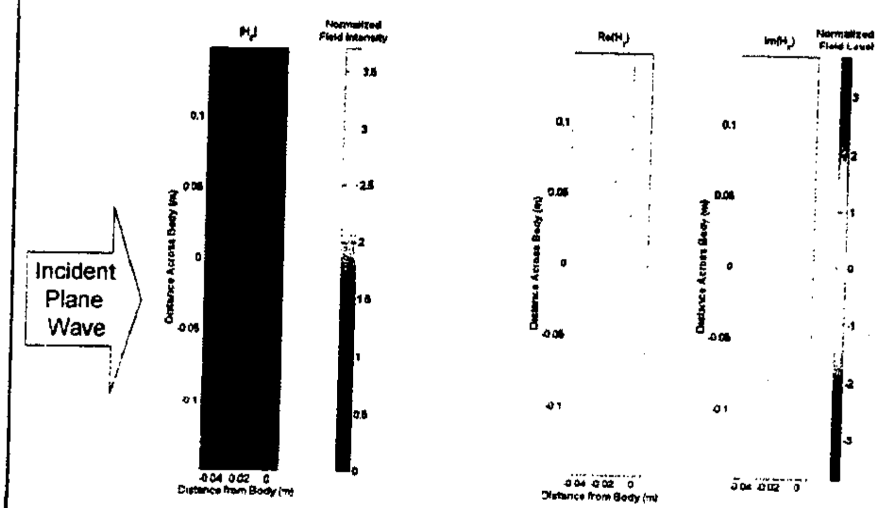
Specular Reflected 25 GHz Field from Flat Body Only



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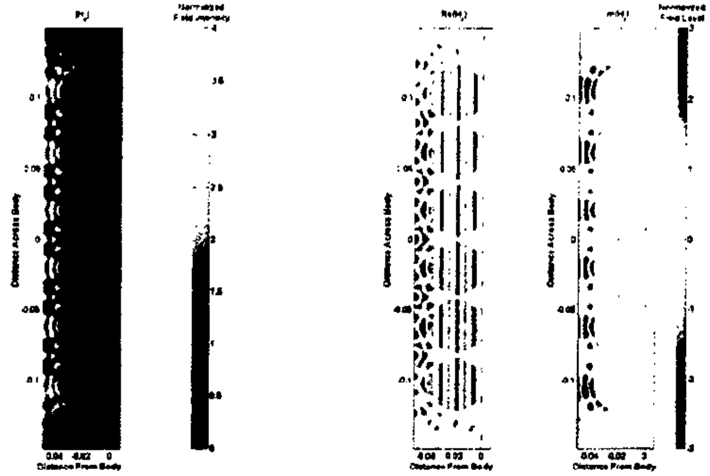
Nearfield 25 GHz Scattered Magnetic Field (H_z) Distribution



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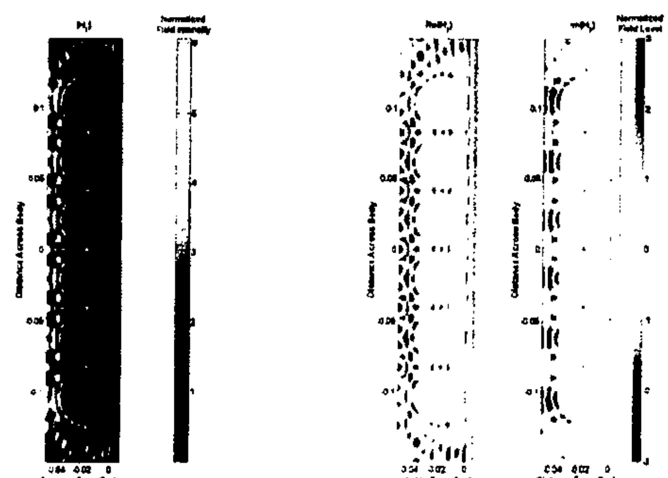
Horizontal Polarization Total Magnetic Field (H_z)



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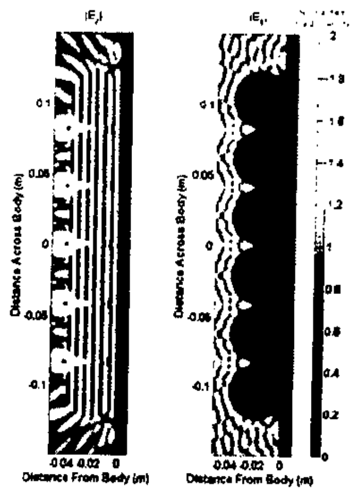
Vertical Polarization (E_z)



Scattered Field

Total Field

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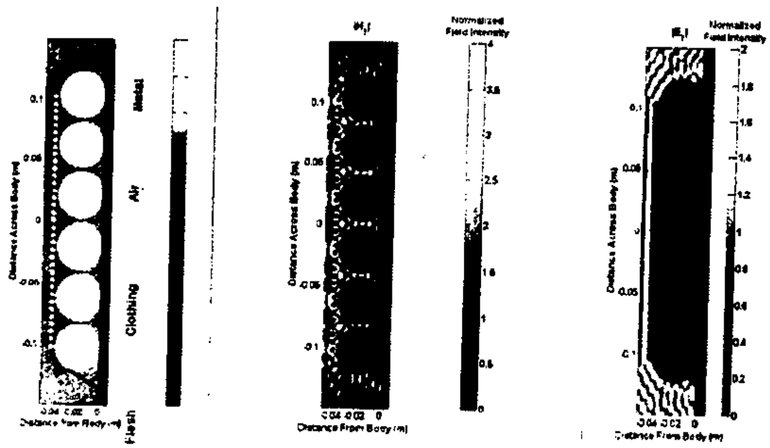
6 Metal Cylinders, 35 Nails: Horizontal (H_z) and Vertical (E_z) Polarization



Total H Field

Total E Field

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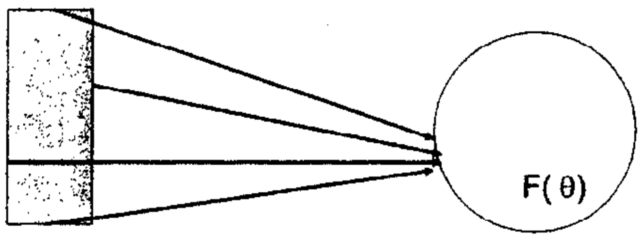
Nearfield to Farfield Conversion

- Integrate fields on bounding box surrounding scatterers
- Use farfield approximations to get intensity as a function of angle



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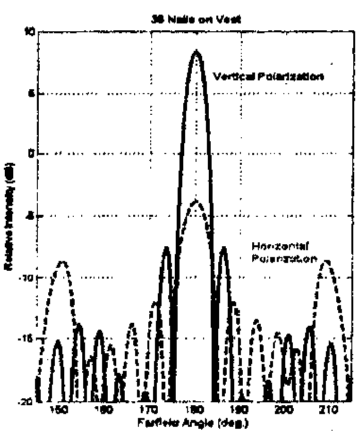
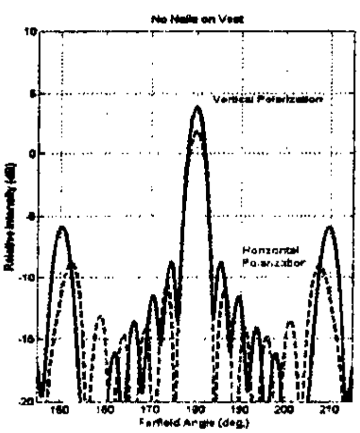
2D Farfield Patterns for Vertically and Horizontally Polarized Illumination



35 Nails on Vest



No Nails on Vest

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Homeland Security — Background Conclusions

- Radar effectiveness depends on characteristics of IED target, body, and background
- Antennas play and important role in distinguishing targets
- Modeling is effective in efficiently analyzing scattering of complex objects in the presence of non-ideal media
- Metal cylinders scatter in unexpected ways
- Nails have a noticeable farfield scatting effect
- Scattering is different for vertical and horizontal polarizations
- Polarization may offer a distinguishing feature for body-worn IEDs

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Homeland Security — Radar Suicide Bomber Detection Tasks - Phase I Get radar, configure processing, establish testing

	Primary	Secondary	Secondary
1 Identify radars to be used/studied on the program	Ray		
2 Obtain transmission license approvals	Ray		
3. Provide radar specifications including, available data, data output format, data rates	Ray		
4 Define required data output	PPT	Ray	
5 Determine if available data is sufficient for gross conclusions that validate existing data	PPT		
6 Determine if available data is sufficient for algorithm input	PPT		
7 Determine basic modifications to radars (if needed) to provide required data output	PPT	Ray	
8 Determine if modifications needed can be accomplished in Phase I	Ray		
9 Define data output format	PPT	Ray	
10 Run initial, simple experiments to baseline radar performance with and without target simulants	PPT	NEU	Ray
11 Evaluate the results (phenomenonological interpretation)	PPT	NEU	
12 Develop detailed experimental testing protocol in indoor/outdoor environments	NEU		
13 Identify subjects, clothing, targets, innocent objects	PPT	NEU	
14 Identify environmental clutter to be used	PPT	NEU	
15 Define the system requirements, software data requirement specifications for Operating Envelope including antenna coverage size	Ray	PPT	NEU
16 If different antenna required, design wider aperture/tighter beam, polarization grating, etc	NEU	Ray	PPT
17 Determine modifications needed to obtain pulse to pulse VV, HH and VH data	NEU		
18 Determine advantages modifications for other polarizations	NEU		
19 Define approach to obtaining pulse to pulse VV, HH, VH, and other polarization data	Ray	PPT	
20 Develop multi-polarization algorithms based on theoretical backscatter predictions	NEU		
21 Design experiments to validate the algorithms	NEU		
22 Investigate clutter reduction approaches	NEU		

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Radar Detection of Suicide Bomber Explosives

Carey Rappaport, NEU
Lester Kosowsky (PPT)

BomDetect Kick-off Meeting August 16, 2006

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Outline

- Accomplishments to Date
- Program Overview and Statement of Work
- Team and Their Tasks

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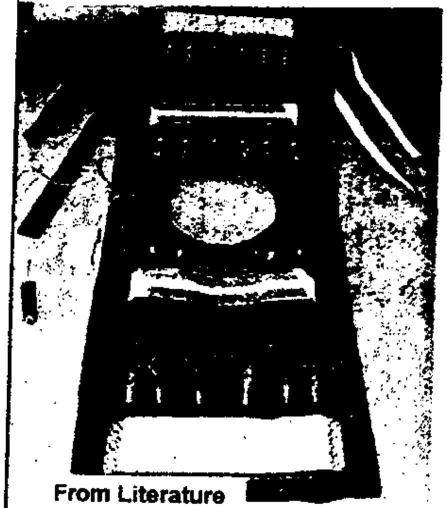
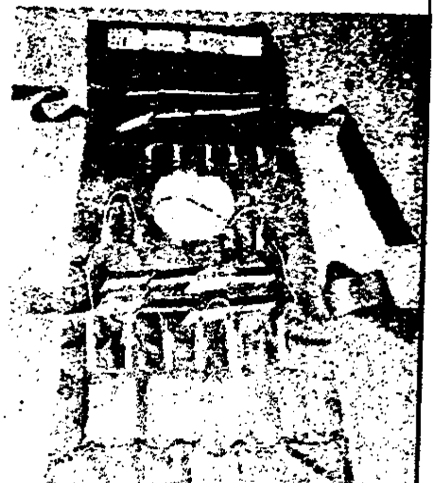
Homicide Vests – Real and Surrogate



From Literature



PPT Mock-up

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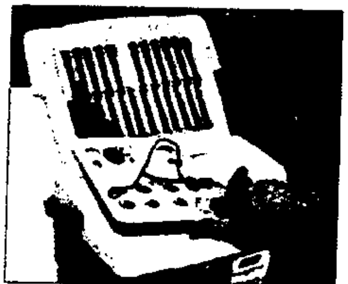
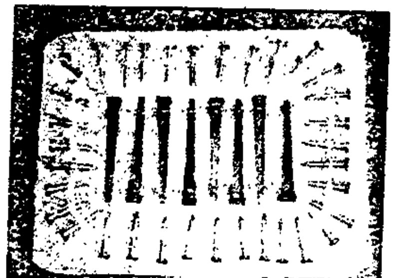
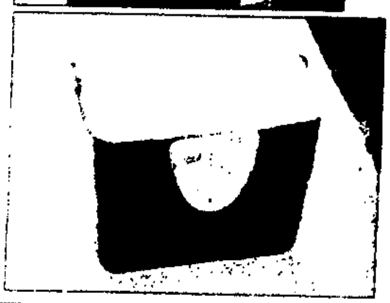
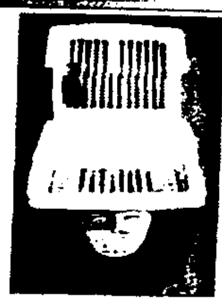
Carried in Explosive Surrogate









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MMW Concealed Weapons Detection Requirements – Past Accomplishment

Homeland Security

- Detection of concealed explosives or metallic and non-metallic weapons carried on persons under clothing
  - in controlled environments
  - in uncontrolled environments
  - at distances < 20 meters
- Design constraints
  - Appropriate indoors and out
  - Benign to people and property

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Typical Set-up – With and Without Vest (Corner Reflector in Background)

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Subject at 14 meters from Radar, Reference Corner Reflector at 17 meters

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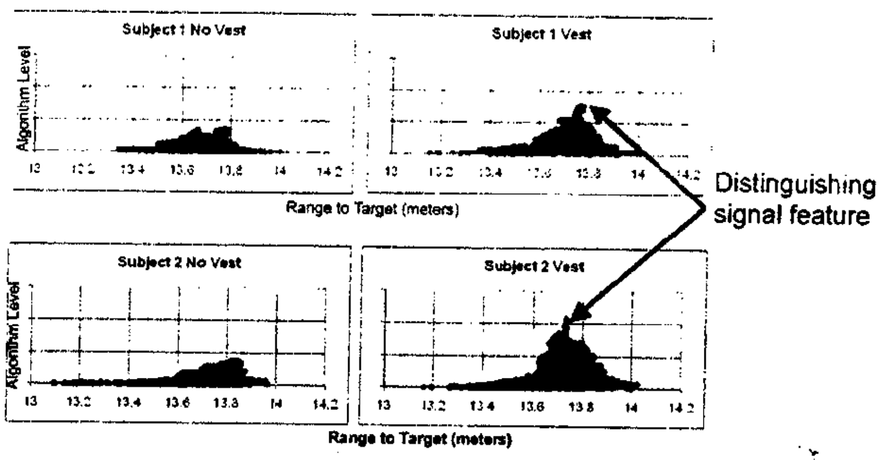
Performance of Algorithm – Vest



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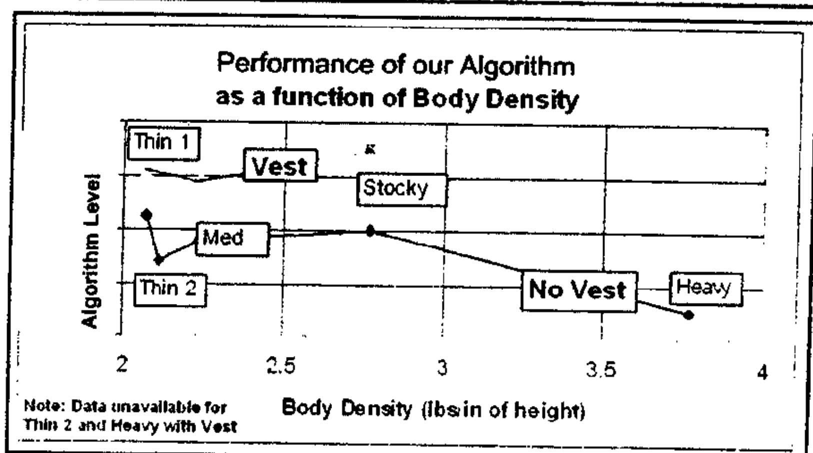
For all Body Densities, a Person Wearing a Vest Always Appeared Dramatically Different



KEY: Heavy – 5'9" 260 lbs;
Stocky 5'6" 185 lbs;
Medium – 5'7" 150 lbs;
Thin 1 and Thin 2 – 5'9" 145 lbs

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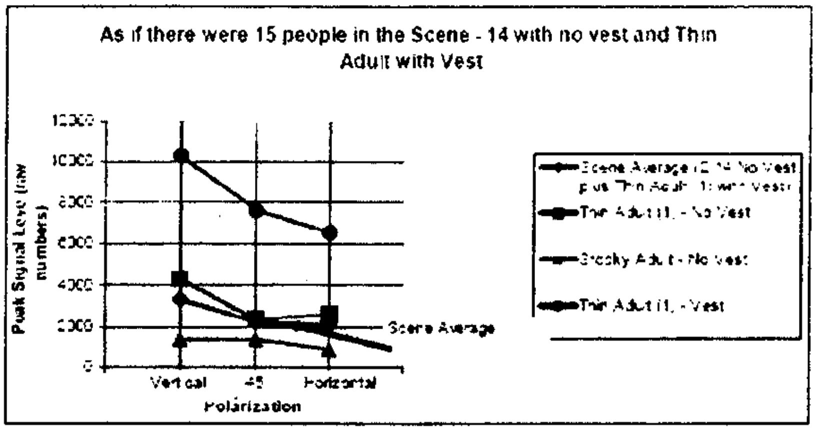
Polarimetric Radar Response from Single Individual Wearing Vest



Person with vest is distinguishable in a crowd

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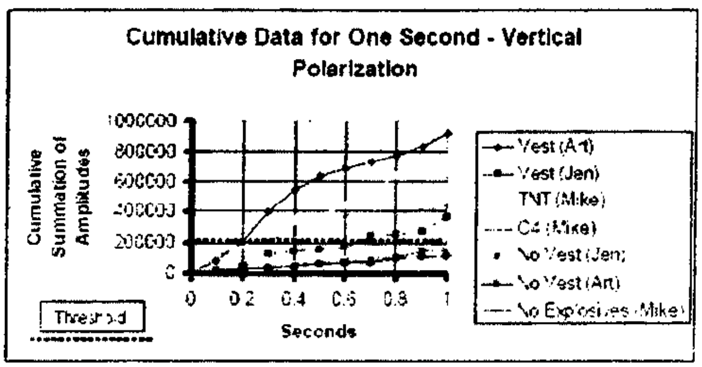
Cumulative Radar Response and Declaration Threshold



Vertical polarization consistently indicates presence of vest

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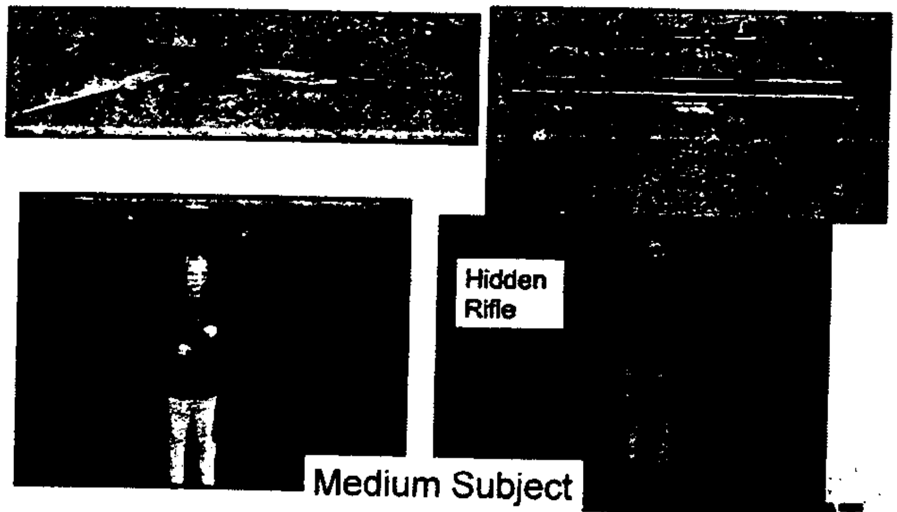
Rifle and Pistol Measurement Scenarios



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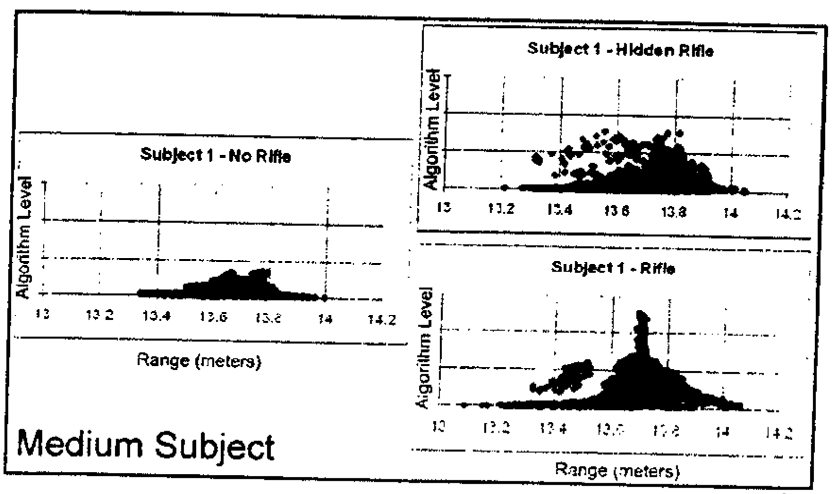
Performance of Algorithm – Rifle



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Deployment Scenarios

- Long Range, on the order of 50 meters, to detect and detain threatening individuals far enough from a potential target to deny a successful attack
- Discrete examination of pedestrian traffic for weapons and explosives at nearer ranges without the need for a designed portal

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Scope

Concealed explosive indications are obtained from measurements of the millimeter wave radar returns using vertical and horizontal polarizations.

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Statement of Work: PPT Task Description

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Radar Program

- Identify radars to be used/studied on the program
- Obtain transmission license approvals
- Provide radar specifications
  - data output
  - data rates
- Define required data output and format
- Determine if available data is sufficient for gross conclusions that validate existing data
- Determine if available data is sufficient for algorithm input

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Radar Program

- Determine basic modifications to radars (if needed) to provide required data output
- Determine if modifications to radar can be accomplished in Phase I
- ID outdoor test range
- Run initial, simple experiments to baseline radar performance with and without target simulants: outdoor testing
- Evaluate the results (phenomenonological interpretation)

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Radar Program

- Identify subjects, clothing, targets, innocent objects
- Identify environmental clutter to be used
- Define the system requirements, software/data requirement specifications for Operating Envelope including antenna coverage/size
- Design antenna required for Phase II, design wider aperture/tighter beam, polarization.

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Radar Program

- Define implementation to obtaining pulse to pulse VV and HH
- Develop multi-polarization algorithms based on theoretical backscatter predictions
- Develop System Configuration Concept (w/ team)

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PPT Program Team

- PPT –Algorithm Development, Data Analysis, Experiment Planning and Execution
- ISL – Data Visualization, Algorithm Implementation, Threat Declaration
- Monarch Associates – Sensor Interfaces, Experiment Management
- New Haven Bomb Squad – Test Environment, Test Subjects, Test Objects and User Perspective

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PPT Tasks

- Evaluate results of radar experiments
- Define interfaces and formats to mate radar output with video presentation
  - Raytheon output to ISL data grooming
  - ISL output to real time display of data as gathered
  - ISL output to data analysis methodology
  - ISL output to Siemens software

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ISL Tasks

- Data Analysis
  - Convert Raytheon output to suitable form for PPT analysis
  - Develop a software / process raw radar data to give near real time amplitude distribution, and provide pulse by pulse intensity of both horizontal and vertical polarization returns.
- Algorithm Development
  - Develop algorithms to process input signals to assess the characteristics of the signal returns and determine the threat status of a target based on permutations of the polarizations of the target signals.
  - Suggest data combining methodology that could augment the PPT methodology
  - Develop the software to provide a signals to Siemens and displayed as a threat indicator to operator.
- Probability of correct identification and probability of false alarm
  - Establish thresholds that maximize the probability of detection while minimizing false alarms. Determine the theoretical limits of the identification process to correctly designate a threat, and the resulting false alarm rate.

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Monarch Associates Tasks

- Manage the interaction between Siemens and ISL by :
  - Overseeing establishment of two-way interface protocol with Siemens and ISL
  - Define, with Siemens and Northeastern, the appearance of the user screens
- Manage and coordinate the experiments and measurements at New Haven and other sites
  - Test plans, test subjects, surrogates, site issues, etc
  - Assure a video record of the experiments
  - Organize the test results for subsequent analysis
- Manage and coordinate the final delivery and demonstration
- Develop methodology for
  - Radar hand-off to camera to center and zoom on threat
  - Camera hand-off to radar to evaluate threat
  - Manual pointing of radar/camera to evaluate a threat
  - Sending the result of threat declaration assessment algorithm to Siemens

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New Haven Dept of Police Services

- Key personnel
  - Lieutenant R.K. Rohloff, Commander Hazardous Devices Unit
  - Officer Ray Crowley, Hazardous Devices Technician
- New Haven Police Academy place for experiments
- Realistic scenario enactments
- Wide range of body types and weaponry

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Radar Hardware and Measurements

John Firda, Raytheon, Inc.

BomDetect Kick-off Meeting August 16, 2006

Raytheon

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Integrated Defense Systems

Homeland Security

Overview

- Team
- Tasks
- Radar description
- Test area overview

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Integrated Defense Systems

Raytheon Key Personnel

- Chris Eversole – Program Lead and System Engineering
- John Firda – Technical Consultant
- Rick McGovern – Contracts
- David Kallmeyer – Hardware Engineering
- Stephen Diehl – DAQ Software Engineering
- Ted Richardson – Mechanical Engineering

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Integrated Defense Systems

Raytheon Tasks

- Raytheon's role is to provide a radar to support experiments and define the antenna for Phase II
- Specific Tasks
  - –Identify radar(s) to be used/studied on the program
  - –Obtain transmission license approvals
  - –Provide radar specifications: data format, data rate
  - –Determine and implement basic modifications to radars (if needed) to provide required data output
  - –Determine if modifications to radar can be accomplished in Phase I
  - –Design antenna required for Phase II, design wider aperture/tighter beam, polarization
  - –Define implementation to obtaining pulse to pulse VV, HH, VH polarization data - radar modification

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Integrated Defense Systems

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Raytheon Support Tasks

- Raytheon provides support to related radar tasks
  - –Definition of required data output and format
  - –ID of outdoor test range
  - –Support running initial, simple outdoor experiments to baseline radar performance with and without target simulants
  - –Evaluation of the results
  - –Definition of the system requirements, software/data requirement specifications for Operating Envelope including antenna coverage/size
  - –Develop System Configuration Concept (with team)

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Radar Equipment

- Plan to use a W Band millimeter-wave radar to collect dual polarization data
- The radar is a Raytheon owned test asset
  - – Bread board FMCW radar operating in the automotive frequency band
- The radar was developed by Raytheon in the mid 1990's for automotive applications
  - – M.E. Russell et. al., "Millimeter-Wave Radar Sensor for Automotive Intelligent Cruise Control (ICC)", IEEE T. Microwave Theory and Techniques, December 1997.
  - – US Patent 5,929,802 - Automotive Forward Looking Sensor Application.
  - – US Patent 6,107,956 - Automotive Forward Looking Sensor Architecture.
  - – Several other patents

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Radar Equipment

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Radar Key Characteristics

Characteristic	Value
Operating Frequency	76-77 GHz
Waveform	FMCW
Range	3 – 100 meters
Range Accuracy	< 0.5 m
Antenna	Electronically switched beam bi-static printed-circuit array (Rotman-Turner lens)
Azimuth Field of View	15.4 degrees
	7 switched beams, each 2 degrees
Elevation Field of View	4 degrees

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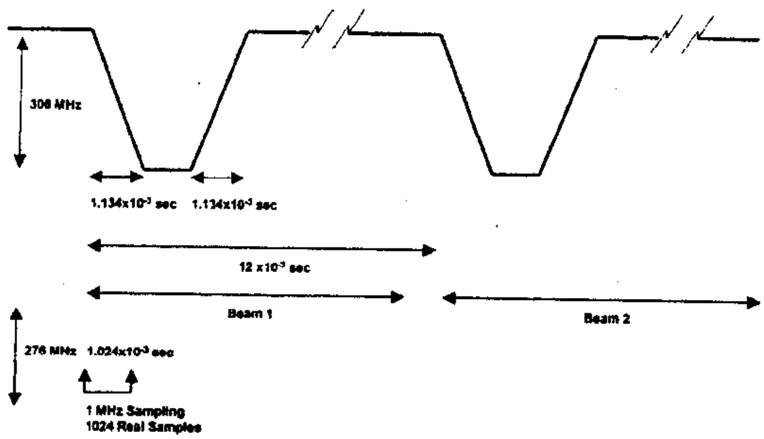
Radar Waveform



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Radar Test Site

- A number of test sites are under consideration
- Primary location is at the Raytheon IDS Surveillance & Sensors Center (SSC) in Sudbury, MA
  - Minimize shipping of radar equipment
  - Use a cleared parking lot to have better than 50 meters of area to conduct experiments
- Alternatives under consideration
  - PPT test area
  - Northeastern University test area
  - Alternate Raytheon site

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