Strategic Study
Workshop Series

Algorithm Development for Security Applications

New Methods for Explosive Detection for Aviation Security

ADSA09
October 2013 Workshop
Final Report

ALERT
AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

A Department of Homeland Security Center of Excellence

Northeastern University

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1. Executive Summary

A workshop focusing on new methods for explosive detection for aviation security was held at Northeastern University in Boston on October 22-23, 2013. This workshop was the ninth in a series dealing with algorithm development for security applications (ADSA09). This workshop also addressed new hardware for improved aviation security.

The topic of new methods for explosive detection was chosen for the workshop in order to support the Department of Homeland Security's (DHS) objective of improving the detection performance of existing technologies. Improved detection performance is defined as: increased probability of detection (PD); decreased probability of false alarms (PFA); lower detected threat mass; increase in the number of types of explosives detected; increased throughput and lower operating costs. Another goal of the workshop was also to support DHS's objective to increase the participation of third parties such as researchers from academia, national labs and industry.

The topics that were addressed at the workshop are as follows:

- Energy sources being used for explosive detection
- Advantages and disadvantages of different methods
- Limitations based on concealment, containment, explosive type, minimum mass and other factors
- Time and barriers for commercialization
- Concept of operations and application

The following applications of explosive detection were reviewed at the workshop:

- Checked baggage
- Personnel screening
- Divested items at the check point
- Cargo
- Standoff detection

The key findings from the workshop, per the editors of this report, are as follows:

- Many promising technologies were discussed; however, many may not be suitable for deployment as stand-alone devices. Instead, these technologies may be more suitable for fusing with other technologies.
- More third parties should be educated about explosive detection so that

they can contribute to field. In particular, more information about threats and the requirements for detecting them should be disseminated.

- It is important to understand why certain technologies (e.g., neutrons) failed to be widely deployed.
- The workshop was successful at fostering interaction between third parties vendors and the government, and reducing barriers to these parties working together.
- The following topics should be considered in detail at future workshops:
    - Air cargo inspection
    - Requirements for deploying equipment as stand-alone and fused with other systems
    - Concept of operations
    - X-Ray diffraction and phase contrast
    - Coded aperture
    - Thermal acoustics
    - Sparse view CT
    - Impact of regulatory and testing on deployment and development
    - Common elements such as image formats and communication protocols

2. Disclaimers

This material is based upon work supported by the U.S. Department of Homeland Security, Science and Technology Directorate, Office of University Programs, under Grant Award Number 2008-ST-061-ED0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

3. Introduction

The Explosive Division (EXD) of US Department of Homeland Security (DHS) Science & Technology Directorate (S&T), in coordination with the Transportation Security Administration (TSA), has identified detection requirements for future explosive detection scanners that include a larger number of threat categories, lower false alarm rates, lower threat mass, increased throughput and lower total operating costs, all at a constant or increased probability of detection. One tactic that DHS is pursuing to achieve these requirements is to create an environment in which the capabilities and capacities of the established vendors can be augmented or complemented by third-party algorithm development. A third-party developer in this context refers to academia, National Labs and companies other than the incumbent vendors. DHS is particularly interested in adopting the model that has been used by the medical imaging industry, in which university researchers and small commercial companies develop technologies that are eventually deployed in commercial medical imaging equipment.

A tactic that DHS is using to stimulate academic and industrial third-party algorithm development is to sponsor a series of workshops addressing the research opportunities that may enable the development of next-generation technologies for homeland security applications. The series of workshops are entitled "Algorithm Development for Security Applications (ADSA)[1]." The workshops are convened by Professor Michael B. Silevitch (NEU) as part of the DHS Center of Excellence (COE) for Awareness and Localization of Explosives-Related Threats (ALERT[2]).

The ninth workshop in the ADSA series was held on October 22-23, 2013, at NEU. The workshop addressed new methods for explosive detection for aviation security.

This report discusses what transpired at the workshop and provides a summary of the findings and recommendations.

1 The name of these workshops will probably be changed in the near future reflect that hardware will also be discussed. If possible, the ADSA acronym will still be used.
2 ALERT in this report refers to the COE at NEU

4. Discussion

4.1 Objectives

The objective of the workshop was to explore new methods for explosive detection. In particular, the objective was to discuss new methods for the following applications:

- Checked baggage
- Personnel screening
- Divested items at the check point
- Cargo
- Standoff detection

The issues that were addressed centered on the following points:

- Energy sources being used for explosive detection
- Advantages and disadvantages of different methods
- Limitations based on concealment, containment, explosive type, minimum mass and other factors
- Time and barriers for commercialization
- Concept of operations and applications

The purpose of this section is to synthesize the discussion and recommendations in response to related questions that surfaced during the discussion.

4.2 New Technologies

Many promising technologies were discussed; however, many may not be suitable for deployment as stand-alone devices. Instead, these technologies may be more suitable for fusing with other technologies.

It is important to understand why certain technologies (e.g., neutrons) failed to be widely deployed.

It is also important to understand all the requirement specifications that a vendor faces before a technology may be deployed. These requirements include, but are not limited to, certification testing, operational testing and cost constraints.

4.3 Third Party Involvement

More third parties should be educated about explosive detection so that they can contribute to field. In particular, more information about threats and the requirements for detecting them should be disseminated.

Ideally, a third-party should have access to training data acquired from a deployed piece of explosive detection equipment and be able to test their ATR at the TSL. It would be very difficult for a third party, without direct assistance from a vendor, to accomplish this goal for the following reasons:

1. Detection requirements are classified.
2. Data from deployed equipment are SSI or classified, and are under export control.
3. There is no publicly available set of images that are representative of challenging ATR problems for explosive detection systems.
4. The business interests of the vendors should be protected.
5. DHS/TSA policies do not allow TSL to test components (e.g., an ATR) separate from a complete scanner.
6. There are privacy concerns with scans on AIT equipment.

These issues can be overcome by understanding how ALERT has executed projects for third-party development of segmentation, reconstruction and ATR algorithms.

4.4 Accelerating Deployment

The following tasks should be performed in order to accelerate the deployment of advanced explosive detection equipment, especially those developed by third parties. Many of these tasks are derived from the presentations made by Doug Pearl at ADA07 and ADSA08, and based on the discussion during his presentations.

1. Provide detailed problem statements including:
    a. Short term for vendors and third-party industry.
    b. Long term for students.
2. Increased incentives from the TSA for vendors to deploy scanners with improved detection performance.
3. Increased incentives for third parties to develop advanced algorithms.
4. Government (DHS/TSA) funding of vendors and third parties.
5. Allowing, if possible, more people access to classified and SSI information

or develop non-classified canonical problems capturing ATR challenges.

6. Developing frameworks for protecting:
   a. Intellectual property.
   b. Commercial interests of vendors and third parties.
7. Reducing transaction costs of working with third parties.
8. Having third parties reduce computational expense of new ATR algorithms. The first of the development of new ATR algorithms should not consider computational expense.
9. Giving third parties access to subject matter expert experts in the field of developing and deploying explosive detection equipment.
10. Fund the science of acceptance criteria (metrics).
11. Modifying acceptance tests (e.g., certification, qualification and CRT) to allow increased involvement of third-parties.

4.5 Future ADSA Workshops

1. The following topics should be addressed in future workshops. Note that classification issues may prevent some of these topics from being discussed:
   a. Air cargo inspection
   b. Requirements for deploying equipment as stand-alone and fused with other systems
   c. Concept of operations
   d. X-ray diffraction and phase contrast
   e. Coded aperture
   f. Thermal acoustics
   g. Sparse view CT
   h. Impact of regulatory and testing on deployment and development
   i. Common elements such as image formats and communication protocols
2. The following changes should be considered for future ADSA workshops:
   a. More and longer breaks.
   b. Presentations:
      i. Shorter in number and duration to allow for more discussion.
      ii. Review slides in advance for adherence to presentation methods used at the ADSA workshops. The presentations should not be re-

viewed for technical content.

iii. Concentrate on results.

iv. Obtain permission to release slides in advance.

v. Provide mentorship to new speakers.

c. Encourage attendees to stay until the end of the workshop.

d. Provide abstracts in advance of the workshop to help people decide whether to attend.

5. Acknowledgements

The planning committee would like to thank the following people and organizations for their involvement in the workshop.

- DHS S&T for funding ALERT and sponsoring the workshop.
- Doug Bauer, DHS (retired), Laura Parker, DHS, and George Zarur, DHS & TSA (retired), for their vision to involve third parties in the development of technologies for security applications.
- Laura Parker, DHS, and Greg Struba, DHS, for coordinating DHS/ALERT activities.
- Northeastern University for hosting the workshop.

The workshop would not have been a success without the participants, the speakers and the students who presented posters. We extend our heartfelt thanks to them for their contributions.

6. Workshop Planning and Support

The planning committee for the workshop consisted of the following people:

David Castañón, Boston University

Carl Crawford, Csuptwo

Harry Martz, Lawrence Livermore National Laboratory

Michael Silevitch, Northeastern University

The workshop was moderated by:

Carl Crawford, Csuptwo

The final report was assembled and edited by:

Carl Crawford, Csuptwo

The final report was assembled by:

Seda Gokoglu, Northeastern University

The final report was reviewed by:

Harry Martz, Lawrence Livermore National Laboratory

Logistics for the workshop were led by:

Melanie Smith, Northeastern University

Other logistics, including minute taking and audiovisual assistance, for the workshop were handled by:

Deanna Beirne, Northeastern University

Seda Gokoglu, Northeastern University

Kristin Hicks, Northeastern University

Teri Incampo, Northeastern University

Anne Magrath, Northeastern University

Can Yegen, Northeastern University

The SSI review was done by:

Horst Wittmann, Northeastern University

7. Appendix: Notes

This section contains miscellaneous notes about the workshop itself and the final report.

1. The timing in the agenda was only loosely followed because of the amount of discussion that took place during the presentations and to allow for additional times for participants to network.
2. Some of the presenters edited their material (mainly redacted information) after the workshop.
3. The minutes were edited for purposes of clarity. All errors in the minutes are due to the editors of this report and not due to the speakers themselves.
4. PDF versions of the presentations from this workshop can be found at the following link: https://myfiles.neu.edu/groups/ALERT/strategic_studies/ADSA09_Presentations/.
5. PDF versions of the student posters can be found at the following link: http://myfiles.neu.edu/groups/ALERT/strategic_studies/ADSA09_Posters/.

8. Appendix: Agenda

8.1 October 22, 2013 - Day 1

TIME	TOPIC	SPEAKER	AFFILIATION
8:00	**Registration/Continental Breakfast**		
8:30	Welcome - ALERT	Michael Silevitch	ALERT / NEU
8:35	Welcome - DHS	Laura Parker	DHS
8:40	DHS Centers of Excellence E2E Program	Matt Clark	DHS
8:45	Workshop Objectives	Carl Crawford	Csuptwo
9:05	Photon Counting CT - Potential Advantages Over Dual Energy	Taly Gilat-Schmidt	Marquette University
9:30	Rapid Colour Tomographic Imaging	Robert Cernick	University of Manchester
9:55	**Break**		
10:20	Multi-Energy X-Ray Detectors	Patrick Radisson	Multix Detection
10:45	System-Independent X-Ray Characterization of Materials	Steve Azevedo	Lawrence Livermore National Laboratory
10:55	PFA Predictions	Richard Bijjani	Robehr Analytics
11:20	Explosives Detection at LANL Based on Novel Magnetic Resonance Methods	Larry Schultz	Los Alamos National Laboratory
11:45	**Lunch**		
12:30	Background Cosmic Ray Produced Charged Particles for the Detection of Bulk Drugs and Other Contraband	Michael Sossong	Decision Sciences International Corporation
12:55	Bottle Scanner Technologies	Ben Cantwell	Kromek
1:20	Multi-Spectral 3D Reconstruction and Data Fusion for Contraband Detection in Cargo Containers	Steve Korbly	Passport Systems
1:45	A Major Advance in the State-of-the-Art in Optical Remote Sensing of Trace Compounds	Arsen Hajian	Tornado Spectral Systems
2:10	Addressing Issues with Sample Collection	Jimmie Oxley	University of Rhode Island
2:35	An Engineering Basis for Improved Swab Technology	Stephen Beaudoin	Purdue University
3:00	Trace in Situ Explosives Analysis Using a Miniature Mass Spectrometer	Ryan Espy	Purdue University

TIME	TOPIC	SPEAKER	AFFILIATION
3:25	An IMS with a Resolution of 1,000 and Parts Per Trillion Sensitivity for Ambient Vapors	Jerry Schmitt	Nano Engineering Corporation
4:00	**ALERT Student Poster Session/ Reception**		
6:50	Detection of Ambient Explosive Vapors at Concentrations Below Parts Per Quadrillion	Juan Fernandez de la Mora	Yale University
7:00	**Adjourn**	Carl Crawford	Csuptwo

8.2 October 23, 2013 - Day 2

TIME	TOPIC	SPEAKER	AFFILIATION
07:30	**Continental Breakfast**		
08:00	Call to Order	Carl Crawford	Csuptwo
08:05	ADSA10 Topics	Carl Crawford	Csuptwo
8:10	Challenges and Opportunities for Improved Mm-Wave Whole Body AIT Threat Discrimination	Carey Rappaport	NEU
8:35	GPU Accelerated Ray Tracer for Simulating a Portal Based Security System	Kate Williams	NEU
9:00	Hurdles to the Adoption of New Methods	Matthew Merzbacher	Morpho Detection
9:15	What's the Problem with Neutrons for Explosive Detection?	Harry Martz	Lawrence Livermore National Laboratory
9:30	Apples to Apples Discussion of Emerging Technologies	George Zarur	Self
9:45	Where Does Video Analytics Go Next for TSA	Octavia Camps	NEU
10:00	**Break**		
10:25	Iterative Reconstruction with Vendor Participation	Charles Bouman	Purdue University Notre Dame University
10:40	DNDO Algorithmic Needs and University Engagements	Timothy P. Ashenfelter	DHS Domestic Nuclear Detection Office

TIME	TOPIC	SPEAKER	AFFILIATION
10:55	Algorithms and Architectures for X-Ray Diffraction Tomography	David Castañón	Boston University
11:20	Coding and Sampling for X-Ray Mollecular Imaging	David Brady	Duke University
11:45	Detection with Spectral X-Ray Detectors and the Complimentary Method of X-Ray Diffraction	Ed Morton	Rapiscan
12:10	**Lunch**		
12:55	The Application of Scatter Attenuation Tomography (SAT) for Explosives Detection	Peter Rothschild	American Science and Engineering
1:20	Gratings-Based Phase Contrast X-Ray Imaging for Improved Material Discrimination	Erin Miller	Pacific Northwest National Laboratory
1:45	Novel Differential Phase Contrast 3D X-Ray Imaging for Aviation Security Application	Bert Hesselink	Stanford University
2:10	**Break**		
2:35	Vigilance Decrement: When Does It Happen and What Might Be Done	Matthew Cain	Harvard Medical School
3:00	Missed Technologies	Tim White	Pacific Northwest National Laboratory
3:25	Next Steps	Harry Martz	Lawrence Livermore National Laboratory
3:50	Closing Remarks - DHS	Laura Parker	DHS
3:55	Closing Remarks - NEU	Michael Silevitch	ALERT / NEU
4:00	Adjourn	Carl Crawford	Csuptwo

Note: The timing in the agenda was only loosely followed due to the amount of discussion that took place during the presentations and to give additional time for participants to network.

9. Appendix: Student Posters

Select posters presented at ADSA09 are available for viewing online at: http://myfiles.neu.edu/groups/ALERT/strategic_studies/ADSA09_Posters/.

The complete list of student posters presented at ADSA09 is:

POSTER TITLE	POSTER AUTHORS
In-The-Exit Video Analytics Transition Solution	Tom Hebble, Oliver Lehmann, Fei Xiong, John Romano, Octavia Camps, Rick Moore, John Beaty *Northeastern University*
Automatic SAR Processing for Profile Reconstruction and Recognition of Dielectric Objects on the Human Body Surface	Yuri Alvarez *University of Oviedo, Spain* Borja Gonzalez-Valdes, Jose Angel Martinez, Carey M. Rappaport, Fernando Las-Heras *Northeastern University*
Tracking in Large Public Spaces	Mustafa Ayazoglu, Caglayan Dicle, Binlong Li, Fei Xiong, Octavia Camps, Mario Sznaier Northeastern University
Microencapsulation for Safer Handling of Explosives	J. Oxley, J. Smith, J. Canino, R. Rettinger, M. Porter *University of Rhode Island*
URI Supporting Explosives Detection	URI Energetics Laboratory, Department of Chemistry
Simulants for X-Ray Bottle Screening	Jimmie C. Oxley, James L. Smith, Austin C. Brown *University of Rhode Island*
A Method for Simultaneous Image Reconstruction and Bea Hardening Correction	Penchong Jin, Charles A. Bouman, Ken D. Sauer *Purdue University*
Advances in Understanding Contact-Based Sampling for Explosives Detection	M. Sweet, S. Beaudoin *Purdue University*
Target Identification in Multi- and Dual-Energy Computed Tomography	Brian H. Tracey, Eric L. Miller *Tufts University*

10. Appendix: Previous Workshops

Information about the previous eight workshops, including their final reports, can be found at:

www.northeastern.edu/alert/transitioning-technology/strategic-studies

11. Appendix: List of Participants

NAME		AFFILIATION
Matt	Aeillo	Northeastern University
Yuri	Alvarez	Northeastern University
Timothy	Ashenfelter	Department of Homeland Security
Stephen	Azevedo	Lawrence Livermore National Laboratory
Kumar	Babu	Ccuneus Solutions, LLC
Rolan	Bangalan	Transportation Security Administration
Douglas	Bauer	University of Connecticut
John	Beaty	Northeastern University
Steve	Beaudoin	Purdue University
Moritz	Beckmann	XinRay Systems LLC
Deanna	Beirne	Northeastern University
Richard	Bijjani	Robehr Analytics
Ralf	Birken	Northeastern University
Carl	Bosch	SureScan
Charles	Bouman	Purdue University
Douglas	Boyd	TeleSecurity Sciences, Inc.
David	Brady	Duke University
Austin	Brown	University of Rhode Island
Emel	Bulat	Northeastern University
Matthew	Cain	Brigham Women's Hospital
Octavia	Camps	Northeastern University
Jonathan	Canino	University of Rhode Island
Ben	Cantwell	Kromek
David	Castañón	Boston University
Robert	Cernik	University of Manchester
Ke	Chen	Boston University
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Matthew	Clark	Department of Homeland Security
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Synho	Do	Massachusetts General Hospital

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Jeffrey	Hamel	IDSS
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Simon	Pongratz	L-3 Communications
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Patrick	Radisson	Multixdetection
Carey	Rappaport	Northeastern University
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James	Smith	University of Rhode Island
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Samuel	Song	TeleSecurity Sciences, Inc.
Michael	Sossong	Decision Sciences International Corporation
Marion (Rocky)	Starns	ScanTechIBS
Greg	Struba	Department of Homeland Security
Zachary	Sun	Boston University
Devon	Swanson	University of Rhode Island
Melissa	Sweat	Purdue University
Ling	Tang	Rapiscan Laboratories, Inc.
Brian	Tracey	Tufts University
Nawfel	Tricha	SureScan
Alex	Van Adzin	Photo Diagnostic Systems, Inc.
Seth	Van Liew	American Science and Engineering, Inc.
Amit	Verma	Capture, LLC
Lou	Wainwright	Triple Ring Technologies
Whitney	Weller	Force 5 Networks, LLC
Dana	Wheeler	Radio Physics Solutions
Tim	White	Pacific Northwest National Lab
Alyssa	White	Massachusetts General Hospital

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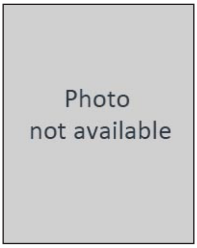
Kathryn	Williams	Northeastern University
Horst	Wittmann	Northeastern University
Kam Lin	Wong	SAIC
Birsen	Yazici	Rensselaer Polytechnic Institute
Can	Yegen	Northeastern University
George	Sarur	XinRay Systems, LLC

12. Appendix: Presenter Biographies

Timothy Ashenfelter

Department of Homeland Security



Dr. Ashenfelter has served as a Program Manager and Physical Scientist at DNDO's Transformation and Applied Research Directorate (TARD), where he manages the Algorithms & Modeling Portfolio as well as the Nuclear Forensics Portfolio. In this role Dr. Ashenfelter manages over two dozen projects within small business, national laboratories, and private industry. Prior to joining TARD, Dr. Ashenfelter was a Principal Scientist at Noblis where he provided broad subject matter support across a cross-section of interagency partners within DHS, DOD, and DOJ. Dr. Ashenfelter has also served as a Senior Scientist at the Department of Energy's Remote Sensing Laboratory (RSL), where he was a Team Scientist and Team Captain numerous federal response teams to include DOE's Aerial Measuring System (AMS) Team, Radiological Assistance Program (RAP), and Nuclear Radiological Advisory Team (NRAT).

When not deploying or training, Dr. Ashenfelter originated, led, managed, and acted as Principal Investigator on a number of Research & Development (R&D) Projects to include several large multi-year, multi-laboratory efforts in improving nuclear search technologies from real-time spatial mapping, tracking in GPS-denied environments, neutron spectroscopy, advanced spectral detection algorithms, and video-fused directional detection systems. Several of his research and development efforts have been successfully transitioned and are currently deployed by DOD and DOE. Before joining RSL, Dr. Ashenfelter received his Ph.D. in Physics from the University of Notre Dame. His dissertation research delved into emerging phenomena in theoretical nuclear astrophysics related to the chemical evolution of the Universe.

Stephen Azevedo

Lawrence Livermore National Laboratory

Dr. Stephen Azevedo is currently Project Engineer for Livermore Explosives Detection Program where he leads R&D efforts in advanced detection systems for aviation security at Lawrence Livermore National Laboratory (LLNL). During his 30+ years at LLNL, he has held a number of technical and leadership positions including Project Leader for National

Ignition Facility Shot Data Analysis, Project Leader of the Micropower Impulse Radar (MIR) Project (working on specialized radar systems for various applications including bridge-deck inspection, low-power communications, search-and-rescue, and mine detection) and Deputy Division Leader. His interests have been in the areas of computational signal and image processing research, including computer algorithms, numerical methods, languages, display techniques, and inspection imaging. For eight years, he was Director of the Center for Advanced Signal and Image Sciences (CASIS), and has been on the International Scientific Advisory Committee for the ICALEPCS conference series. He has been a principal investigator for computed tomography research and radar remote sensing, x-ray inspection, nondestructive evaluation and imaging. He has earned four R&D 100 awards for technical excellence.

Dr. Azevedo graduated with his B.S. in Electrical Engineering from U. C. Berkeley in 1977 and received a Masters in E.E. and Biomedical Engineering from Carnegie-Mellon University in 1978. He earned his Ph. D. in 1991 from U. C. Davis (EECS) for his research in model-based tomographic reconstructive imaging. He has been employed at LLNL since 1979.

Stephen Beaudoin
Purdue University

Stephen P. Beaudoin received his Bachelor of Science degree from MIT in 1988, his Master of Science degree from the University of Texas at Austin in 1990, and his PhD from North Carolina State University in 1995. All of his degrees are in Chemical Engineering.

Dr. Beaudoin was appointed Assistant Professor in Chemical Engineering at Arizona State University in the Fall of 1995, and was promoted to Associate Professor with tenure in the Fall of 2000. In the Spring of 2003, he joined the faculty of the School of Chemical Engineering at Purdue, where he was promoted to the rank of Professor in the Fall of 2006. Dr. Beaudoin has served the School of Chemical Engineering at Purdue as Associate Head, as Director of Undergraduate Studies, and as Director of Graduate Admissions. Dr. Beaudoin has won the Faculty Early Career Development Award from the National Science Foundation, and has been named a Purdue University Faculty Scholar and Purdue University Provost Fellow for Student Success. He has won numerous teaching and mentoring awards, including being the inaugural recipient of the Purdue University Student Government Teaching Excellence Award.

Dr. Beaudoin's areas of research interest are focused on particle and thin film adhesion. His work finds applications in explosives detection and in microelectronics, food, and pharmaceutical manufacturing.

Richard Bijjani
Robehr Analytics

Dr. Richard Robehr Bijjani has been a thought leader in security technology for over 20 years. He designed and developed many security products including a dozen different Explosive Detection Systems (EDS) utilizing various technologies. The systems he designed managed to successfully exceed the certification requirements of every known EDS detection standard in the world; a unique achievement. In 1990, Richard managed R&D during the development of a dynamic signature verification product at Kumahira Inc., one of the very first biometrics products in the industry. In 1994, he joined InVision Technologies as head of the Algorithm and Machine Vision group where he oversaw the development effort that led to the first successful certification by the FAA, a historic event for the then still nascent industry. He went on to design and certify multiple EDS systems for InVision (now Morpho Detection) and later for Vivid (now L3). In 2002, he co-founded Reveal Imaging (now an SAIC company) where he designed and developed the world's highest performing automated explosive detection systems to date, which also happen to be the least expensive and the smallest. In January 2012, Richard founded Robehr Analytics which provides focused consulting services to key government agencies. In June 2012 he became an advisor for nCrypted Cloud which enables privacy, security and collaboration in the cloud. In October 2012 Richard co-founded Quanttus Inc. a consumer health care company that will forever change the way we view our personal health. Dr. Bijjani has a Ph.D. in Electrical Engineering from Rensselaer Polytechnic Institute.

Charles Bouman
Purdue University

Charles A. Bouman is the Showalter Professor of Electrical and Computer Engineering and Biomedical Engineering at Purdue University where he also serves has a co-director of Purdue's Magnetic Resonance Imaging Facility. He received his B.S.E.E. degree from the University of Pennsylvania, M.S. degree from the University of California at Berkeley, and Ph.D. from Princeton University in 1989. Professor Bouman's research focuses on inverse problems, stochastic modeling, and their application in a wide variety of imaging problems including tomographic reconstruction and image processing and rendering. Prof. Bouman is a Fellow of the IEEE, AIMBE, IS&T, and SPIE and is currently the IEEE Signal Processing Society's Vice President of Technical Directions. He has also served as the Editor-in-Chief of the IEEE Transactions on Image Processing and the Vice President of Publications for the IS&T Society.

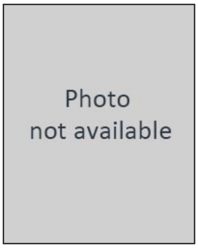
David Brady
Duke University

David Brady is the Michael J. Fitzpatrick Endowed Professor of Photonics at Duke University, where he leads the Duke Imaging and Spectroscopy Program. Brady's contributions to computational imaging system development include lensless white light imaging, optical projection tomography, compressive holography, reference structure tomography, coded aperture snapshot spectral imaging and coded aperture x-ray scatter imaging. He is currently the principal investigator for the DARPA AWARE Wide Field of View project, which aims to build compact streaming gigapixel scale imagers and the DARPA Knowledge Enhanced Exapixel Photography project, which focuses on code design for high pixel count spectral imagers. He is the author of Optical Imaging and Spectroscopy (Wiley-OSA, 2009) and is a Fellow of IEEE, SPIE and OSA.

Matthew Cain
Duke University

Matthew S. Cain received his Ph.D. at the University of California, Berkeley, where he studied cognitive control, task switching, attention, and video game players. He has since worked as a postdoctoral researcher with Steve Mitroff at Duke University, studying miss errors in multiple-target visual search as well as trying to understand the impact of media multitasking behavior in attentional control and with Takeo Watanabe and Yuka Sasaki at Brown University studying lower-level perceptual-learning processes and how they are affected by sleep in a postdoc with. He is currently a postdoctoral fellow in the Visual Attention Lab of Brigham & Women's Hospital and Harvard Medical School where he studies attention, vigilance, and multiple-target visual search, especially ecologically inspired foraging models.

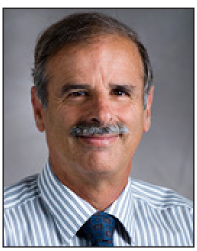
Octavia Camps
Northeastern University



Benjamin Cantwell
Kromek

Dr. Ben Cantwell completed high Ph.D. in the growth of CZT crystals, and was one of the founders of Kromek, formed to commercialise this technology. He has worked on the development of a number of products, including taking Kromek's multispectral Identifier Bottle Scanner to the highest level of certification by the European Union. Dr. Cantwell has interests in a range of fields for new technology development, including multispectral detectors, applications physics and decision algorithms.

David Castañón
Boston University



Prof. David Castañón is the Chair of the Electrical and Computer Engineering Department at Boston University. He received his Ph.D. in Applied Mathematics at Massachusetts Institute of Technology, and his B.S. in Electrical Engineering at Tulane University. Before joining Boston University, he was Chief Scientist of ALPHATECH, Inc. He has served as a member of the Air Force Scientific Advisory Board and is a former president of the IEEE Control Systems Society. He is the director of the Center for Information and Systems Engineering at Boston University. His research interests include optimization, inverse problems, stochastic control and machine learning, with diverse applications such as target recognition, compressive sensing and tomographic image reconstruction.

Robert Cernik
University of Manchester

Bob Cernik graduated in physics from University College Cardiff (University of Wales) in 1976 and obtained his PhD from the same university. He came to Manchester in 1979 to work in crystal structure analysis as a joint appointment for the chemistry departments of UMIST and the Victoria University of Manchester. After this 3 year postdoctoral fellowship he left for industry where he joined Ferranti Electronics working in semiconductor process evaluation. In 1986 he joined Daresbury laboratory in Cheshire working on the world's first synchrotron radiation source dedicated for scientific research. He began working as a station scientist interested in powder X-ray diffraction; subsequently becoming head of the X-ray diffraction group and then director responsible for the physical sciences. In 2000 he sat on two government committees to shape the direction of science in the region and helped to launch the new company incubator initiative at Daresbury. In 2002 he renewed his association with Manchester becoming a joint appointment with the Materials Science Centre. This collaboration lasted until 2006 when he joined the the School of Materials full time, he also holds a visiting chair at the Department of Crystallography, Birkbeck College London. He is currently responsible for the administration of the hard materials grouping within the School (ceramics, metallurgy and corrosion).

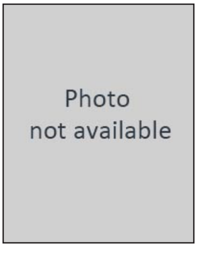
Bob's research interests cover the development of synchrotron radiation as an analytical tool in materials science, especially developing the technique of dark field hyperspectral X-ray imaging (colour imaging of X-rays) which has most recently led to a patent filing. He is also interested in the structural evaluation and design of multiferroic materials and functional ceramics and makes significant use of X-ray, neutron and electron sources.

Carl Crawford
Csuptwo

Carl R. Crawford, Ph.D., is president of Csuptwo, LLC, a technology development and consulting company in the fields of medical imaging and Homeland Security. He has been a technical innovator in the fields of computerized imaging for more than thirty years. Dr. Crawford was the Technical Vice President of Corporate Imaging Systems at Analogic Corporation, Peabody, Massachusetts, where he led the application of signal and image processing techniques for medical and security scanners. He developed the reconstruction and explosive detection algorithms for a computerized tomographic (CT) scanner deployed in airports worldwide. He was also employed at General Electric Medical Systems, Milwaukee, Wisconsin, where he invented the enabling technology for helical scanning for medical CT scanners, and at Elicit, Haifa, Israel, where he developed technology for cardiac CT scanners. He also has developed technology for magnetic resonance imaging (MRI), single photon emission tomography (SPECT), positron emission tomography (PET), ultrasound imaging (U/S), dual energy imaging and automated threat detection algorithms based on computer aided detection (CAD). Dr. Crawford has a doctorate in electrical engineering from Purdue University. He is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), is a Fellow of the American Association of Physicists in Medicine (AAPM), and is an associate editor of IEEE Transactions on Medical Imaging.

Ryan Espy
Purdue University

Juan Fernandez de la Mora
Yale University



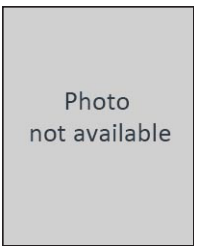
Taly Gilat-Schmidt

Marquette University

Taly Gilat Schmidt, Ph. D., is an assistant professor of Biomedical Engineering at Marquette University. Her research interests include medical imaging system design, optimization, and reconstruction. Dr. Schmidt earned an undergraduate degree in Electrical Engineering from the University of Illinois at Urbana Champaign, after which she was employed in the Edison Engineering Program at GE Healthcare. Dr. Schmidt received her M.S. and Ph. D. in Electrical Engineering from Stanford University. She directs the Medical Imaging Systems Laboratory at Marquette University, which is currently conducting research funded by the NIH, DOE, and GE Healthcare.

Arsen Hajian

Tornado Spectral Systems, Inc.



Dr. Hajian is currently the Founder and Chief Technology Officer of Tornado Spectral Systems, Inc. He was educated as a classical astronomer at MIT and Cornell University, and has previously worked as an associate professor at the University of Waterloo in the Department of Systems Design Engineering and as a research astronomer (civil servant) at the U.S. Naval Observatory in the Department of Astrometry. He has spent his career developing new instrumentation packages for a variety of government, academic, and industry customers. He has an established record of bringing new technologies to fruition and a strong publication record, with over 40 peer-reviewed journal articles, and more than 100 conference proceedings.

Lambertus Hesselink

Rapiscan Systems

Professor Hesselink's research interests are focused on Novel 3-D X-ray Imaging systems for application in medical and aviation security applications, nano photonics, efficient energy systems and remotely accessible laboratories that are infinitely scalable (iLabs first developed at Stanford in 1996) and form an integral part of Massively Open On-line Courses (MOOCs). He is a member of the Royal Dutch Academy of Arts and Sciences and a serial entrepreneur, with extensive business experience.

Steve Korbly

Passport Systems

Dr. Stephen Korbly is the Director of Science at Passport Systems. He received his Ph.D. from the Massachusetts Institute of Technology (MIT) in plasma physics with a concentration in accelerator physics, and his AB in physics from Princeton University. At Passport Systems, Dr. Korbly has managed the research and development efforts for the design of two products: 1) a scanner based on several new technologies for the inspection of air, land and sea cargo, and 2) a system of networked radiation detectors. Dr. Korbly has seen the cargo inspection system go from the feasibility stage through government testing and is now leading the effort to deploy a system in an operational port. Prior to Passport, Dr. Korbly led the testing of the 20 MeV, 17 GHz linear electron accelerator at the Plasma Physics Laboratory at MIT to measure the length of the sub-picosecond electron bunches produced by this accelerator. Dr. Korbly is an experienced project leader/manager who has delivered various projects on time and within budget from the beginning requirements to development, testing and product rollout phases. In addition to being an experienced practitioner of experimental physics, Dr. Korbly has extensive experience in developing new technologies and managing a diverse set of people and technical requirements.

Harry Martz

Lawrence Livermore National Laboratory

Harry Martz is currently the Center Director for Nondestructive Characterization and PI on DHS S&T Explosive Division Explosive Detection Projects and DNDO Nuclear and Radiological Imaging Platform. Harry joined the Laboratory in 1986 as a Physicist to develop the area of x-ray and proton energy loss computed tomography for the nondestructive inspection of materials, components, and assemblies.

Harry's interests include the research, development and application of nonintrusive characterization techniques as a three-dimensional imaging tool to better understand material properties and inspection of components and assemblies, and generation of finite element models from characterization data. He has applied CT to inspect one-millimeter sized laser targets, automobile and aircraft components, reactor-fuel tubes, new production reactor target particles, high explosives, explosive shape charges, dinosaur eggs, concrete and for nondestructive radioactive assay of waste drum contents. Recent R&D efforts include CT imaging for explosives detection in luggage and radiographic imaging of cargo to detect special nuclear materials. Dr. Martz has authored or coauthored over 100 papers and is coauthor of a chapter on Radiology in Nondestructive Evaluation: Theory, Techniques and Applications, Image Data Analysis in Nondestructive Testing Handbook, third edition: Volume 4, Radiographic Testing, and contributed a chapter entitled Industrial Computed Tomographic Imaging to the Advanced Signal Processing Handbook: Theory and Implementation for Radar, Sonar and Medical Imaging Real-Time Systems. Dr. Martz has presented a short course on CT imaging at The Center for Nondestructive Evaluation, Johns Hopkins University and a course on X-ray Imaging for UCLA's Extension Program. Currently Dr. Martz is writing a text book on Industrial X-ray Imaging.

Matthew Merzbacher

Morpho Detection

Dr. Merzbacher is manager of the Machine Vision and Innovation group at Quantum Magnetics (part of the SAFRAN group's Morpho Detection). In addition to managing the group, Dr. Merzbacher works on technical projects, such as break-bulk cargo, DICOS, and the detection algorithms for the MDI family of explosives detection systems. He was chair of the NEMA DICOS Threat Detection Working Group, charged with developing a standard for image interchange in security applications. He joined what was, at the time, InVision Technologies in 2003 as a Research Scientist in the Machine Vision group. Dr. Merzbacher has a Ph.D. in Computer Science from UCLA, specializing in data mining. He has several pending patents on image processing for explosives detection.

Erin A. Miller

Pacific Northwest National Laboratory

Erin Miller is a scientist in the Radiation Detection & Nuclear Sciences group at Pacific Northwest National Laboratory. She received her PhD in physics from the University of Washington. Her research includes phase contrast x-ray imaging using a gratings-based interferometer for applications including explosives detection and structure-function relationships for microbial biofilms, synchrotron-based x-ray measurements, developing algorithms for combining passive and radiographic data for source detection and characterization, and exploring a of deterministic and hybrid methods for radiation transport simulation and inverse problems.

Edward Morton

Rapiscan

Dr. Edward Morton is the Technical Director for Rapiscan Systems. Following an academic career with a research focus on X-ray imaging, he moved to Rapiscan Systems where he has worked primarily on real-time X-ray tomography and high energy X-ray inspection techniques.

Jimmie C. Oxley

University of Rhode Island

Prof. Jimmie Oxley is a Professor of Chemistry at the University of Rhode Island. She earned a Ph.D. in Chemistry from the University of British Columbia and joined the faculty of New Mexico Institute of Mining and Technology where she founded a Ph.D. program in explosives and created a Thermal Hazards Research group. Oxley's lab specializes in the study of energetic materials—explosives, propellants, and pyrotechnics.

Laura Parker

Department of Homeland Security

Laura Parker works as a Program Manager in the Explosives Division of the Science and Technology Directorate at the Department of Homeland Security (DHS). She works on multiple projects for algorithm development for improved explosives detection as well as in the trace explosive detection area. Laura is also the Program Manager for the ALERT Center of Excellence, a DHS-sponsored consortium of universities performing research that address explosive threats co-lead by Northeastern University and University of Rhode Island. Previous to her present position at DHS, Laura has worked as a contractor providing technical and programmatic support of chemical and biological defense and explosives programs for several Department of Defense (DoD) offices. She has also worked in several DoD Navy laboratories in the field of energetic materials. She obtained her Ph.D. form the Pennsylvania State University in chemistry.

Patrick Radisson

Multix Detection

Patrick Radisson is Chief Technical Officer of MultiX. Graduated from Ecole Nationale Supérieure des Telecommunication (ENST) PARIS with an electronics engineering degree he also got a MicroElectronics advanced degree (DEA Microélectronique) and a degree in Management (MASTER MSGO) from IAE Grenoble.

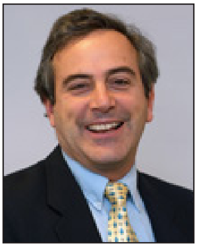
He has extensive experience in the development of X-ray based detection systems when he was at Thales Electron Devices where he managed a X-ray detector Product line before taking in charge Advanced Technologies activities in X-Ray and THZ giving rise to the development of emerging X-ray spectrometric solutions for security applications through the creation of MultiX.

He is co-founder with Jacques Doremus of MultiX a French spin-off from Thales dedicated to Xray spectrometric detection solution for security application. He is managing a team of highly trained engineers and scientists developing new spectrometric detectors for security applications and define the technical and product Road map.

He also has a strong experience in Detection and Imaging, microelectronics and micro- technologies through different positions in THOMSON CSF, SOFRADIR, PHSMEMS and THALES.

Carey M. Rappaport

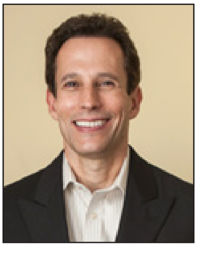
Northeastern University



Prof. Carey Rappaport is a co-Princial Investigator of the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems NSF ERC, and the Deputy Director for the Homeland Security Center of Excellence for Awareness and Localization of Explosives Related Threats (ALERT). Prof. Rappaport received five degrees from the Massachusetts Institute of Technology: the SB in Mathematics, an SB, SM, and EE in Electrical Engineering in 1982, and a Ph.D. in Electrical Engineering in 1987. He joined the faculty at Northeastern University in 1987, and has been Prof. of Electrical and Computer Engineering since 2000 and Distinguished Professor since 2010. In 2006, he became a Fellow of IEEE. He was Principal Investigator of an ARO-sponsored Multidisciplinary University Research Initiative on Humanitarian Demining. Prof. Rappaport has authored over 400 technical journal and conference papers in the areas of microwave antenna design, electromagnetic wave propagation and scattering computation, and bioelectromagnetics, and has received two reflector antenna patents, two biomedical device patents and three subsurface sensing device patents.

Peter Rothschild

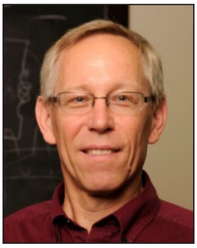
American Science and Engineering



Peter is the Chief Scientist at American Science & Engineering, where he has been involved for more than 15 years with the design and development of novel backscatter x-ray imaging systems. He is the author or co-author of more than 30 issued U.S. patents in x-ray imaging for security applications. Peter received his Ph.D. degree from MIT in high-energy nuclear physics.

Ken Sauer

University of Notre Dame



Ken Sauer received the B.S.E.E. in 1984 and the M.S.E.E. in 1985 from Purdue University, West Lafayette, IN. He completed the Ph.D. in Electrical Engineering as an AT&T Foundation Fellow at Princeton University in 1989. Since then he has been with the University of Notre Dame, currently holding the position of Associate Professor and Director of Undergraduate Studies in the Department of Electrical Engineering. Prof. Sauer's research interests are primarily within the domain of inverse problems, with particular concentration in tomography for medical diagnostic imaging and nondestructive evaluation. His research has been funded by GE Health Care, the Department of Homeland Security, NASA, the National Science Foundation, GE Energy, Electricite de France and the State of Indiana's 21st Century Fund.

Jerry Schmitt

NanoEngineering Corporation

A serial entrepreneur, Jerry is the founder and president of NanoEngineering Corporation with focus on development of the DMA technology for ion and nanoparticle detection and classification. A student of Prof. Juan Fernandez de la Mora, Jerry earned his BS in Mechanical Engineering from Yale.

Larry Schultz

Los Alamos National Laboratory

Dr. Larry Schultz has developed a number of national security solutions at Los Alamos National Laboratory over the last 12 years. He specializes in information extraction and algorithm development for detection systems and radiography.

Michael Silevitch

Northeastern University

Michael B. Silevitch is currently the Robert D. Black Professor of Electrical and Computer Engineering at Northeastern University in Boston, an elected fellow of the IEEE, and the Director of the Homeland Security Center of Excellence for Awareness and Localization of Explosives Related Threats (ALERT).

His training has encompassed both physics and electrical engineering disciplines. An author/co-author of over 65 journal papers, his research interests include laboratory and space plasma dynamics, nonlinear statistical mechanics, and K-12 science and mathematics curriculum implementation. Of particular interest is the study of the Aurora Borealis, one of nature's most artistic phenomena. Avocations include long distance hiking and the study of 17th Century clocks and watches.

Prof. Silevitch is also the Director of the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS), a graduated National Science Foundation Engineering Research Center (ERC). Established in September of 2000, the mission of Gordon-CenSSIS is to unify the methodology for finding hidden structures in diverse media such as the underground environment or within the human body.

Michael Sossong

Decision Sciences International Corporation

Recipient of the 2011 prestigious Christopher Columbus Homeland Security Award, Columbus Scholar Dr. Michael Sossong has revolutionized the state of the art for passive nuclear threat detection using cosmic ray muon tomography. Dr. Sossong currently heads research efforts for Decision Sciences International Corporation (DSIC), advancing cutting-edge research and application of advanced technologies. He joined DSIC as Director of Nuclear Technology Research in April 2008, leading the commercial development of the multi-mode passive detector system (MMPDS) and other proprietary scanners and methods. Previously working on the early development of muon tomography (MT) at Los Alamos National Laboratory (LANL), he was instrumental in the creation of full-physics simulation models for MT development, the application of tomographic algorithms to muon data, and the design and construction of

DSIC' first prototype MMPDS. Additionally, Dr. Sossong contributed to several homeland security, nuclear stockpile stewardship and arms control related projects. Dr. Sossong earned his Ph.D., M.S. and B.S. degrees in Physics at the University of Illinois at Urbana-Champaign.

Timothy White

Pacific Northwest National Laboratory

Photo
not available

Kathryn Williams

Northeastern University

Photo
not available

Kate Williams has been with Northeastern University's ALERT Center since 2010, working with various electromagnetic methods to simulate millimeter-wave security systems. Kate graduated from Northeastern University in 2010 with a BS degree in electrical engineering and physics. During her time as an undergraduate, she completed co-ops at EMC, Boston Scientific, and SiOnyx. She graduated from the Gordon Engineering Leadership Program in 2011 and is currently a candidate for an MS degree in electrical engineering.

George Zarur

Self

Photo
not available

Dr. Zarur has advanced Degrees in Chemistry and Physics and was educated at Georgetown University, Catholic University, Princeton and Stanford. His career is split between the private sector in the scientific engineering consulting industry and with the Federal Government, with the Justice Dept, Marshals Service and then with the Department of Homeland Security. Dr. Zarur was recruited right after 911 to help stand up TSA with responsibility for technology including the acquisition of several billion dollars of CT and Trace Detection systems. He later joined L3 Communications as the VP of Technology for the security and detection Division and was responsible for identification of new technology and acquisitions, including the mmwave portal, and the start of the non rotating gantry effort.

After three years, he was again asked to join DHS as the Science Advisor to the Deputy Secretary of DHS for next generation Detection systems. in 2009 he transferred to TSA as the Science Advisor till his retirement in 2011. Since then, he has been advising several start-ups in X-ray and mmwave technologies.

13. Appendix: Questionnaire

Attendees were asked to fill out a questionnaire providing feedback on the workshop. The questions are listed below; the answers appear in the next section. Responses are grouped by question and then by person; the first respondent is response A for each question, the second respondent is B, and so on.

1. What is your relationship to ALERT?
2. Which technologies discussed during this workshop show promise?
3. What promising emerging technologies were not discussed at the workshop?
4. What should be done to expedite the deployment of emerging technologies?
5. How can third parties be involved in the development of new explosive detection equipment?
6. Do you have recommendations for future workshop topics?
7. What did you like about this workshop?
8. What would you like to see changed for future workshops?
9. What other comments do you have?

14. Appendix: Questionnaire Responses

Question 1: What is your relationship to ALERT?

A	Trade Association
B	Academia
C	Industry
D	Industry
E	Industry
F	Industry
G	Industry
H	National lab
I	Industry
J	ALERT team member
K	Academia
L	Industry
M	ALERT team member
N	Industry
O	Industry
P	Industry
Q	Academia
R	Industry
S	National lab
T	Industry
U	Academia
V	Consultant

W ALERT team member

X Government

Y Industry

Z Academia

Question 2: Which technologies discussed during this workshop show promise?

A x-ray, trace

B iterative reconstruction and advanced filter back projection fusion of X-ray with optical spectrometers (Toronto presentation) Maybe, maybe compressive sensing and coded aperture (It still sounded pretty much in a fundamental research state) I'm not sure of the comparative advantages/disadvantages of mm wave/x-ray back scatter.

C I'd say only the mm-wave improvement technologies showed much promise of being fieldable in anything like the short term. In the medium term, some of the coherent scatter technologies might function as add-ons to CT systems. System cost, flux, and throughput are going to be major challenges.

D Photon-counting multi-energy detectors seem to show a lot of promise with respect to diffraction and material discrimination.

E Various CT technologies Algorithm enhancements

F X-Ray diffraction, advanced gantry-less CT systems, XRF tomography, diffraction tomography, structured beam illumination with sparse detectors, multi-energy transmission

G No response

H Dual-energy, Multi-energy, X-ray diffraction,

I NMR+X-ray, multispectral, diffraction

J AFM

K No response

L X-ray diffraction and scatter imaging show promise for hold baggage and checkpoint applications, however the development challenges and timeline will be much longer and more difficult than DHS is trying to achieve. It was also interesting to get an over-view of the trace detection technologies and applications for cargo screening.

M No response

N No response

O Improved reconstruction techniques and new simulation tools. The work on X-ray diffraction also show a lot of promise

P No response

Q No response

R Several interesting technologies were discussed. It's hard to say which ones show the most promise.

S No response

T X-ray Diffraction Multi-Energy X-ray detectors

U No response

V No response

W No response

X I think that fusion of NMR and X-ray CT could be promising. Also, the cosmic rays for bulk detection is definitely interesting and could really simplify things in the future.

Y X-Ray Diffraction

Z Trace methods which are becoming more portable, and cargo methods which are being enabled by more sensitive detectors

Question 3: What promising emerging technologies were not discussed at the workshop?

A No response

B More focus on compressive sensing/coded aperture to see if it is real in the airport security contexts in which we are concerned. I agree that a focus on cargo for ADSA 10 would be useful. acoustic technology based on dielectric properties thermal imaging IR spectroscopy

C Machine learning and Bayesian techniques for algorithms and reconstruction

D I wished there were more topics on sparse view reconstruction; something that we had assumed the TSA is moving towards.

E Integrated Checkpoint. Integrated technologies. More emphasis on Operational impact and benefit and specific operational metrics- lower operational costs, reduced manning/staffing, Faster scans/ higher throughput.

F No response

G No response

H No response

I No response

J Synthesis

K No response

L Can not think of anything significant.

M No response

N No response

O Would liked to see a bit more on progress on standoff detection

P No response

Q No response

R Not sure.

S No response

T Stationary CT Sparse View CT

U No response

V No response

W No response

X No response

Y Non-uniform Pixel Size & Spacing (required for better segmentation)
Segmentation Classification

Z No response

Question 4: What should be done to expedite the deployment of emerging technologies?

A Clearly define the testing process, and steps between testing and procurement. What factors influence progress?

B Fundamental overhaul of the acquisition policies of TSA change incentive structure so that the best technologies are, indeed, rewarded. Now, passing cert is all that is required (Doug Pearl's perspectives)

C It might be worth having a "Rate this Technology" app at the conference, with a scorecard for each talk in many dimensions--System Cost, Robustness, Deployability, Reliability, Speed, ConOps, Discrimination, Expected Time to Market--allowing quasi-real time "crowd-sourced" opinions from the experts to guide development. As the above shows, making a new technology deployable requires a technology to be workable in more than just the technical dimension of discrimination, and while they should not throttle development too early, they need to be considered fairly early on with at least a conceptual outline of how they might be achievable. This will help DHS winnow down faster to technologies that have a chance of making it into the field, and less time and resources spent on "technology of the month".

D More collaboration between the different institutions and within the industry would be more beneficial to the entire security community. The DHS should pro-actively encourage this.

E 1. Focus on technology transfer and pilot deployments 2. Streamline the certification and regulation process 3. Clearer acquisition requirements from Government to industry 4. System engineering analysis to assess issues/challenges and operational impact of the new emerging technologies, algorithms and concept of operations. Need to do perform analysis and perform trials and pilot deployments to assess impact in the airport environment.

F Funding directed specifically to technologies that show a promising level of practical application, rather than just theoretical application

G Include TSA in the meeting

H Get more involvement by the government people (DHS, CBP, etc.) who have an influence in supporting and funding these ideas

I Greater input from customers - at present it is too much trial and error and second guessing

J More funding.

K No response

L More funding for technology development and less protracted government contracting process for new technology.

M No response

N No response

O Create incentives at the TSA, either as incentives for new procurements or as part of a continuous improvement program for already deployed systems

P No response

Q No response

R It would be good to have more engagement from the DHS S&T customer to keep workshop participants informed of their plans and road maps going forward. Industry could then better understand which emerging technologies the customer is most interested in.

S No response

T Increased DHS S&T Funding

U No response

V No response

W No response

X More communication between DHS/TSL and acadamia and industry so that everyone can be on the same page moving forward. If people aren't aware of the solutions to the problems they have, they can be left in the dark and not foster change.

Y Pay for case studies

Z More opportunity for field testing emerging technologies

Question 5: How can third parties be involved in the development of new explosive detection equipment?

A No response

B In the ways that DHS S&T has initiated. Future BAAs from S&T should establish policies by which third parties are encouraged

C At least in checked baggage, there's a difficult and strict certification process. Unless and until that process is modified, no vendor is going to let its certification stamp be dependent on the performance of an outside third party, except under terms of subcontracts. (Rightly so--it is not in DHS's interest either, to have new and better developments hindered and delayed by fingerpointing!) If DHS wants to encourage third party development, it either has to be as subcontractors to a manufacturer who is capable of going into production, or DHS has to present a credible vision of how an equipment manufacturer will not have to depend on those third parties for its products to be sellable. As a large equipment manufacturer, we have had good success engaging third parties as subcontractors for various pieces of detection technology, reconstruction, and algorithm development. So it definitely can work to have third parties involved.

D Open image specification standards from the industry should allow academia to evaluate different technologies in a way similar to the Imatron data reconstruction shown on the 24th of October.

E Make DICOS a requirement for all TSEs Share DICOS data with 3rd parties (academia, national labs, 3rd party small businesses, large businesses) Partnerships with industry - Government should encourage

F Many industrial companies are working in isolation, rather than collaborating together, due to competitive and IP concerns

G No response

H Develop new algorithms and methodologies that can help, then making them available to vendors.

I There is a big role for data mining/decision techniques to play, but seems to be an afterthought at present. More 3rd parties with these skills involved in this technology could significantly improve tool performance.

J Bring equipment to center sites.

K No response

L Participate in collaboration with the vendors ... assuming practical IP terms can be negotiated.

M No response

N No response

O My recommendation is the following model 1) Third parties develop ideas/technologies with the help of government funding 2) ALERT is one of the venues for the third parties to show their progress to the incumbent vendors 3) TSA creates a business model which incentivizes improvements in IQ, detection or both 4) The incumbent vendors work with the third parties directly without further government involvement. The role of the government should be to create the conditions (market) for the third parties to sell their products to the incumbent vendors (or to become EDS providers themselves) , but it should not to force a specific technology or third party

P No response

Q No response

R Not sure.

S No response

T No response

U No response

V No response

W No response

X Third parties should make trusting relationships and move forward more openly.

Y Fund them

Z No response

Question 6: Do you have recommendations for future workshop topics?

A No response

B air cargo checkpoint of the future, including mm wave and x-ray back scatter comparative analysis

C No response

D Great workshop! Many of the algorithms shown are agnostic to the hardware implementation and therefore their practicality is not very well understood. This is fine for academia, but ultimately, it would need to be fielded from the DHS standpoint. An algorithm should describe: 1) Scan/Exposure time 2) Processing cost (cache/far memory access, integer instructions, floating point instructions) 3) Parallelism cost (10% overhead, lock-step cost, etc.) 4) Potential host hardware for deployment

E 1. Systems integration and issues/challenges of transitioning technologies to the airport in my evaluation. 2. Focus on key operational performance metrics and goals: reduced staffing/manning, reduced operational costs, faster scan and algorithm times, higher throughput, high performance (high Pd, low Pfa), smaller physical footprint in the airport, etc 3. Future Integrated Checkpoint – status and current roadmap and current efforts 4. Risk based screening and analytics 5. Opportunities to streamline the certification and testing process at TSIL and TSIF

F I really appreciated the breadth of topics and ideas that were presented at this year's workshop

G Cargo, standoff trace detection

H No response

I No response

J No response

K No response

L Suggest a workshop (or a portion of a workshop) on fixed source and/or sparse view systems for compressive sensing in EDS applications.

M No response

N No response

O Technologies for cargo scanning and technologies for standoff detection of explosives

P No response

Q No response

R Eye-safe stand-off trace detection seems to be a hot topic that DHS S&T has a great interest in.

S No response

T Stationary CT

U No response

V No response

W No response

X I think it would be helpful for academia and industry to better understand how the certification process works, but not necessarily the details of what values of what are used, but more so to the overall process and types of algorithms used. I think if everyone generally knew where everyone else was, more progress could be made.

Y Validation & Testing (both external and internal) of technologies

Z Discussions of how the field is changing from traditional to improvised/homemade explosives.

Question 7: What did you like about this workshop?

A No response

B Carl Crawford did a terrific job in assembling people from all walks of life to provide a comprehensive summary of where we stand on x-ray systems. He has cultivated and maintained an important community of interest which has many important benefits.

C The talk format (open to questions, etc) was a good one, and the mix of technologies and applications was a good one.

D The format is very well respect. Thank you Carl!

E Well-organized, diverse representation from academia, government, national labs and industry

F I really appreciated the breadth of topics and ideas that were presented at this year's workshop

G Attendance by a diverse set of people.

H Good cooperation amongst attendees; good level of trust

I The open discussion feel of the workshop. All of the major players seemed to be there.

J Blueberry bread.

K No response

L Opportunity to network with other stakeholders from Industry/Academia/Government. Opportunity for an efficient review of current technologies.

M No response

N No response

O Openness of the discussions

P No response

Q No response

R Great range of topics Great group of participants from many different stakeholders involved in this activity Great networking opportunities

S I found it useful to hear perspectives on what has been seen to NOT work. I thought several of the technical talks were very interesting.

T The open discussions of challenges and gaps in technology. The ability to ask questions during the presentations rather than at the end of a presentation.

U No response

V No response

W No response

X I really liked the variety of topics discussed, the fostering of important conversations, and the ability to meet people across many different areas.

Y New speakers & variety of topics - a great combination and highly engaging. Even if it was a topic that I didn't care so much about, the variety meant that I paid attention (because it wasn't a half-day - just a speaker or two.

Z The organizers. Top notch.

Question 8: What would you like to see changed for future workshops?

A No response

B Could we organize presentations insistently around; problem addressed (why is it important); status of research (things working and things not working); future directions; what is required (resources) and how long will it take.

C As mentioned before, might one consider a "Score this Technology" app for use in real time at the conference?

D Other than more topics related to the application of the algorithms in current and fielded system; I wouldn't change a thing.

E More presentations and government representation from TSA, airport security officers/managers, operators, etc

F Not much - the length of the workshop was just right, as was the length of the individual talks. It would be helpful to hear more from the customers about the needs of the customers (airport operators, Customs, etc).

G No response

H Perhaps a panel discussion on some topic that encourages broad audience participation and interaction

I No response

J Poster session. Too few students and not enough interaction.

K No response

L I suggest coordinating some breakout sessions that could facilitate people from Industry/Academia/Government to interact on a topic of interest. There are enough participants to separate into 6-10 groups of 8-12 people. It would probably be better for logistics to have the breakouts on the first evening and report-out on the second day. Topics like "What is the future of DICOS?" or "How to create a common database of scan data?" would be interesting.

M No response

N No response

O No response

P No response

Q No response

R Not sure

S No response

T No response

U No response

V No response

W No response

X I would like to see more collaboration and more communication. I think that a large poster session would allow people to see more work being done and go after specific work that they would find interesting and helpful. I also think that opening up the workshop to more institutions (say in the medical field and other areas solving other problems with similar methods) would produce more relationships that the government and industrial partners could work with. People in academia and national labs want to tell other people about their work and most of the time would welcome collaboration and would definitely want helpful questions and comments.

Y I like the "present conclusions first", but I would suggest limiting Q&A during that time

Z Location (quite difficult and stressful for out-of-towners)

Question 9: What other comments do you have?

A Quite informative, even for the non-PhD.

B Excellent meeting!

C No response

D Great week, and great job putting the workshop together! I am sure it wasn't easy! Many thanks to Carl Crawford for moderating the topics and staying focused!

E Would recommend adding at least 1 hour panel discussion each day on key topics like the ones I recommended. Invite and include representatives from the end users: TSA, airport security officers/managers, and operators.

F No response

G No response

H No response

I No response

J No response

K No response

L Alternate building had some advantages, but audio had issues and the front projection screen was blocked by people sitting in front rows and side screens weren't usable unless you were sitting in the back third of the room (where audio was worse). If the A/V issues can be worked out the 140 Fenway location would be fine. It was also good to have the refreshments located in the back of the room.

M No response

N No response

O No response

P No response

Q No response

R Keep up the good work Looking forward to ADSA 10

S No response

T No response

U No response

V Screen in Raytheon room is visible by all at all times. Easy to see. Screen in 140 is often not visible by many, even with all the added screens around the room. At least move the image up higher if use 140.

W No response

X Great job to all!

Y Would like to have a talk on matching test results vs. field results (especially for false alarms, which is all that there is in the field)   More Students from More Places! Have a mixer.   I suggest Fall "problems" and Spring "solutions" workshop (or other way around). That need not be exclusive, but perhaps as a "general focus".   We want to see ideas & people - anything that increases that is good.

Z No response

15. Appendix: Acronyms

TERM	DEFINITION
2D	Two-dimensional
3D	Three-dimensional
ADSA	Algorithm Development for Security Applications (name of workshops at ALERT)
ADSA01	First ADSA workshop held in April 2009 on the check-point application
ADSA02	Second ADSA workshop held in October 2009 on the grand challenge for CT segmentation
ADSA03	Third ADSA workshop held in April 2010 on AIT
ADSA04	Fourth ADSA workshop held in October 2010 on advanced reconstruction algorithms for CT-based scanners.
ADSA05	Fifth ADSA workshop held in May 2011 on fusing orthogonal technologies
ADSA06	Sixth ADSA workshop held in November 2011 on the development of fused explosive detection equipment with specific application to advanced imaging technology
ADSA07	Seventh ADSA workshop held in May 2012 on reconstruction algorithms for CT-based explosive detection equipment
ADSA08	Eighth ADSA workshop to be held in October 2012 on automated target recognition (ATR) algorithms
ADSA09	Ninth ADSA workshop held in October 2013 on new methods for explosive detection
ADSA10	Tenth ADSA workshop to be held in May 2014 on air cargo inspection
AIT	Advanced imaging technology. Technology for find objects of interest on passengers. WBI is a deprecated synonym.
ALERT	Awareness and Localization of Explosives-Related Threats, a Department of Homeland Security Center of Excellence at NEU
AT	Advanced technology. Second generation of TRX.
AT2	Second generation of AT.
ATD	Automated threat detection
ATR	Automated threat resolution; a synonym of ATD.
BAA	Broad agency announcement
BDO	Behavioral detection officer. A type of TSO.
BHS	Baggage handling system

TERM	DEFINITION
BIR	Baggage inspection room
BLS	Bottle Liquids Scanners
CERT	Certification testing at the TSL
COE	Center of Excellence, a DHS designation
CONOP	Concept of operations
CRT	Certification readiness testing
CT	Computed tomography
DHS	Department of Homeland Security
DHS S&T	DHS Science & Technology division
DICOS	Digital Imaging and Communications in Security. NEMA standard for image format for security; NEMA IIC Industrial Imaging and Communications Technical Committee.
EDS	Explosive detection scanner that passes TSL's CERT.
ETD	Explosive trace detection
EXD	Explosive detection directorate of DHS
FA	False alarm
HME	Homemade explosive
IED	Improvised explosive device
IMS	Ion mobility spectrometry
IP	Intellectual property
IQ	Image quality
IR	Infrared or iterative reconstruction
LLNL	Lawrence Livermore National Laboratory
MMW	Millimeter wave
NEU	Northeastern University
OSARP	On screen alarm resolution protocol/process
OSR	On screen resolution
PD	Probability of detection
PFA	Probability of false alarm
QR	Quadruple resonance
SNM	Special nuclear materials
SOC	Stream of commerce
SOP	Standard operating procedure

TERM	DEFINITION
SSI	Sensitive security information
TBD	To be determined
TCO	Total cost of ownership
TIP	Threat image projection
Trace	Synonym of ETD
TRX	TIP-ready X-ray line scanners
TSA	Transportation Security Administration
TSL	Transportation Security Lab, Atlantic City, NJ
TSO	Transportation security officer; scanner operator
WBI	Whole body imaging; a deprecated term for AIT
XBS	X-ray back scatter
XRD	X-ray diffraction

16. Appendix: Minutes[3, 4]

The ADSA09 minutes were edited for purposes of clarity. All errors in the minutes are due to the editors of this report and not due to the speakers themselves.

16.1 Day 1 Minutes: October 22, 2013

Michael B. Silevitch: Director of ALERT, Welcome. Intro to ADSA, intro to Ceremony to Launch ALERT Phase 2.

Laura Parker: Intro to DHS COE, intro to Ceremony, intro to

Matt Clark: How many academics? (1/3 raise hands) How many industry? (2/3 raise hands) How many students? (2 or 3). Intro to DHS COEs.

Speaker: Carl Crawford

CC: What do get out of the workshop/what is the state of terrorism?

MBS: By 'mass', you mean detection mass?

CC: Yes.

Tim Rayner: What about EU System costs? People travel from US to EU, there is a high cost.

CC: That's right, I mean for all operational costs.

Dave Shaffer: When you talk about false alarms, that obviously varies by site location, are there users for this, or are there people that we can bring to give insight.

Matt Mertzbacher: Systems have to be understandable, and not too complex.

MBS: By definition this seems to be centered to portal detection, but what about on-the-move check points? I think it will move towards screening people as they move, especially in open spaces. How do we develop detection for those?

John Beaty: I don't think that we are emphasizing the cost of goods and cost of operation. The way to get into this market is simply to do the equivalent for half the cost. I think the TSA buys on cost, and performance takes a second place.

3 Unidentifiable speakers will be indicated as "??".

4 Inaudible or missing portions of the minutes will be indicated in parentheses as (???).

CC: Is Doug Bauer in the room? He said that we have to assume that the TSA is going to fix their problems.

Marcus: If this machine is the same today as it was before, it is not just about cost.

Horst Wittmann: What I see missing is the time you have, and discrimination. We have many targets, and they are close to each other. Time is also of great essence.

CC: Throughput is time.

Harry Martz: Detection is Binary. Discrimination is saying I have C4 vs hydrogen peroxide. Typically we think of detection, PD PFA and Throughput. You can't do one without the other. That's not practical.

Doug Bauer: Is there anything about automated detection?

CC: It is a goal to take the human out of the equation.

Speaker: Taly Gilat-Schmidt

??: What energy resolution do you need?

TGS: These need to be optimized for different tasks. There is a lot of room for where you put the thresholds.

JB: Are you looking at reducing clouds?

TGS: Yes.

CC: Do you use K edges?

TGS: We could use K edges imaging for that, we have some images of salt here. They are usually too low to be detected.

Andrew: Improves SNR? Is that total cost of the system?

TGS: It is compared to the exposure or the dose, we fix both for that.

Fernando Quivira: Do you mean rotating the detector?

TGS: Yes, we rotate it. When we talk about the clouds, we see the threat here, but (slide 3) we see that these clouds overlap so we can't see the threat vs non-threat.

CC: Can you explain CNR?

TGS: It is the mean element in the background divided by the noise radiation.

Homer Pien: Can you say more about the benchtop system? What materials, etc?

TGS: We have a photon counting detector from Nova. We tried lots of different bins, so for this I don't know exactly what the bins were.

??: It this a coincidence?

TGS: There was pile-up in these, and there were degradations?

CC: How did you avoid false pile-up?

TGS: This was not an issue, we haven't encountered that yet.

??: Maximum flux for your detector?

TGS: We are finding 1 million counts, but we think it's lower.

??: Are you normalizing to keep the exposure constant?

TGS: Yes.

Jimmy Oxley: There used to be a device that could see the K edge of lead.

TGS: Yes, led can be seen, I should have highlighted that.

HM: Usually people do cross absorption.

TGS: It's before and after.

Dominic Heuscher: In order to cover the whole spectrum, wouldn't it be useful to switch it for particular k-edge.

TGS: It is possible, and we can and do switch it.

Speaker: Robert Cernick

RC: The sensitivity to detect has to be high, but you can have a number of arches and put them in an array. We have replicated this.

Mike Massey: How are you able to make an image from this diffraction?

RC: The X-Ray photon comes in through a pixel and it generates an electron. You're measuring the full diffraction pattern in the pixel. In a sample you have a different energy. The detector plots out the energy against the whole diffraction pattern.

Smiths Detection: Opening anvil?

RC: We use a 200 micron pinhole which you can expand to 400. You can shift and choose based on the beam.

??: When you say high energy it's a relative term.

RC: I'm talking between 50 and 300 keV.

??: Does your pencil beam have to be (???)

RC: You're going to integrate the cones at the end. There's no (???) after sample. It's a very simple technique.

??: How long did it take to acquire the image?

RC: Not that long. Some in a matter of seconds.

??: Have you looked at liquids and tried to distinguish?

RC: Yes we have. It doesn't matter what it is really, you're looking at a difference in density.

CC: Any thoughts on scaling?

RC: Yes, we're going to need a higher energy beam. This single pixel diffraction data was collected in 2 seconds. How big are you talking?

CC: 20 seconds?

(???)

??: Eventually you want to know where it is.

RC: Even in the high energy source, you can use different sources (???) That will give you an image through the different part of the beam. If you didn't need to know where in the suitcase it was, you wouldn't need to do anything else. It would be very simple. If you did, you would need to do something else, perhaps some kind of rotation. If you're thinking about the number of X-Ray sources coming in, in parallel, you'll have a number of detectors connected in addition to the standard tomographic data.

Speaker: Patrick Radisson

??: How thick is the (???)

PR: 2/5 millimeter. This is our first product in terms of global simulation (???) There might be some trade off depending on our progression.

??: It is a linear detector. Do you have plans to expand?

PR: Yes we have plans to expand but we are a startup and have worked up from 16 pieces. We are focusing on this one, this definition and are working on a new configuration.

(???)

PR: All this is in real time, two or one millisecond. We have the flexibility to play with that. Energy resolution can be improved and increased so here you have the resolution measure (???) There are tradeoffs; we can adapt this for low flux application. We have thinking of adjusting for 5 killi.

??: What is the advantage of having (???)

PR: For imaging it is just to play with the band and then to have discrimination where just two. Discrimination improvement and we can show improvement thanks to (???) We can approach more precisely the definition and keep that in mind. There is a difference between the definition and the noise.

??: You do the subtraction, do you have to know that it is 26 millimeters?

PR: So far it is an occurrence (???)

??: The active face is 20 cm, is this one single piece?

PR: No it is not one single piece.

??: If the number of were reduced to 64 (???)

PR: We are similar in mode and flexible and there are modes (???)

(???)

PR: We have a couple of modes, X-Ray. We have simulated more than three years of X-Ray line scanner information to see the change (???)

Speaker: Steve Azevedo

??: The part that is missing is how do we use these measures to transfer them to an actual CT and use it for future false alarm rates. It is a question of a transfer function.

SA: Let's take it off line.

Speaker: Richard Bijjani

CC: Why would I want to do this? If I am a company and looking for money to build it, I probably don't want to talk to the vendor.

RB: You are going to build something that is a least to or worse than what exists. First, you need to understand what needs to happen.

??: That range may have to be expanded.

RB: My information is really dated here.

??: In the earlier slides, you are using their density for measure. So you use their materials to know what the range is.

RB: I will use different materials. That is a case by case. It is not meant to be said this is before and this is now.

Rex Richardson: This technique implemented with dual energy has worked very well for us in cargo simulations.

RB: That is great to hear.

Speaker: Larry Schultz

CC: What type of static field, imaging, and metals are you talking about?

LS: If you give me some leeway, I will address some of that in my talk and whatever you have left I can address at the end. I will talk about the metal and others in the presentation.

??: What is your definition of can't see?

LS: In order to achieve a 5% false alarm rate, there were some threats we could not target for detection without an exorbitant false alarm rate. We couldn't get detection strong enough to.

??: Is "can't see," the same as cannot detect?

LS: You can detect yes. You are familiar with ROC curve methodologies. If you add the "can't see" threats and achieve any detection rate, you'd be detected half the benign material too. That is not where we stand right now with NMR only. We caught almost every threat TSL had at the machine. There are some that are not easy to test in the TSL environment, some threats that we had to develop at Los Alamos and test in an explosives safe environment. We were aware that the signature was non-detectable for that instrument. They are detectable with added X-Ray to NMR.

??: Question on slide ten, it looks like T2 is not helping at all here. It looks like just T1.

LS: That is somewhat accurate. It is possible for material signatures to move in the space and some materials that lie to the lower right of the T1, T2 space. It is possible for them to exist closer to the blue dots. Substantially you are correct about the instrument we took to TSA. In the newest instrument we rely only on the relaxation parameters.

Tim Rayner: In relationship to the combined NMR and X-Ray portal scanner, the X-Ray is capable of screening, what takes the hits by using the low frequency? Why not boost it? 30 seconds is too long in the real world.

LS: 17 seconds is maybe more acceptable. This machine can scan materials in modest metal (a coke can). We cannot scan thick metal but that is rare in the stream of commerce.

TR: There are NMR base bottle scanners out there that run in like 10 megahertz, different sizes in about two or three seconds. Why not just boost the field on the NMR side?

LS: Our objective has been to scan trays of multiple bottles. I am not aware of everything going on around the world and a medium field NMR technology capable of scanning multiple bottles in that amount of time. Multiple bottles are what we are going for.

TR: In relationship to threats associate with (???) what are the relaxation parameters associated with the material?

LS: Solids have short relaxation times and are more difficult to measure the NMR signals that go away quickly. There are some that detect modest relaxation times. It can be hard to detect in solids. There is one can liquid explosives that begin to look like a solid. It is somewhat more difficult but not impossible.

Speaker: Michael Sossong

HM: Is there clutter around there?

MS: Some is clutter, it's all data taken in from pallets sitting in a container.

CC: Are there issues if you go to less than 25 milligrams?

MS: There are, but if you make your volume smaller you can do that. These are all 5 min. scans, but we believe that for 25 and up we can get it down to 1 min or 1.5 mins.

Robert: How do you count the rays in any angle?

MS: We try to cover that at any angle. Or we can add wings or sides on the detector, so we stop gaining once we go over a certain angle.

??: What is green?

RC: Slide 19, this is an engine block, these are gas bottles, and we have a picture of 8" of steel. This here is a signal, and if you were to hide uranium in something dense, it would look suspicious.

Rick Moore: do you have do so anything special to get the noisy scattering.

Michael Massey: Do you have to deal with the response time of the detectors, as far as pile-up?

MS: No we don't get any build up, they are large detectors.

??: As your voxal size increases, do you get more (???)?

MS: we are looking into some that do not voxilize. That is one of the biggest issues.

??: What is the distribution of the materials of what's inside that voxal.

MS: Right.

Speaker: Ben Cantwell

CC: What you're trying to say is that your job is to sell this.

BC: We are trying to meet a need for security.

MBS: What is to stop a threat where it isn't smooth?

BC: Well we looked at different options. We take a hit on scan time, but that is necessary to build a tool that is safe.

MM: What source are you using?

BC: 160 K source.

Robert: Have you discussed putting sensors around the outside?

BC: We essentially have a system that is very price-sensitive, and so it would be very expensive.

??: The bottles have thick regions or thin regions.

BC: We don't really care about the shape, but we care about how big it is or how much it holds.

CC: What does it mean for selection of items?

BC: If you want more benign results, we put more benign items in to scale it.

CC: Eventually don't you have to pass a test?

BC: Yes we do. What you have passed the ecat test, you should be set. There is a difference of what different airports are looking at.

??: Did you actually scan all of those? (slide 13).

BC: This is a way to not have to do millions of combinations.

CC: So the 2.3 on false alarms is the ecat for detection systems?

BC: Yes.

??: Does your scanner control the position?

BC: Yes.

CC: How accurately does it measure length?

BC: .5 milliliter.

CC: What are they doing for secondary inspection?

BC: There is a type b systems, depending on the airport.

??: What is the type C system?

BC: What you want from resolution systems is to have your threats correlated and your false alarms uncorrelated.

Speaker: Steve Korbly

??: How long did it take to do this?

SK: It took about 15 seconds. The battery took about 2 seconds.

??: Have you tested the limits?

SK: We haven't tested it.

??: Have you found the difference in the composition?

SK: Yes, we have.

??: How do you handle volume?

SK: You set up a model of the image boxal, which is a partial filling. It's dominated by the material. It goes from Z^4.

??: Do you have a special algorithm to handle that.

SK: It is intrinsic of the algorithm. There is no simple formula for the effective Z.

RR: How much differentiation?

SK: Intrinsically the technique has the capability of differentiating alcohol and water. You can see the difference between those two liquids.

RR: One unit of low Z, and 9 units of high Z?

SK: It's not a challenge for that, because there is nothing on the low end that's out there.

(???)

SK: The first scan is within the legal limits.

??: What is the purpose of the system at Massport?

SK: The system at Massport is to run real cargo and detect nuclear material and contraband.

??: What do they do with an X-Ray detection?

SK: Now if they have X-Ray detection they open the container up.

Speaker: Arsen Hajian

??: How is the pupil related to the slit in the physical relationship? Is it a conventional slit?

AH: If we don't block most of the light with a slit it can be difficult to focus the photons on the focal point and would need a larger pupil. If the pupil is smaller, the cost is scaled. If you live in a constricted environment, we can accomplish the same operation with a 3X to 4X smaller tool.

MBS: Have you tested this in explosive detection trails in a security environment?

AH: We have not done those tests yet, we are in a process. In scenarios, we beat in terms of 300-200. I am happy to send you the data.

MBS: It would be interested to work with you and your data to benchmark some of the work you are doing.

AH: You are making my day. If you look up a group spectroscopy, we have a program that verifies the data and would be happy to share it with you.

Speaker: Jimmie Oxley

(???)

JO: That is remaining. We apply to and see how much comes back off. How long is that residue there after the washings.

??: 20% left or removed?

JO: 20% left.

??: Washings (???)

JO: It is chemically dependent. It is not water soluble. TNT is water soluble.

(???)

JO: Two washings.

??: What is the percentage by volume?

JO: I don't know. It looks like powder, so not very much.

??: Can it be used for the purpose of both?

JO: I don't see why not.

JB: It looked like decomposition. When the curve is not retraced and you have chemistry going on there.

JO: The first cycle is unique. There is some literature on this. If you reduce the NO2 groups, it is concerning. You re-oxidize them. We are playing with polymers. We didn't intend to create sensors but we may end up there.

Speaker: Stephen Beaudoin

??: What is the intergram?

SB: It integrates overall volume. This is the simplest integration scheme model.

??: (Humidity chart) Why does it turn around?

SB: There are no continuum liquid water droplets present. So from here there are continuum water droplets. It changes the force.

JB: I am surprised that the mechanical portion of what you are studying seems to predominate. I thought hydrogen bonding would have a stronger influence. The first part really said mechanical.

SB: I don't think there is much chemical bonding in these.

JB: You said hydrogen bonding. The way I think about surfaces and what you mentioned is mechanical.

SB: What you are thinking is true to an extent. Once they get closer than a certain amount then the dyfo interactions increase greatly and become the clear winners when they become closer together.

??: The better swabs you develop more contaminants?

SB: Yes. We are doing calculations with 30 and 40 times the surface without interaction with the swab at all. I don't think we will ever have a totally selective swab.

Speaker: Ryan Espy

MS: How portable is this?

RE: We have a version that's partially handheld and part backpack and weighs about 20 pounds.

CC: So it's borderline. The state of the art mass spectrometers are a few hundred pounds.

MS: Do you know about what's happening at Woods Hole?

CC: From what I can tell, it's similar to other things that are out there.

JB: (explanation of what's happening at Woods Hole and the mass spectrometer they have).

??: What kind of distance is it from the ionization source to the sample?

RE: (???)

MS: Is there a spark?

RE: There is no spark. The current is quite low and so is the temperature.

??: Do you have a (???) false alarms?

RE: We've never taken this into the field with real samples.

??: Mass spec is very sensitive and selective, so probably under 1%.

MS: Have you ever thought of using a laser to do the same thing?

RE: Yes, there are many who do that. Laser desorbtion is not very good at ionizing though. It's two distinct steps.

George Zarur: Last time I talked to Graham he said he was working on a (???) Where is he on that development?

RE: We're working with statisticians to see if we can achieve as good of results. The LTP is going well, the larger DESI is a work in progress.

GZ: (???)

RE: The biological have a higher weight and (???). For our machines that's not good.

JB: Your spectrometer is for 1 atomic mass. That's great for trace.

RE: Yes. It's all we need.

JB: I think it's all about sampling, it's always been about sampling, and it will always be about sampling.

RE: I haven't been told where most of them are, but I think most are in other academic institutions, maybe in hospitals, but I don't know about in airspace.

Speaker: Jerry Schmitt

JS: We're talking about native vapor pressure. It's not a chemical method, it's a physical method.

??: What is your ionization source?

JS: We use (???) 63, but we're also trying to use secondary (???)

16.2 Day 2 Minutes: October 23, 2013

Possible topics for ADSA10

MM: Something about creating test objects and validation. A whole validation meeting is a possibility.

CC: What do you mean by validation?

MM: The academic community is great at stand-alone validation, but nobody does integration. You think everything is beautiful until you integrate it, so being able to design tests that don't immediately fail but fail progressively so you know what's wrong. Validation of fusion, components, testing, how do you know that your tests are complete.

CC: We have to be careful and still be sensitive towards people whose jobs it is.

Dave Shafer: It would be interesting to think about soft targets. The marathon, the shopping malls, what are we doing about protecting those areas?

CC: Is that okay?

MBS: That's something we're working on. It's part of the COE. There's still the check-point of the future. You're walking around towards the gate and you're being scanned on the move. Maybe that's a topic.

??: What about data analytics? What are people doing with all the data that's out there? How we integrate (???)

CC: The NYTimes had an article yesterday about collecting information.

MBS: There's a sister COE at Purdue called VACCINE, and the VA stands for video analytics. We're developing a working relationship with them around security. That could relate to that topic because they do a lot of video analytics.

??: We need to think of new metrics about the operational meanings of false alarm rates.

MM: They include also, if you work in an integrated real-world.

??: If you have a good imaging system you only open a fraction of the bags. It's a significant change in operational costs and time.

??: Some sort of phantom (???) So you can jumpstart things like airport (???) for system design and next-level integrations.

CC: Any thoughts about talking about explosives simulants?

MBS: Whatever themes we come up with, we need to embrace our whole community, and not only involve a small percentage. Cargo is an interesting topic, but I don't know how many people here are really working on cargo.

BC: I've spent years working on cargo, and it's the fastest growing segment in the market. We've seen nothing (???)

MBS: We did have a few talks this time on cargo. Can we see a show of hands who's interested in cargo?

½ room raises hands

MM: You can cut on application or you can cut on approach.

CC: A criticism of this ADSA is that we're not working to solve a problem.

Speaker: Carey Rappaport

??: Trade offs, I didn't realize, were using such a wide frequency range. Is there also a penetration issue through clothing?

CR: At the w band there's a bit at GhZ. When you get up to (???) GhZ, there's also a problem. It depends though if you wear a t-shirt or a sweater. And if it's wet with sweat it's pretty impenetrable.

Jose Martinez: Can you describe thinned arrays?

CR: You can go (???) If you do it uniformly the problem is that (???) If you do it non-uniformly, (???) Bottom line is if you intelligently do it, you can do just as well.

CC: There has been perceived attention due to innovation.

(???)

CR: Material characterization weak dielectrics. I didn't talk about this because its algorithms use existing tech. Waves penetrate (???) Then the lay in the signal due to the slower wave velocity in the dielectric results in an image that looks like it's further away. I also think that we have a good approach for multistatic sensing that can handle issues with nonspecular reflection.

Speaker: Kathryn Williams

JM: Method of moments is what you would measure?

KW: No, (???)

JB: So the reconstruction in the green, is the reconstructed image of the black?

KW: Yes, the green is the outline of the black.

??: From the perspective, what's the time it took?

KW: These all took less than 16 seconds. The advantage of retracing is that it can also do 3d simulations very fast. In other methods it would take hours.

??: Are you (???)

JB: Rather than plotting numbers of rays, the fidelity is the real measure.

KW: Right. If you wanted to simulate the body, you would want to use 3000, so you have to smartly choose the numbers.

JB: The plot doesn't determine the measure of fidelity. That's the time it becomes important for the computation.

Speaker: Matthew Merzbacher

CC: What is a corner case?

MM: If I need to detect 7 things, but I can only detect 6 things, then the new system is not going to be accepted.

Tim Ashenfelter: In a regulated market, if there are no regulations no one is going to buy anything.

MM: Agreed. There is skepticism on the part of the companies and the regulators, because they are viewed as adversaries.

CC: If you fix to total cost of ownership for an accelerator, you could sell it.

MM: I think that goes against safety.

CR: Shouldn't you want it to work well?

MM: Well, yes. It depends on how you define working, but I would say you have to define it as working well.

Rex Richardson: I think waiting 30 years for something in a regulated market violates your guidelines.

MM: Right.

MM: Carl wanted me to answer for specific technology, but I think if you look at those 10 I defined, you will find out why.

Speaker: Harry Marz

JO: Historically, the idea at the time was that if it has nitrogen in it, it looked like it was covered.

HM: There is a lot of nitrate in things that became a problem.

RR: Harry, you didn't mention associated particle analyses that we have been working on with Raytheon. That eliminates the complexity of the multi detector for small volumes and checked baggage.

HM: There are problems with getting the source. If you go out with the technology, and you are trying to sell something that isn't right there, you may limit a lot of things for that technology.

JO: Do you have a personal favorite for which one will get there for air cargo?

HM: I have thought about this, and I don't know if I do have a personal favorite. If you go to these larger containers, you will have issues. It's hard enough to get these with the cost and logistics.

DC: It's really difficult to get something like this into the field. With the accelerator and shielding, you need a neutron, and there is one system in Saint Petersburg, there are almost no neutrons.

JB: We have to remember the enterprise and the cost of running it. It's about $150,000 million, which maybe low, and multiply that, and focus on the dollars. You have to convince the government and regulators that it is worth it, because we can't afford the new version.

Speaker: George Zarur

Tim Rayne: As the (???) is non-federalized, it is hard to convince a large organization it always comes down to the guy who is trying to check and the cost to inquire.

GZ: Your opinions are not as sensitive as people's in the US.

TR: I disagree. Ours is tempered.

GZ: Businesses think that the government (???) to get them off our back. I think TSA is going to start looking at that. Less expenditures.

MBS: Looking for anomalies on the move is the one of the major projects in ALERT. Hopefully there will be an integration with the video and check point technologies to cut cost and time.

CC: There is a direct relationship between ALERT and TSA.

Speaker: Octavia Camps

DC: What are they doing with false alarms and operators?

OC: It is impossible to complete being the operator; we are just trying to help the operator.

??: Are you doing any video analytics with people standing in lines such as at check in or security?

OC: No but Rich Radke at RPI is doing research similar with security. But no we are not doing that.

John O'Connor: What do you think about accuracy? For predictive capability what percentage of accuracy are you aiming for? What is the problem you are trying to solve?

OC: Aid and operate, so we could reduce down to one operator. There must be a human present. I am trying to accomplish pure detection and have the operator there to check. Trying to reduce the amount of data they have to process. Another thing we are going to do is help the officers analyze the video briefly. It will improve their interface.

MBS: The problems that we are addressing in this research are the ones that TSA are bringing to our attention. The real point is that this is a partnership with TSA Cleveland. They say what the problem is they want us to solve. It will reduce their man power, the cost of the breach, etc. That is guiding our research every step of the way.

Speaker: Charles Bowman

RR: One more thing you should put on the obstacle level is security.

CB: So you are talking about security. That falls over here in obstacles. Here one of them would be security in the sense of government security.

RR: Yes, a professor with several non-US citizens working in the lab that must be compartmentalized.

CB: Yes. That is a big challenge for the university; having a large number of non-US citizens. You have to work within the system and adjust things to bring in more US citizens. I squirreled away money and tried to support students who had potential to be rolled into these projects.

RR: I love that attitude. That is something that I would like to see more of.

CB: Yes, and that involves people who are sensitive, who don't go to the department and make demands.

MBS: A lot of proprietary work that they want universities to do involves having a person who pays attention to schedules and deliverables which allows the faculty to work without being bound by those kinds of responsibilities.

CB: I completely agree with you, Michael. These are really hard problems to solve, managing all these risks. You need a team, as a way of thinking about it. Not everybody on the team should be doing the same thing.

??: You have to have hard working technical managers.

MBS: We take that seriously and have those capabilities.

CB: How do we take individual successes and scale up? There should remain individual interactions and connections but make those interactions happen more efficiently and see them. This is the sort of thing that John Beaty and Michael Silevitch do. They go around and look for partnerships. You increase the probability if you oversee it and nurture it.

CR: Sometimes it is more than just the researchers. It is the whole culture. Academia doesn't charge by the hour like industry does. It is a cultural obstacle.

CB: They are intrinsic to the organizations so it can't be changed or taken away but we can help people learn about those differences and have cross-cultural communication.

??: These models apply between industry and national labs and sometimes even within industries' substrates.

MM: This is great. This is stuff that worked on a successful project. This is logistics. What happens when technical failures occur?

CB: Honestly when you are smart about how you put things together, the times when things fail is hard to recall. You have to redefine success a little bit. We always fail but never completely. If you have good communication and identify what the clear problem is, there is an interesting technical solution. Usually you can find a solution.

Speaker: Timothy Ashenfelter

MBS: What is the link between DNDO, DOE, DOD, NSA, the agency there?

TA: We have laws govern what our missions are. The unique quality of DHS and DNDO is being the systems integrator and understanding each of the components. DOE provides intensive capability in terms of science, technology and infrastructure. They handle challenging nuclear physics problems.

DOD has connections overseas so the domestic problems can be applied to those there.

Speaker: David Castañón

(???)

DC: Why is that the case? Look at the operator. The other architectures you are seeing here is a smoother operator, it breaks symmetry.

??: So it's the orientation?

DC: Yes, no doubt, it is the orientation. Multi-view is going to be essential.

??: What's the maximum throughput? Can you get up to something like 50% transmission?

DC: No I would have guessed less than that. It's a question of being able to populate the detectors on the outside. At the end of the day there's a cost issue too. So, that's why I don't think we'll ever get to 50%. Maybe 30%. Also because there's an inefficiency of what the pinholes look like.

DC: CT is used to define the absorption value. You need CT information first.

??: Do you ???

DC: Only in one version of the algorithm. If I had an initialization of the segmentation that was based on some of the information I could have (???)

(???)

DC: It's a minor issue because it's being used to initialize the reconstruction. If It were a definite step we would have had some morphological (???), but it's minor because the data isn't involved in the integration.

Speaker: David Brady

??: (???) Transition efficiency (???) 200 detectors (???) You're only ten times less (???) That seems to be very exciting.

DB: I agree with you.

CC: One of your slides shows the pixels shows them to be what size?

DB: Three centimeters. That is where David pointed out that you need multiple aspects. The only way to handle it is to be in multiple directions. It is not as important as total signal.

??: Looks like delta z.

DB: You are limited by the angular range that you have. The actual space resolution is combining ith CT. With the thin materials you can't look at it as clearly without.

(???)

DB: The machines that we are building combine intonation measurement with the scatter measurements. We are looking at data and agnostic to all sort of different designs.

Speaker: Edward Morton

CC: (???)

EM: I don't think it's necessary to take the transmission from that point, when you are looking at bag detection.

Speaker: Peter Rothschild

JB: Is that Section 5?

PR: Right.

Speaker: Erin Miller

CC: Is there any evidence?

EM: There are a lot of explosives that do have texture.

CC: So these are all transmission images.

EM: What you're seeing is the texture is read more strongly than other materials.

JB: How are you creating these structures?

EM: Atomic layer deposition of platinum.

JB: And the spacing is 4 microns?

EM: 1 micron wide silicon pillers and 3 micron wide (???)

JB: This is semiconductor mass manufacturing?

EM: Yes.

JB: It seems to me that you're ready to do this kind of work in the (???)

??: It's the aspect ratios that are the problem.

EM: Yes, it's the depth that's the problem.

JB: So what are the aspect ratios you're talking about?

EM: 35:1.

JB: Have you talked to people who've been doing this kind of work for semiconductors?

EM: Not specifically in semiconductors.

CC: Any thoughts on predicting PFA?

EM: What we really need is (???)

(???)

EM: When you're going through a thick sample you can get saturation and actually lose (???) your small angle can have a lot of coherence. At higher energies the cross section is lower so you can do that in thicker objects.

Speaker: Bert Hesselink

JB: I understand your photo electrons, but I don't understand how you get coherence. I understand that you release the electrons but how does it release on the Tungston. How do you transfer the beam coherently?

BH: So 2 things. So the course is partially coherent so you put in a grating. We put in a photocathode and that produces a photoelectron. In an imaging (???) of 1:1, that (???) to the tungsten target (???). The resolution is determined by the scattering in the tungsten. That's why you want a 1:1 ratio.

Speaker: Matthew Cain

??: Is this people not paying attention? (false alarm errors).

MC: Some people are just taking in the information about the probability of the threat.

MBS: Do you they know how many bags they are going to look at?

MC: They know how long they are going to be there, or how many bags they get, but they don't know how many targets they are seeing. I think people care more about being accurate more than finding the problems. These are not security people, they are just regular people.

MBS: I am curious. In a screening system we have auto target recognition that helps guide this. Did you ever try any of that to guide the searchers to an area?

MC: We have done some of those experiments with Radiologists. We find that it doesn't change overall performance. It does change what is found. It re-directs detection. They just search the area flagged, and they don't search the areas not flagged.

RR: Customs and border patrol asks us not to flag things for that very reason.

MC: Talking with Radiologists, they agree, and they don't want something interfering with the image. They want to let the person study the image themselves, and decide to check the area.

??: What about directing the user to mark off each section of the screen to indicate they looked.

MC: We have found that it doesn't necessarily work better, as people change what they are trying to do (e.g. the whole image instead of finding problems).

EM: Does that change if the instruction is broader?

MC: Yes, that changes if it is broader, otherwise people have tunnel vision to what they are looking for. (per the white spots vs gorilla in the lung).

HM: I saw something once where if you have two people looking for the same thing vs two people looking for different things, it was more effective.

MC: That can be true, and if you have someone searching after they have found something they think they know what's there, so breaking up between two people, that can help with default searching.

??: One of the requirements that we have is that they have to count down.

MC: Especially if it's two (???) that for checked bags?

??: Yes.

MM: If you tell your screeners that you will have your alarm on for a certain percentage, is there different affectivity for those two groups? If you guys keep your false alarms different?

MC: That probably would not change your sensitivity, but you could change your criteria.

MM: That's an important question for TSA.

MC: Do you have to at least a certain number of false alarms. My intuition is that it would have that effect, but I don't know for sure.

Alex Van Adzin: Have you found that if they are afraid they are better at this?

MC: If you are worried it does not change improve their ability. Calm and happy works better.

HM: If you had longer training would that help?

MC: The training that they get is 2 weeks total, so it's taking a long time, but if you could, it might jump that problem.

DC: If you have a detector that is 100%, and produces false alarms, do the screeners look at it and identify the false alarms?

MC: You are still going to have sensitivity, and your demand will shift the criteria.

Speaker: Tim White

CC: One of the problems we have is that it's hard to come to this audience on how to deal with fusion, etc.

TW: I think that plays to another point I said, which is that you can't solve a problem that has already been solved. Someone has to tell me and there has to be a hint. You could talk about ways to address that. I think in cases where we have new technologies, you have to say that this is a complimentary technology. You can't do it in a vacuum.

MM: That has been our model for success. ALERT has been a great help with our links.

JB: You can talk about physical properties, and abstractions. There is a language that allows you to talk to them in a secure space.

TW: I have to know what the thing is to know that there is a property.

JB: Then you can talk about density, and bound it. You are not in a secure space. I thought it was about carrying on a public conversation.

TW: I think you are on a long way down that path.

HM: I think if you say that 'these are the features, etc.'

JB: It is all about the application. A general public discussion of multi modalities will be understood only by a group of people in the audience. Non-specific applications.

HM: Are you trying to say you didn't hear much fusion today or yesterday? I thought I did.

TW: We are hearing about fusion. Right. There is more to be done.

CC: You may want to mention what a trace portal is.

TW: It would try to limit particles or vapor.

??: For trace portals, is there a problem with that in Europe?

TW: Is that cleaner than the US?

??: Yes.

??: What about NQR? (per the research being held up in the lab).

TW: We heard from Matt Merzbacher, that there is a hole in NQR.

CC: The only talk we lost was on signatures.

MM: Signature and detect of presence vs absence? Are the bags safe to put on planes?

TW: I will have to think about that.

HM: Some of it is that they will take CT and QR, and test that. There is a question of why did that not work?

TW: Right.

Speaker: Harry Martz

CC: It is not fair of me to have asked some of the industry to talk about the negative parts of their technology. You're trying to sell products.

HM: I don't disagree, because I don't see what the holes are, or what the classifications are.

MM: I would rather not bring all of that to our academic counterparts with that, I would rather do it after discussion. Let's not put constraints on too early.

MBS: This primes the pump.

MM: If anyone thinks (???).

LP: We want faster, better, cheaper, but that's not me, it's above me. But you know, if it's not possible to get all of those, there are trade-offs.

HM: Any other comments, questions, etc.? The analysis that went into that, (???).

RR: You mean about the analysis of your failures?

??: Is there a report on why the puffer failed?

MM: I don't know – there is a report, but I don't know how foible it is.

PR: Backscatter hasn't worked so well for aviation security. But we sell it to others, like the military, customs, etc. It's going to change in application.

??: (what do you want to hear from ADSA) If we hear about what they are doing, and we can address it here, it is an ongoing collaboration. Some years we are interested in it.

??: This is my first meeting here, and I thought it was just going to be about algorithms, but this was a lot more than that. Openly sharing ideas, etc., some of us are pretty guarded for the right reasons, given some of the cutting edge technologies. There is a lot of data out there, and if there are other technologies and companies that we can use to make some sense of this, we can use them.

??: The one thing about the university is that they have a unique way of bringing people from different backgrounds. They are able to have more discussion, etc.

??: This is an opportunity to work more with academia on more levels. Making them more aware of positions, etc. We could facilitate more interaction with students.

MM: The reason I come to ADSA is to hire people, but I haven't yet. I want more students and a broader variety.

CC: Senior students or junior students?

MM: Anyone looking for a job.

MBS: We have ASPIRE, which brings industry and students together. You have to be a part of ALERT for this. Talk to Emel if you want more info on this.

DC: I like the thought that the short term things would be interesting, maybe not this conference, but in order to go forward and think about new technology. I don't know how we would have a conference on that.

??: I want to put a fourth bullet on there. Customers. We want to find out what they need, and what they want, etc. They all have separate channels into the government. We want a wish list.

JB: The customer is what initially drove ADSA. There was dialogue where partners didn't know how to talk to each other. So it's important to understand the customer and find out what the issues are. That way we can find out the issues and get data. We want it to be directly associated with the problem.

??: I would describe it as an industry road map. Where are we trying to go, and where are we today. That is more neutral.

CC: It's hard to put vendors on the spot vs federal employees on the spot.

??: What about industry day? There is not just one federal customer, it is a chain of customers that come up with a final solution. There is a lot that goes into it, and all of the stakeholders look into something specific. There are other mechanisms for this. We are getting the end users that way.

DC: I think one of the most interesting things is the data fusion, and what level we do that. To have an infrastructure that can support that is crucial. What that leads to is how to tie together different acquisition devices.

DS: I think what we like is to get a perspective of where everyone else is. Industry wants to make their stuff better. Most of them have academic partners, and that model works well.

EM: I have been to just about all of the ADSAs, and they are always interesting. It is nice to solve problems and to be relevant. I think they are a good use of time.

CK: I will say that the student connections is good and bad because of the security aspect. Domestic students are all aware that there is less interest in pursuing a PhD.

EM: A lot of students are looking for professional masters programs. It could be a different type of relationship per the relationship between students and industry. The money would be for tuition instead of research, so they would be more advance.

KS: I appreciate getting feedback. Immediate reality shed.

MBS: With ALERT over the last 5 years with the ADSA conferences to focus on the challenge of transition. Getting the new ideas out into the field. ADSA has helped with that a lot. Industry may not be aware of this that there is not a funded vehicle within DHS.

RR: The problem with the wish list of the government, the problem with the wish list is that the problem needs to be solved. The quality has gone up, and now when you deliver something and it breaks, it gets returned, and it costs money.

HM: We have an issue in hiring new people too. It is good to bring industry and academia together, and we are interested in working with students. National Labs are not cheap, but we are unique. Something comes up, and we find out that we sometimes have the best capability. They have this state of the art, but it’s not cheap. You don’t know when you need that to get over hurdles. That saves time and money even though it costs money. It’s a hard problem.

ES: For the international perspective. The national labs are extremely helpful. There are a lot of things we can do with the national labs. It is easier for me to get into that account than with the academia.

EM: I would have to say that the national labs can help bridge the gaps. Personally I think it has been very helpful.

Speaker: Laura Parker

LP: Thinking about the government needs, etc. We do industry day, that is one way we do outreach. I will tell you why, it is because when we talk about our needs it is very formal. We have really come a long way from how it started (ADSA). It is not as formal as things like industry day.

17. Appendix: Presentations

This section contains the slides presented by speakers at the workshop. The slides appear in the order that talks were given as shown on the agenda. Some of the presentation slides have been redacted to ensure their suitability for public distribution.

PDF versions of selected presentations can be found at the following link:
https://myfiles.neu.edu/groups/ALERT/strategic_studies/ADSA09_Presentations/

17.1 Carl Crawford: Workshop Objectives

Ninth Algorithm Development for Security Applications Workshop (ADSA09):

New Methods for Explosive Detection for Aviation Security

Workshop Objectives

Carl R. Crawford
Csuptwo, LLC

1

Conclusions / Questions

- What new methods exist to detect explosives?
- What methods should have been presented?
- What are their strengths and weaknesses?
- How to accelerate their deployment?
- Why are x-rays commonly used?
  - What happened to neutrons?
- How to involve parties in addition to the equipment vendors?

2

Bin Laden Dead, But …

3

10 News Investigators find memo warning about terrorist "dry-runs" on airplanes

Orlando, Florida -- It was a flight bound for Florida, and some airline pilots believe it also may have been a dry-run for terrorists.
The 10 News Investigators have obtained an internal memo that details a frightening incident that brings back memories of the September 11, 2001 terrorist attacks.

4


1500 m
ADSA09
Boylston St
Newbury St
Marlborough St
Beacon St
Hynes Convention Center
Boston Architectural College
Massachusetts
Boston Locksmith
Belvidere St
Dalton St
Edgerly Rd Playground
Hemenway St
Symphony Community Park
Westland Ave
Back Bay Fens
Kelleher Rose Garden
North Parking Area
Huntington Ave
Titus Sparrow Park
Columbus Ave
Harriet Tubman Square
Worcester Street Community Garden
Satellite
Traffic
Map data ©2013 Google, Sanborn

Problem

- Terrorists still trying to take down airplanes
- Terrorists are making home-made explosives (HME)

7

DHS Goals

- Vendors doing an excellent job
- But, need
  - Increase probability of detection (PD)
  - Decreased probability of false alarm (PFA)
  - Detect more threats including wide-variation of home-made explosives (HMEs)
  - Reduced mass
  - Reduced labor costs
    - Eliminate human in the loop if possible
  - New algorithm ideas
  - New people working in the field

8

DHS Tactics

- Augment abilities of vendors with 3rd parties
  - Academia
  - National labs
  - Industry other than the vendors
- Create centers of excellence (COE) at universities
- Hold workshops to educate 3rd parties and discuss issues with involvement of 3rd parties
  - Algorithm Development for Security Applications (ADSA)

9

Detection Requirements

- Probability of detection (PD)
- Probability of false alarm (PFA)
- # types of threats
- Minimum mass
- Minimum sheet thickness
- Total cost of ownership
  - Purchase price
  - Siting
  - Labor
  - Maintenance
- Extensibility
- Ability to fuse
- Compatible with risk-based screening
- False alarm resolution methodologies
- Siting
- HVAC, space, weight shielding
- Throughput
- Safety

10

Questionnaire

- Request for everyone to answer questions preferably during the workshop
- Hand in at end of workshop or email
- Typed or handwritten acceptable
- Name is optional
- Also available via Survey Monkey
  - https://www.surveymonkey.com/s/ADSA09Survey

SurveyMonkey.com
because knowledge is everything

11

Reception and Dinner

- Reception and dinner tonight part of workshop
- Student poster session during the reception before dinner
- ALERT Phase II kickoff before dinner

12

Minutes & Participant Identification

- Minutes will be taken, but edited for final report
- Please identify yourself and institution first time you speak or ask questions

13

Internet Access

- Most invitees will be fine with the *NUwave-guest* access
- Run into problems (e.g., VPN) - use the following SSID: *adsa_guest*
  - Individual usernames and passwords will be provided by front desk staff

14

Acknowledgements

- Northeastern University (NEU)
- Awareness and Localization of Explosives-Related Threats (ALERT) DHS Center of Excellence
- Department of Homeland Security (DHS)
- Presenters
- Participants
- Students

15

Logistics

- Melanie Smith***
- Deanna Beirne
- Kristin Hicks
- Teri Incampo
- Seda Gokoglu
- Can Yegen
- Anne Magrath

Let them know if you need support during or after workshop.

16

Rule #1 – Open Discussions

- This is a workshop
- Conversation and questions expected at all times, especially during presentations
- Moderator responsible for keeping discussions focused
- Not grip-and-grin

17

Rule #2 – Public Domain

- Do not present classified, SSI, FOUO and proprietary material
- Presentations, minutes and proceedings will be placed in the public domain
  - After review for SSI and classified material

18

Rule #3 – Speaker Instructions

- 2nd slide has to be "so what who cares"
  - State how technology will improve explosive detection
  - Optimum presentation: stop at 2nd slide
- Expect discussion during presentation
- Allocate 50% of time slot for discussion
- Do not repeat material from prior speakers
- Delete math
- Concentrate on results
- Details into backup slides
- Delete slides now if necessary
- Put presentation on ALERT laptop in advance.

Beware of Moderators!

19

Vendors*

- DO's
  - Clearly communicate your expectations
  - Be Open: Accept new ideas
  - Share Data
  - Actively manage the project (find your 'Man from Milwaukee'). Invest more than money!
- DON'T 's
  - Don't be paranoid about protecting your IP, you're not that unique!
  - You're Not!
  - Don't expect 3rd parties code/design to work right out of the box, invest in learning and applying/improving the idea. There are no free lunches.

*Slide from Richard Bijjani's ADSA07 presentation

20

Academics/3rd Party

- DO's
  - Research the Problem before you approach vendors
  - Communicate/Manage expectations
  - Insist on involving the vendor in your research group
  - Get approval for publications
  - Work on a schedule, deadlines are real!
- DON'T 's
  - Stop solving problems that are only problems because they make good papers but hold no practical merit.
  - Don't solve problems that don't need to be solved (Research)
  - Don't ignore the vendors' experience. You really do not understand the problem better than they do. You really don't!
  - Under-promise and over-deliver
  - Talk to your technology transfer people, not every idea is worth $10M

*Slide from Richard Bijjani's ADSA07 presentation

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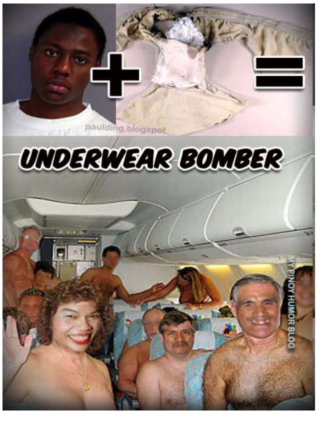
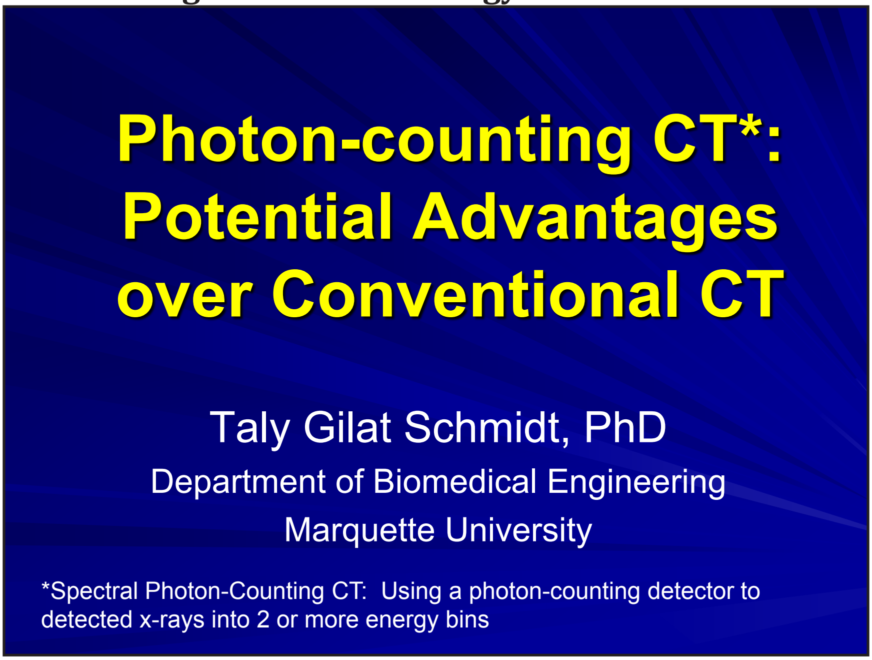
Final Remarks

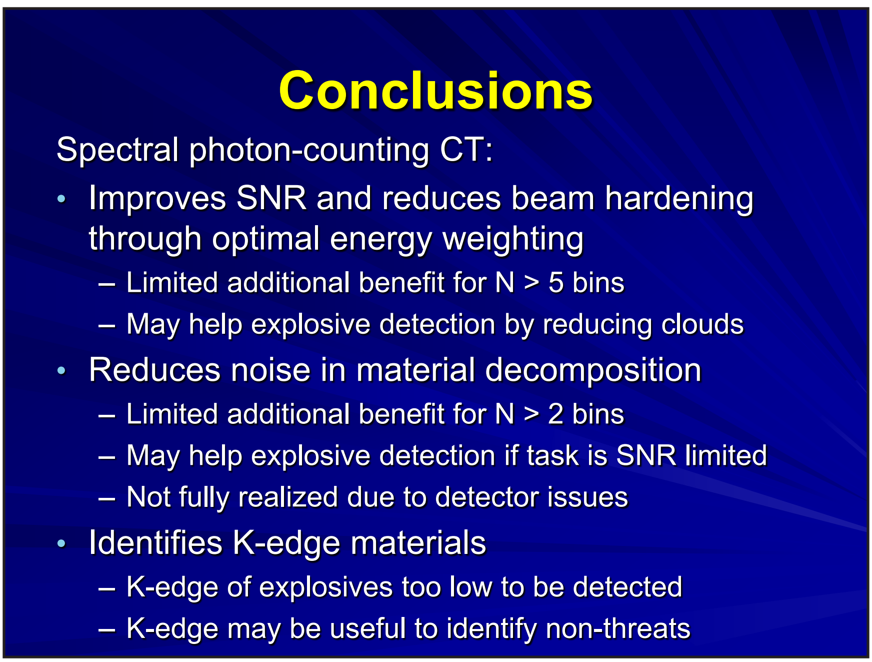
- "Terrorism causes a loss of life and a loss of quality of life," Lisa Dolev, Qylur
- Need improved technology
- Thank you for participating

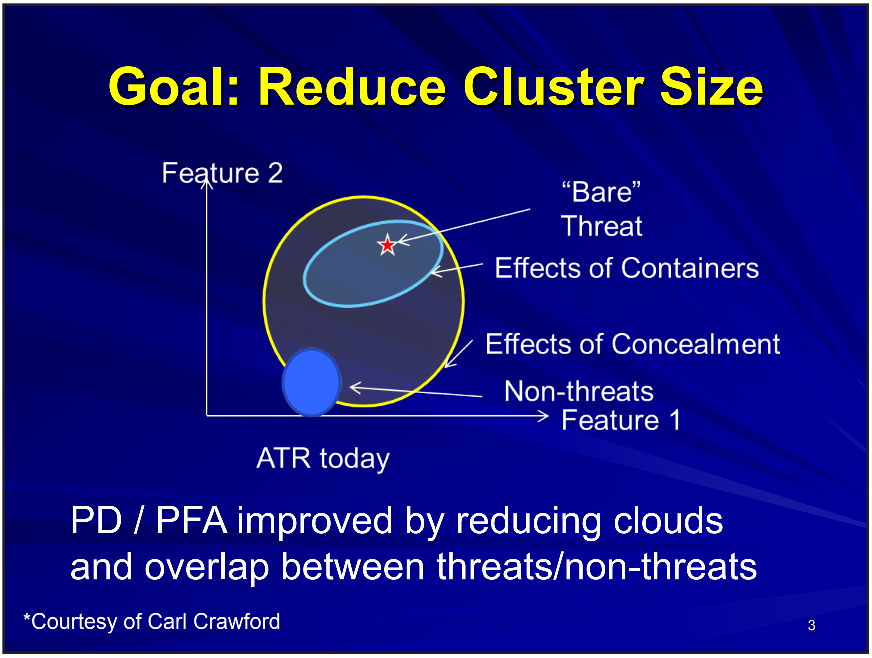


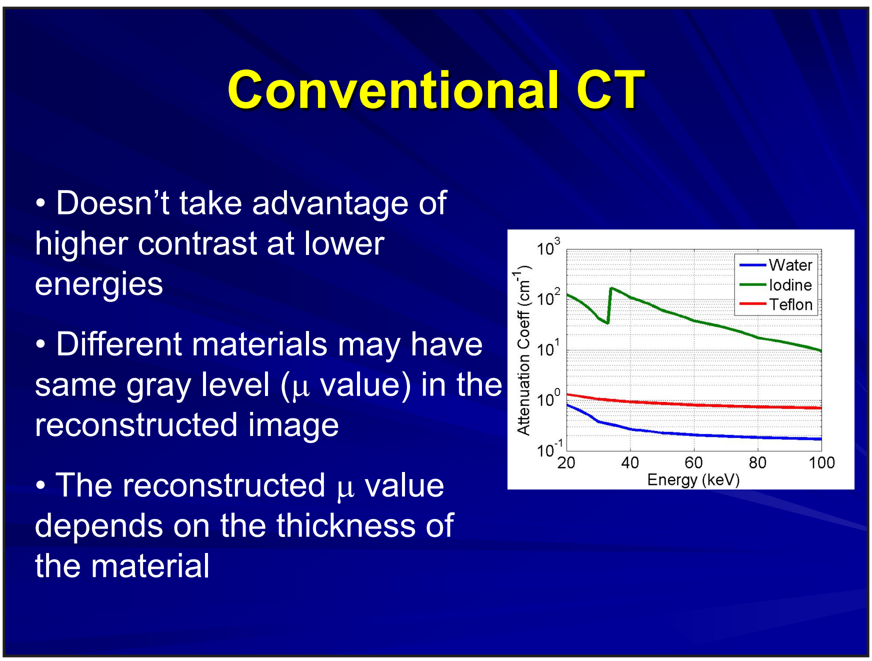
22

17.2 Taly Gilat-Schmidt: Photon Counting CT - Potential Advantages Over Dual Energy



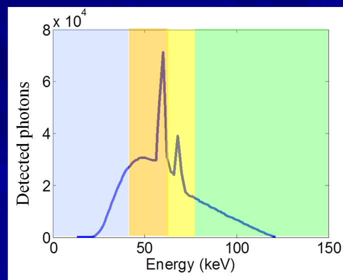



Goal: Reduce Cluster Size
Feature 2
"Bare"
Threat
Effects of Containers
Effects of Concealment
Non-threats
Feature 1
ATR today
PD / PFA improved by reducing clouds
and overlap between threats/non-threats
*Courtesy of Carl Crawford
3


Conventional CT
• Doesn't take advantage of higher contrast at lower energies
• Different materials may have same gray level (μ value) in the reconstructed image
• The reconstructed μ value depends on the thickness of the material
Attenuation Coeff (cm⁻¹)
10^3
10^2
10^1
10^0
10^-1
20
40
60
80
100
Energy (keV)
Water
Iodine
Teflon

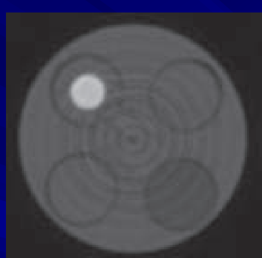
Spectral Photon-Counting CT

- Photon-counting detectors sort photons into energy bins
- What can you do with energy information?
  - Energy Weighting: Optimally weight and combine energy-bins to form improved HU image
  - Material Decomposition

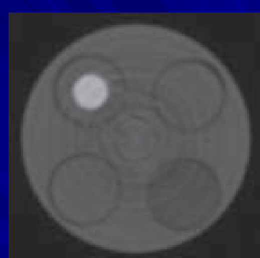


Energy-weighted Images

- Energy weighting increased CNR by 40% over photon-counting
- CNR improvement depends on energy-bin configuration
- Opportunity to optimize bins for explosive imaging



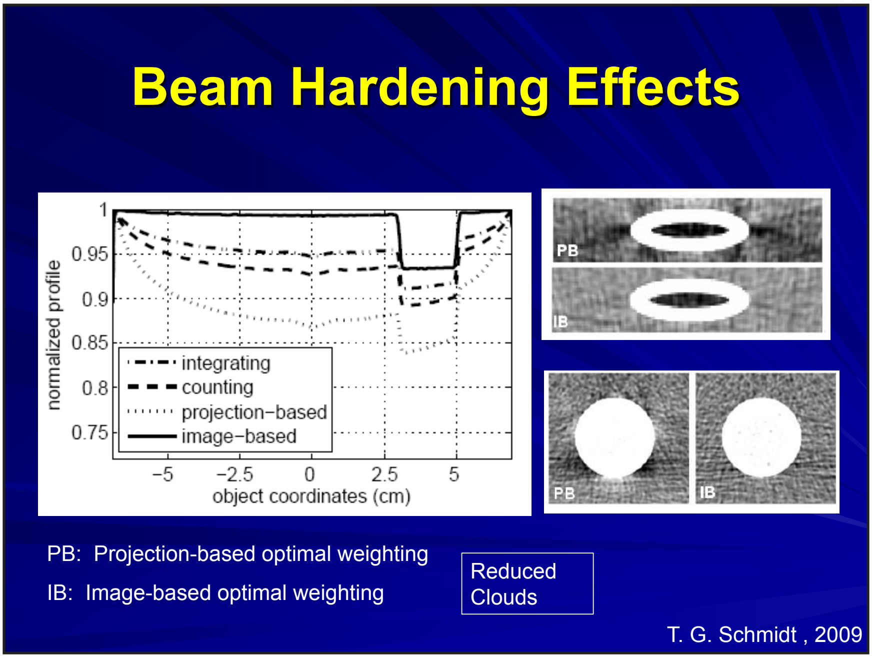
Photon-counting

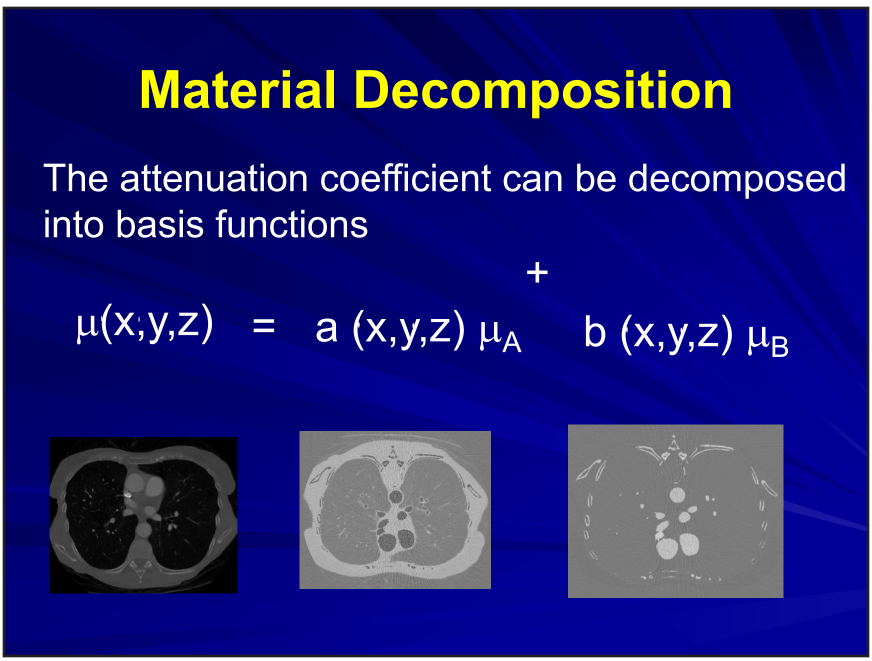


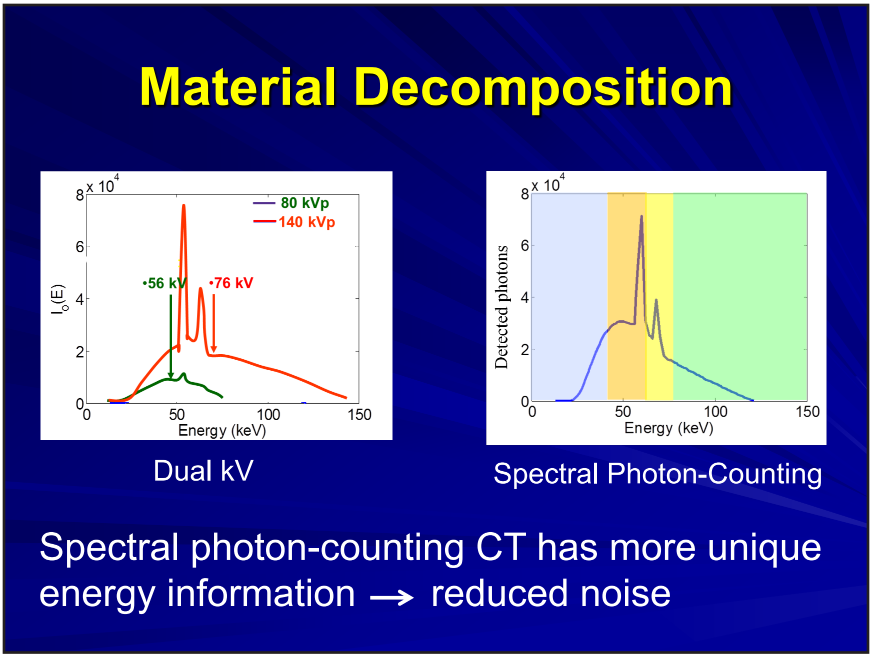
Optimal Energy Weighting

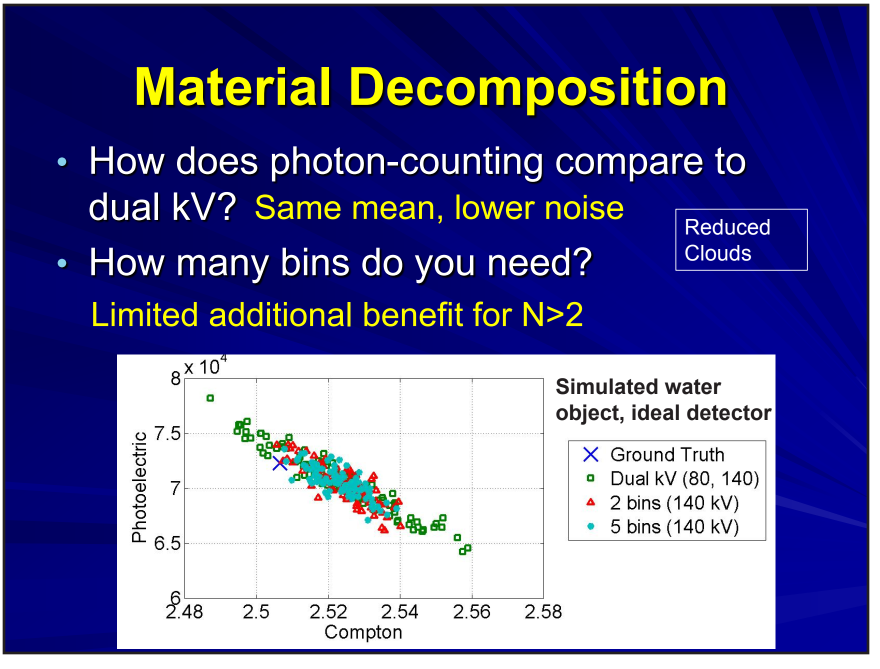
Reduced Clouds

Rupcich & Schmidt (2013
Shikhaliev & Fritz (2011)
Le et. al (2010)


Beam Hardening Effects
normalized profile
1
0.95
0.9
0.85
0.8
0.75
integrating
counting
projection−based
image−based
−5
−2.5
0
2.5
5
object coordinates (cm)
PB
IB
PB
IB
PB: Projection-based optimal weighting
IB: Image-based optimal weighting
Reduced Clouds
T. G. Schmidt , 2009

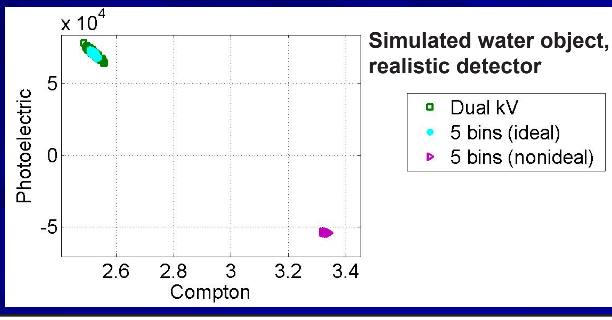

Material Decomposition
The attenuation coefficient can be decomposed into basis functions
μ(x,y,z) = a (x,y,z) μA + b (x,y,z) μB


Material Decomposition
x 10^4
80 kVp
140 kVp
•56 kV
•76 kV
I_o(E)
Energy (keV)
Detected photons
Energy (keV)
Dual kV
Spectral Photon-Counting
Spectral photon-counting CT has more unique energy information → reduced noise


Material Decomposition
• How does photon-counting compare to dual kV? Same mean, lower noise
• How many bins do you need?
Limited additional benefit for N>2
Reduced Clouds
Simulated water object, ideal detector
Ground Truth
Dual kV (80, 140)
2 bins (140 kV)
5 bins (140 kV)
Photoelectric
Compton

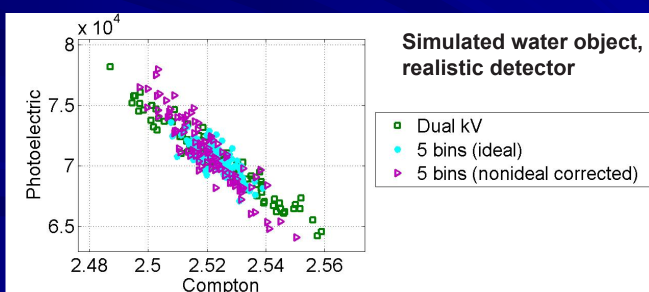
Material Decomposition

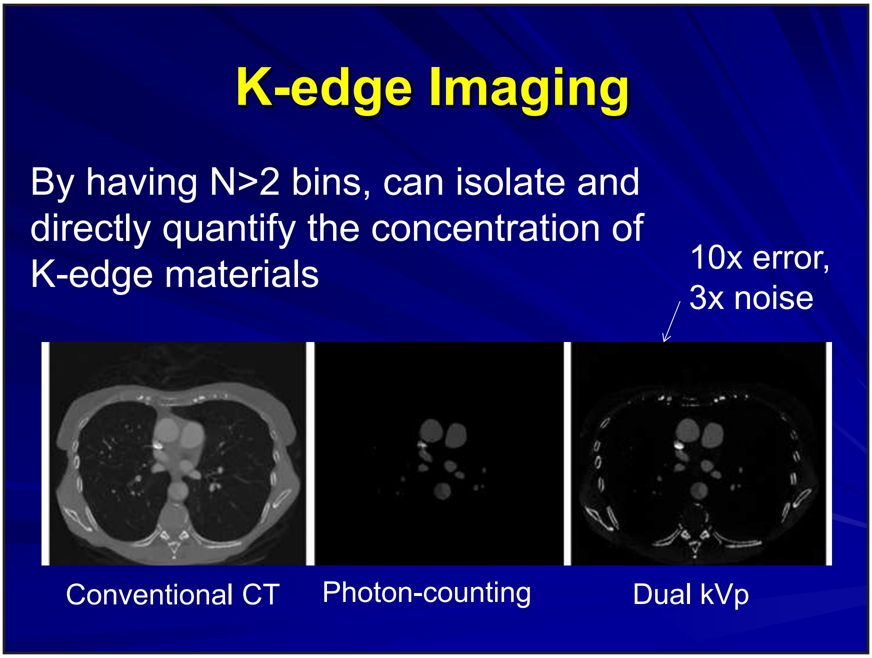
- How does photon counting compare to dual-kV when a realistic photon-counting detector is simulated (photons detected in incorrect bins)? Large bias for photon counting

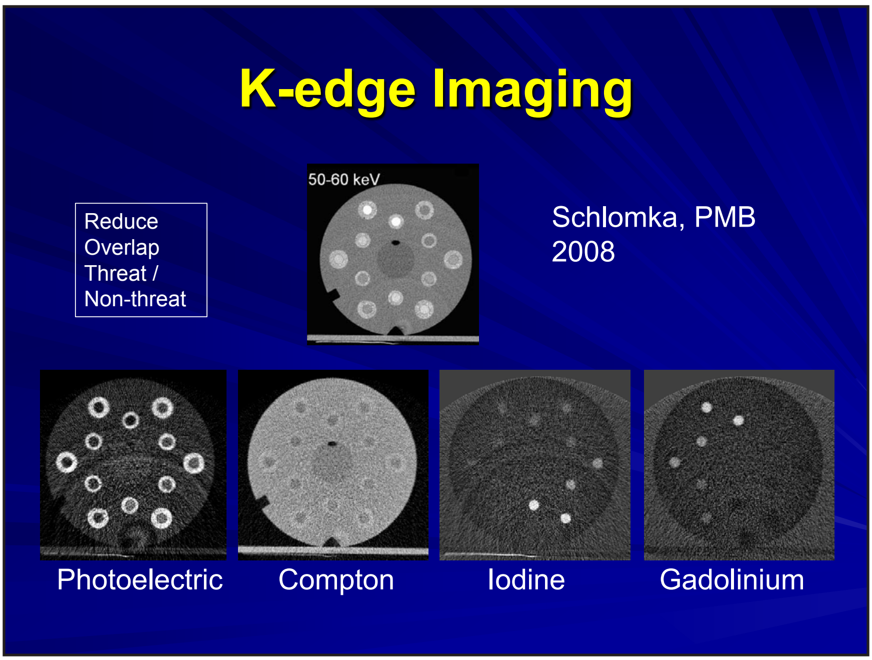


Material Decomposition

- How does photon-counting perform when detector nonidealities included in decomposition algorithm? Bias corrected, but same noise as dual kV. No benefit for PC




K-edge Imaging
By having N>2 bins, can isolate and directly quantify the concentration of K-edge materials
10x error, 3x noise
Conventional CT
Photon-counting
Dual kVp


K-edge Imaging
Reduce Overlap Threat / Non-threat
50-60 keV
Schlomka, PMB 2008
Photoelectric
Compton
Iodine
Gadolinium

K-edges of Explosives

- K-edges of explosives too low to be detected
- Could be detected by removing object from bag

Material	K-edge (keV)
H	0.01
C	0.3
N	0.4
O	0.5

K-edges of Non-threats?

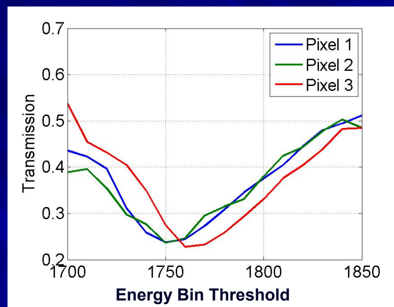
Material	K-edge (keV)
Sn	29
Sb	30
Te	32
I	33
Xe	35
Cs	36
Ba	37
La	39
Ce	40
Pr	42
Nd	44

Material	K-edge (keV)
Pm	45
Sm	47
Eu	49
Gd	50
Tb	52
Dy	54
Ho	56
Er	57
Tm	59
Tb	61
Lu	63

Material	K-edge (keV)
Hf	65
Ta	67
W	69
Re	72
Os	74
Ir	76
Pt	78
Au	80
Hg	82
Th	85
Pb	88

K-edge of Iodine

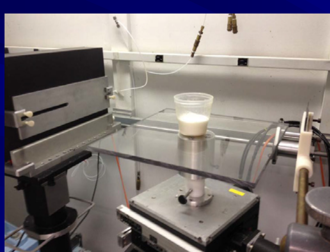
- X-ray transmission generally increases with energy
- Transmission decreases sharply at K-edge
- K-edge can be identified for iodinated contrast agent



Iodinated X-ray Contrast Agent

370 mg/cm^3 Iodine

Detect the K-edge of Salt?



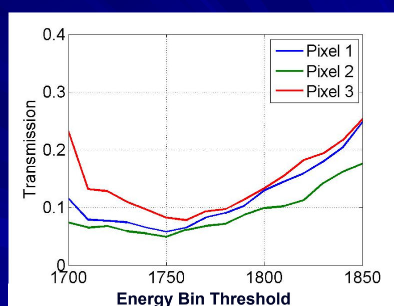
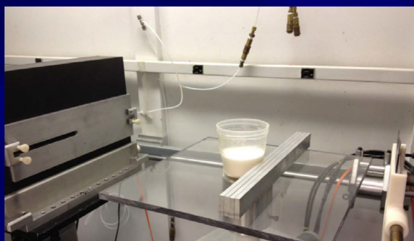


Table Salt

0.1 mg/cm^3 Iodine

Identifying salt may be useful for discriminating non-threat

Detect the K-edge of Salt?



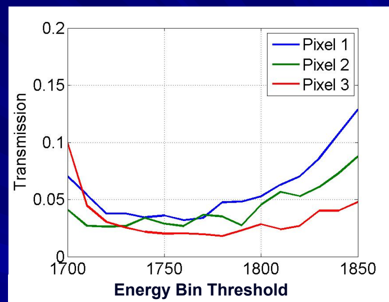


Table Salt

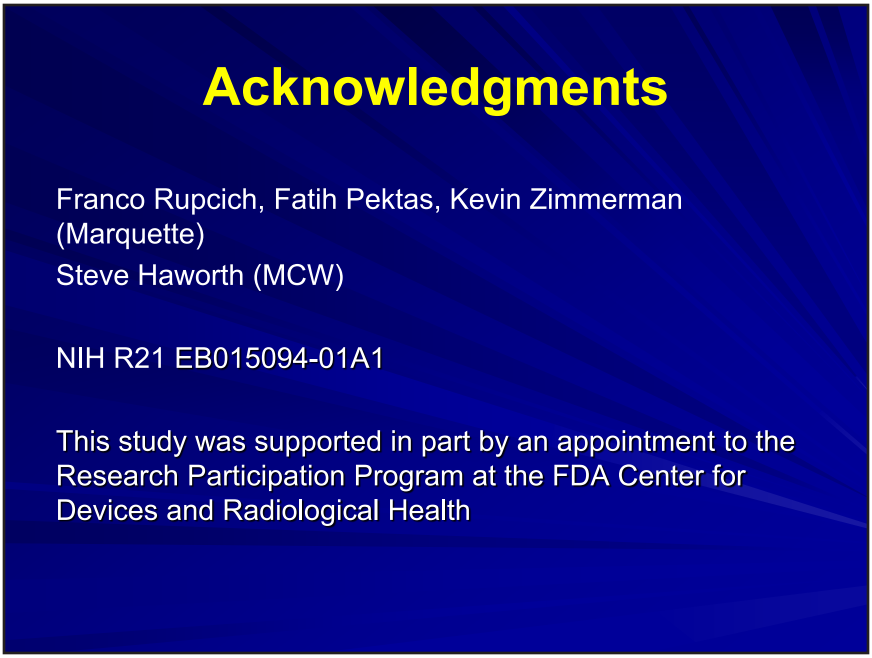
0.1 mg/cm^3 Iodine

Not many 30-40 keV photons penetrate, difficult to see K-edge

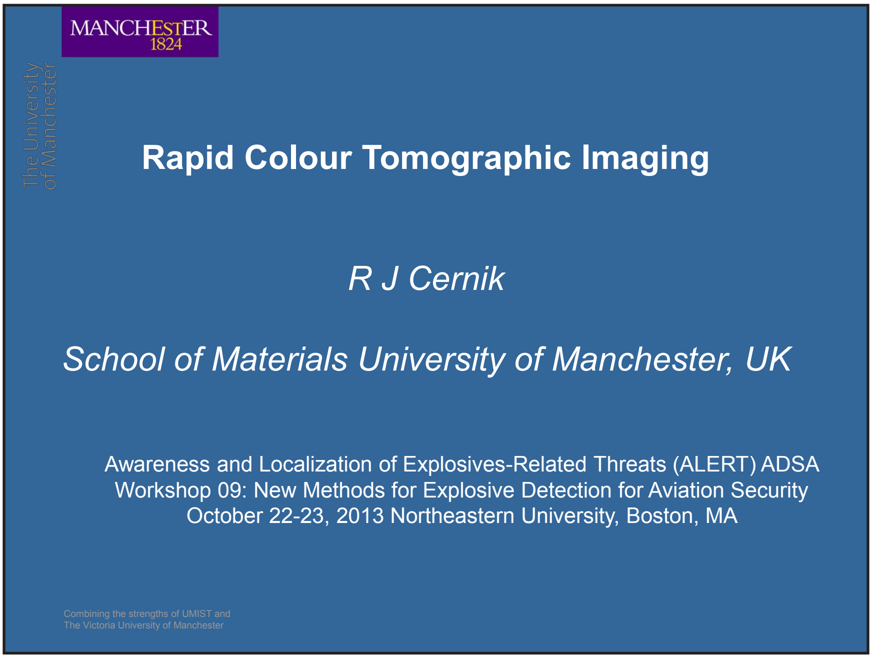
Conclusions

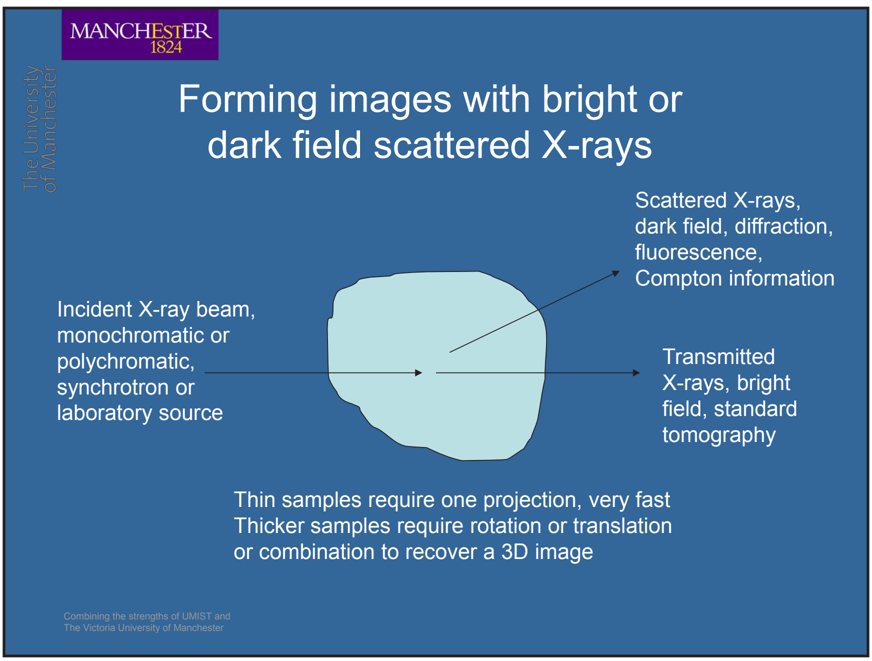
Spectral photon-counting CT:

- Improves SNR and removes beam hardening through optimal energy weighting
  - Limited additional benefit for N > 5 bins
  - May help explosive detection by reducing clouds
- Reduces noise in material decomposition
  - Limited additional benefit for N > 2 bins
  - May help explosive detection if task is SNR limited
  - Not fully realized due to detector issues
- Identifies K-edge materials
  - K-edge of explosives too low to be detected
  - K-edge may be useful to identify non-threats


Acknowledgments
Franco Rupcich, Fatih Pektas, Kevin Zimmerman (Marquette)
Steve Haworth (MCW)
NIH R21 EB015094-01A1
This study was supported in part by an appointment to the Research Participation Program at the FDA Center for Devices and Radiological Health

17.3 Robert Cernick: Rapid Colour Tomographic Imaging





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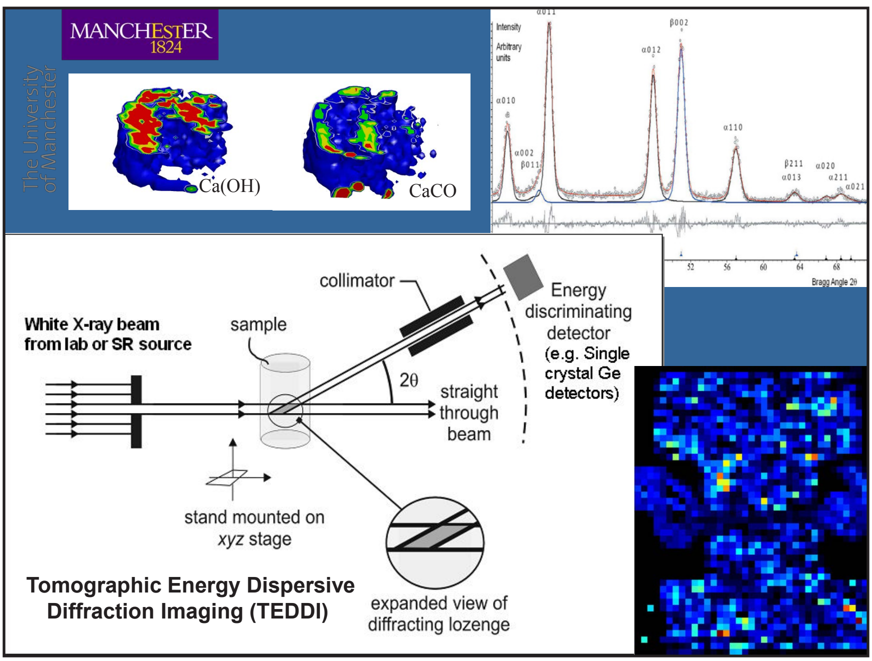
It is difficult in practice to collect the scattered signals, the signal to noise tend to be poor. The signals can be 10^4 or 10^5 times weaker than the transmitted beam used for conventional tomography.

This is a shame since all the really useful information for phase identification, fingerprinting structural information is contained in the scattered beam.

The next slide shows the first attempt to extract this information by a technique called Tomographic Energy Dispersive diffraction Imaging (TEDDI). Note this method needs long collimators to define the gauge volume

Combining the strengths of UMIST and
The Victoria University of Manchester



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The next slides show the same TEDDI geometry but also using tomographic reconstruction. This is very informative but very slow. The maps too 16-20 hours to collect and several weeks of student processing time!

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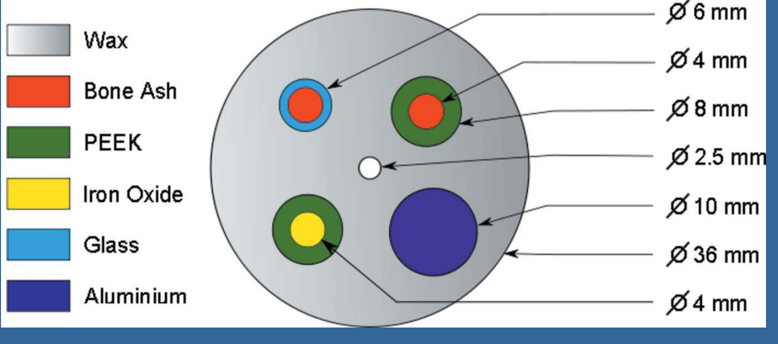
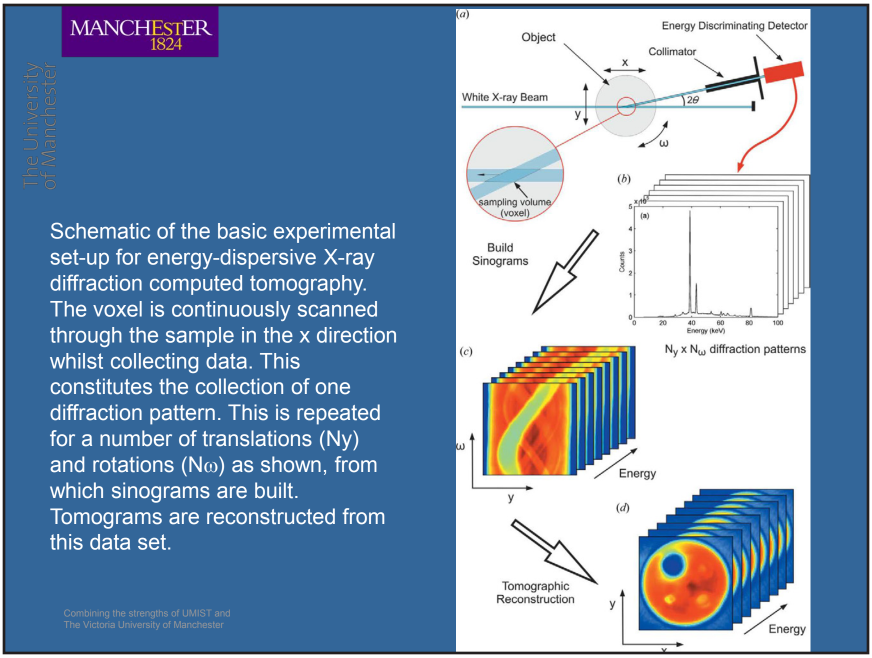
Lazzari et al. *J. Synchrotron Rad.* (2012). 19, 471-477

Full XRD CT with a test object



Combining the strengths of UMIST and
The Victoria University of Manchester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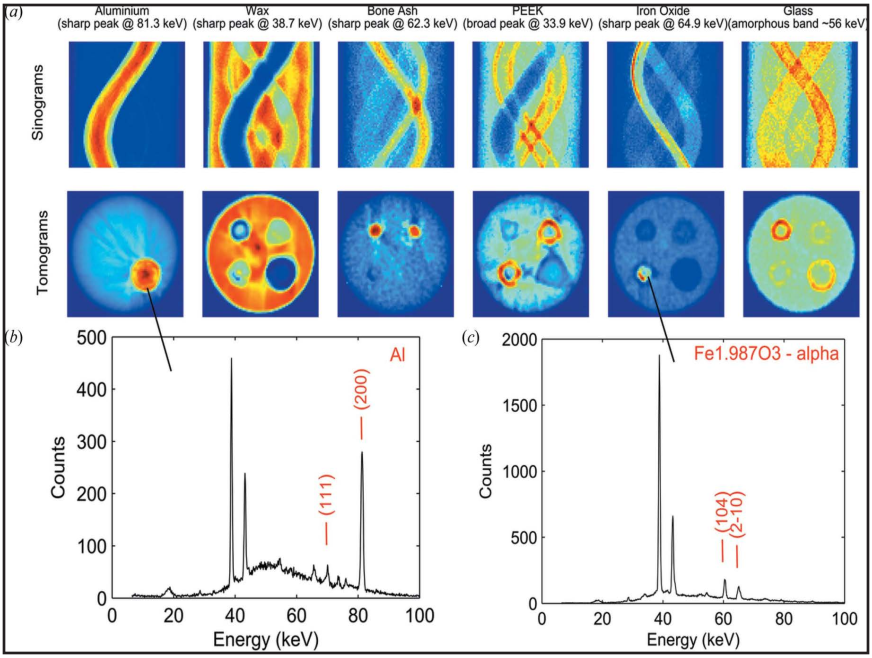
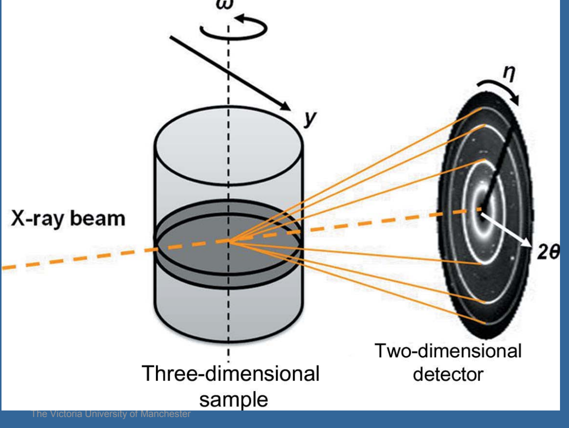
Schematic of the basic experimental set-up for energy-dispersive X-ray diffraction computed tomography. The voxel is continuously scanned through the sample in the x direction whilst collecting data. This constitutes the collection of one diffraction pattern. This is repeated for a number of translations (Ny) and rotations (Nω) as shown, from which sinograms are built. Tomograms are reconstructed from this data set.
Combining the strengths of UMIST and
The Victoria University of Manchester
(a)
Object
Energy Discriminating Detector
Collimator
White X-ray Beam
2θ
ω
sampling volume
(voxel)
(b)
Build
Sinograms
Counts
Energy (keV)
Ny x Nω diffraction patterns
(c)
Energy
(d)
Tomographic
Reconstruction
Energy


(a)
Aluminium
(sharp peak @ 81.3 keV)
Wax
(sharp peak @ 38.7 keV)
Bone Ash
(sharp peak @ 62.3 keV)
PEEK
(broad peak @ 33.9 keV)
Iron Oxide
(sharp peak @ 64.9 keV)
Glass
(amorphous band ~56 keV)
Sinograms
Tomograms
(b)
Al
(200)
(111)
Counts
Energy (keV)
(c)
Fe1.987O3 - alpha
(104)
(2-10)
Counts
Energy (keV)

We can also get diffraction tomograms by using a monochromatic beam and a conventional area detector. This gives you the ability to look at samples with very fine spatial resolution, also the ability to examine nanocrystalline materials and to look at crystalline structure.

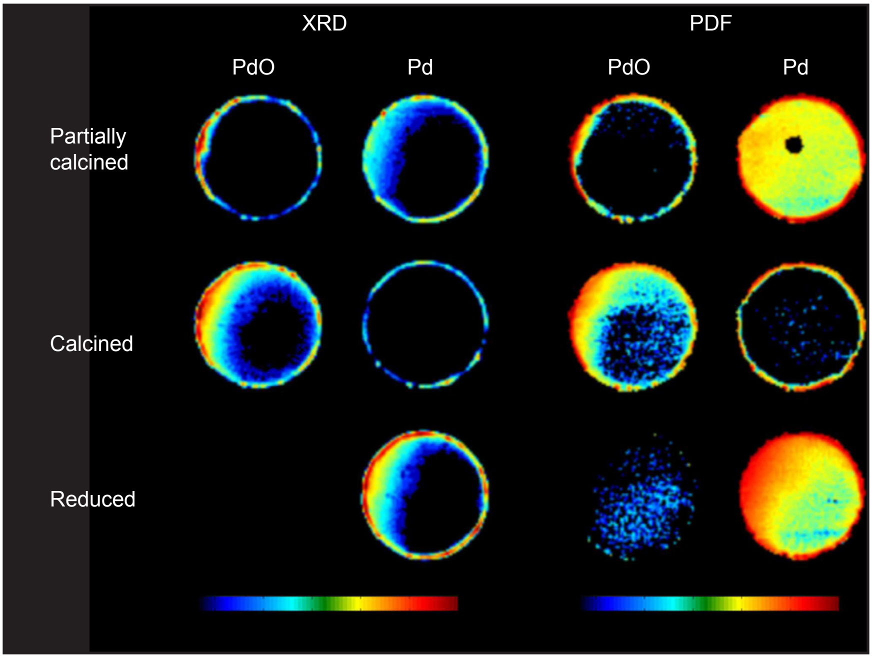
This is academically very interesting but needs a synchrotron source and even longer scan times than Tomographic TEDDI method.

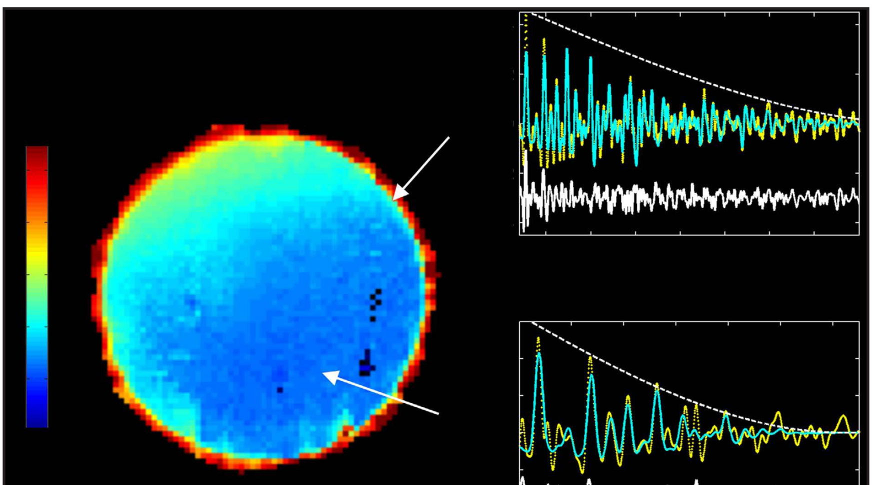
M. A lvarez-Murga et al.
J. Appl. Cryst. (2012). 45, 1109–1124



Can also use this approach for PDF Analysis

Jacques et al.
Nature Comm 2013
DOI:
10.1038/ncomms3536





Distribution of particle sizes of fcc Pd within the catalyst body under reducing conditions. Portions Of the PDF data for selected pixels at the edge and interior of the catalyst body (yellow data points) with an fcc model fit (cyan) and difference (white).

In order to really speed up the process we need large numbers of solid state detectors all looking simultaneously at the sample. This is very difficult.

Silicon pixellated detectors are ubiquitous but far too low in energy efficiency or stopping power for higher energy X-rays.

We are almost exclusively interested in the energy ranges from 60 – 300 keV (or higher) to get through large objects. That means we need high Z material for the detectors, pixellated, with excellent energy resolution and highly uniform in response. The HEXITEC project has done hjust that as you can see in the next slides.

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HEXITEC Detector

1 mm CdTe; 80 × 80 pixels on 250 μm pitch; active area: 2 × 2 cm^2

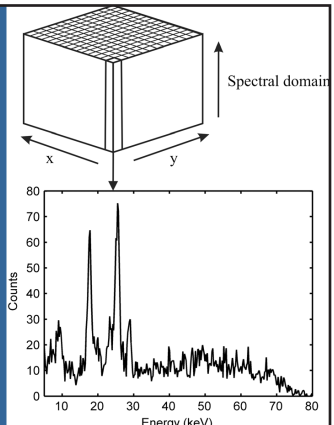
Energy range: 5 – 200 keV

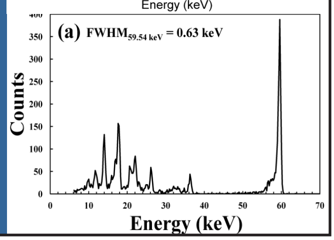
Energy resolution: ≤800 eV @ 60 keV

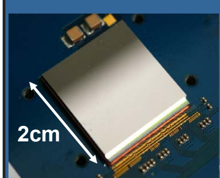
Rolling row readout @ 20MHz

Events extracted in soft/firmware → really understand the data

10 Mphotons/sec/80x80 (charge sharing)







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The next slides shows the very simple set up in the lab with images being collected in minutes from conventional sources.

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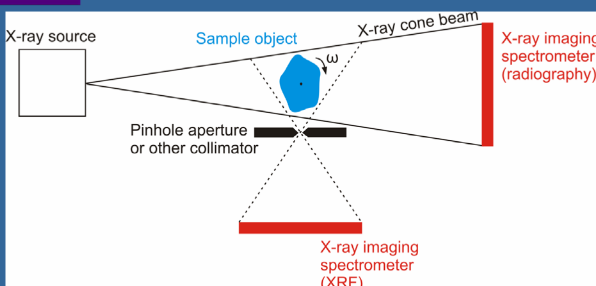
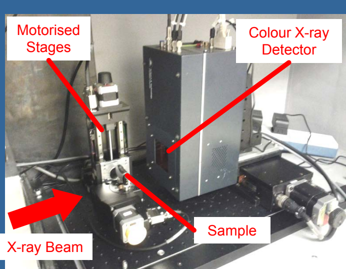




Laboratory X-ray system

225 keV tungsten target

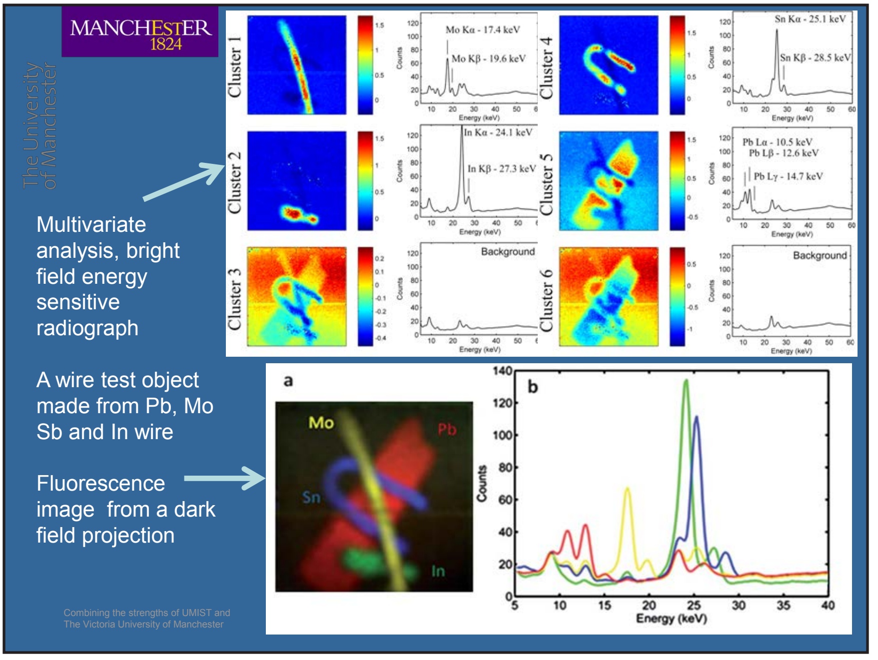
HEXITEC detector

80 x 80 array

500 eV resolution

250 micron square pixel

The Victoria University of Manchester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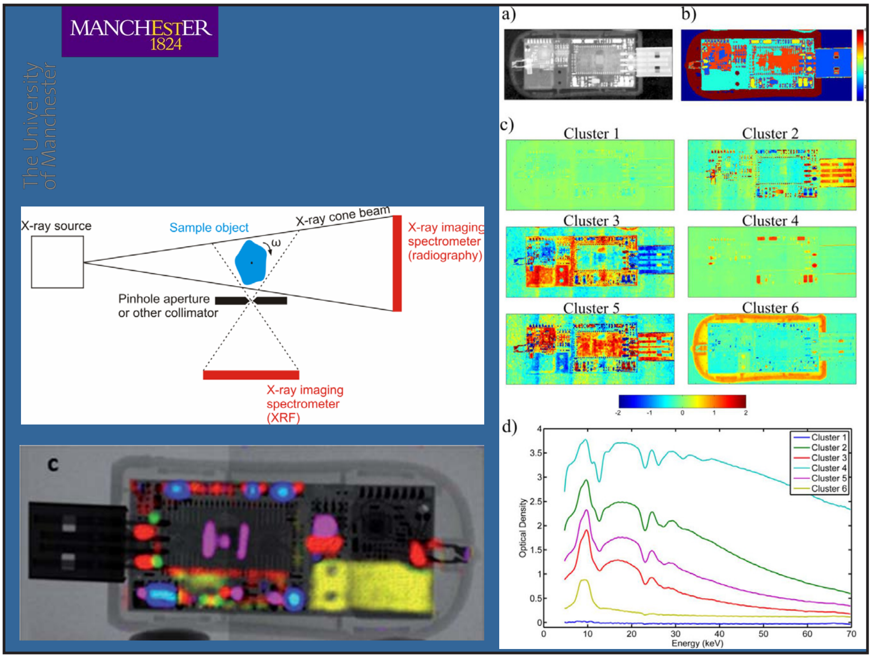
Multivariate analysis, bright field energy sensitive radiograph
A wire test object made from Pb, Mo Sb and In wire
Fluorescence image from a dark field projection
Combining the strengths of UMIST and The Victoria University of Manchester
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6
Mo Kα - 17.4 keV
Mo Kβ - 19.6 keV
In Kα - 24.1 keV
In Kβ - 27.3 keV
Sn Kα - 25.1 keV
Sn Kβ - 28.5 keV
Pb Lα - 10.5 keV
Pb Lβ - 12.6 keV
Pb Lγ - 14.7 keV
Background
Mo
Pb
Sn
In
Counts
Energy (keV)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X-ray source
Sample object
X-ray cone beam
X-ray imaging spectrometer (radiography)
Pinhole aperture or other collimator
X-ray imaging spectrometer (XRF)
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6
Optical Density
Energy (keV)

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We have very recently shown how diffraction signals can be projected through pinholes onto a HEXITEC detector module to give the whole plane structural image all at once (data collection in seconds).

We can also carry out full diffraction CT in n times the projection data collection time. This gives the possibility of retro flitting colour sensors onto existing CT and imaging modalities to provide extra identification of threat substances to reduce the number of false positives.

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Applications:

Battery charge/discharge chemistry
Fuel cell membrane chemical imaging
Fracking shale in situ
Pharma crystallisation
In situ catalysis, hetero
Water supply contamination
Medical biopsy
Security scanning
Stress –strain scanning in whole components

Combining the strengths of UMIST and The Victoria University of Manchester

MANCHESTER
1824

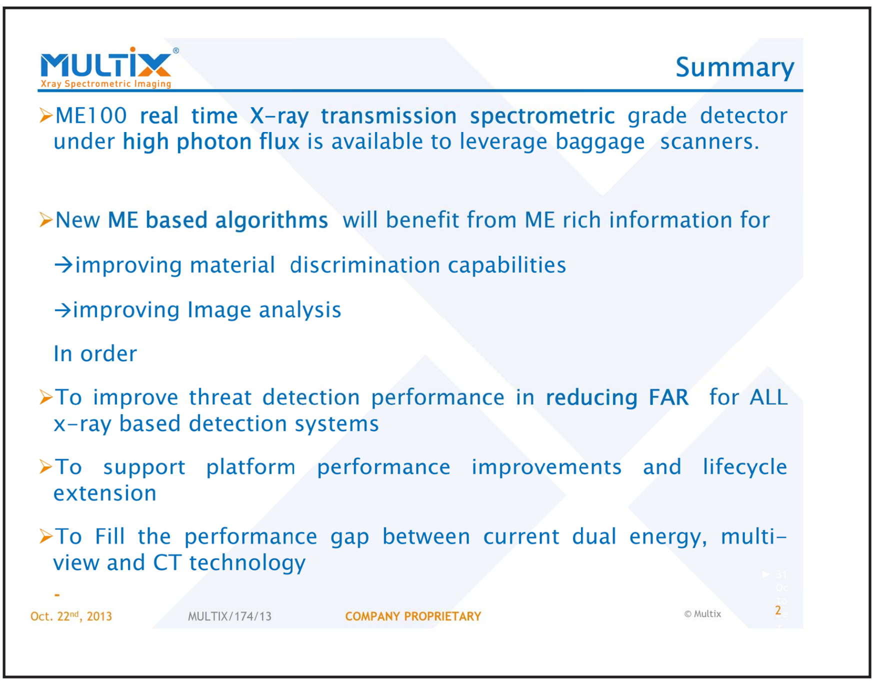
The University
of Manchester

Main credits to:
Simon Jacques
Chris Egan
Paul Seller
Matt Wilson
Matt Veale
Beamline staff at Diamond and ESRF

Thank you for the invitation and thank you for listening

Combining the strengths of UMIST and
The Victoria University of Manchester

17.4 Patrick Radisson: Multi-Energy X-Ray Detectors



MULTIX Xray Spectrometric Imaging

Executive summary

- Description: French start-up company incorporated in 2010. Spin off from Thales and venture capital backed.
- Business: High resolution multi-energy X-ray detector acquisition system developer for new builds or retrofit to existing x-ray systems dedicated for automated explosives identification/discrimination.
- Market: X-ray scanner manufacturers (conventional, CT and XRD), new build or retrofit to meeting existing and future regulations.
- Technology: Mature building blocks, major partnership with CEA/LETI French public Lab, patent portfolio.
- Maturity: Team engaged in the project since 2007. COTS product (ME100). CT and scatter development started in 2013.

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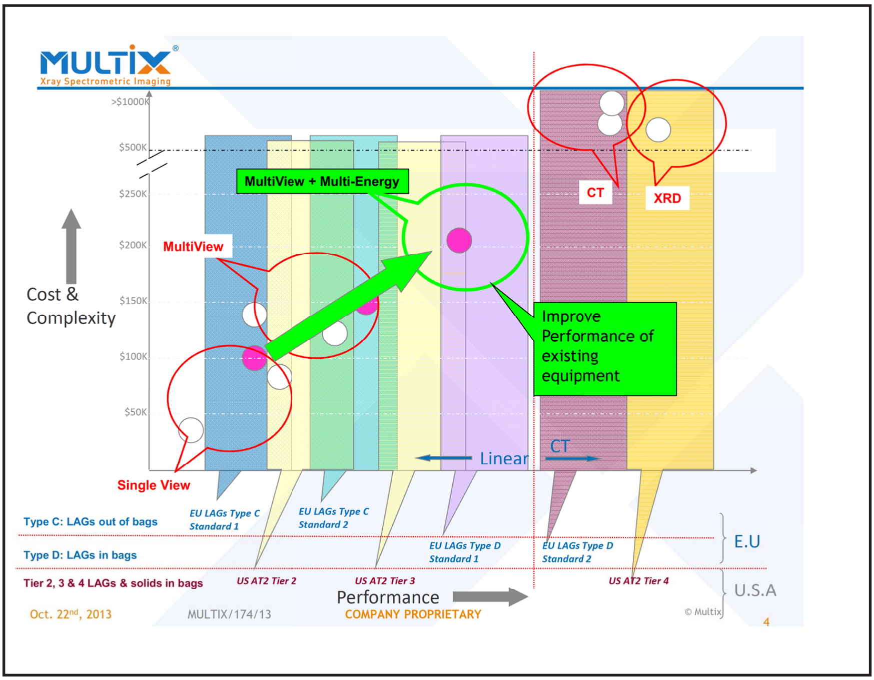

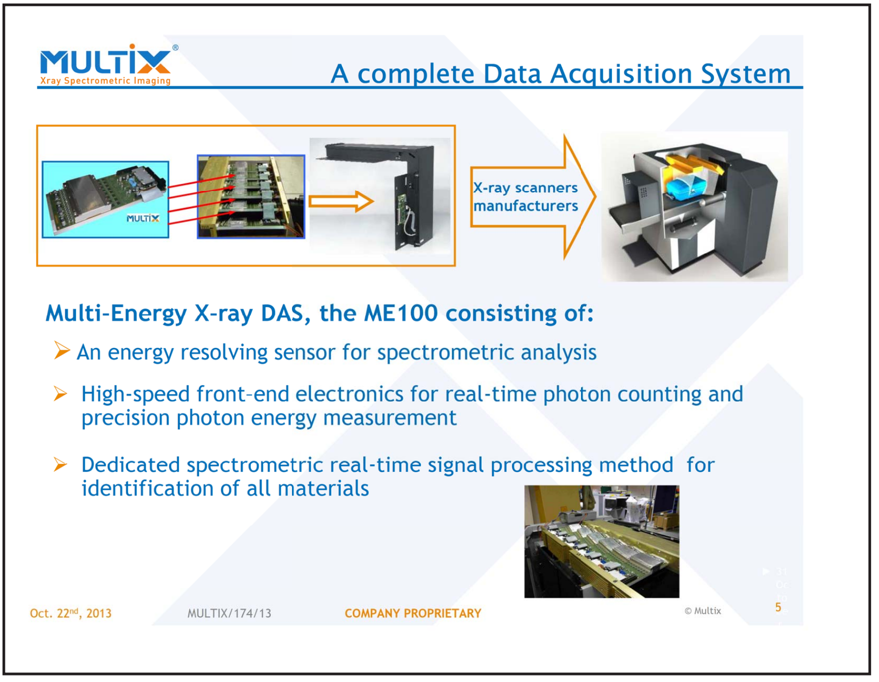
MULTiX
Xray Spectrometric Imaging
A complete Data Acquisition System
MULTiX
X-ray scanners manufacturers
Multi-Energy X-ray DAS, the ME100 consisting of:
An energy resolving sensor for spectrometric analysis
High-speed front-end electronics for real-time photon counting and precision photon energy measurement
Dedicated spectrometric real-time signal processing method for identification of all materials
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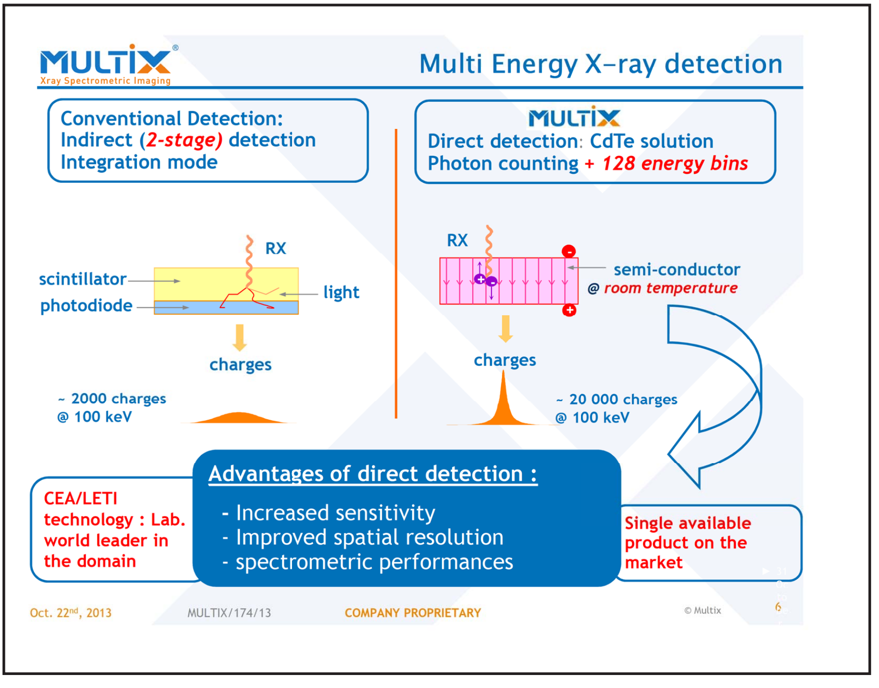
MULTiX
Xray Spectrometric Imaging
Multi Energy X–ray detection
Conventional Detection:
Indirect (2-stage) detection
Integration mode
MULTiX
Direct detection: CdTe solution
Photon counting + 128 energy bins
RX
scintillator
photodiode
light
charges
~ 2000 charges
@ 100 keV
RX
semi-conductor
@ room temperature
charges
~ 20 000 charges
@ 100 keV
Advantages of direct detection :
- Increased sensitivity
- Improved spatial resolution
- spectrometric performances
CEA/LETI technology : Lab. world leader in the domain
Single available product on the market
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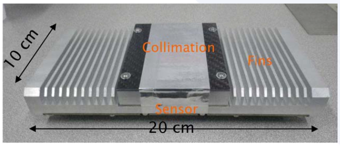
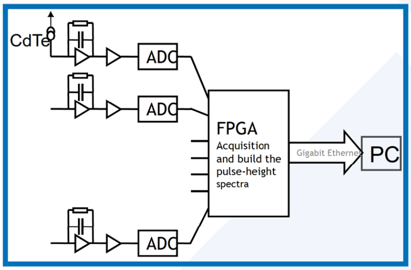
Xray Spectrometric Imaging

COTS ME100 DAS



Current COTS ME100 Detector board



Original architecture combining high-speed electronics and advanced signal (pulse) processing :

- Charge Induction
- Charge sharing
- Pile-up

To provide

- "cleaned spectra"
- Reduced "dead time"
- High photon dynamic range
- Non paralyzable behaviour

In real time!

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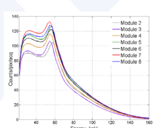
MULTIX
Xray Spectrometric Imaging

ME100 DAS Specification

- **Main features:**
  - Linear array, N modules 128 pixels
  - Pixel pitch: 800 µm
  - Material: CdTe or CdZnTe
  - Energy range: 20 - 160 keV
  - Spectrometry up to 128 energy bins within a single acquisition

Typ. acquisition time = a few ms
With Sub-ms capabilities



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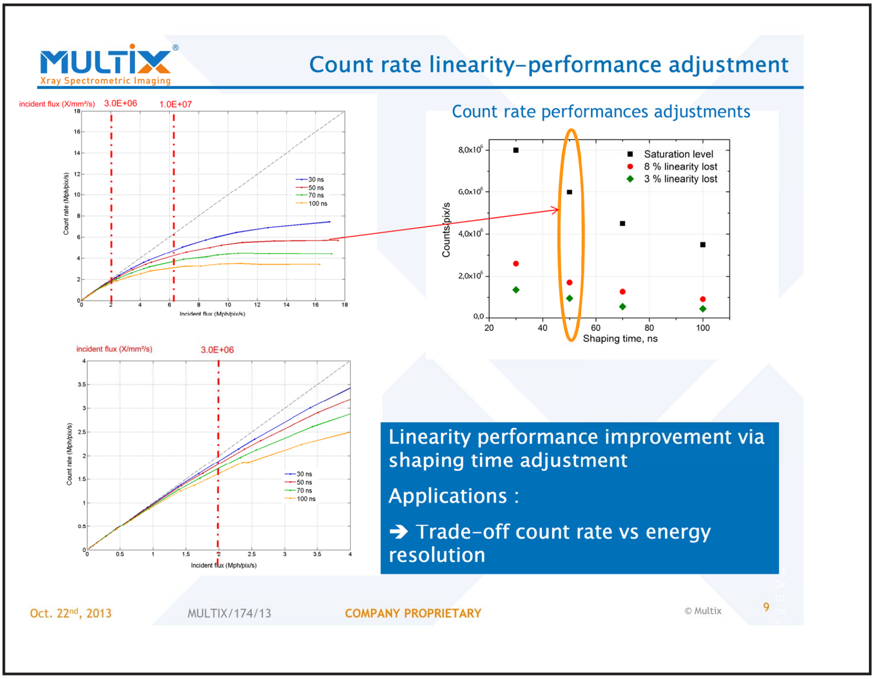
MULTIX
Xray Spectrometric Imaging
Count rate linearity-performance adjustment
incident flux (X/mm²/s) 3.0E+06 1.0E+07
Count rate performances adjustments
Saturation level
8 % linearity lost
3 % linearity lost
Counts/pix/s
Shaping time, ns
incident flux (X/mm²/s) 3.0E+06
Linearity performance improvement via shaping time adjustment
Applications :
➔ Trade-off count rate vs energy resolution
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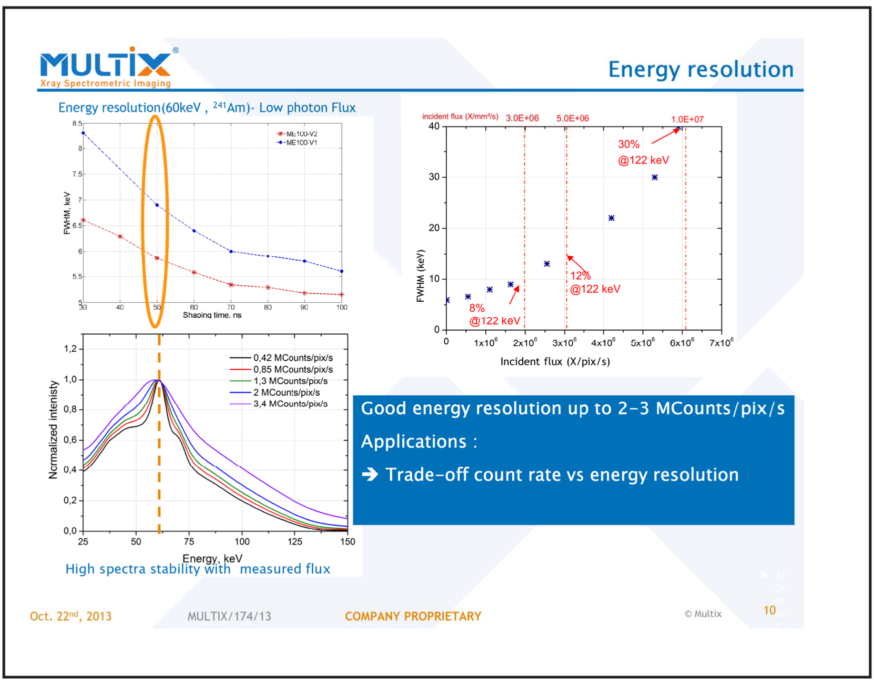
MULTIX
Xray Spectrometric Imaging
Energy resolution
Energy resolution(60keV , 241Am)- Low photon Flux
FWHM, keV
Shaping time, ns
incident flux (X/mm²/s) 3.0E+06 5.0E+06 1.0E+07
30% @122 keV
12% @122 keV
8% @122 keV
FWHM (keV)
Incident flux (X/pix/s)
0,42 MCounts/pix/s
0,85 MCounts/pix/s
1,3 MCounts/pix/s
2 MCounts/pix/s
3,4 MCounts/pix/s
Normalized intensity
Energy, keV
High spectra stability with measured flux
Good energy resolution up to 2-3 MCounts/pix/s
Applications :
➔ Trade-off count rate vs energy resolution
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MULTIX
Xray Spectrometric Imaging

IMAGE ANALYSIS IMPROVEMENTS ALLOWED THANKS TO

→Inherent Image Quality (IQ) improvement (spatial resolution..)

→Processing of Multiple Band of energy

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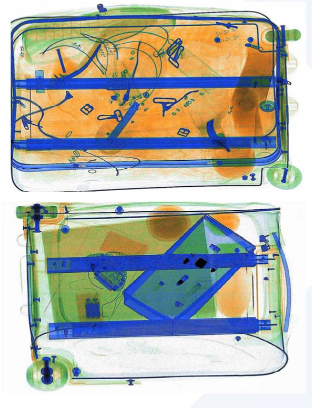
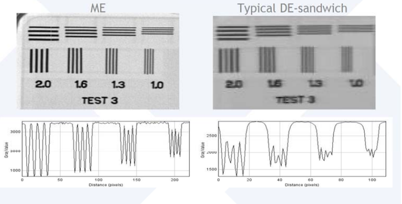
MULTIX
Xray Spectrometric Imaging

Performances of ME100

- Improved Image quality (DE like images)



Standard ASTM
- Test 1 Wire Resolution: 36 AWG in air
- Test 2 Wire Resolution: 32 AWG under 9.5 mm Al
- Test 3 Spatial Resolution: less than 1 mm V and H
- Test 4 Steel Penetration: 30 mm



(12)

(1) Look up table for ME still to be optimized

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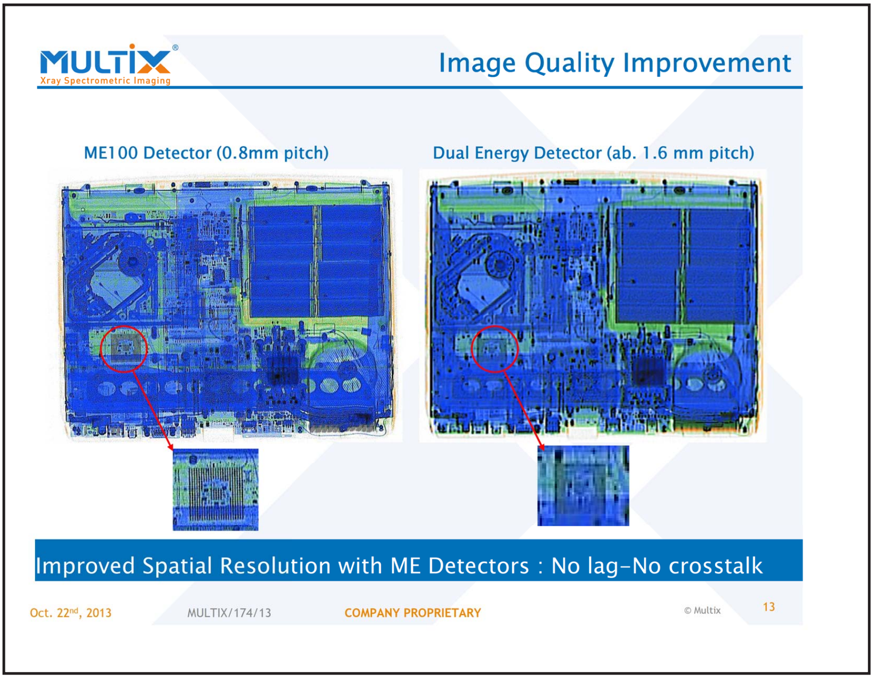
MULTIX
Xray Spectrometric Imaging
Image Quality Improvement
ME100 Detector (0.8mm pitch)
Dual Energy Detector (ab. 1.6 mm pitch)
Improved Spatial Resolution with ME Detectors : No lag-No crosstalk
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MULTIX
Xray Spectrometric Imaging
Image Quality Improvement
ME100 Detector (0.8mm pitch)
Dual Energy Detector (ab. 1.6 mm pitch)
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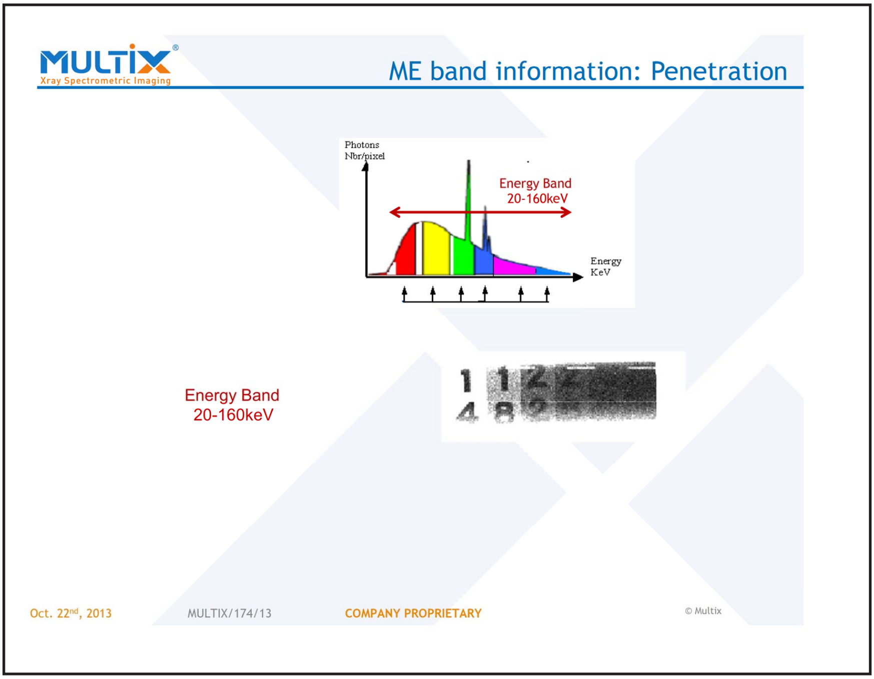
MULTIX
Xray Spectrometric Imaging
ME band information: Penetration
Photons
Nbr/pixel
Energy Band
20-160keV
Energy
KeV
Energy Band
20-160keV
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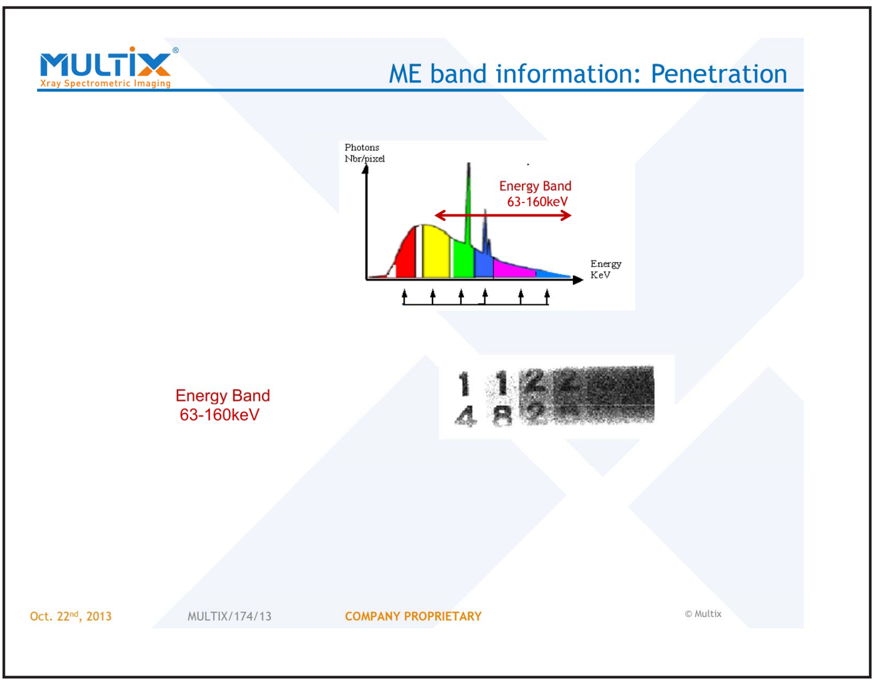
MULTIX
Xray Spectrometric Imaging
ME band information: Penetration
Photons
Nbr/pixel
Energy Band
63-160keV
Energy
KeV
Energy Band
63-160keV
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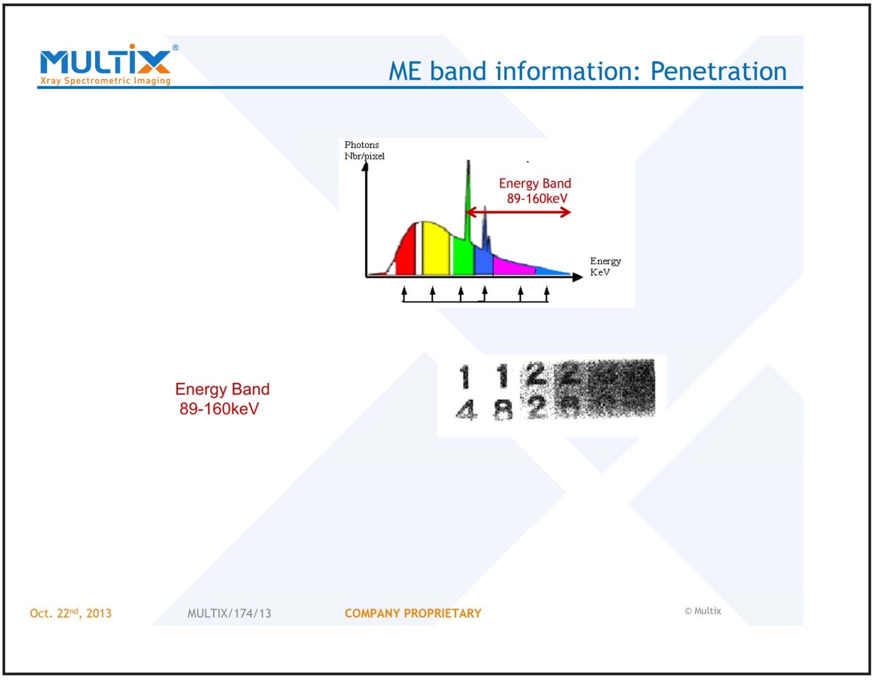
MULTIX
Xray Spectrometric Imaging
ME band information: Penetration
Photons
Nbr/pixel
Energy Band
89-160keV
Energy
KeV
Energy Band
89-160keV
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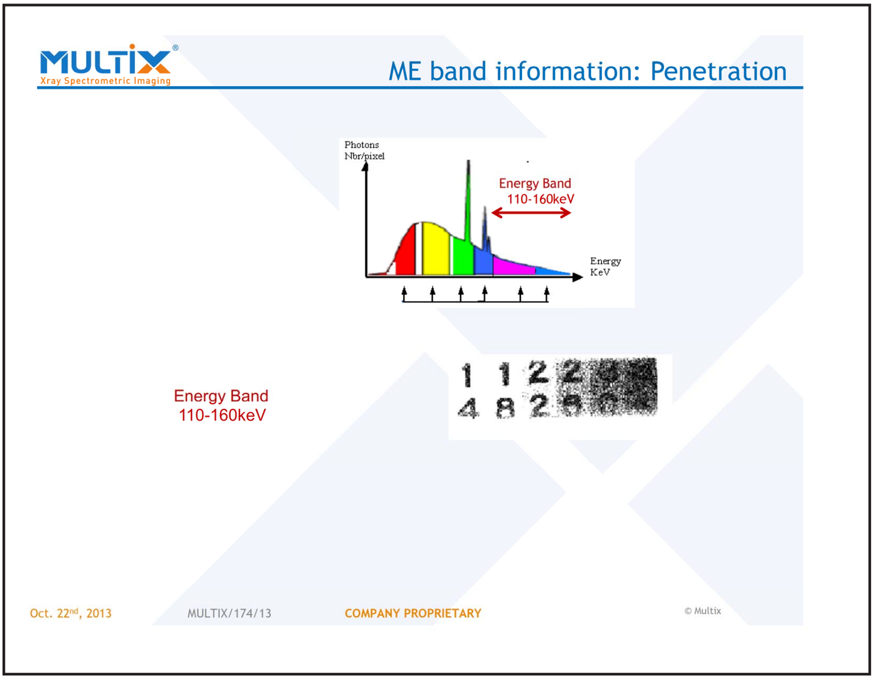
MULTIX
Xray Spectrometric Imaging
ME band information: Penetration
Photons
Nbr/pixel
Energy Band
110-160keV
Energy
KeV
Energy Band
110-160keV
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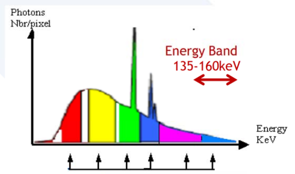
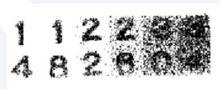
MULTIX Xray Spectrometric Imaging

ME band information: Penetration



Energy Band
135-160keV



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MULTIX Xray Spectrometric Imaging

ME band information: Image analysis

1. Plastics
   1. Delrin 13 mm
   2. Pmma 15 mm
   3. Delrin 5mm
2. metals
   1. Aluminium foil 4 mm
   2. Fe 2mm
   3. A piece in steel with a number W
3. Other organics
   1. Orange
   2. Shampoo
   3. 2 packs of cigarettes

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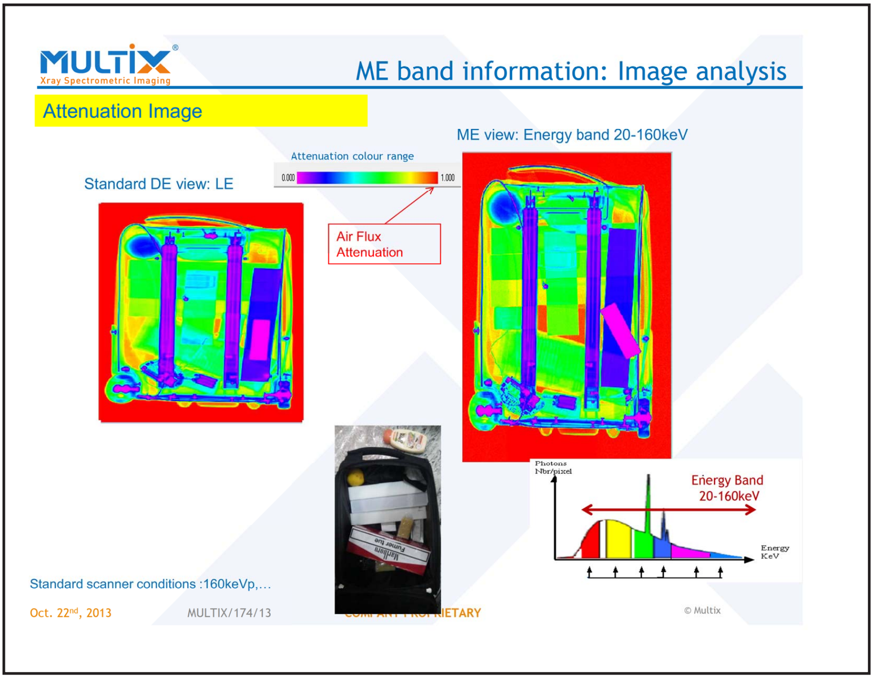
MULTIX
Xray Spectrometric Imaging
ME band information: Image analysis
Attenuation Image
ME view: Energy band 20-160keV
Attenuation colour range
Standard DE view: LE
Air Flux Attenuation
Photons Nbr/pixel
Energy Band 20-160keV
Energy KeV
Standard scanner conditions :160keVp,…
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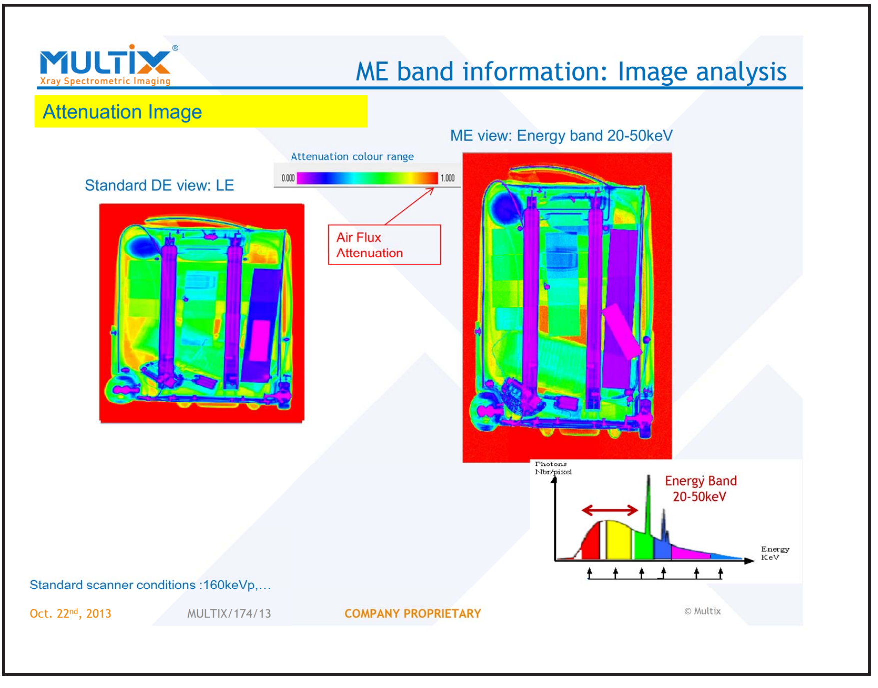
MULTIX
Xray Spectrometric Imaging
ME band information: Image analysis
Attenuation Image
ME view: Energy band 20-50keV
Attenuation colour range
Standard DE view: LE
Air Flux Attenuation
Photons Nbr/pixel
Energy Band 20-50keV
Energy KeV
Standard scanner conditions :160keVp,…
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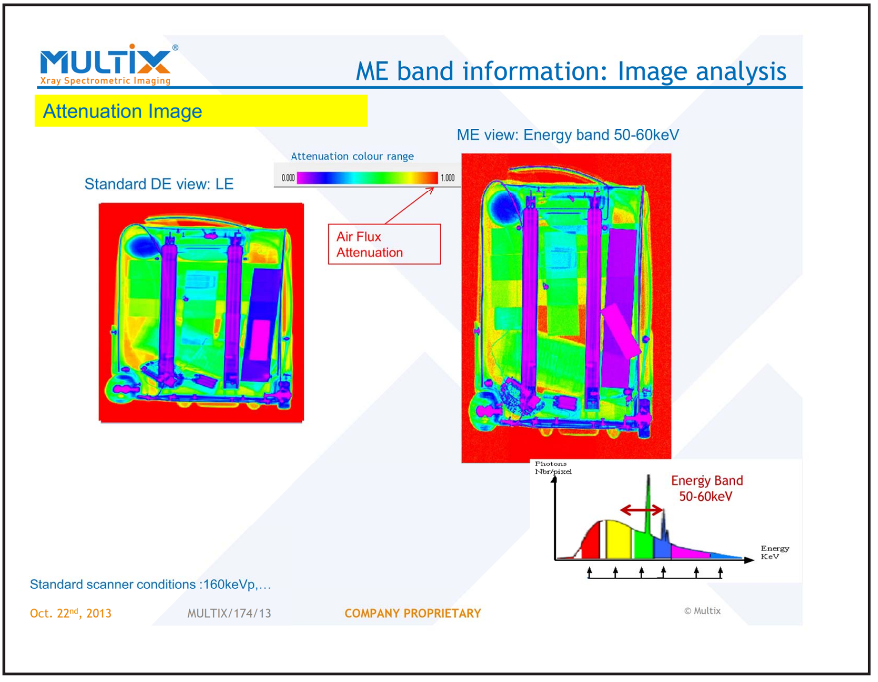
MULTIX
Xray Spectrometric Imaging
ME band information: Image analysis
Attenuation Image
ME view: Energy band 50-60keV
Attenuation colour range
0.000
1.000
Standard DE view: LE
Air Flux
Attenuation
Photons
Nbr/pixel
Energy Band
50-60keV
Energy
KeV
Standard scanner conditions :160keVp,…
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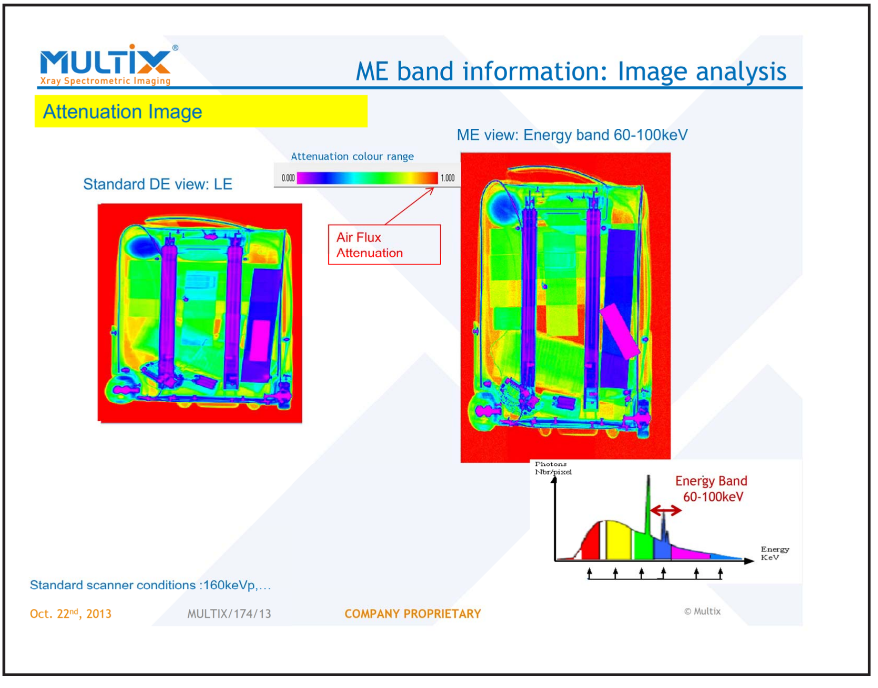
MULTIX
Xray Spectrometric Imaging
ME band information: Image analysis
Attenuation Image
ME view: Energy band 60-100keV
Attenuation colour range
0.000
1.000
Standard DE view: LE
Air Flux
Attenuation
Photons
Nbr/pixel
Energy Band
60-100keV
Energy
KeV
Standard scanner conditions :160keVp,…
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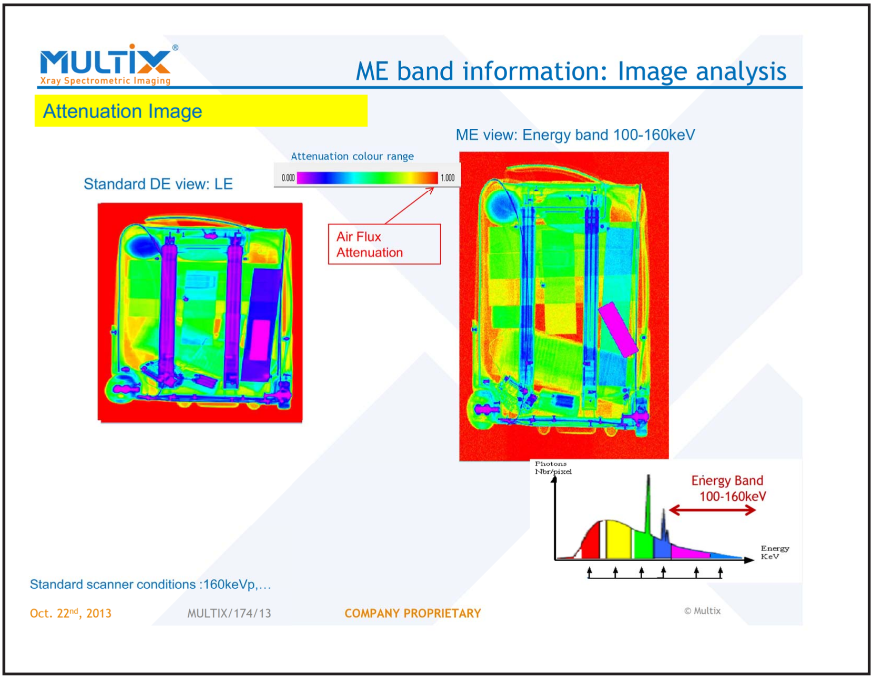
MULTIX
Xray Spectrometric Imaging
ME band information: Image analysis
Attenuation Image
ME view: Energy band 100-160keV
Attenuation colour range
Standard DE view: LE
0.000
1.000
Air Flux
Attenuation
Photons
Nbr/pixel
Energy Band
100-160keV
Energy
KeV
Standard scanner conditions :160keVp,…
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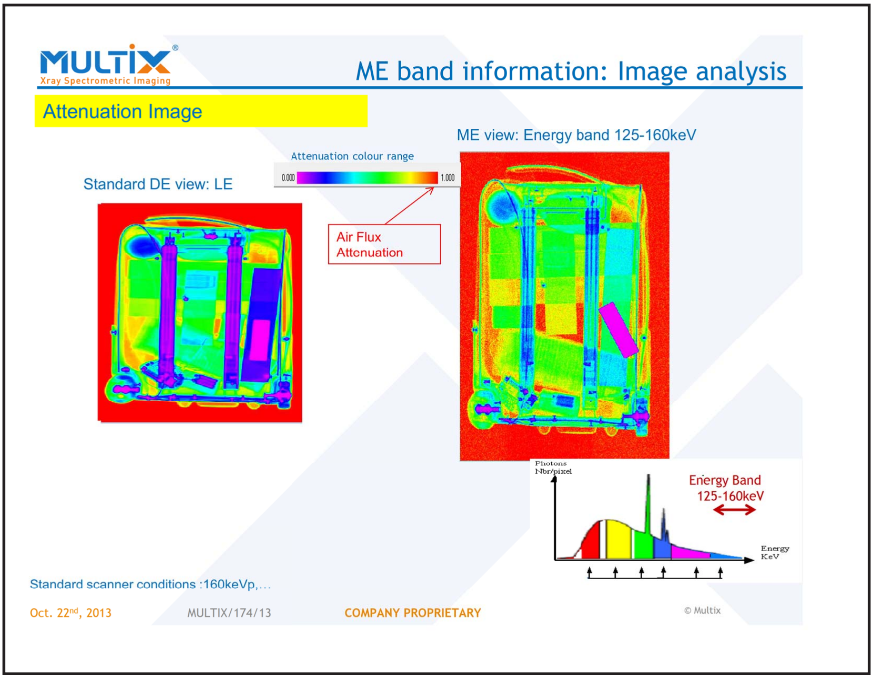
MULTIX
Xray Spectrometric Imaging
ME band information: Image analysis
Attenuation Image
ME view: Energy band 125-160keV
Attenuation colour range
Standard DE view: LE
0.000
1.000
Air Flux
Attenuation
Photons
Nbr/pixel
Energy Band
125-160keV
Energy
KeV
Standard scanner conditions :160keVp,…
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MULTIX Xray Spectrometric Imaging

MATERIAL DISCRIMINATION IMPROVEMENTS ALLOWED THANKS TO

→Spectral information

→Dedicated ME algorithms

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MULTIX Xray Spectrometric Imaging

Material identification method

› Multi-energy information :

→Dual energy method can't be used

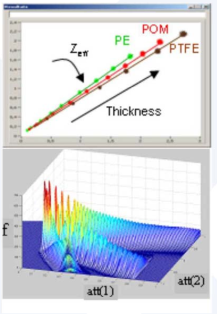
› Developpement of a specific method :

- N-dimensional space(attenuations)
- Calibration with noise learning,
- Multi-Gaussian approximation
- Method using probability densities

› Output :

- Material likelihood
- Equivalent thickness
- Density
- Zeff
- False detection rate

… A tool to be integrated into equipments



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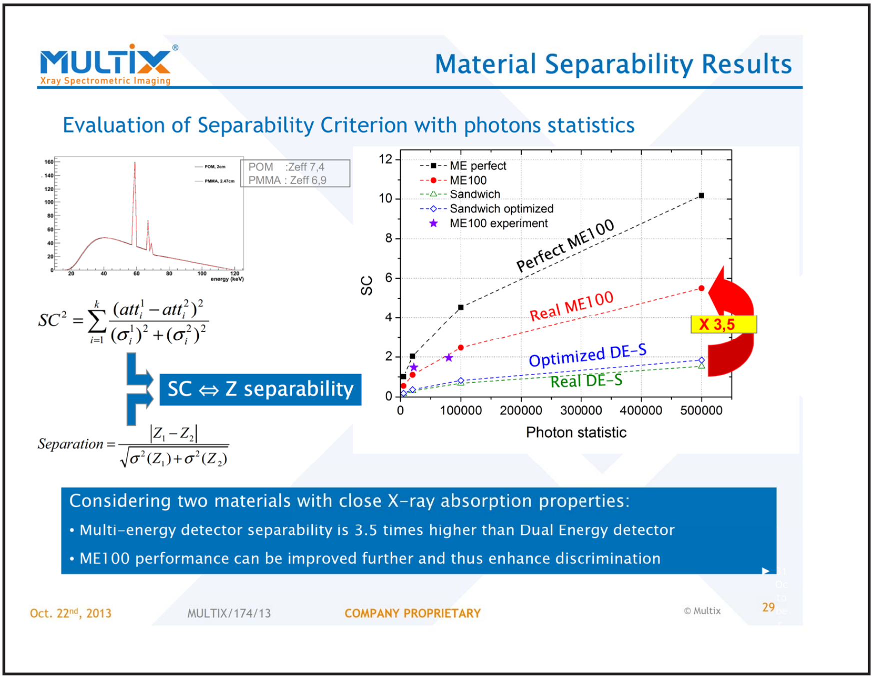
MULTIX
Xray Spectrometric Imaging
Material Separability Results
Evaluation of Separability Criterion with photons statistics
POM :Zeff 7,4
PMMA : Zeff 6,9
energy (keV)
$SC^2 = \sum_{i=1}^{k} \frac{(att_i^1 - att_i^2)^2}{(\sigma_i^1)^2 + (\sigma_i^2)^2}$
SC ⇔ Z separability
$Separation = \frac{|Z_1 - Z_2|}{\sqrt{\sigma^2(Z_1) + \sigma^2(Z_2)}}$
ME perfect
ME100
Sandwich
Sandwich optimized
ME100 experiment
Perfect ME100
Real ME100
X 3,5
Optimized DE-S
Real DE-S
SC
Photon statistic
Considering two materials with close X-ray absorption properties:
• Multi-energy detector separability is 3.5 times higher than Dual Energy detector
• ME100 performance can be improved further and thus enhance discrimination
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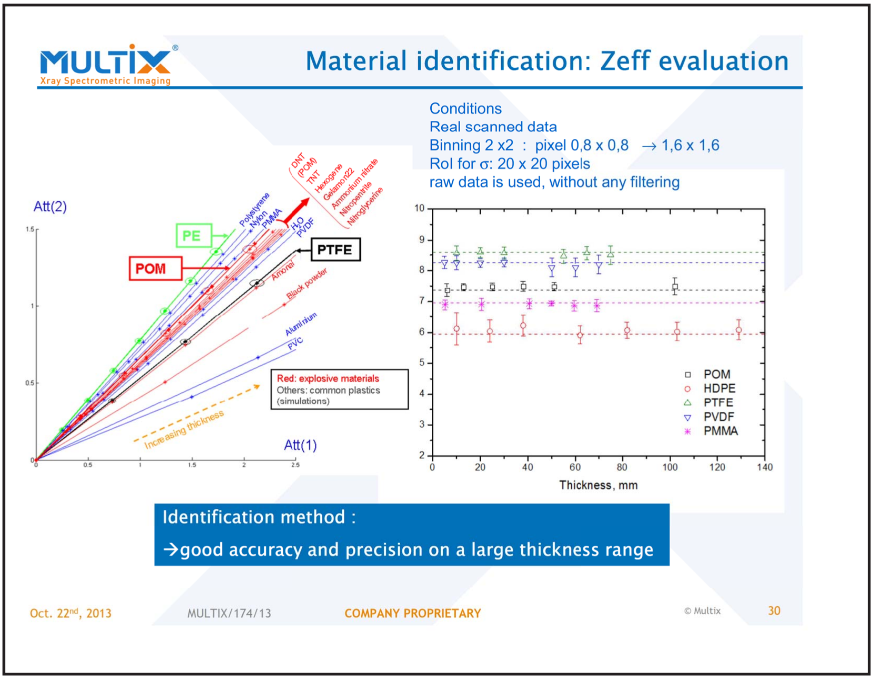
MULTIX
Xray Spectrometric Imaging
Material identification: Zeff evaluation
Conditions
Real scanned data
Binning 2 x2 : pixel 0,8 x 0,8 → 1,6 x 1,6
RoI for σ: 20 x 20 pixels
raw data is used, without any filtering
Att(2)
Att(1)
PE
POM
PTFE
Red: explosive materials
Others: common plastics
(simulations)
Increasing thickness
POM
HDPE
PTFE
PVDF
PMMA
Thickness, mm
Identification method :
→good accuracy and precision on a large thickness range
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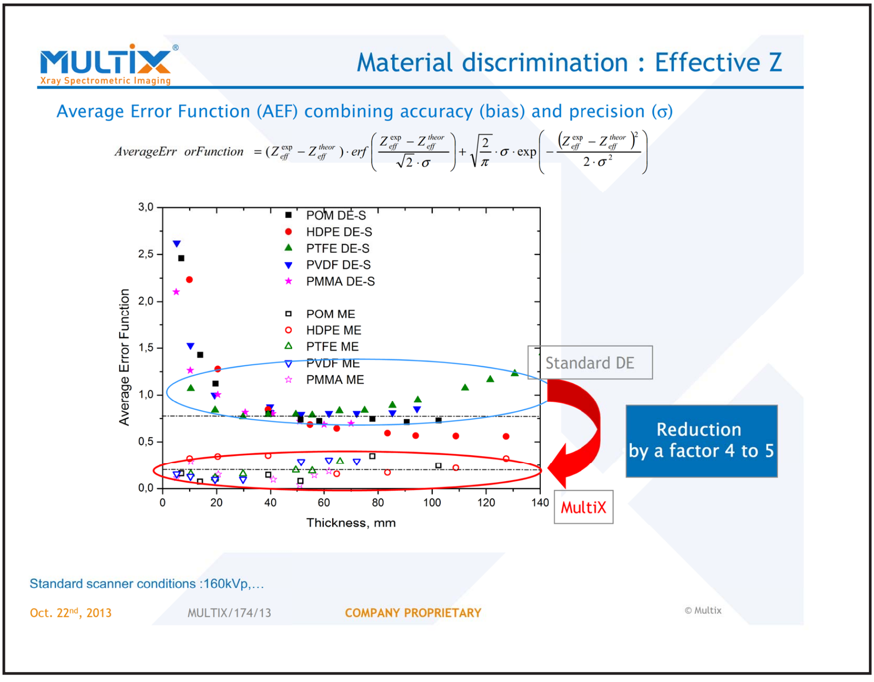
MULTIX
Xray Spectrometric Imaging
Material discrimination : Effective Z
Average Error Function (AEF) combining accuracy (bias) and precision (σ)
$AverageErrorFunction = (Z_{eff}^{exp} - Z_{eff}^{theor}) \cdot erf\left(\frac{Z_{eff}^{exp} - Z_{eff}^{theor}}{\sqrt{2}\cdot\sigma}\right) + \sqrt{\frac{2}{\pi}}\cdot\sigma\cdot\exp\left(-\frac{(Z_{eff}^{exp} - Z_{eff}^{theor})^2}{2\cdot\sigma^2}\right)$
POM DE-S
HDPE DE-S
PTFE DE-S
PVDF DE-S
PMMA DE-S
POM ME
HDPE ME
PTFE ME
PVDF ME
PMMA ME
Average Error Function
Thickness, mm
Standard DE
Reduction by a factor 4 to 5
MultiX
Standard scanner conditions :160kVp,…
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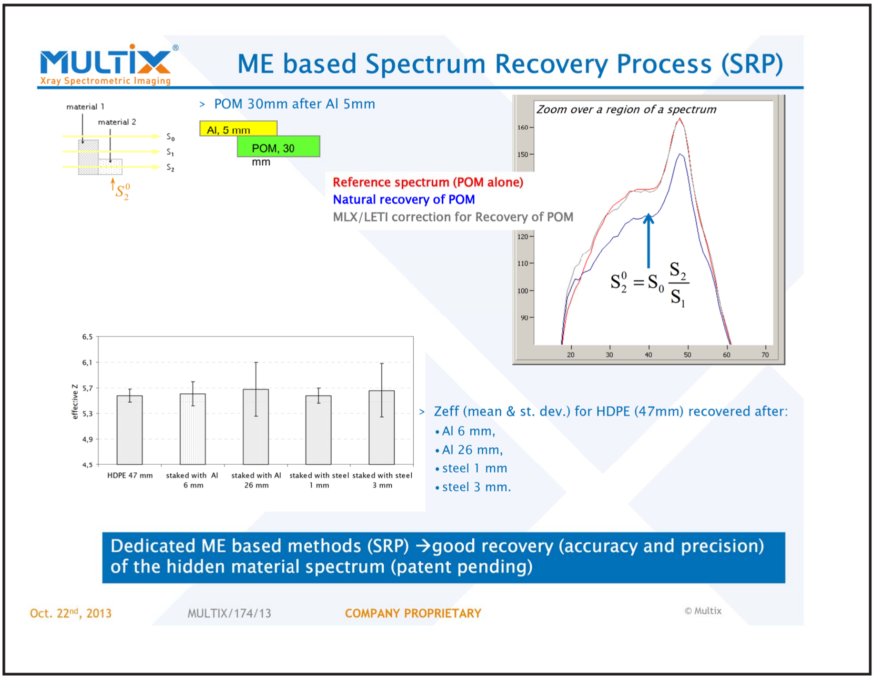
MULTIX
Xray Spectrometric Imaging
ME based Spectrum Recovery Process (SRP)
material 1
material 2
> POM 30mm after Al 5mm
Al, 5 mm
POM, 30 mm
Zoom over a region of a spectrum
Reference spectrum (POM alone)
Natural recovery of POM
MLX/LETI correction for Recovery of POM
$S_2^0 = S_0 \frac{S_2}{S_1}$
effective Z
HDPE 47 mm
staked with Al 6 mm
staked with Al 26 mm
staked with steel 1 mm
staked with steel 3 mm
> Zeff (mean & st. dev.) for HDPE (47mm) recovered after:
• Al 6 mm,
• Al 26 mm,
• steel 1 mm
• steel 3 mm.
Dedicated ME based methods (SRP) →good recovery (accuracy and precision) of the hidden material spectrum (patent pending)
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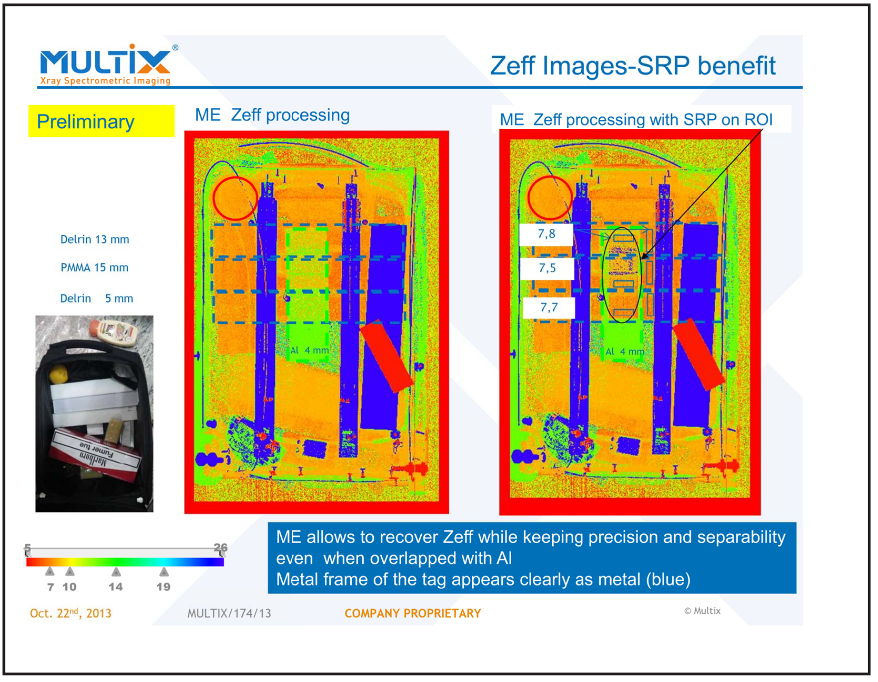
MULTIX
Xray Spectrometric Imaging
Zeff Images-SRP benefit
Preliminary
ME Zeff processing
ME Zeff processing with SRP on ROI
Delrin 13 mm
PMMA 15 mm
Delrin 5 mm
7,8
7,5
7,7
Al 4 mm
Al 4 mm
5
26
7 10 14 19
ME allows to recover Zeff while keeping precision and separability even when overlapped with Al
Metal frame of the tag appears clearly as metal (blue)
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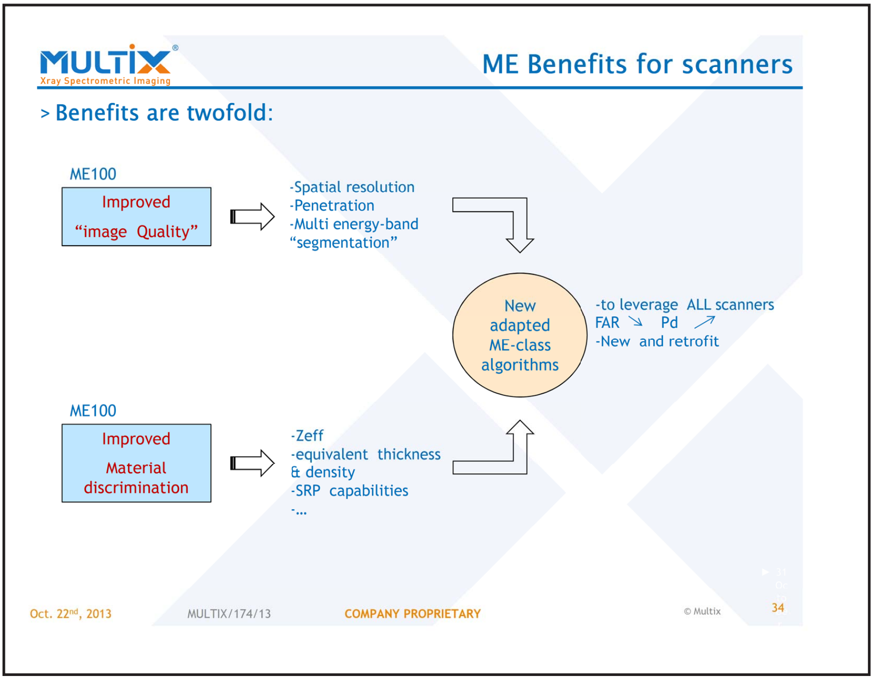
MULTIX
Xray Spectrometric Imaging
ME Benefits for scanners
> Benefits are twofold:
ME100
Improved
"image Quality"
-Spatial resolution
-Penetration
-Multi energy-band
"segmentation"
New
adapted
ME-class
algorithms
-to leverage ALL scanners
FAR ↘ Pd ↗
-New and retrofit
ME100
Improved
Material
discrimination
-Zeff
-equivalent thickness
& density
-SRP capabilities
-...
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MULTIX Xray Spectrometric Imaging

Conclusions

- ME100 **real time X-ray transmission spectrometric** grade detector under **high photon flux** is available to leverage baggage scanners.

- New **ME based algorithms** will benefit from ME rich information for

  →improving material discrimination capabilities

  →improving Image analysis

  In order

- To improve threat detection performance in **reducing FAR** for ALL x-ray based detection systems

- To support platform performance improvements and lifecycle extension

- To Fill the performance gap between current dual energy, multi-view and CT technology

-

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MULTIX Xray Spectrometric Imaging

MULTIX

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patrick.radisson@multixdetection.com

www.multixdetection.com

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92200 Neuilly sur Seine - France

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17.5 Steve Azevedo: System-Independent X-Ray Characterization of Materials

System-independent X-ray Characterization of Materials

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Lawrence Livermore National Laboratory
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Version 5

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LLNL-PRES-645110 VG-1

Unclassified

PCD provides more precise X-ray features for detection

- DHS needs ways to characterize HMEs wrt all X-ray-CT-based EDSs
  - As new threats appear, vendors need to know their physics-based X-ray features
  - Gov't could measure X-ray features on a non-EDS CT system that maps to EDS
- Problem:
  - Current X-ray features based on (μ_{high}, μ_{low}) can vary greatly with different scanners looking at the same specimen. Need better discrimintators.
- Objective:
  - Find a "system-independent" X-ray feature space (with <3% uncertainty)
- Results:
  - New PCD* method using (ρ_e,Z_e) feature space shows good results on two different scanners and over wide spectral ranges (80 to 200 keV)
  - Seven different materials were characterized with PCD in the (ρ_e,Z_e) feature space and demonstrated averages of <2% accuracy and <1% precision
  - PCD requires
    - Reference materials that span the Z range
    - Good knowledge of X-ray spectral response
    - No beam-hardening compensation (BHC) needed
- PCD may improve Pd/Pfa because of more precise features

* PCD = Photoelectric-Compton Decomposition

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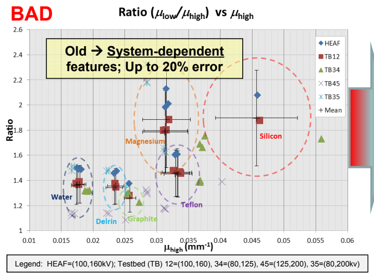
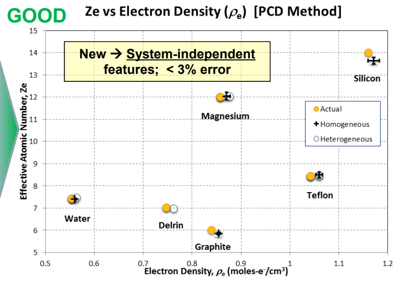
Results Summary leads to Recommendations





- New X-ray features (ρ_e,Z_e) gave system-independent results without BHC
  - Tested with 7 specimens on 2 different MCT scanners, 2 different detectors and 5 spectra
- Recommendations
  - Employ Photoelectric-Compton Decomposition (PCD) and (ρ_e,Z_e) features across all MicroCTs at TSL, TAFRL, and LLNL
  - Show it translates to EDS and is backward compatible
  - Replace (μ_{high}, μ_{low}/μ_{high}) regions of responsibility (RORs) with (ρ_e,Z_e)

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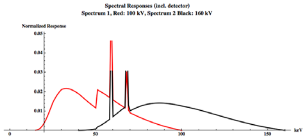
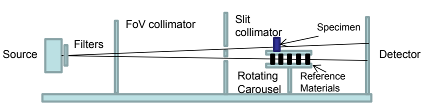
Unclassified

Experiments involved two different MicroCT systems

- MicroCTs are LLNL-built devices specifically for HME characterization
  - Brehmsstrahlung source with end-point energy of up to 450kV
  - ~150 um isotropic voxels reconstructed
  - Two-slit collimator with 2-mm slits to produce fan beam to reduce scatter
- Rotating carousel rotates through 400 angles at half-degree intervals
  - HME specimen is positioned on the upper level for X-ray features (60-250 mL bottle)
  - 6 reference samples of known composition on the lower level
- The two MicroCTs used (HEAF and TestBed) differed in detector
  - HEAF MicroCT used Thales amorphous silicon (AS) panel; Scanned at 100 and 160 kV
  - TestBed MicroCT used Perkin-Elmer AS panel; Scanned at 80, 100, 125, 160, 200 kV
- Scans were processed pairwise to simulate scanners with very different spectra



Example Spectra (100kV – red, 160kV – black)



General layout of a MicroCT system

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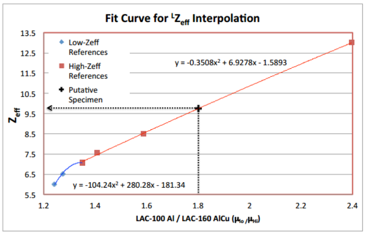
Current Methods: Simple Transfer Function

- Current LLNL processing techniques make use of Z_{eff}, defined as:

$$Z_{eff} = \sqrt[p]{\sum_i a_i (Z_i)^p}$$

  - The a's represent electron fractions contributed by constituent elements, and p is a constant tuned to approximate observed behavior. At the direction of TSL/DHS, we use p = 3.8
- Low- and high-energy measured attenuation values for known reference materials are combined with nominal Z_{eff} values to yield quadratic fit lines between Z_{eff} and attenuation ratio.

- Reference materials are separated into lower and higher Z groups.
- The lower group is used for a quadratic fit, while the upper group uses a constrained quadratic fit to generate a continuous curve.
- The specimen attenuation ratio is entered into the curve equation to yield a $^{L}Z_{eff}$ value, which is plotted against the high-energy attenuation value, in LMHU (where values are normalized such that water at high energy has mean value 1000 and air is zero).



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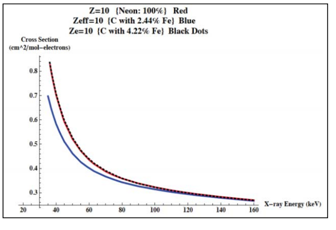
What are Z_e and ρ_e?

- **Z_e is an alternative definition of effective atomic number***
  - **Based on X-ray cross sections for the spectrum used**
  - **Relates the degree of attenuation and scattering using published tables**
  - **ZeCalc is a Java app to calculate Z_e given composition and spectrum**
  - **Calculates ρ_e also if given physical density**
- **ρ_e is the electron density, defined for a single element material as:**

$$\rho_e = \frac{\rho Z}{A}$$ **, where ρ is mass density and A is atomic mass**

- Experimental results show that (Ze, ρ_e) features have better resolution of different materials than methods using the high- and low-energy reconstructions.
- In addition, materials with identical Z_e are shown to have closer x-ray cross section than materials with identical Z_{eff}.



* J. A. Smith, H. E. Martz, J. S. Kallman, *Case for an Improved Effective-Atomic-Number for the Electronic Baggage Scanning Program*, Lawrence Livermore National Laboratory, LLNL-TR-520312, December 14, 2011.

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Unclassified

History of Photoelectric-Compton Decomposition

- **Alvarez & Macovsky (1976)**
  - **Decomposition uses photoelectric, Ap, and Compton, Ac, contributions to specify features**
  - **Introduced that full attenuation features at every energy can be represented using a set of energy-independent values**
    - **Do not need many narrow energy bands across a range of interest to characterize a material.**
    - **Instead, scan with a few broad energy peaks over the applicable range, and use the results to validate the system**
  - **Plots are in Ac, Ap feature space**
- **Ying, Naidu, Crawford (2006)**
  - **Propose optimization technique using iso-transmission curve intersections**
  - **Propose scatter, streak and spectral corrections for EDS machines**
  - **Plots are in the Zeff vs high-energy channel feature space**
- **New Photoelectric-Compton Decomposition (PCD)**
  - **Propose calibration of the system to known reference materials**
  - **Propose plot of Ze vs ρ_c to more closely follow material x-ray properties as a transfer method**

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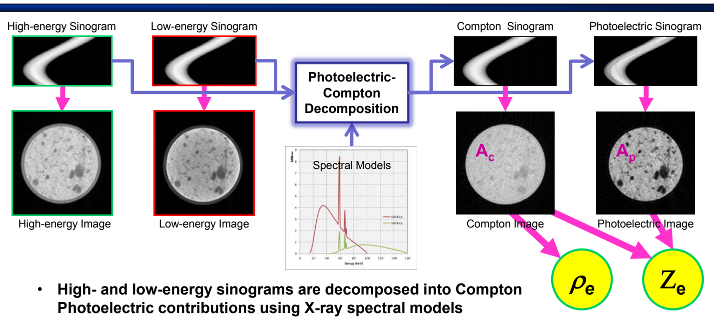
Photoelectric Compton Decomposition (PCD) Method



- **High- and low-energy sinograms are decomposed into Compton Photoelectric contributions using X-ray spectral models**
- **These sinograms are reconstructed into Compton (A_c) and Photoelectric (A_p) images**
- **Mean values inside the specimen are calculated: $\bar{a}_c$ and $\bar{a}_p$**
- **Then, $\rho_e = K(\bar{a}_c)$ and $Z_e = k(\bar{a}_p/\bar{a}_c)^{1/n}$**
  - **where K, k and n are empirically determined constants obtained through a calibration procedure using well-known reference materials**

Note that beam-hardening compensation (BHC) is *not* needed.

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Unclassified

R&D Experimental Plan: Reference Materials

- New reference materials were acquired and assayed at LLNL.
  - Higher confidence in material composition
  - More accurate Ze, ρ_e values for higher confidence in output results
  - References selected to expand the range in Z relative to current reference materials

Material	Diam (mm)	Density g/cm^3	RhoE Mol-e/cm^3	Ze	Nominal Purity %
Graphite	12.956	1.804	0.901	6.00	99.997
Delrin	12.694	1.403	0.748	7.01	copolymer
Teflon	12.707	2.175	1.044	8.44	99.99
Magnesium	12.700	1.736	0.857	12.00	99.98
Silicon	12.620	2.331	1.162	14.00	99.99
Water	10.8	0.998	0.554	7.43	Reagent Grade 1

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Unclassified

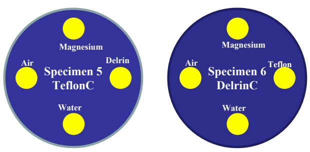
R&D Experimental Plan: Reference Specimens

- Homogeneous Reference Specimens were selected to cover a wide range of Z values (from graphite, Z=6, to silicon, Z=14)
- Specimens matched the composition of corresponding reference materials to establish a baseline on system performance
- Inhomogeneous Reference Specimens were two composite specimens also scanned to examine system behavior for inhomogeneous samples
- All specimens were cylinders measured for size and weight (density)

Homogeneous Reference Specimens

Name	Material	Dia (mm)
Specimen 1	Graphite	50.8
Specimen 2	Teflon	56
Specimen 3	Magnesium	25.4
Specimen 4	Silicon	25.4
Insert A	Teflon	10
Insert B	Delrin	10
Insert C	Magnesium	10
Insert D	Water	10
Substrate 1	Teflon Plug	56
Substrate 2	Delrin Plug	50.8
Specimen 7	Water² (60 ml)	36.9/38.9

Inhomogeneous Reference Specimens



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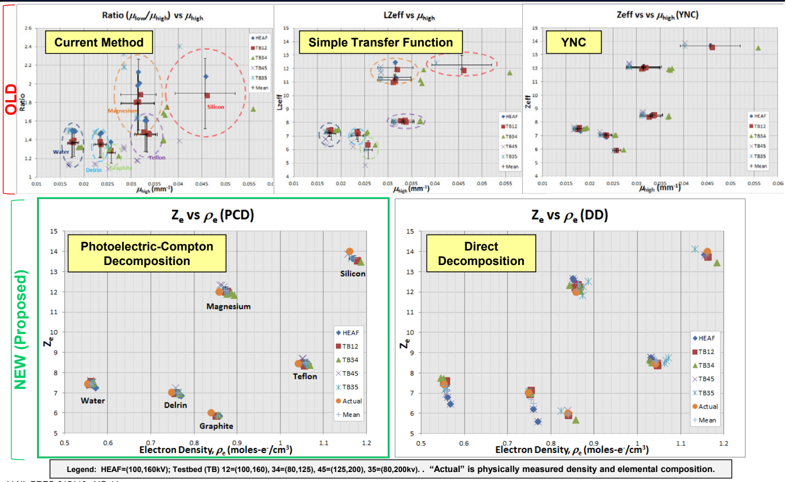
The PCD and DD methods produce similar results



Legend: HEAF=(100,160kV); Testbed (TB) 12=(100,160), 34=(80,125), 45=(125,200), 35=(80,200kv). . "Actual" is physically measured density and elemental composition.

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Precision and accuracy values yield insight into (ρ_e,Z_e)

Average (Mean %)	With RbBr & Refs		Without RbBr & Refs	
	All spectra	100/160 only	All spectra	100/160 only
Ze Precision	1.10	0.72	1.18	0.72
Ze Accuracy	0.87	0.98	0.69	0.84
Rho-e Precision	0.77	0.74	0.64	0.62
Rho-e Accuracy	1.80	1.85	1.66	1.75
mu-lo Precision	14.59	0.21	14.58	0.28
mu-hi Precision	7.72	0.28	7.62	0.38

Worst-case (Max %)	With RbBr & Refs		Without RbBr & Refs	
	All spectra	100/160 only	All spectra	100/160 only
Ze Precision	3.29	3.63	1.96	2.74
Ze Accuracy	3.73	2.95	2.57	2.93
Rho-e Precision	6.17	5.82	1.03	1.22
Rho-e Accuracy	8.02	7.69	2.43	2.47
mu-lo Precision	23.02	0.73	21.10	0.73
mu-hi Precision	14.47	0.76	14.00	0.76

* Note: actual mu values are not known, so accuracy cannot be computed.

If systems are nearly the same, μ_{low} and μ_{high} are good. More processing, such as PCD, can slightly increase the error.

If systems are not the same, (ρ_e,Z_e) is much better.

If materials are beyond the Z of reference materials, some of the worst-case (ρ_e,Z_e) errors are slightly higher; they are still better than μ_{low} and μ_{high}.

(ρ_e,Z_e) is a valid new System-independent X-ray feature space.

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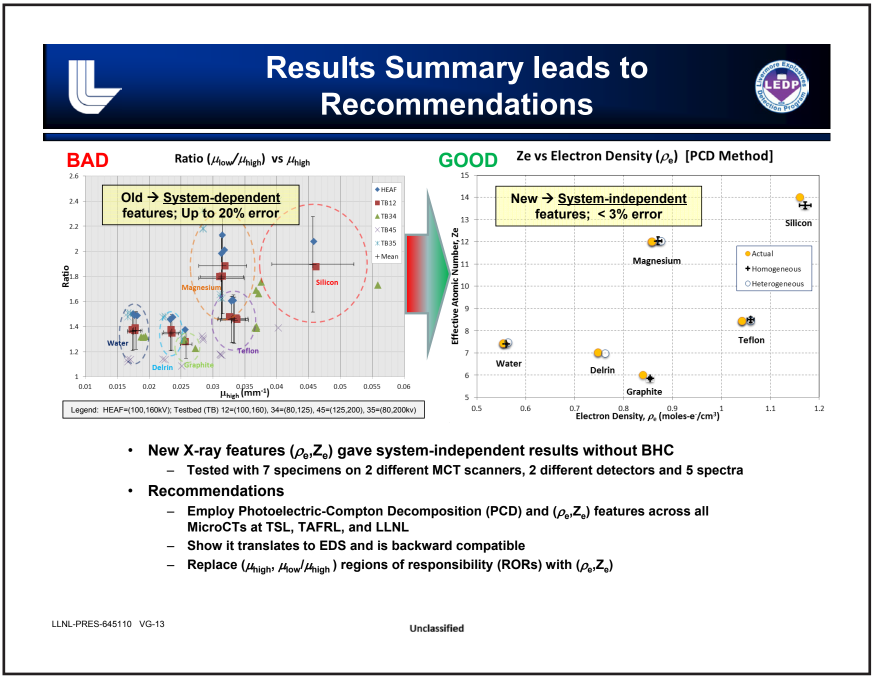
Unclassified


Results Summary leads to Recommendations
BAD
Ratio (μ_{low}/μ_{high}) vs μ_{high}
Old → System-dependent features; Up to 20% error
Water
Delrin
Graphite
Magnesium
Teflon
Silicon
Ratio
μ_{high} (mm^{-1})
HEAF
TB12
TB34
TB45
TB35
Mean
Legend: HEAF=(100,160kV); Testbed (TB) 12=(100,160), 34=(80,125), 45=(125,200), 35=(80,200kv)
GOOD
Ze vs Electron Density (ρ_e) [PCD Method]
New → System-independent features; < 3% error
Effective Atomic Number, Ze
Electron Density, ρ_e (moles-e$^-$/cm^3)
Actual
Homogeneous
Heterogeneous
Silicon
Magnesium
Teflon
Water
Delrin
Graphite
• New X-ray features (ρ_e,Z_e) gave system-independent results without BHC
– Tested with 7 specimens on 2 different MCT scanners, 2 different detectors and 5 spectra
• Recommendations
– Employ Photoelectric-Compton Decomposition (PCD) and (ρ_e,Z_e) features across all MicroCTs at TSL, TAFRL, and LLNL
– Show it translates to EDS and is backward compatible
– Replace (μ_{high}, μ_{low}/μ_{high}) regions of responsibility (RORs) with (ρ_e,Z_e)
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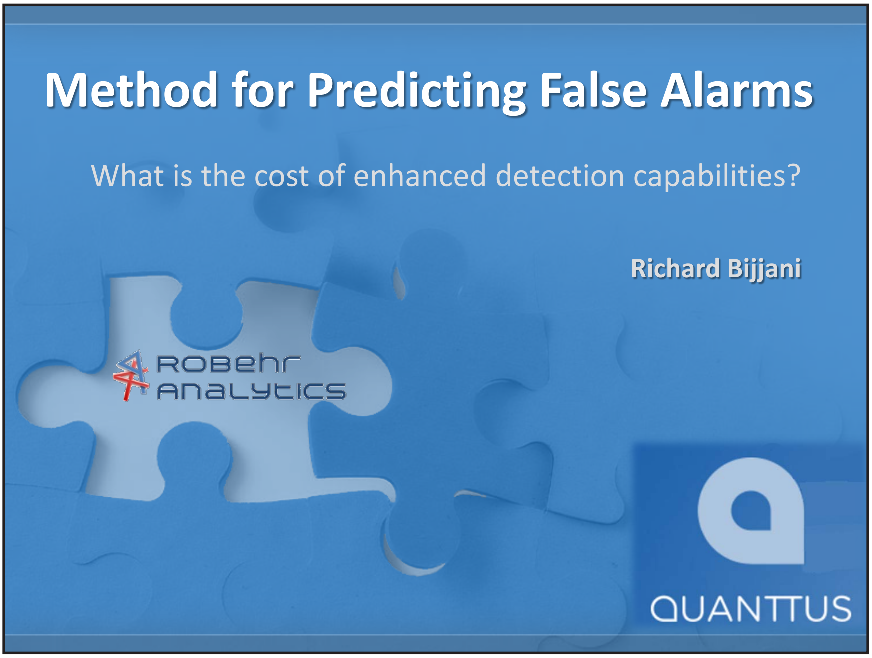
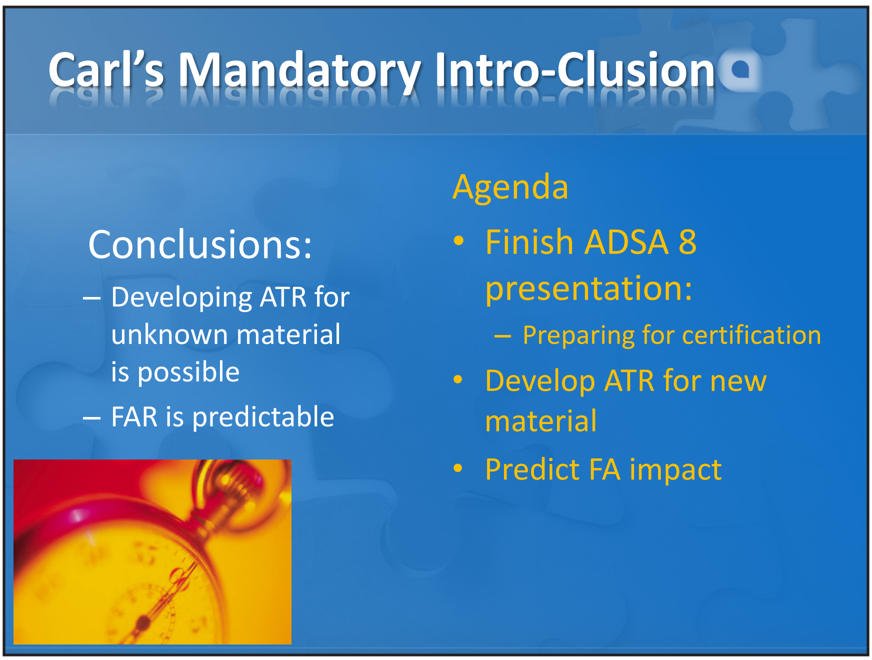
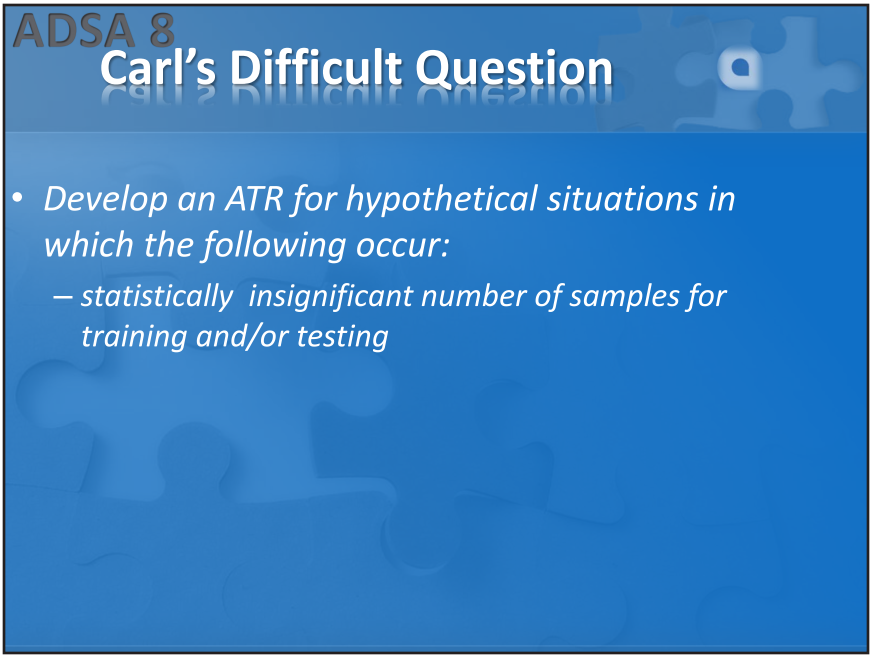
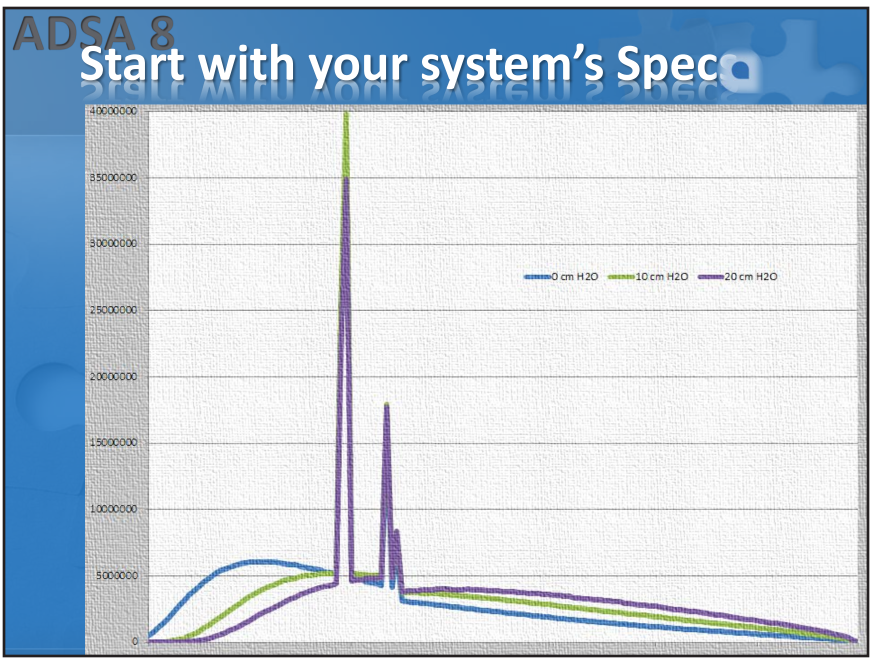
Unclassified

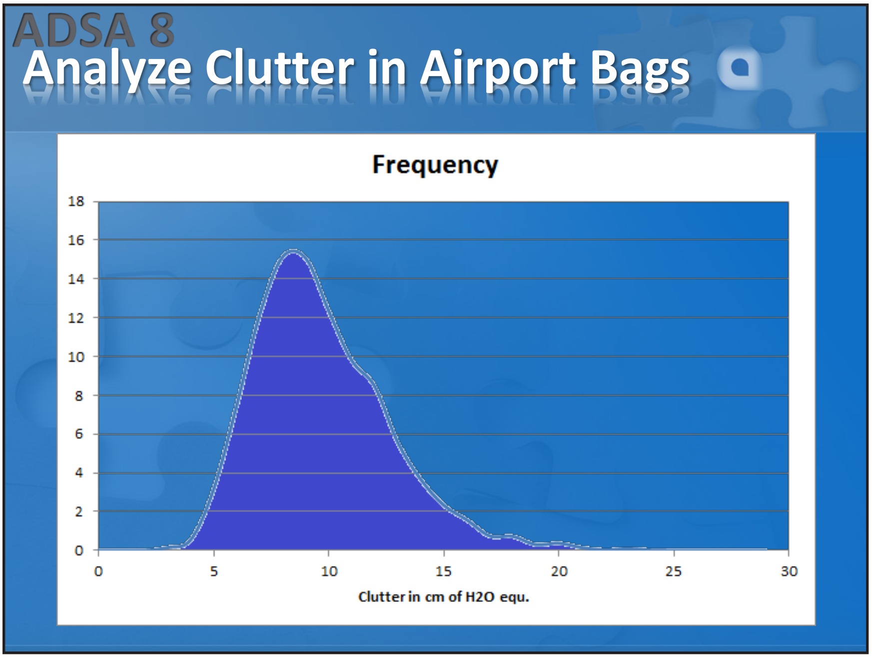
17.6 Richard Bijjani: PFA Predictions

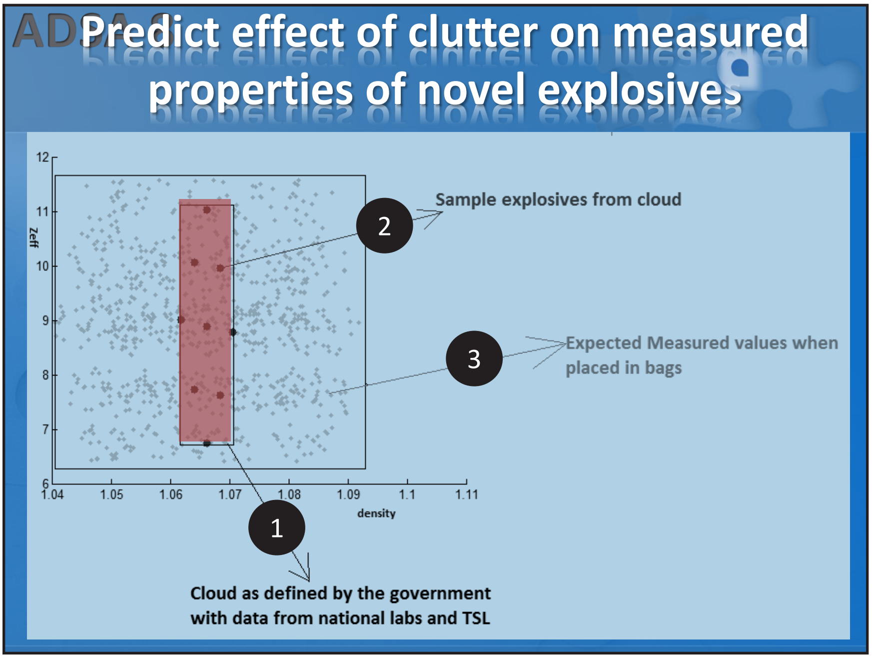





ADSA 8
Carl’s Difficult Question
• Develop an ATR for hypothetical situations in which the following occur:
– statistically insignificant number of samples for training and/or testing


ADSA 8
Start with your system’s Spec
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
0 cm H2O
10 cm H2O
20 cm H2O


ADSA 8
Analyze Clutter in Airport Bags
Frequency
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
Clutter in cm of H2O equ.


ADSA 8
Predict effect of clutter on measured properties of novel explosives
12
11
10
9
8
7
6
Zeff
1.04
1.05
1.06
1.07
1.08
1.09
1.1
1.11
density
2
Sample explosives from cloud
3
Expected Measured values when placed in bags
1
Cloud as defined by the government with data from national labs and TSL

ADSA 8

Algorithm Black Box

- Algorithm Development
  - Concentrate on edge and corner cases first
  - Cycle back to ‘normal’ cases
  - Design and implement an architecture to support current development plan, future improvement plan, and backup plan in case of failure
  - In your schedule allow for failing the test at least once

ADSA 9 Objectives

Method for predicting FAR associated with detecting a novel threat (which has not been scanned yet):

1. Analyze Airport Data
2. Calculate relevant properties of such novel threat (from μCT , EDS scan or theoretical analysis)
   If data from μCT, apply appropriate transformation to EDS in order to maintain density, Zeff (if appropriate) and texture to the appropriate resolution
3. Use data from 1 to develop a realistic clutter model
4. For the threat material apply the appropriate ‘cloud’ variations in density, Zeff and texture
5. Randomly place the threat under investigation into bags with clutter profiles from 3.
6. FAR prediction will be the statistical result of running step 5 .

Airport Data

- Find *all* objects in a bag set and calculate relevant features
- Save data in a csv or other file format *(avoid need to re-run algorithm many times)*
- For each object generate an entry, e.g.

Bag #	Object #	Density	Volume	Mass	Zeff	Texture	Thickness	…	..
3576	7	1.254	378	474	7.92	0.96	7.9	…	..

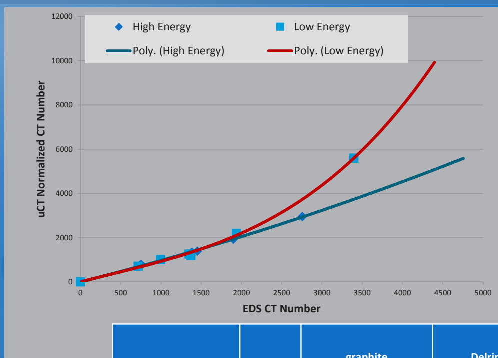
µCT to EDS

- Use reference material values to map voxel values between the 2 systems (any 2 systems)
- Exact same reference material should be scanned in both systems e.g.

		graphite	Delrin	H2O	Al	Novel Explosive
uCt	Lo	1197	1256	1000	5593	1134
	Hi	1384	1342	1000	2950	1064
EDS	Lo	1330	1360	1003	3328	?
	Hi	1431	1365	1008	2734	?

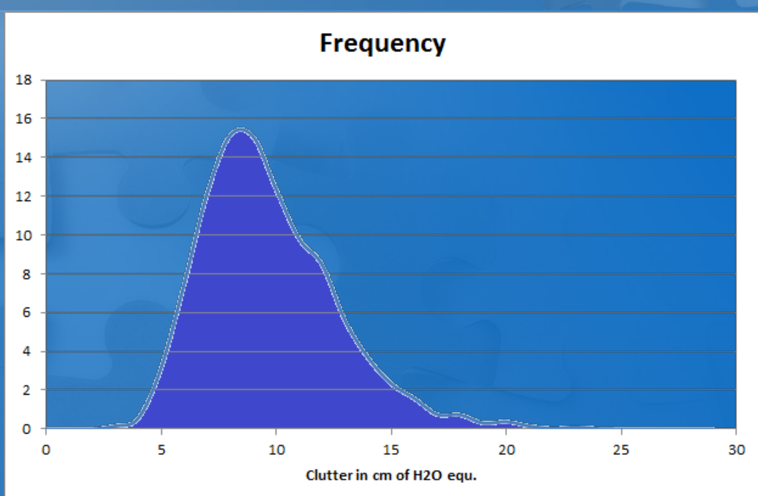
- Predicting values of unknown threat on EDS is then easily deduced

µCT to EDS



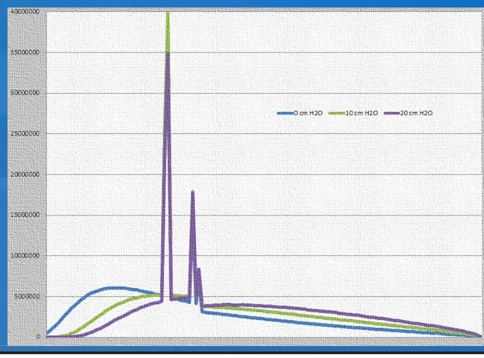
		graphite	Delrin	H2O	Al	Novel Explosive
uCt	Lo	1197	1256	1000	5593	1134
	Hi	1384	1342	1000	2950	1064
EDS	Lo	1330	1360	1003	3328	1108
	Hi	1431	1365	1008	2734	1061

Clutter Model



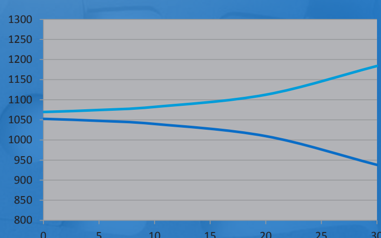
Clutter Model

- Using publically available x-ray simulation programs like spekCalc, predict spectrum hardening for each clutter index

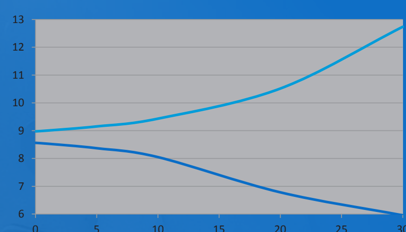


'Cloud' Dilation

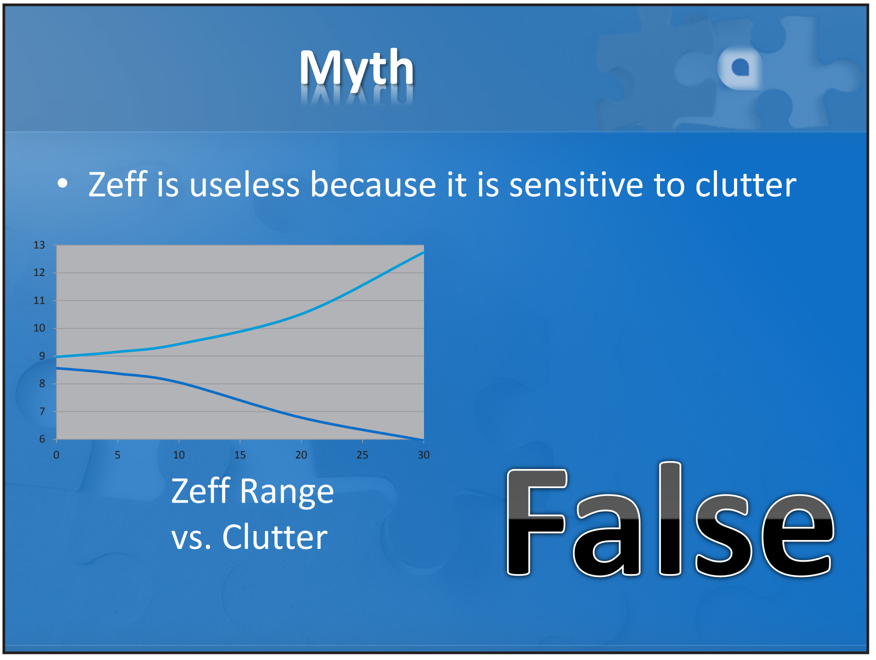
- Dilate the values of the theoretical cloud by the noise predicted from clutter.

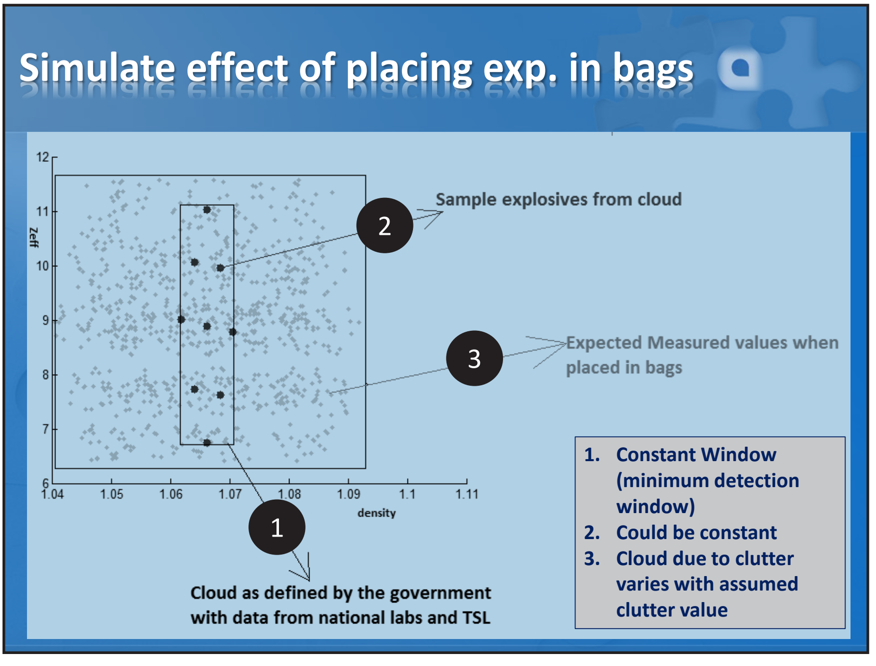


Density Range vs. Clutter



Zeff Range vs. Clutter


Myth
• Zeff is useless because it is sensitive to clutter
13
12
11
10
9
8
7
6
0
5
10
15
20
25
30
Zeff Range
vs. Clutter
False


Simulate effect of placing exp. in bags
12
11
10
9
8
7
6
Zeff
1.04
1.05
1.06
1.07
1.08
1.09
1.1
1.11
density
2
Sample explosives from cloud
3
Expected Measured values when placed in bags
1
Cloud as defined by the government with data from national labs and TSL
1. Constant Window (minimum detection window)
2. Could be constant
3. Cloud due to clutter varies with assumed clutter value

Predict FA

- For each bag in data set, calculate number of objects that overlap the dilated threat window
- Predict overall *additional* FAR by identifying the objects in the bag that did not already alarm but will alarm if this novel threat is to be detected.

Questions we should be asking

- **Can we** ***(or will we be likely able to)*** **find all the explosives on the 'list' using current machines?**
- **What capabilities do we need from the next generation systems?**
- **What are the appropriate Alarm Resolution Tools for this threat?**

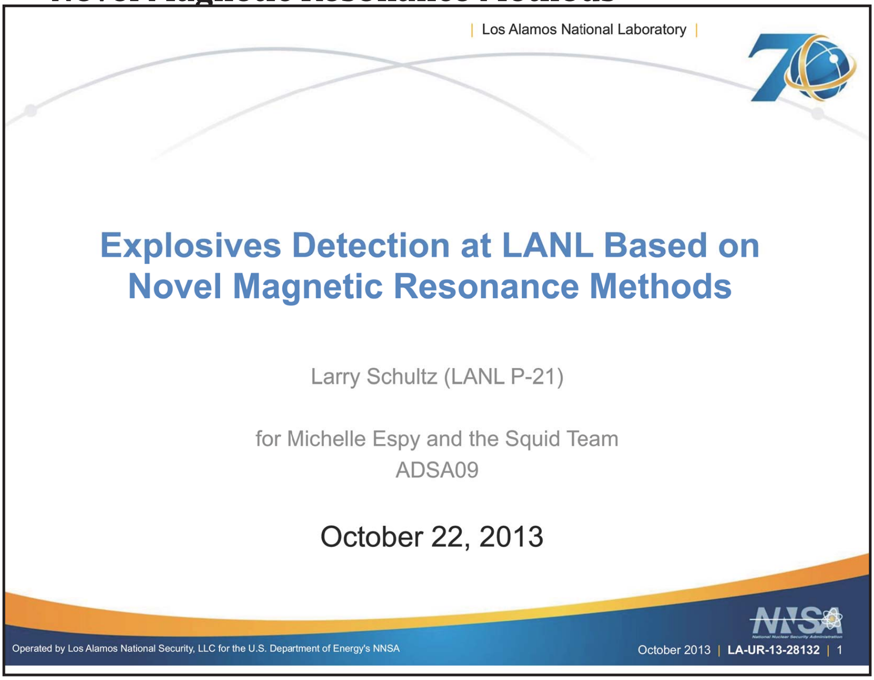
Prioritized List of Problems

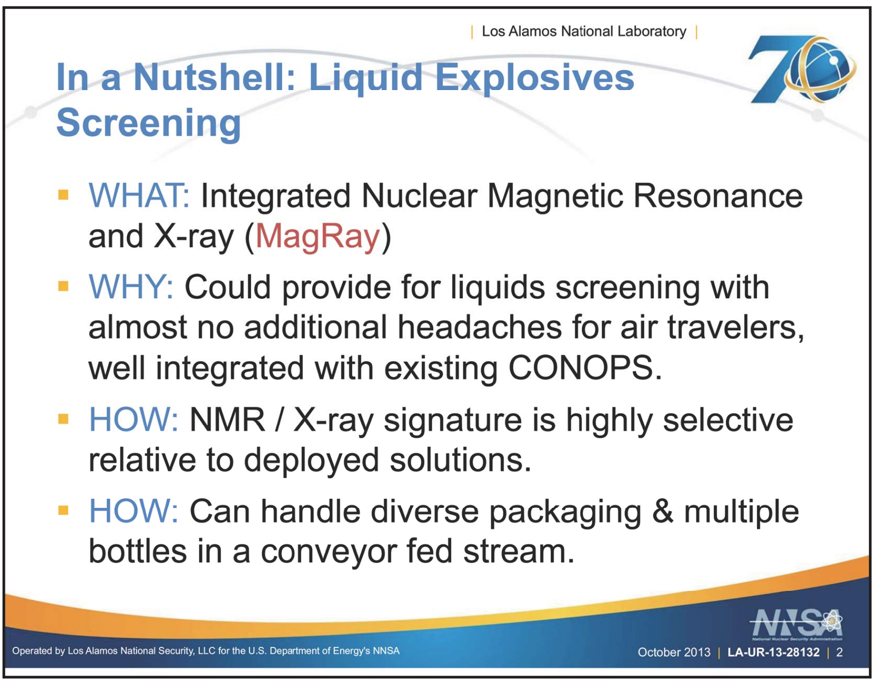
Current or new technologies will need to tackle the following problems in a cost effective and operationally acceptable manner. In order to detect more explosives, FA need to be reduced.

1. True Alarms
2. Shield or Partial Shield alarms
3. Clutter, artifact correction
4. Improving measurement accuracy
5. Identifying new relevant features
6. Signal conditioning

Questions

17.7 Larry Schultz: Explosives Detection at LANL Based on Novel Magnetic Resonance Methods





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In a Nutshell: Explosives Detection (in partnership with ALERT)

- WHAT: Nuclear Quadrupole Resonance (NQR) with polarization enhancement.
- WHY: Non-invasive, safe detection of 14N based IED's in ground, packages, or in the body.
- HOW: NQR has demonstrated sensitivity but signal is weak.
- HOW: Polarization enhancement boosts signal such that practical application is enabled.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

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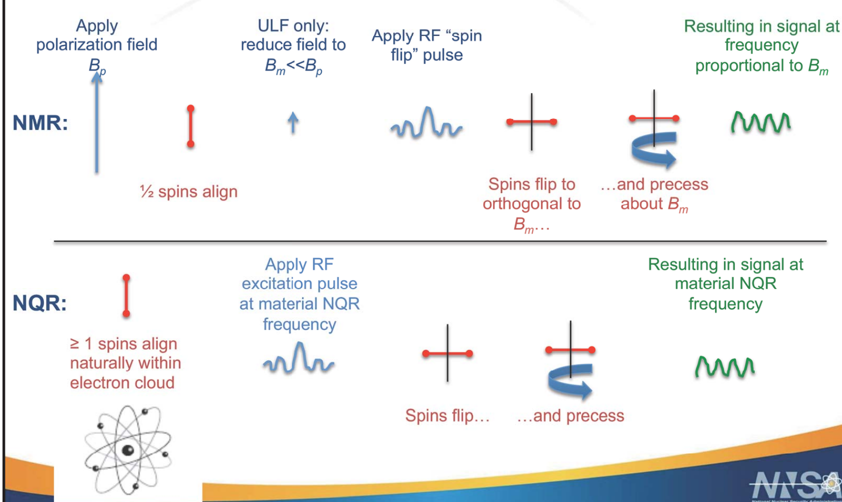
NMR and NQR Basics



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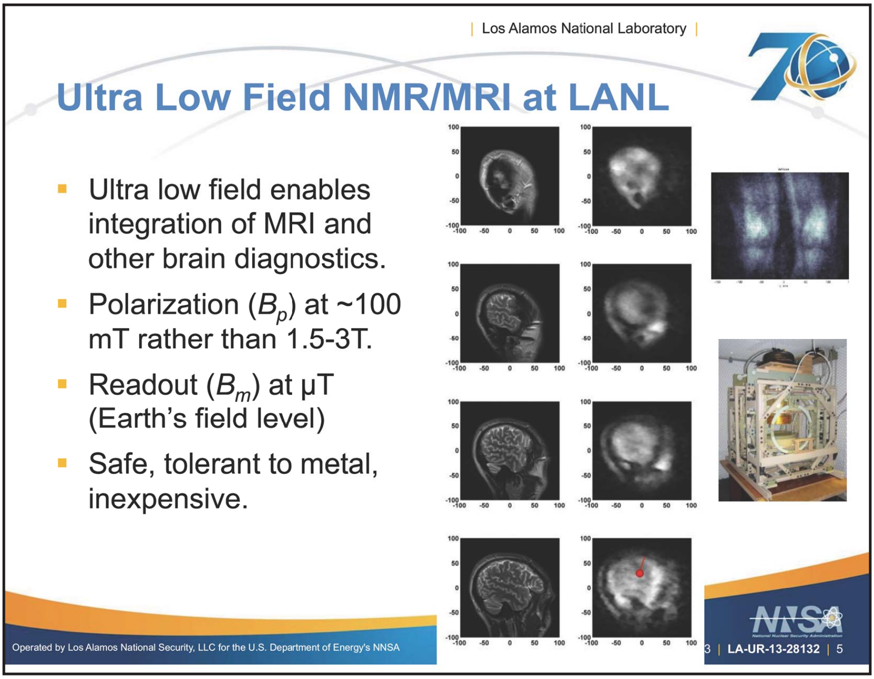
Los Alamos National Laboratory
Ultra Low Field NMR/MRI at LANL
- Ultra low field enables integration of MRI and other brain diagnostics.
- Polarization (B_p) at ~100 mT rather than 1.5-3T.
- Readout (B_m) at μT (Earth's field level)
- Safe, tolerant to metal, inexpensive.
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NNSA
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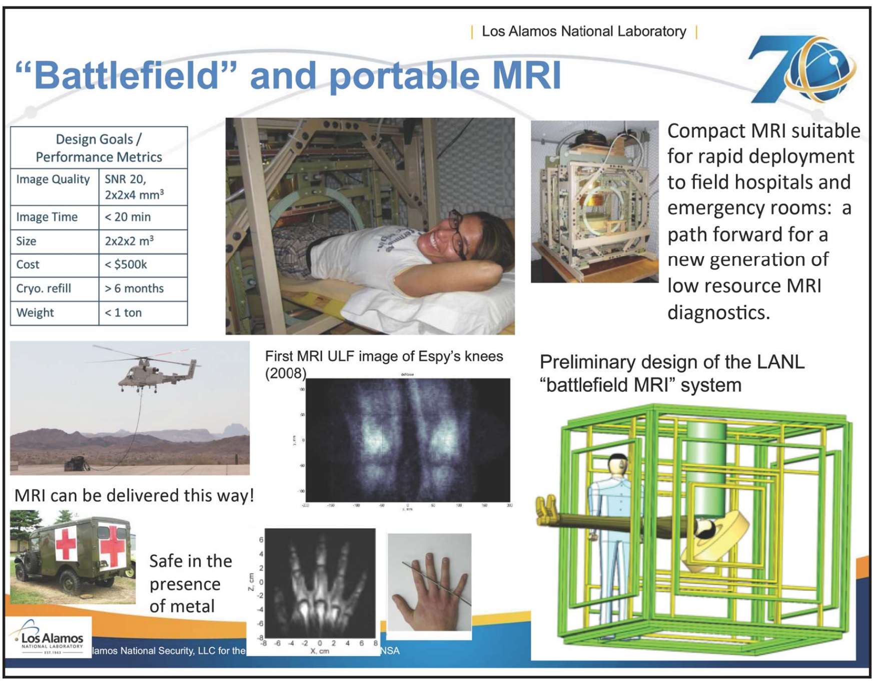
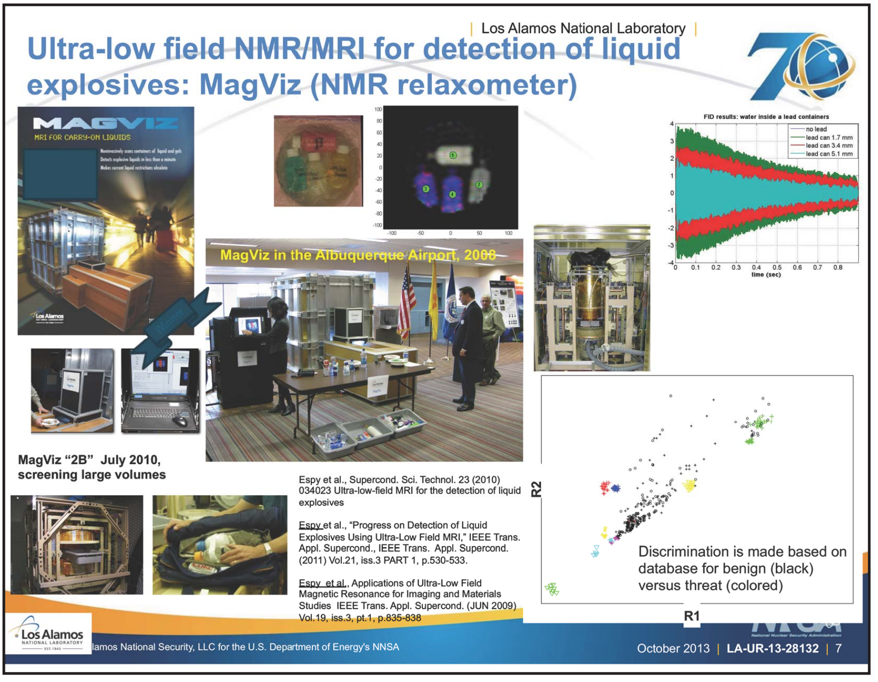

Los Alamos National Laboratory
"Battlefield" and portable MRI

Design Goals / Performance Metrics	
Image Quality	SNR 20, 2x2x4 mm³
Image Time	< 20 min
Size	2x2x2 m³
Cost	< $500k
Cryo. refill	> 6 months
Weight	< 1 ton

Compact MRI suitable for rapid deployment to field hospitals and emergency rooms: a path forward for a new generation of low resource MRI diagnostics.
First MRI ULF image of Espy's knees (2008)
Preliminary design of the LANL "battlefield MRI" system
MRI can be delivered this way!
Safe in the presence of metal
Los Alamos National Laboratory


Los Alamos National Laboratory
Ultra-low field NMR/MRI for detection of liquid explosives: MagViz (NMR relaxometer)
MAGVIZ
MRI FOR CARRY-ON LIQUIDS
MagViz in the Albuquerque Airport, 2008
FID results: water inside a lead containers
no lead
lead can 1.7 mm
lead can 3.4 mm
lead can 5.1 mm
time (sec)
MagViz "2B" July 2010, screening large volumes
Espy et al., Supercond. Sci. Technol. 23 (2010) 034023 Ultra-low-field MRI for the detection of liquid explosives
Espy et al., "Progress on Detection of Liquid Explosives Using Ultra-Low Field MRI," IEEE Trans. Appl. Supercond., IEEE Trans. Appl. Supercond. (2011) Vol.21, iss.3 PART 1, p.530-533.
Espy et al., Applications of Ultra-Low Field Magnetic Resonance for Imaging and Materials Studies IEEE Trans. Appl. Supercond. (JUN 2009) Vol.19, iss.3, pt.1, p.835-838
R2
R1
Discrimination is made based on database for benign (black) versus threat (colored)
Los Alamos NATIONAL LABORATORY
lamos National Security, LLC for the U.S. Department of Energy's NNSA
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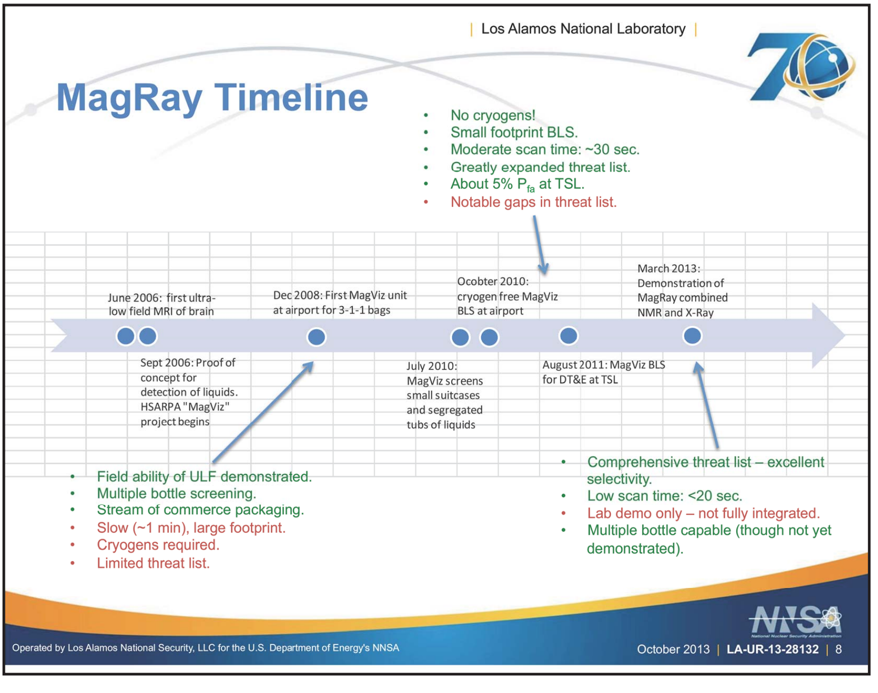
Los Alamos National Laboratory
MagRay Timeline
No cryogens!
Small footprint BLS.
Moderate scan time: ~30 sec.
Greatly expanded threat list.
About 5% P_{fa} at TSL.
Notable gaps in threat list.
June 2006: first ultra-low field MRI of brain
Dec 2008: First MagViz unit at airport for 3-1-1 bags
Ocober 2010: cryogen free MagViz BLS at airport
March 2013: Demonstration of MagRay combined NMR and X-Ray
Sept 2006: Proof of concept for detection of liquids. HSARPA "MagViz" project begins
July 2010: MagViz screens small suitcases and segregated tubs of liquids
August 2011: MagViz BLS for DT&E at TSL
Field ability of ULF demonstrated.
Multiple bottle screening.
Stream of commerce packaging.
Slow (~1 min), large footprint.
Cryogens required.
Limited threat list.
Comprehensive threat list – excellent selectivity.
Low scan time: <20 sec.
Lab demo only – not fully integrated.
Multiple bottle capable (though not yet demonstrated).
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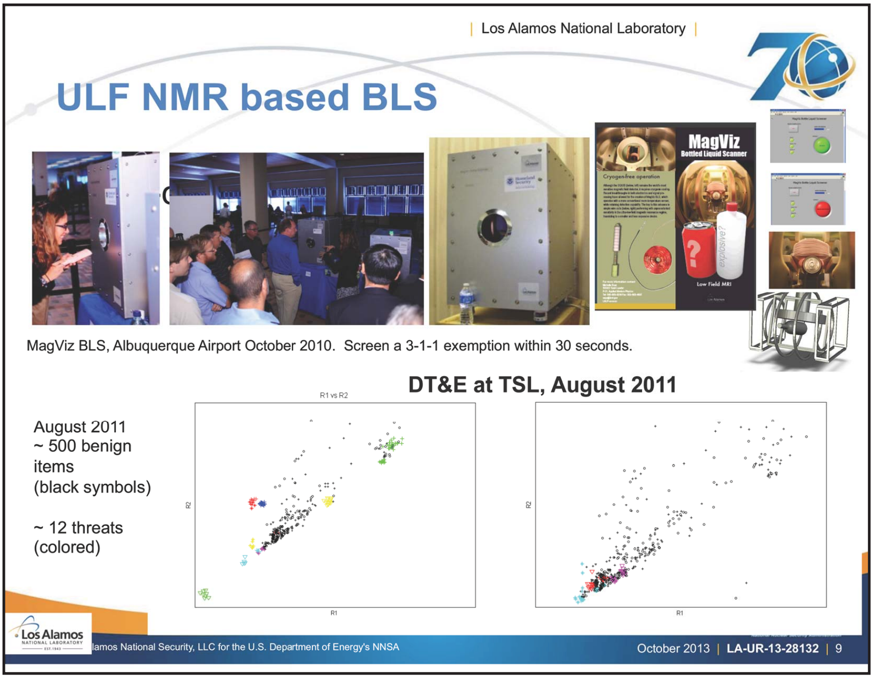
Los Alamos National Laboratory
ULF NMR based BLS
MagViz
Bottled Liquid Scanner
MagViz BLS, Albuquerque Airport October 2010. Screen a 3-1-1 exemption within 30 seconds.
DT&E at TSL, August 2011
August 2011
~ 500 benign items
(black symbols)
~ 12 threats
(colored)
R1 vs R2
R2
R1
Los Alamos
NATIONAL LABORATORY
lamos National Security, LLC for the U.S. Department of Energy's NNSA
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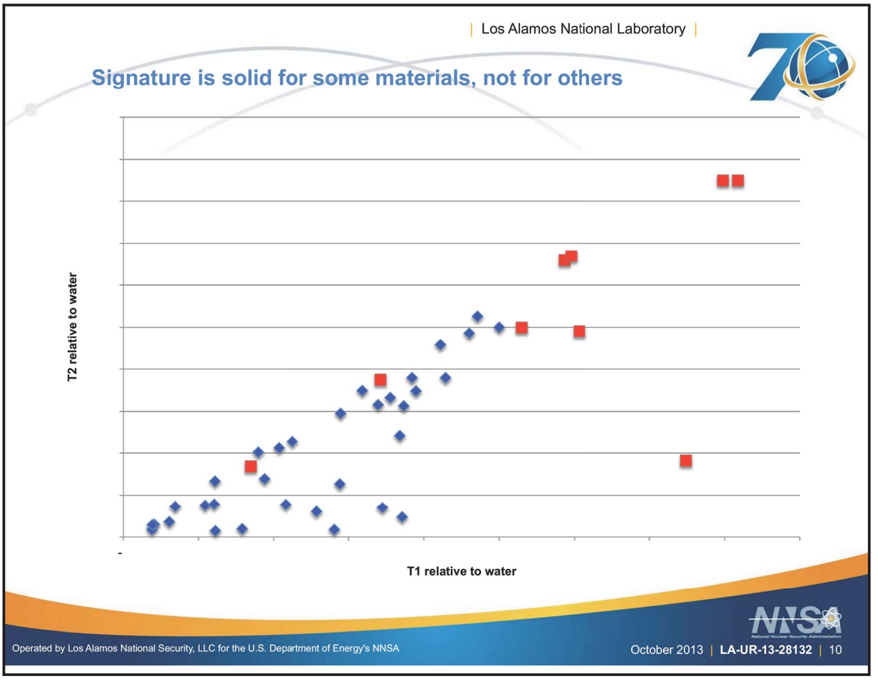
Los Alamos National Laboratory
Signature is solid for some materials, not for others
T2 relative to water
T1 relative to water
NNSA
National Nuclear Security Administration
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Los Alamos National Laboratory

Improving Selectivity

- X-ray imaging allows extraction of volume dependent NMR information.
- X-ray attenuation is also informative.
- An integrated NMR / X-ray dataset provides much better selectivity than does either mode individually.
- Dual energy or multispectral X-ray could enhance signature even further.

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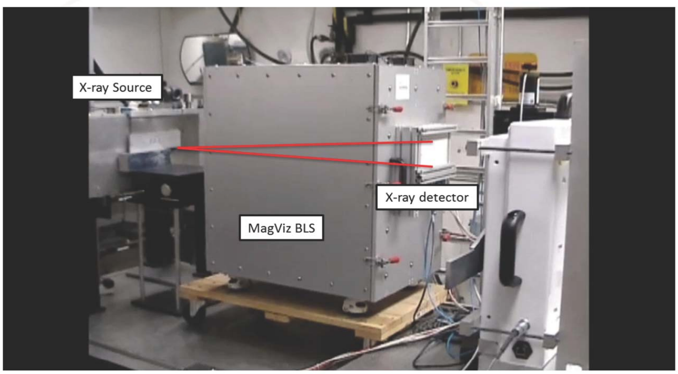
MagRay: combined ULF NMR and X-ray



Setup of the MagRay demonstration experiment. The existing X-ray source is shown on the left. The X-ray detector is attached to the rear of the MagViz BLS.

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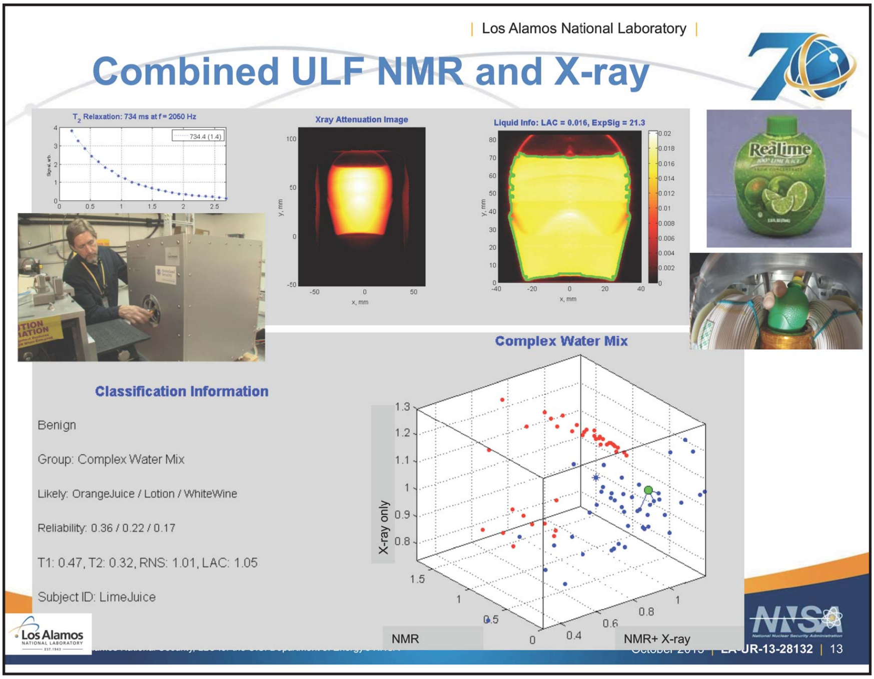


Performance Estimate

Detection of threat liquids	P_d
All but nine threat liquids	>99.9%
Two neat threats, two HME's,	>99%
Four HME's	>90%
One HME	>80%
OVERALL PROBABILITY OF DETECTION	**97.4%**
Screening of benign liquids	Pfa
Nine benign liquids	<0.1%
Eleven benign liquids	<1%
Six benign liquids	1-5%
Four benign liquids	5-10%
Six benign liquids	10-25%
OVERALL PROBABILITY OF FALSE ALARM	**4.2%**

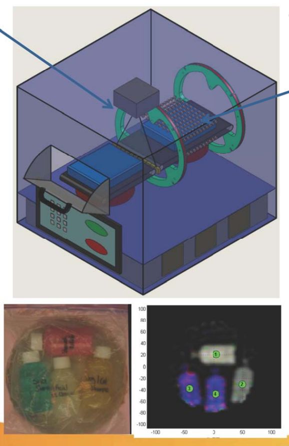
Simulated 1,000 scans of each liquid in our study, assuming a mean signature per our experimental measurements and assuming conservative measurement errors of 5% for X-ray and NMR.

We classified each simulated run as threat or benign based on the closest signature from our experimental library.

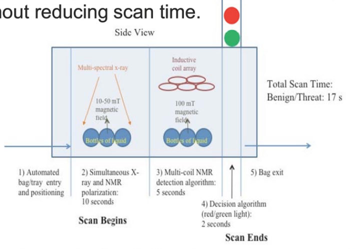
Based on this simulated study, for the liquids studied herein, **we estimate a probability of detection of 97.4%, with a false alarm rate of 4.2%.**

Back to 3-1-1 / multiple bottles: Concept

- X-ray image acquired via linear array as bag transits



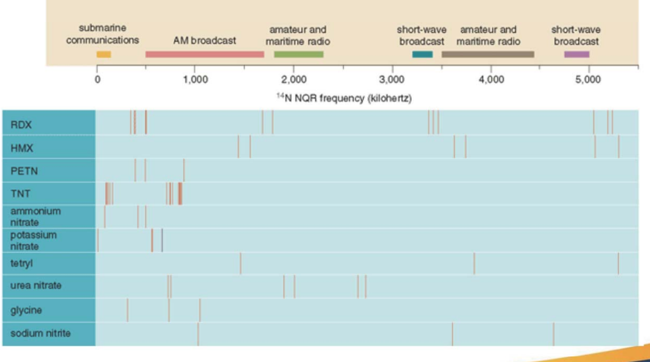
- Low-cost NMR hybrid: single gradient and multi-coil detection
  - Detector coil array encodes NMR signal to assign signature to particular bottles.
  - Single field gradient resolves vertical ambiguity without reducing scan time.



- Add-on to end of existing baggage scanners?

NQR for solid explosives detection

DARPA project: Non-contact detection of explosives at stand-off (~ 10cm) in high water content opaque media

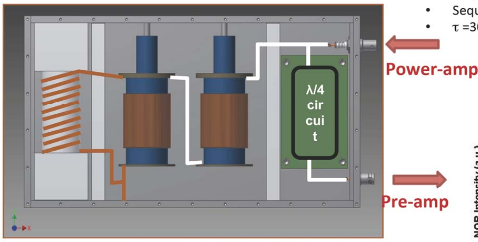


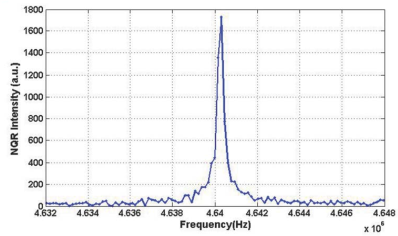
NQR capability development at LANL

Performance test: NQR signal with $NaNO_2$

$$(\text{pseudo}\,180^0) - \tau - (\text{pseudo}\,90^0) - Acq$$

- Pulse duration of 1st and 2nd pulse = 185μs and 86μs, respectively. Power =250 W.
- Acquisition at 180μs after the second pulse.
- Sequence repeated **50** times (repetition time= 400ms).
- τ =300 ms

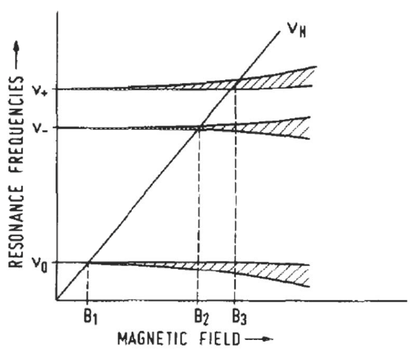




Polarization enhanced NQR

When spin 1 nucleus is near a spin ½ nucleus, double resonance may occur when the Larmor frequency of the spin ½ nucleus equals the NQR frequency of the spin 1 , the two spin populations can become linked.

- Sweeping an applied field through the overlap region of Larmor and NQR frequencies can transfer polarization to spin 1 nucleus, enhancing NQR signal.
- Because spin populations are mixed during the overlap, the relaxation rate of the spin ½ nuclei are typically altered
  - Measuring relaxation time vs. magnetic field can reveal NQR frequencies.



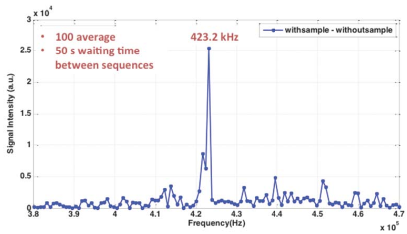
Plot showing conditions for double resonance.

Los Alamos National Laboratory

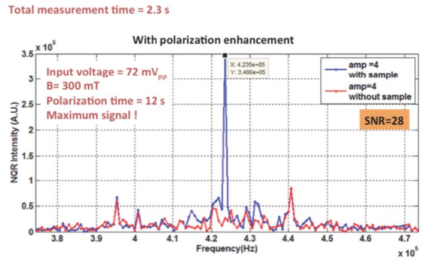
Ammonium Nitrate: polarization enhancement helps significantly!

423 kHz: an order of magnitude lower SNR than $NaNO_2$

No PE: ~1.5 hour scan



With PE: ~15 second scan



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Implementing a practical geometry

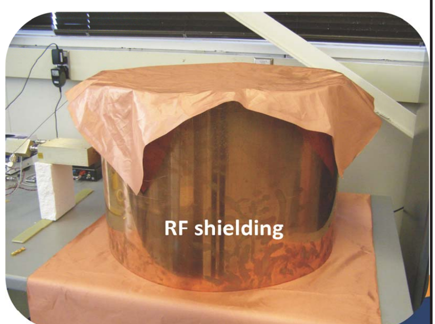
4-Nitrotoluene (PNT) ($CH_3C_6H_4NO_2$):

Molecular Weight 137.14, Density: 1.392 g/cc, $N = 6.1 \times 10^{21}$ 14N/cc

The NQR frequencies of PNT are : f_+ = 1.2 MHz and f_- = **887 kHz (we used this transition frequency)**

- **Spiral coil has been made.**
- **Copper RF shielding houses the coil.**

ID = 9.57 mm; OD = 178.11 mm
Number of turns = 34 turns; Wire gauge = 15 AWG
L ≈ 79 μH



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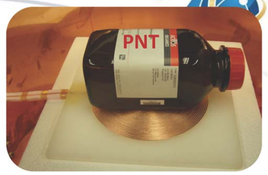
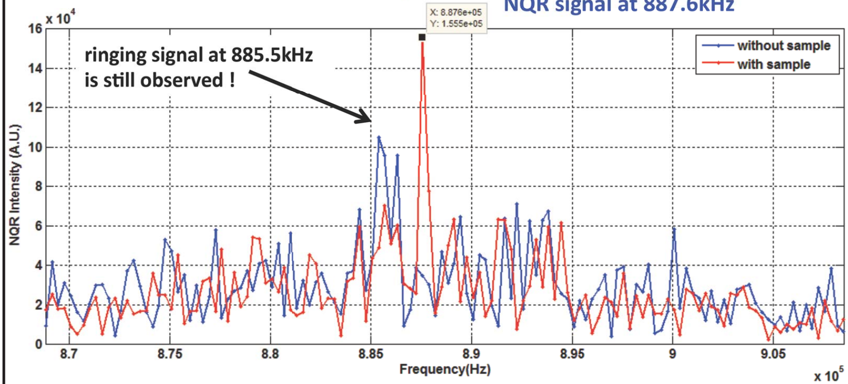
NQR signals from PNT



~6 sec scan, no PE

Pulse width ~ 100 μs, Current ~ 4.3 A_{peak}

NQR signal at 887.6kHz



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Questions?

Acknowledgements:
U.S. DHS: HSARPA, TSL, TSA
DARPA
Kromek
ALERT Team at NEU

NNSA

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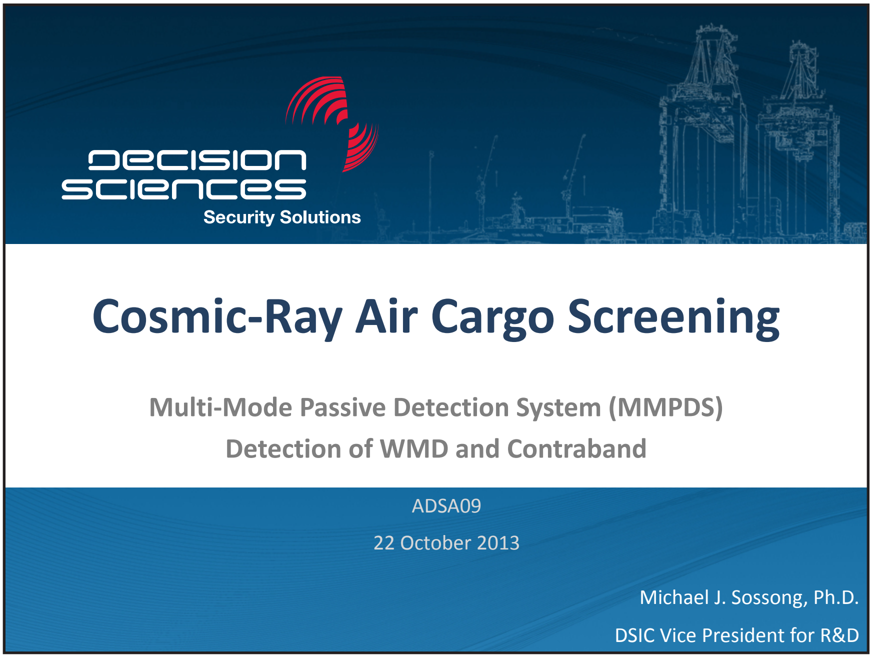
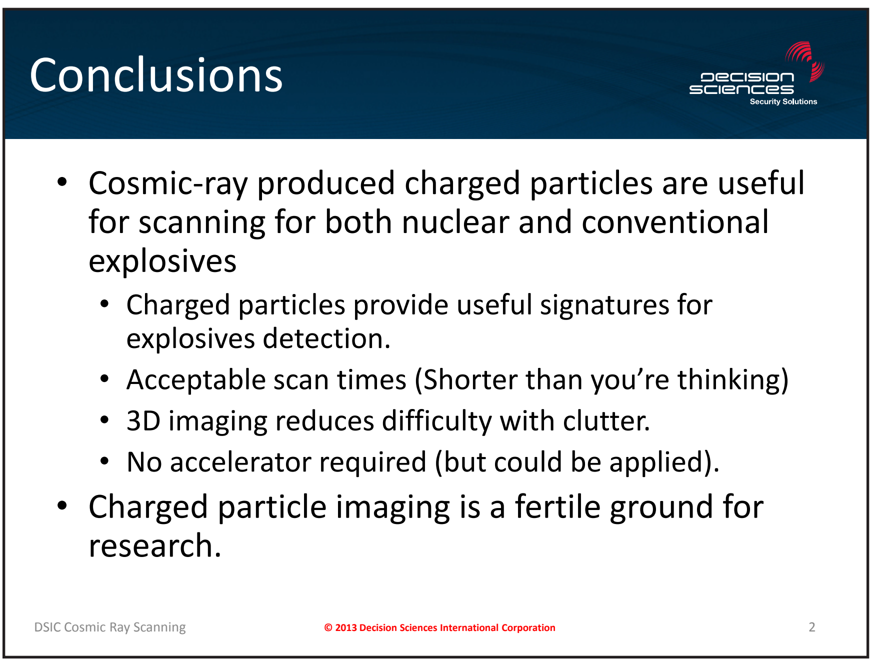
17.8 Michael Sossong: Background Cosmic Ray Produced Charged Particles for the Detection of Bulk Drugs and Other Contraband





Team

decision sciences
Security Solutions

- Michael Sossong – Particle Physicist
- Sankaran Kumar – Physicist
- Gary Blanpied – Particle Physicist
- Priscilla Kurnadi – Particle Physicist
- Andre Lehovich – Medical Imaging Mathematician
- Sean Simon – Particle Physicist
- Joel Kindem – Medical Imaging Physicist
- Weidong Luo – Medical Imaging Physicist
- Chuanyong Bai – Medical Imaging Physicist
- Shawn McKenney – Algorithms and Software
- Limited University/National Lab Collaboration

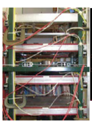
DSIC Cosmic Ray Scanning

3

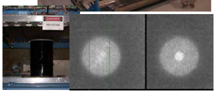
Development History

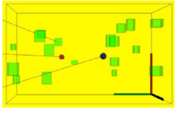
decision sciences
Security Solutions

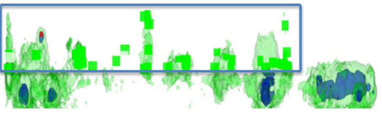
- Technology invented at Los Alamos National Laboratory (LANL)
  - Early funding from LDRD, NA-22, DTRA, DNDO
- DSIC begins funding LANL development in 2006
  - Completely privately funded
- First system demonstrated at DSIC in 2009
  - Independent testing
- First truck scanner constructed at DSIC in 2011
- First port deployment at Freeport Container Port in Bahamas 2012
- Work begins on explosives detection, 2012
- US Government (DNDO) (Nuclear) characterization ongoing
  - Expected completion Q2, 2014









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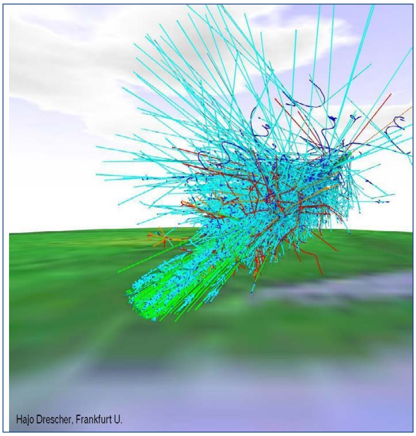
6

Cosmic Ray Generated Charged Particles



- High energy protons interact with upper atmosphere producing showers of secondary particles
  - Muons:
    - Long lived (~60 μs or 60,000 feet)
    - Highly penetrating
      - Heavy (200x mass of electron)
      - Mean energy 3 GeV
      - No nuclear interaction
    - 100/liter/minute
  - Electrons:
    - Less penetrating than muons
    - 25/liter/minute
- Distributed with $\cos^2$ off-zenith (37° mean)

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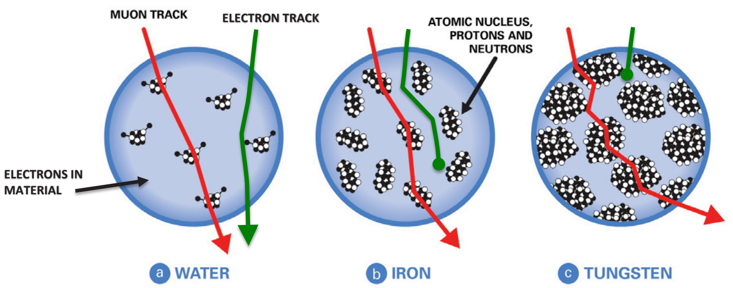
Charged Particle Interactions



- Scattering is interaction with nuclear charge
- Stopping is due to energy loss to electrons in material
- Muons primarily penetrate and are used for scattering
- Electrons stop much more readily and are useful for discriminating low-Z materials

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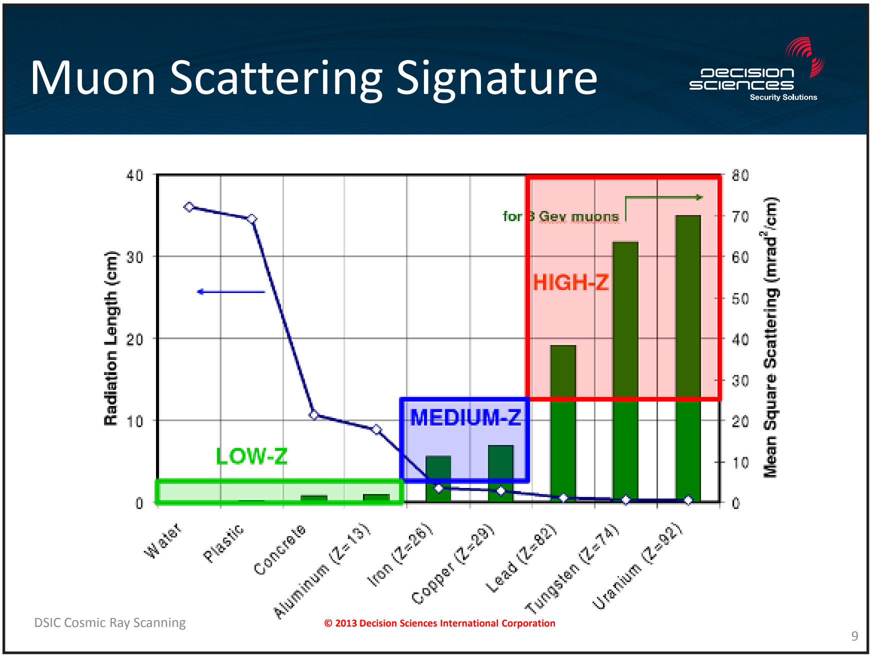
Muon Scattering Signature
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Radiation Length (cm)
Mean Square Scattering (mrad²/cm)
for 3 Gev muons
HIGH-Z
MEDIUM-Z
LOW-Z
Water
Plastic
Concrete
Aluminum (Z=13)
Iron (Z=26)
Copper (Z=29)
Lead (Z=82)
Tungsten (Z=74)
Uranium (Z=92)
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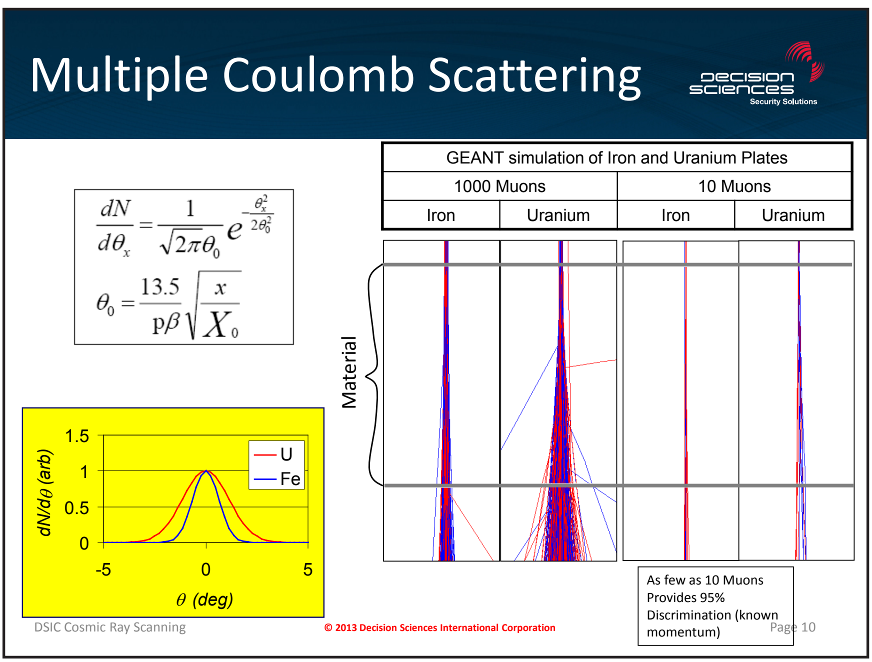
Multiple Coulomb Scattering
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$\frac{dN}{d\theta_x} = \frac{1}{\sqrt{2\pi}\theta_0} e^{-\frac{\theta_x^2}{2\theta_0^2}}$
$\theta_0 = \frac{13.5}{p\beta}\sqrt{\frac{x}{X_0}}$
GEANT simulation of Iron and Uranium Plates
1000 Muons
10 Muons
Iron
Uranium
Iron
Uranium
Material
dN/dθ (arb)
θ (deg)
U
Fe
As few as 10 Muons Provides 95% Discrimination (known momentum)
DSIC Cosmic Ray Scanning
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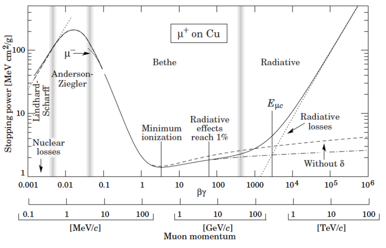
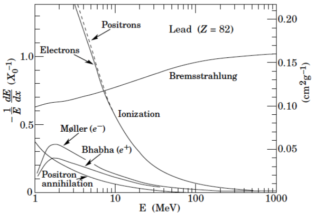
Charged Particle Attenuation

From Particle Data Book 2012





- Developing physics model incorporating relevant interactions
- Implemented simple uniform dE/dx model for fully attenuated (stopped) particles
- Measure Stopping Power for materials by counting stopped particles

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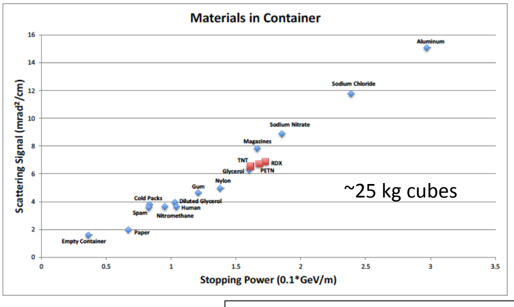
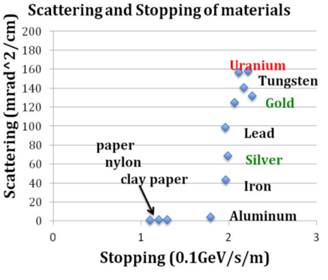
Combined Signatures





10 minute exposures, statistical uncertainty smaller than points
Blue diamonds measured, Red squares simulated

- Materials can be discriminated based on combined scattering/stopping signatures
- Regions of interest can be defined on this plane to provide automatic detection

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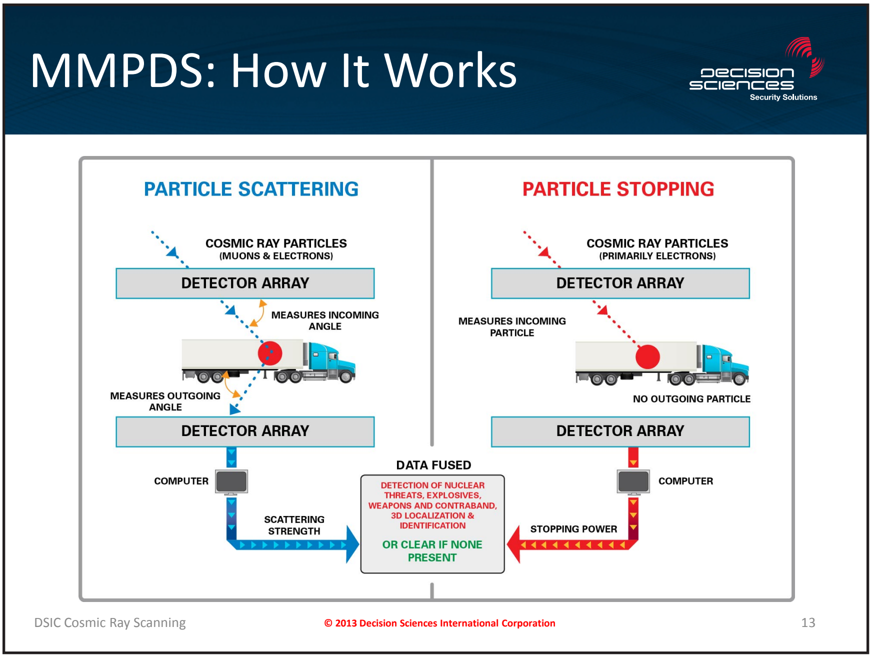
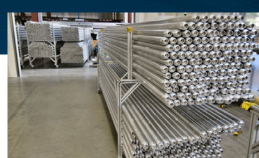
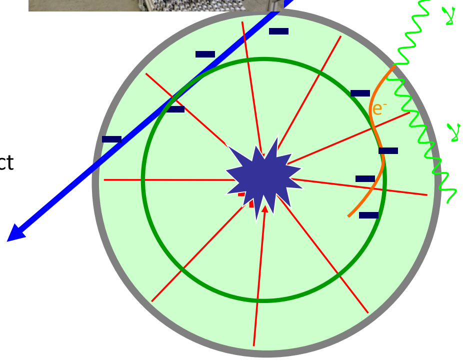


Base Technology: Sealed Drift Tubes

Simple "light-bulb" design

- Positive voltage on center wire generates radial electric field
- Muon ionizes gas along path
- Electrons drift at constant velocity along E-field toward anode wire
- High field near wire causes charge amplification via "avalanche" effect
- Drift time converted to closest approach distance giving radius to ~250 micron
- Gammas produce Compton electrons in tube wall which ionize gas as well, providing raw gamma count rates





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Layers of Tubes Provide Tracking

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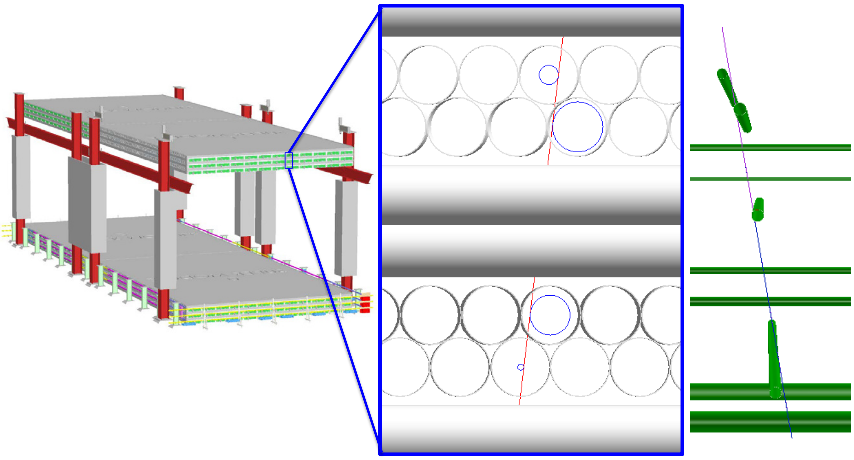

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3D Imaging Using Charged Particles – Scattering

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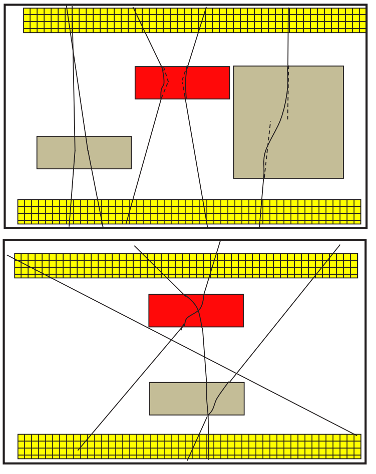
- Particle scattering reflect atomic density
  - Scattering angle – Radiation length
  - PoCA/path – location
  - DoCA – thickness
- Particles explore volume from many angles
  - Provides better vertical localization
  - Resolves vertical clutter
- Reconstruction techniques adapted from medical imaging
  - PET



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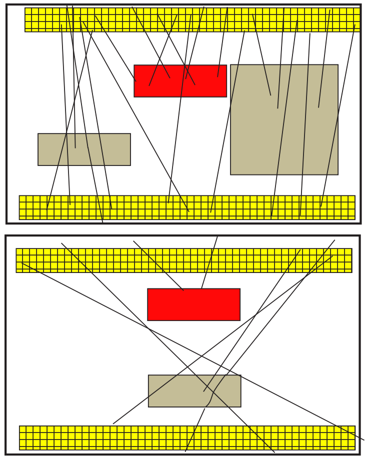
3D Imaging Using Charged Particles – Stopping

- Each incoming particle is tracked
  - Stopped trajectories point to region of stopping
- Volume explored from many angles
  - 3D imaging
  - Path lengths through objects
    - Absolute measurement of density, not relative contrast
- Measurement of momentum is better for lower energy particles that stop
  - Helps identify materials
- Ratio of stopped to through particles provides more statistically significant data than standard attenuation radiography
- Stopping is incorporated with existing scattering reconstruction
  - SPECT



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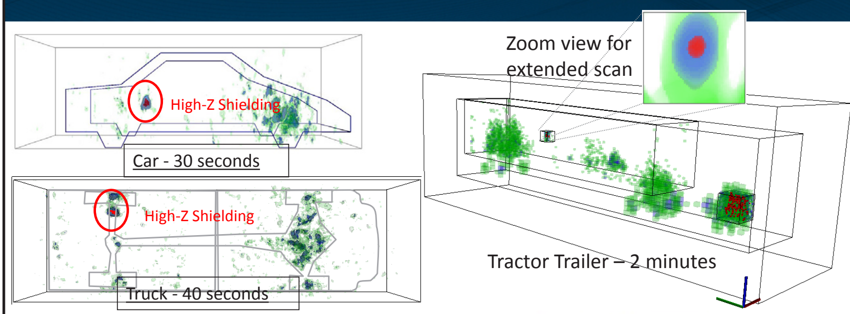
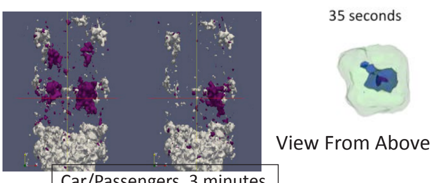
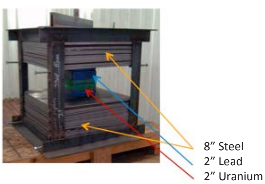
Scattering Images







DSIC Cosmic Ray Scanning

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Basic detection system concept (SNM/RDD)

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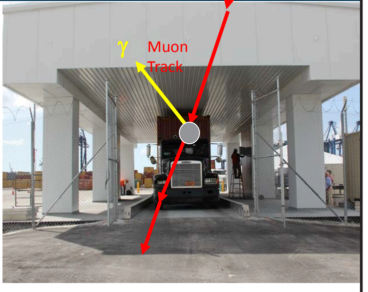
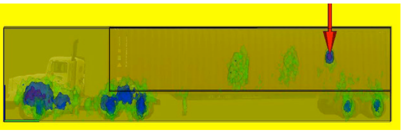
- Cosmic-RayTomography – Non-Intrusive Imaging (NII) using background muons/electrons, tracked by simple sealed drift tubes
  - Searches for SNM or enough shielding to block gamma emissions
  - Highly penetrating (> 16" steel demonstrated)
  - Identifies material by atomic number/density
  - Fast results (sub-minute times to clear)
  - Only available **passive** NII solution
- Sensitive gamma detection is built-in
  - Very large area gives high sensitivity
  - Natural cosmic background count subtraction
  - Many independent sensors allows position and distribution measurement for better discrimination of NORM
  - Provides a great deal of information in combination with MT
    - Source strength
    - Gamma energy





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20 20

Combined Scattering/Stopping Reconstruction

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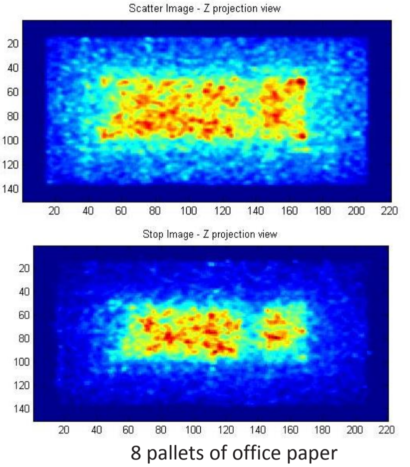
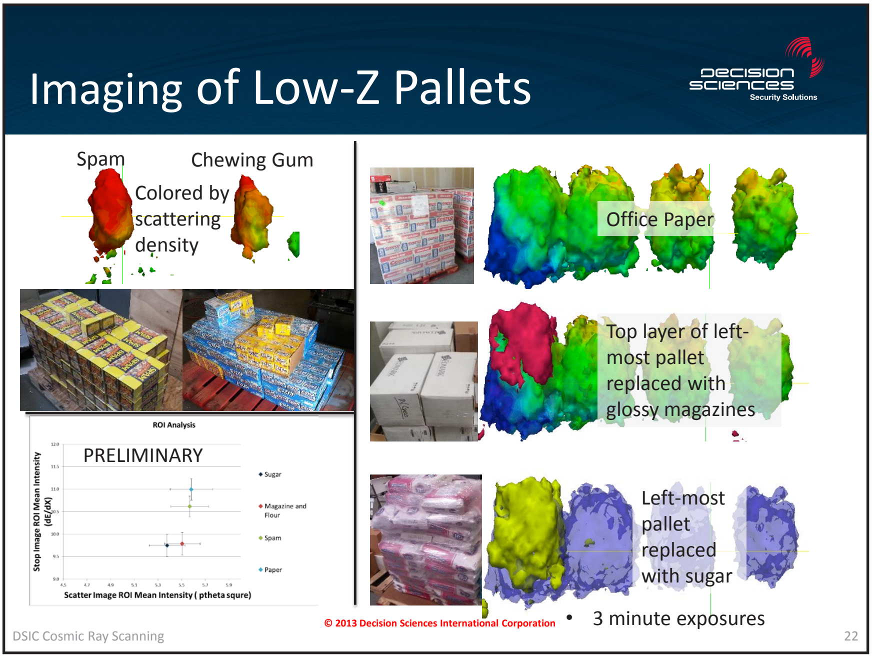
- Use scattering image as prior for attenuation reconstruction and vice versa
- Two reconstructed scalars for each voxel
  - Stopping power
  - Scattering density
- Detect threats/contraband of interest based on library of scattering/stopping signals for threat materials



8 pallets of office paper
3 minute exposure

DSIC Cosmic Ray Scanning

21



Advanced Imaging Algorithm Development

Challenges

- Sparse data
- Limited angular acceptance
  - Vertical thickness measurement critical to material discrimination
- Measurement uncertainty
  - Tracking and momentum
- Low latency required
- Complex, high-clutter scenes

Approaches

- Higher fidelity physics models
- Compressive sensing/adaptive measurement
- Iterative algorithms
- Filtering/deconvolution
  - Filtered back-projection
- Point cloud approaches

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First Production Unit – Freeport, Bahamas

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Scanning Containers Daily – US Government Characterization Ongoing – Expected Completion 2014

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Page 25

MMPDS Is Scalable to Provide Complete Architecture

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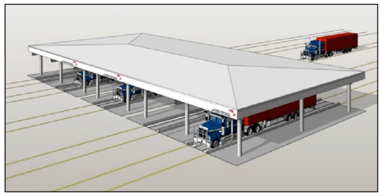

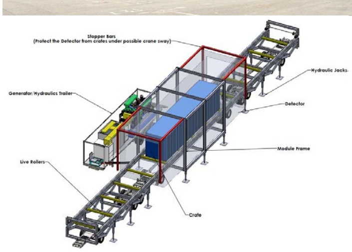

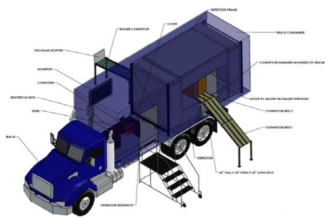

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Current Threats to Air Cargo Industry

decision sciences Security Solutions

- Printer ink cartridge terror plot containing plastic explosives and a detonating mechanism discovered on two separate cargo planes. (Oct. 2010)

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Scanning Logistics for Small Threat Quantities

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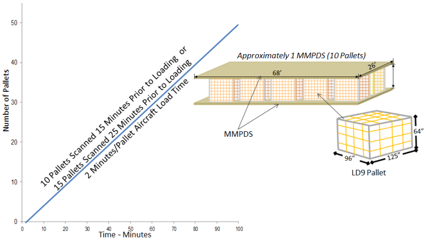
- For small threat sizes, the number of particles decreases for a set scan time
- For sub-kilogram quantities of explosives, resolution of false positives may require 45 minute scan times
  - Package scanners could be used in drop-off locations while awaiting pick-up
  - Many pallets could be scanned simultaneously during loading process



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Summary

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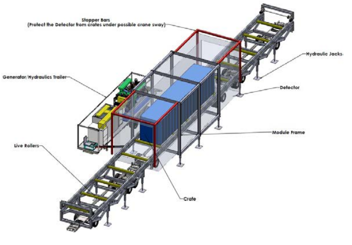
- Cosmic-ray charged particles are useful
  - Nuclear materials detection
  - Explosives detection (in development)
  - Numerous application spaces including air-cargo scanning
- Charged particle imaging algorithm development is fertile ground for research

www.dsic.com



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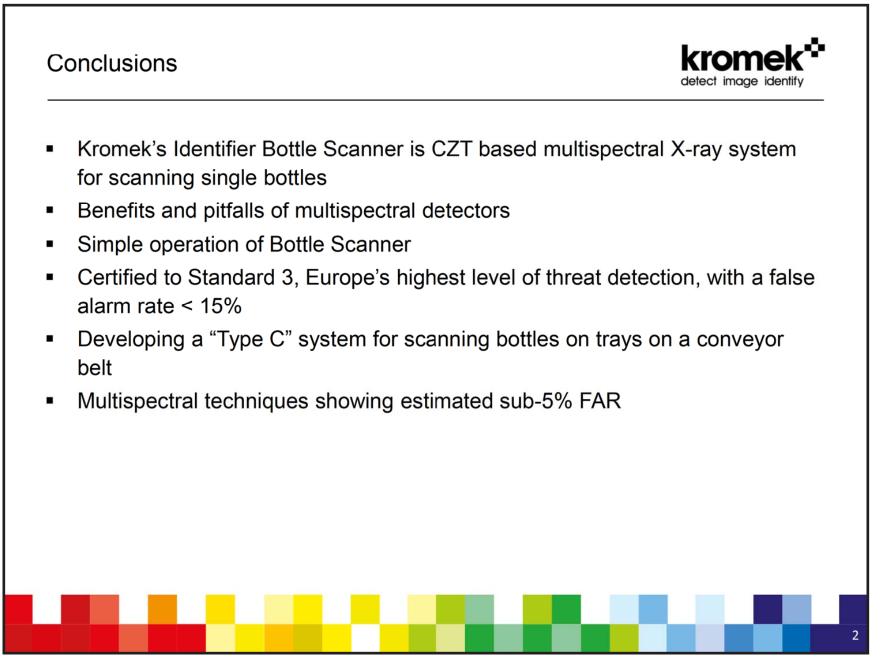
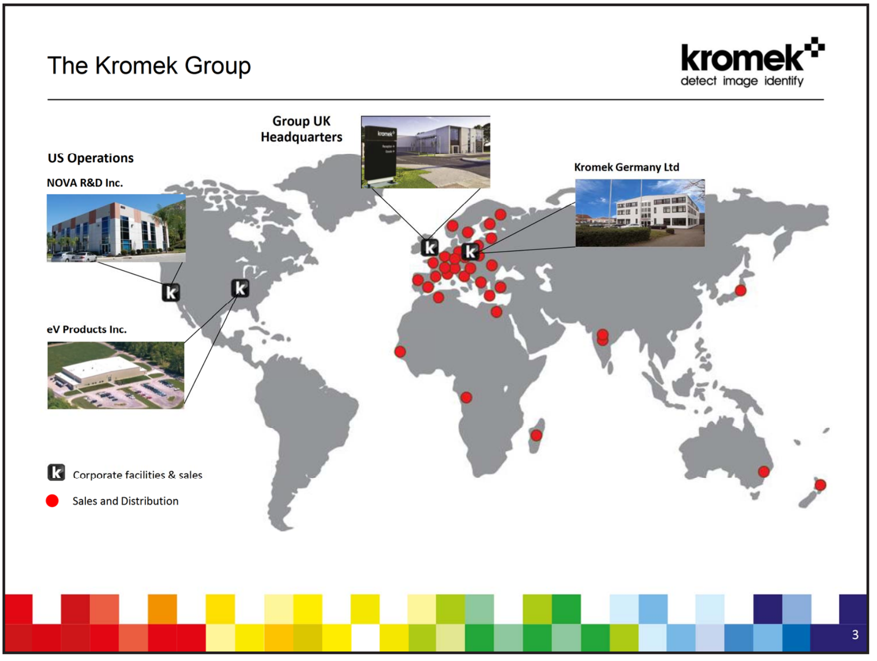
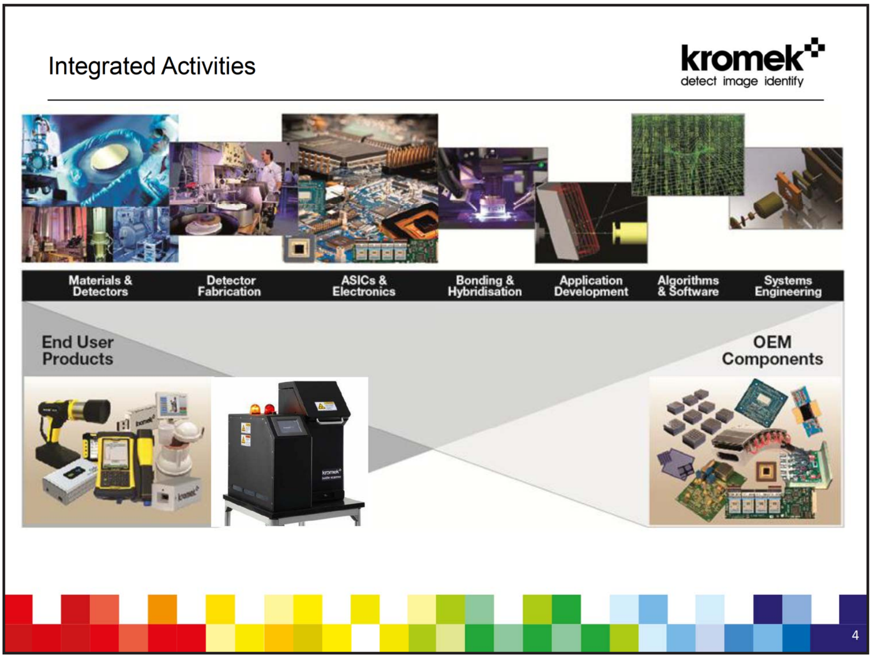
17.9 Ben Cantwell: Bottle Scanner Technologies




The Kromek Group
kromek
detect image identify
Group UK
Headquarters
US Operations
NOVA R&D Inc.
Kromek Germany Ltd
eV Products Inc.
Corporate facilities & sales
Sales and Distribution
3


Integrated Activities
kromek
detect image identify
Materials &
Detectors
Detector
Fabrication
ASICs &
Electronics
Bonding &
Hybridisation
Application
Development
Algorithms
& Software
Systems
Engineering
End User
Products
OEM
Components
4

Multispectral detectors

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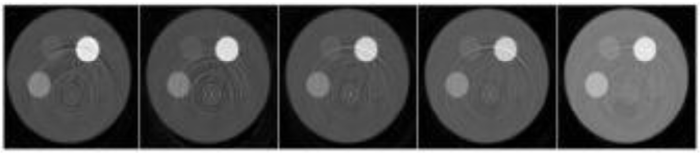
- Semiconductor detectors such as cadmium zinc telluride (CZT) allow energies of incoming photons to be measured with good resolution, unlike conventional energy-integration dual energy detectors.
- Allows you to make use of energy dependency of absorption coefficient to separate material
- Already making progress in medical industry
- Example below* shows imaging of phantom containing 5 different materials at 5 different energy levels – clear separation



*Wang et al, *Phys Med Biol* (2011)

5

Artefacts with detectors – beam hardening

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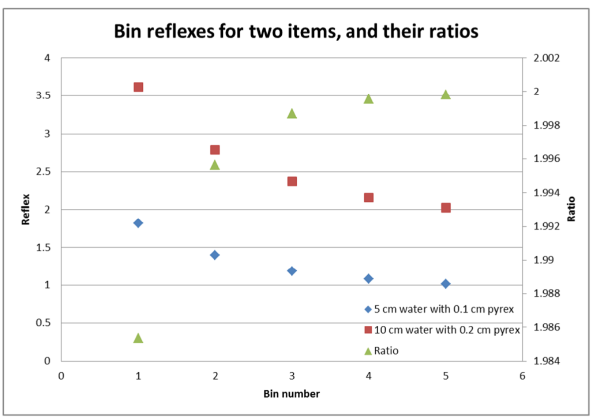

Reflex = -Ln (Transmission)

6

Artefacts with multispectral detectors – count rate effects

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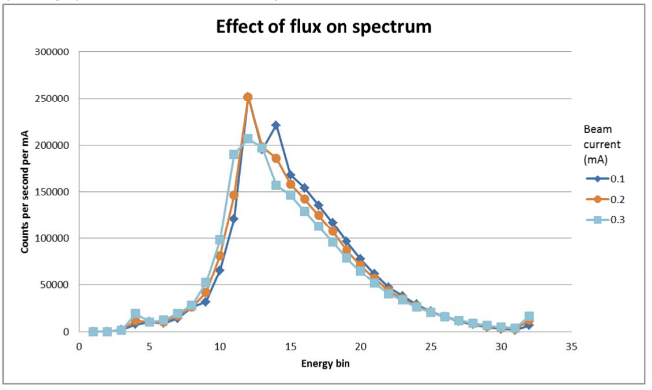
- Pulse pileup occurs when photon is absorbed before the charge from the previous photon is fully detected
- Charges add and information about energy and number of photon events is distorted
- Effect higher at higher photon rates
- Depending upon electronics, baseline may also shift as count rate varies



7

Effects on transmission

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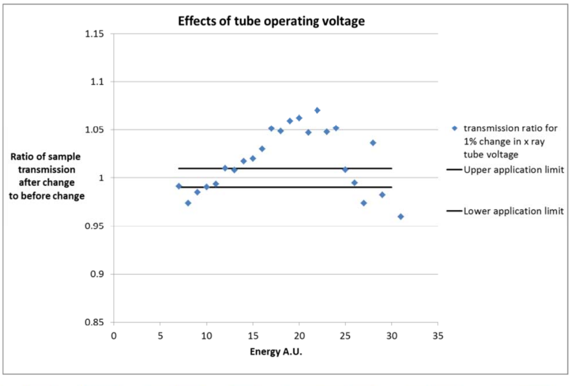
- Artefacts mean small changes in e.g. tube voltage can lead to large changes in transmission



8

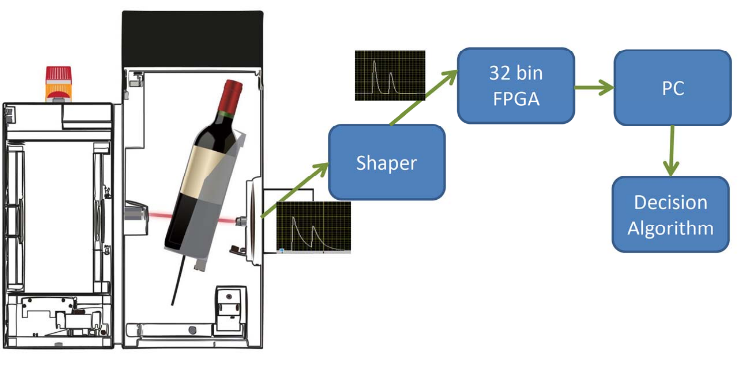
Ways around multispectral artefacts

- Do not try to reconstruct NIST!
- Teach/calibration method should take detector effects into account
- Take steps to keep measurements you will wish to compare in the same count rate regime

9

How the Bottle Scanner Works

- Scans one bottle at a time using single CZT detector



10

Results – Bin 1

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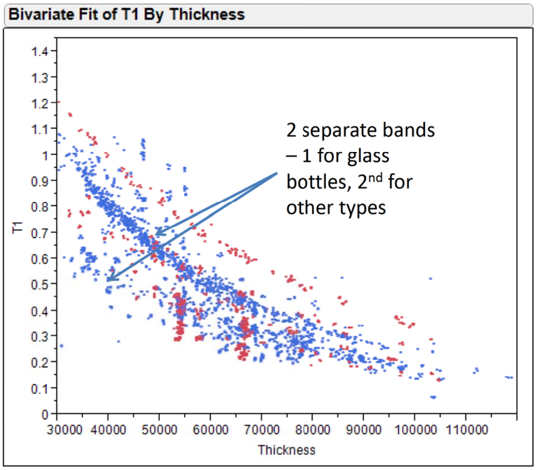

Red – THREAT Blue - BENIGN

11

Results – All 6 bins

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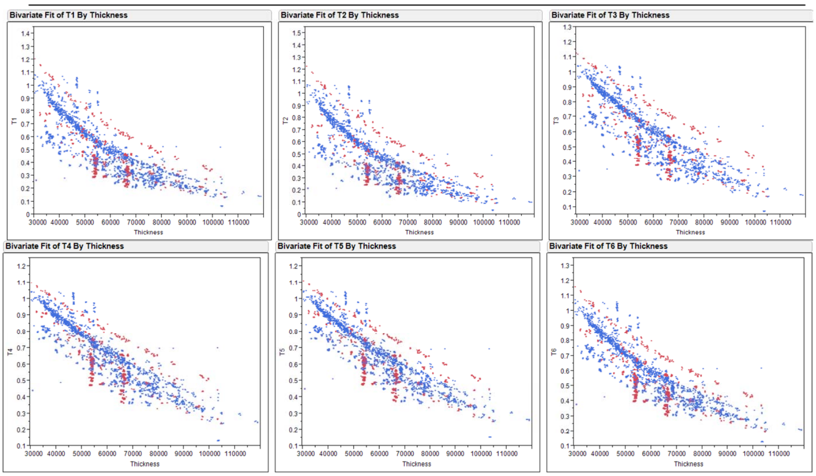

Red – THREAT Blue - BENIGN

12

Database Teach

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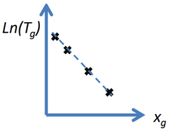
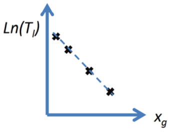
- Scan different sized liquid filled glass cuvettes

...



- Similar for different sized glass thicknesses, get Ln(T_g) vs thickness function
- Remove effect of cuvette walls to get liquid Ln(T_l) vs thickness graph
- Repeat for different liquids and wall materials
- Have range of equations to generate transmissions as function of liquid and wall thickness to create database



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What is bottle scanner - algorithm

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- Scan is measured against items in taught database
- THREAT/BENIGN classification based on taught materials it matches to
- Trade-off between False Alarms and Probability of Threat Detection
- ROC curve can be manipulated by
  - Selection of items in database
  - Match criteria
  - Decision on items which are matched

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Results

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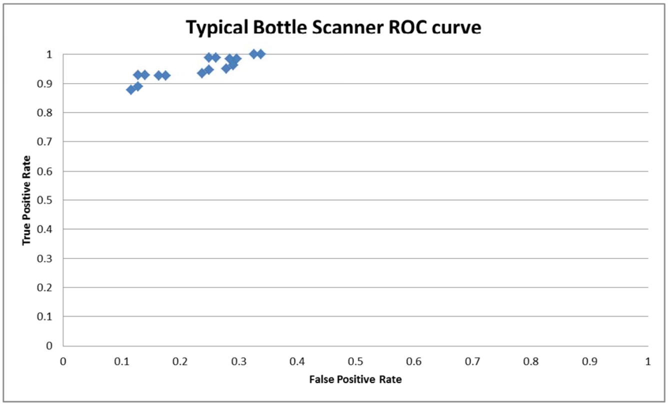

False Alarm Rate < 15% at Standard 3, Europe's highest level of threat detection

15

Eurostars scanner – what it is

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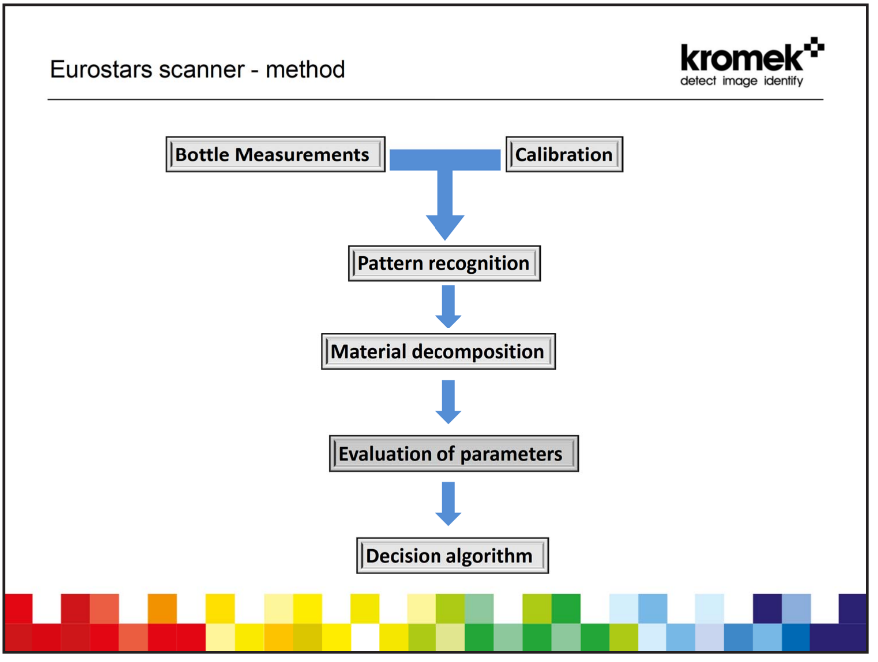
detect image identify

- Wheras Identifier Bottle Scanner scans 1 bottle at a time (called "Type B" in Europe), this is a "Type C" scanner which will scan mutiple bottles in the same load
- It is likely bottles will be placed in trays which will go on a conveyor belt
- Current design has two generators and linear arrays which scan items in 2 planes
- Target False Alarm Rate <5%

16


Eurostars scanner - method
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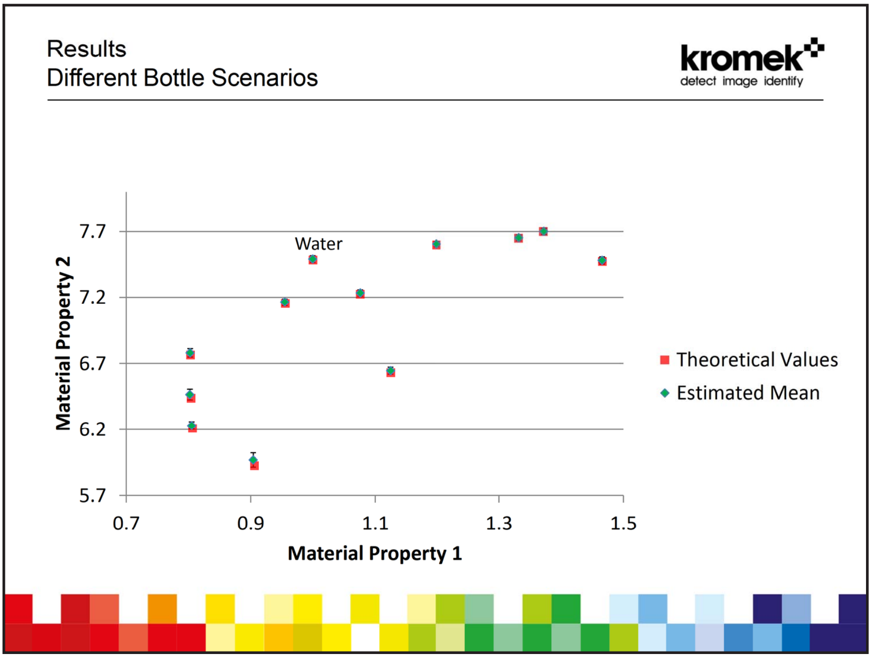
Bottle Measurements
Calibration
Pattern recognition
Material decomposition
Evaluation of parameters
Decision algorithm


Results
Different Bottle Scenarios
kromek
detect image identify
Material Property 2
7.7
7.2
6.7
6.2
5.7
Water
0.7
0.9
1.1
1.3
1.5
Material Property 1
Theoretical Values
Estimated Mean

Eurostars scanner - results

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detect image identify

- Testing with simulations using artefacts from real multispectral detectors
- On target for sub 5% False Alarm Rate
- Targeting ECAC approval testing in April 2014
- Looking for potential partners for commercialisation

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17.10 Steve Korbly: Multi-Spectral 3D Reconstruction and Data Fusion for Contraband Detection in Cargo Containers

Multi-Spectral 3D Reconstruction and Data Fusion for Contraband Detection in Cargo Containers

Algorithm Development for Security Applications 2013

Steve Korbly, Ph.D.
Passport Systems, Inc.

Work Supported by U.S. Department of Homeland Security Domestic Nuclear Detection under competitively awarded Contract No. HSHQDC-08-C-00124. This support does not constitute an express or implied endorsement on the part of the government. All claims and representations contained herein are those of Passport Systems, Inc. alone

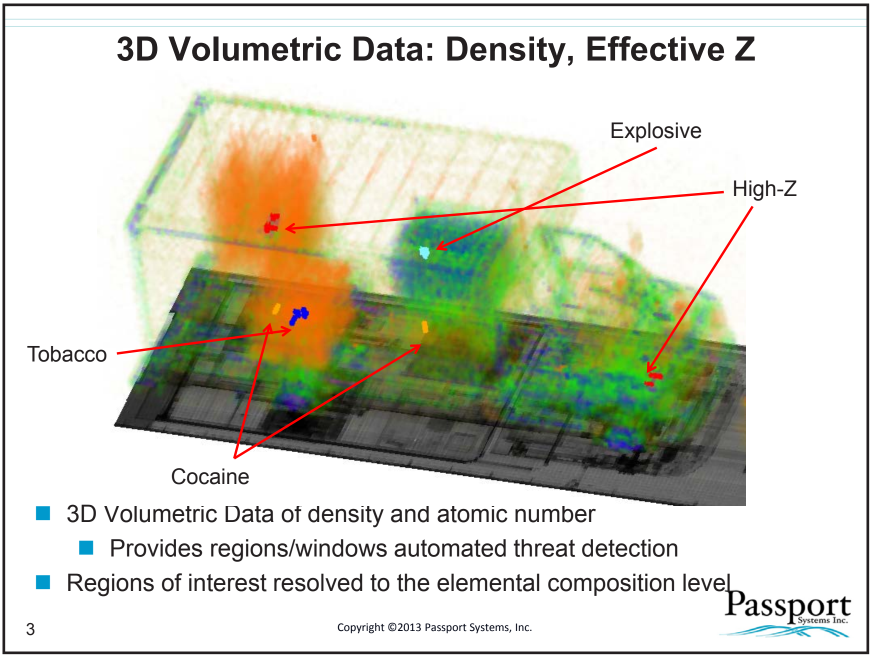
Passport Systems Inc.

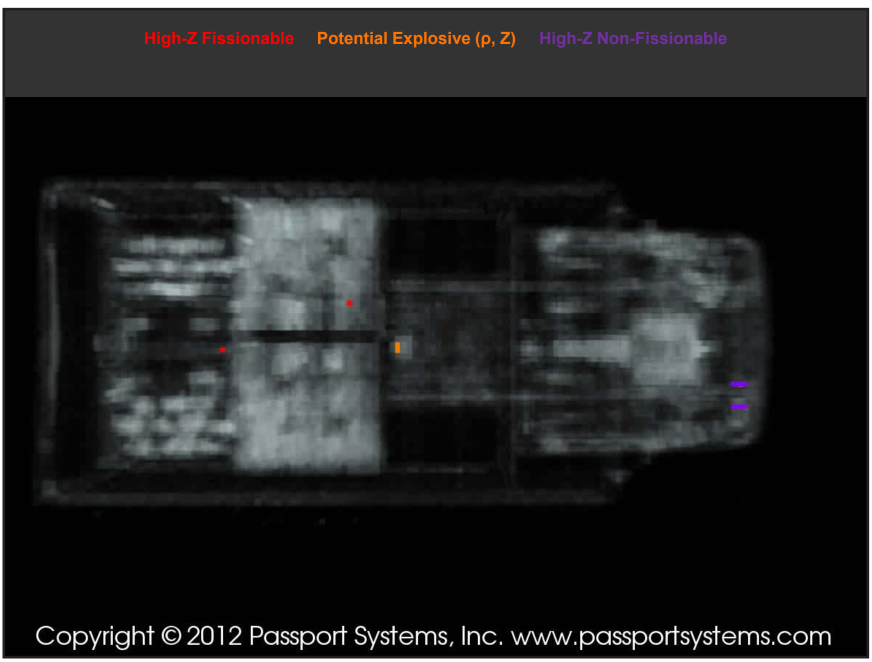
Passport Systems Company Overview

- Private U.S. company founded in 2002 to address cargo security
  - Passport's technology allows prompt, thorough, and precise cargo screening
  - Identifies cargo by what is inside - not by how it 'looks'
- Passport has strong intellectual property position
  - Passport patents on core detection technologies, HW and applications
  - Unique automated threat detection algorithms
- $80 million invested in Passport to date
  - Major funding from U.S. Department of Homeland Security ($42M)
- Passport products
  - Cargo Scanner
  - Networked Sensor Systems (NetS2) SmartShield™ G300

2

Passport Systems Inc.


3D Volumetric Data: Density, Effective Z
Explosive
High-Z
Tobacco
Cocaine
3D Volumetric Data of density and atomic number
Provides regions/windows automated threat detection
Regions of interest resolved to the elemental composition level
Passport
Systems Inc.
3
Copyright ©2013 Passport Systems, Inc.


High-Z Fissionable
Potential Explosive (ρ, Z)
High-Z Non-Fissionable
Copyright © 2012 Passport Systems, Inc. www.passportsystems.com

Passport Scanner Advantages

- Every one of the 700,000 Tennis ball-sized pieces of the 3D vehicle image contains discrete and independent data
- Image analysts: rotate, zoom, slice, and set alarms
  - Just like doctors with an MRI
- Operator-assist algorithms alarm automatically in the background
  - matches to preset density & atomic number
  - anomalies in cargo which should be uniform
  - cargo which does not match the manifest
- Material identification in minutes or seconds without opening the vehicle
  - Materials have unique signature
  - Continuously monitors confidence levels and forecasts time to ID
  - Confidence thresholds fully customizable to support shifting CONOPS
- Confirmed innocent cargo is on its way in minutes
- Dangerous material identified?
  - High resolution image and 3D coordinates inform the response
    - Just explosives? – Devanning team trained to handle explosives
    - Explosives with wires? – Bomb squad

5

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Standalone Cargo Scanning Facility

Conceptual design for facility to be installed at Massport (Boston, MA)

6

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Passport Scanner Technologies

Beam
9 MeV Bremstrahlung Photons

Measured Particle
Photons: Effective-Z (EZ-3D™)
Photofission (prompt and delayed)
Nuclear Resonance Fluorescence (NRF)
Neutrons: Photofission (prompt)

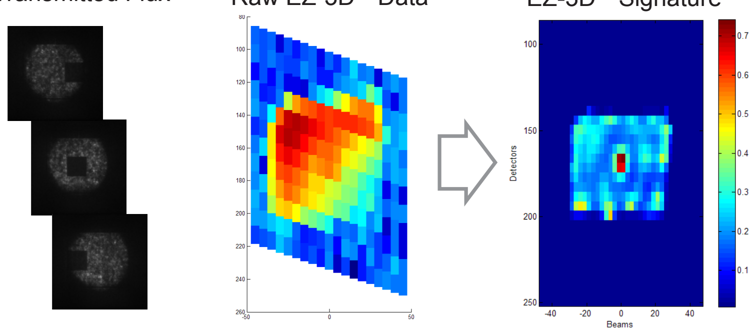
Scan	Algorithm	Input	Functionality / Output
Initial	EZ-3D™ Reconstruction	Medium-resolution energy spectrum	3-D density and Effective-Z map Anomaly identification/3D location
Initial	Transmission X-ray	Medium/High spatial resolution transmission image	Anomaly 2D location & density Shape/edge recognition
Initial	Portal Networked Detection System	Medium-resolution passive spectrum	Identification and localization of radioactive sources
Initial & Prolonged	Photofission	Digitized pulses from liquid organic scintillator	Identifies presence of fissionable material
Prolonged	NRF 3D	High-resolution energy spectrum	Complete isotopic composition in the region-of-interest
	Anomaly Classification	Output of NRF 3D, PNPF, EZ-3D™ and transmission algorithms	Performs data fusion, classifies anomaly as threat or innocuous, predicts detect/clear time

7

Passport Systems Inc.

EZ-3D™ Anomaly Detection
Lead cube in steel chain example

Transmitted Flux — Raw EZ-3D™ Data — EZ-3D™ Signature



- Combine Transmitted Flux and Raw EZ-3D™ data
- Reconstruct EZ-3D™ signature
- Determine anomaly locations for threat ID

8

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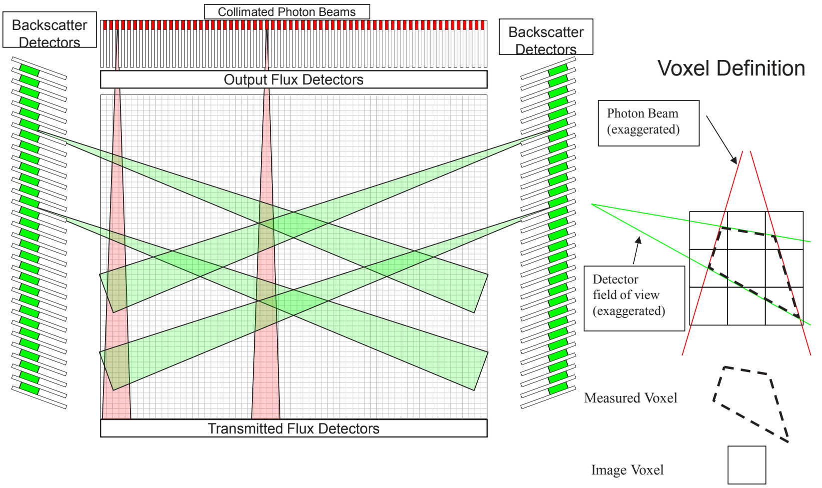
EZ-3D™ Geometry



9

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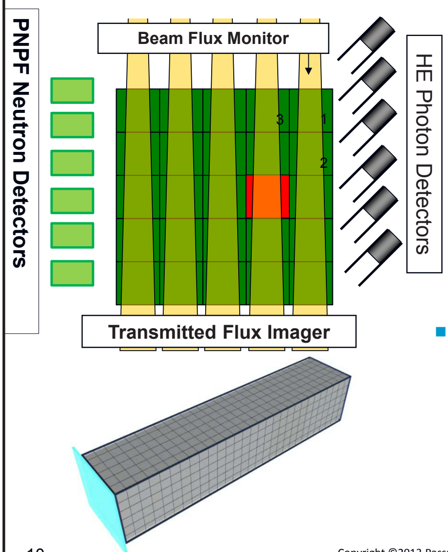
Scan Geometry and Process



- **Primary Scan:**
  - Beam scans in the beam plane
  - Container traverses the beam
  - → 3D backscatter image (EZ-3D™)
    - ~15 s/20' container
    - 3D map of effective Z & density
  - → 2D transmission image
  - → 2D neutron image
    - Fissionable Material Alarm
  - → ROIs for secondary scan
- **Secondary Scan – ROI inspection:**
  - PNPF, beam dwell on ROIs (~seconds)
    - Fissionable Material Alarm
  - NRF, beam dwell on ROIs (~minutes)
    - Isotopic ID:
    - HEU, explosives, cocaine

10

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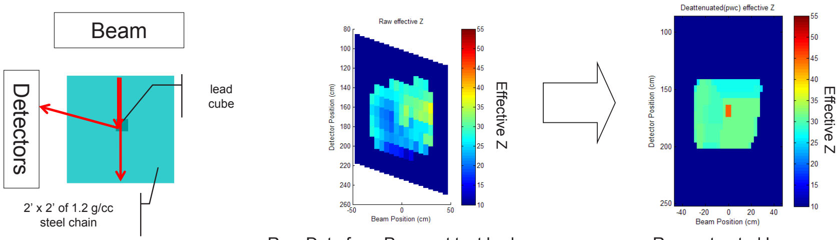
EZ-3D™ Reconstruction



Raw Data from Passport test bed

Reconstructed Image

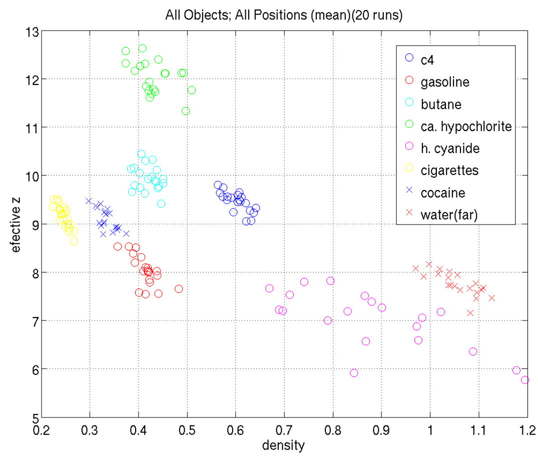
- Constraints
  - Transmission
  - Attenuation In
  - Attenuation Out
  - Regularizer – Biases toward "likely" solutions

Output for Data Fusion

- Position
- Surface area
- Attenuation In
- Photon Attenuation Out
- Neutron Attenuation Out
- Density
- Effective Z

11

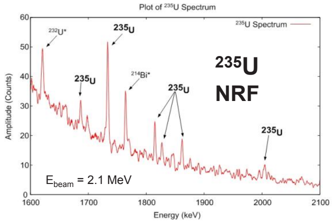
Discrimination via EZ-3D™



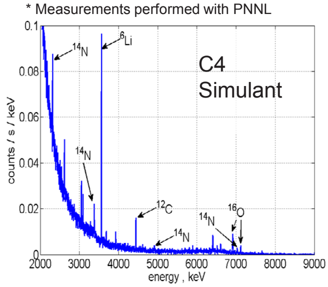
- Improving reconstruction to reduce spread in density and EZ

12

NRF Algorithms Overview



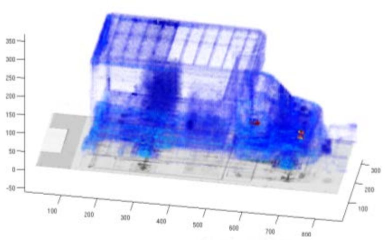
* Measurements performed with PNNL

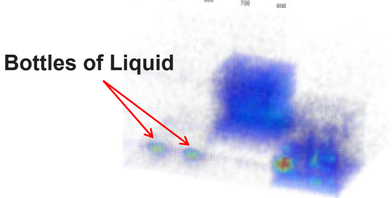


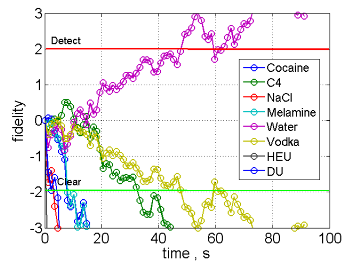
- NRF Data
  - Integrated counts for each line / detector
  - Background rate for each line / detector
- Anomaly identification
  - Calculate expected signal count rate for threat hypothesis
  - Calculate likelihood of measured NRF counts for hypothesis
  - Determine if anomalies from user-defined list are present / absent at defined level of PD / FP
- Supporting functions
  - Background estimation
  - Spectrum smoothing

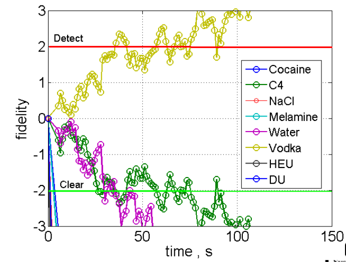
13

Material Identification via NRF









- Time to identify each: <1.5 minutes

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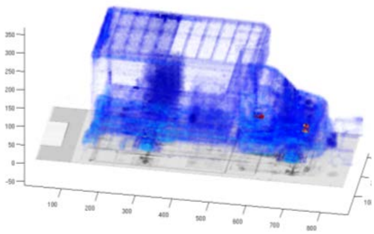
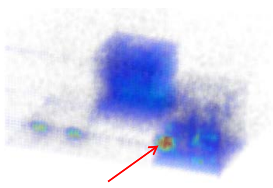
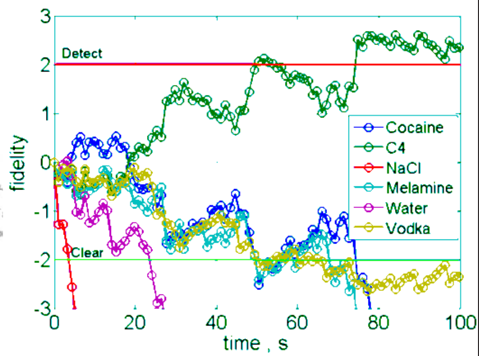
Explosive Detection Example





'Explosive' Anomaly detected by density & EZ



- Potential explosive anomaly detected by density, EZ
- Identified as C4 in <1.5 minutes

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Passport Systems Inc.

Summary

- Passport building land/sea cargo container scanner at port of Boston
- EZ-3D™ reconstruction - novel imaging technique for automated contraband detection
- NRF provides isotopic/elemental identification
- Data fusion provides predictive detection/clear times
- Passport's scanner provides unique solution for
  - SNM detection
  - Contraband
  - Material Identification

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Passport Systems Inc.

Thank You

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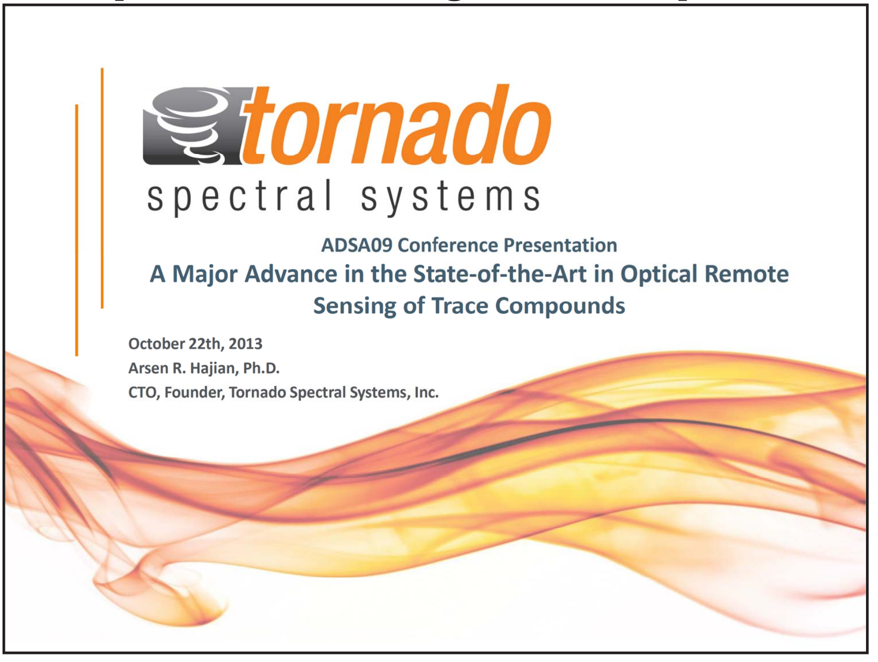
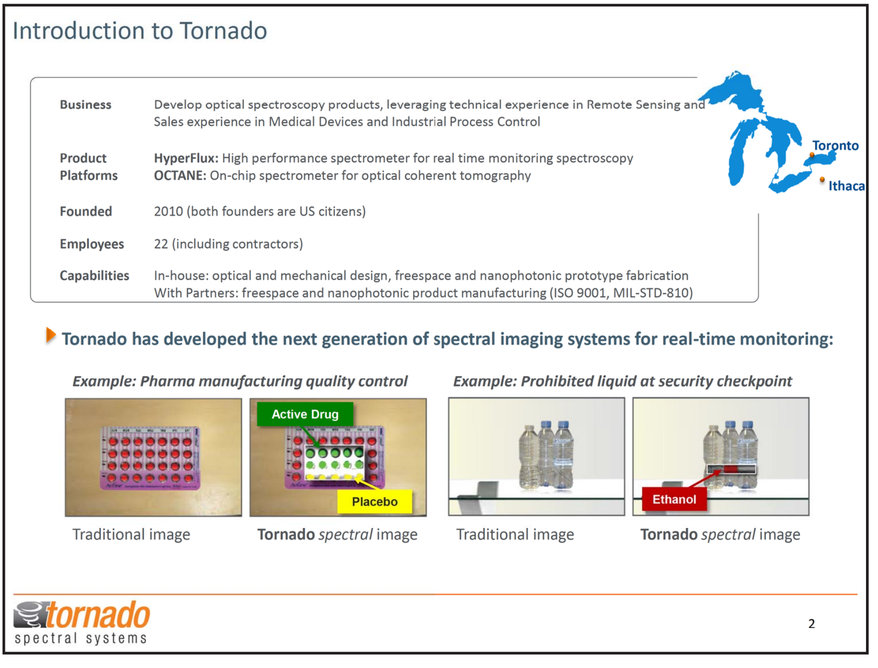
17.11 Arsen Hajian: A Major Advance in the State-of-the-Art in Optical Remote Sensing of Trace Compounds

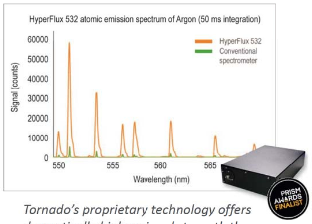




HyperFlux: Tornado's fundamental improvement to spectrometer design dramatically outperforms conventional systems for Real-time Spectral Monitoring (RTM)

Current: Quality control relies on complex and bulky systems to approach required performance

Price: $250,000
Weight: 200 lbs



Tornado's proprietary technology offers dramatically higher signal strength than conventional spectrometers

Future: Tornado will produce high sensitivity devices with reduced size and cost, facilitating wide spread adoption of easy-to-use non-destructive testing

HyperFlux spectrometer system
High Throughput Virtual Slit (HTVS) is inside

Price: $70,000
Weight: 20 lbs

- Tornado's patented technology eliminates the greatest source of reduced signal inherent in conventional designs
- The HyperFlux enables industry-leading ***higher sensitivity with smaller size and lower cost*** than can be achieved with conventional devices

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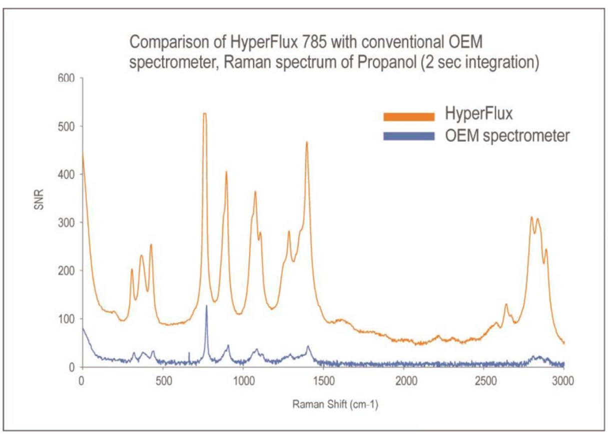
Tornado's HyperFlux Spectrometer



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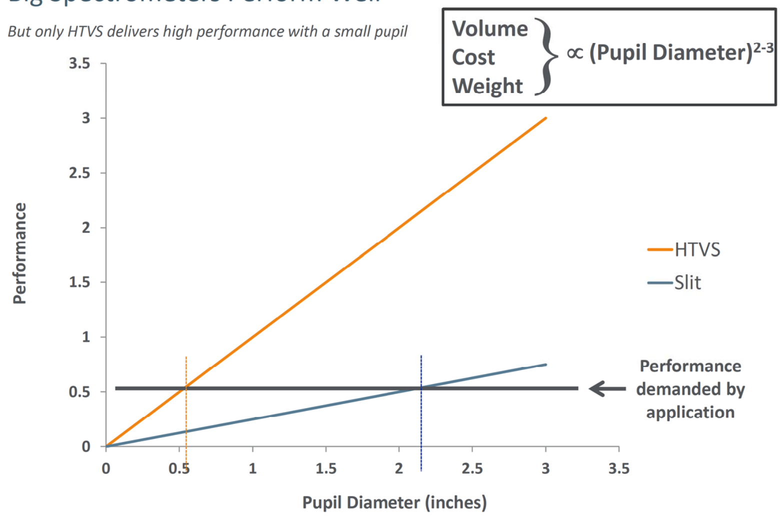
Big Spectrometers Perform Well

But only HTVS delivers high performance with a small pupil



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Tornado's HTVS technology has disruptive performance

Tornado has rebuilt the concept of the optical dispersive spectrometer by integrating the high throughput virtual slit

Technical impact

- Can efficiently change f-ratio and spot size independently
- Greatly mitigated/solved resolution vs throughput trade for spectroscopy
  - No need to trade detection time with specificity (have both!)
- Delivers 3-200x photons to the detector than is otherwise possible
- Can extract more information/sec than is otherwise possible
- Solution is robust, scalable, in-production
- Purely reflective, achromatic designs

Logistical impact

- Literally "do more with less" (sorry, it's an LED vs. a filament)
- 3-200x performance in same volume/weight package
- 1x performance in much smaller volume/weight package
- Can remove cost from auxiliary components
  - Photon-counting camera to 1-stage cooled (or uncooled!) camera
  - 1m aperture to 0.3m aperture

Mission impact

- **HSI:** Can trade slit length with width
- **Baggage:** more sensitivity, fast processing, higher confidence
- **CBRNE:** better limits, larger standoff range, handheld device capability

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For more information please contact:

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Summary: Tornado's Products and Current (Public) OEM Partnerships

Tornado Core Products

HyperFlux 532
Fixed-Configuration 532 nm Raman Spectrometer

Launch date: Jan 2012

HyperFlux 785
Fixed-Configuration 785 nm Raman Spectrometer

Launch date: Jan 2012

HyperFlux U1
High Resolution Spectrometer Platform

Launch date: Jan 2013

OCTANE-860
OCT Nanophotonic Spectrometer-on-Chip

Launch date: Jan 2013

Tornado 'Labs' Partnerships

Ocean Optics APEX 785

Launch date: Jan 2013

AVANTES solutions in spectroscopy AvaRaman XHS

Target launch date: Jan 2014

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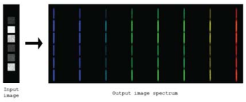
High Throughput Virtual Slit (HTVS)

Tornado has developed an advanced "spectral imaging" system using the HTVS technology

New product under development:

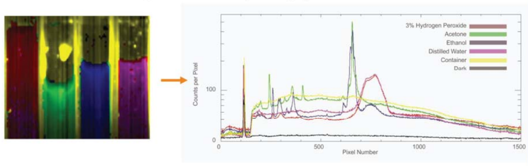
HTVS-enabled HSI system



ZEMAX simulation of reformatting along a slit input

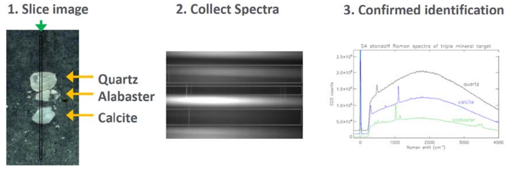
Example 1: Identifying multiple liquids simultaneously

1. Process scanned image
2. Corresponding spectra identification



Example 2: identifying different minerals that 'look' similar

1. Slice image
2. Collect Spectra
3. Confirmed identification



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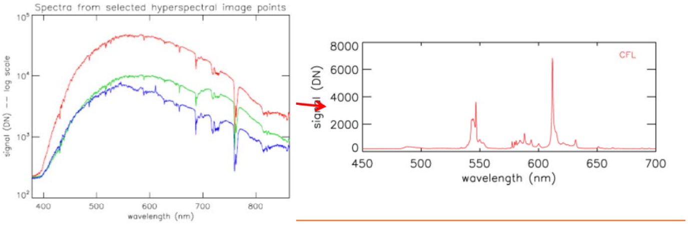
Tornado's S4 Hyperspectral Imager

A demonstration of an HTVS-equipped hyperspectral imager

HyperSpectral Imaging

- The high spectral resolution of can identify fine spectral features that otherwise are lost
- Operates well in high-background scenarios

Original scene | HSI of scene using S^4 | Filtered HSI



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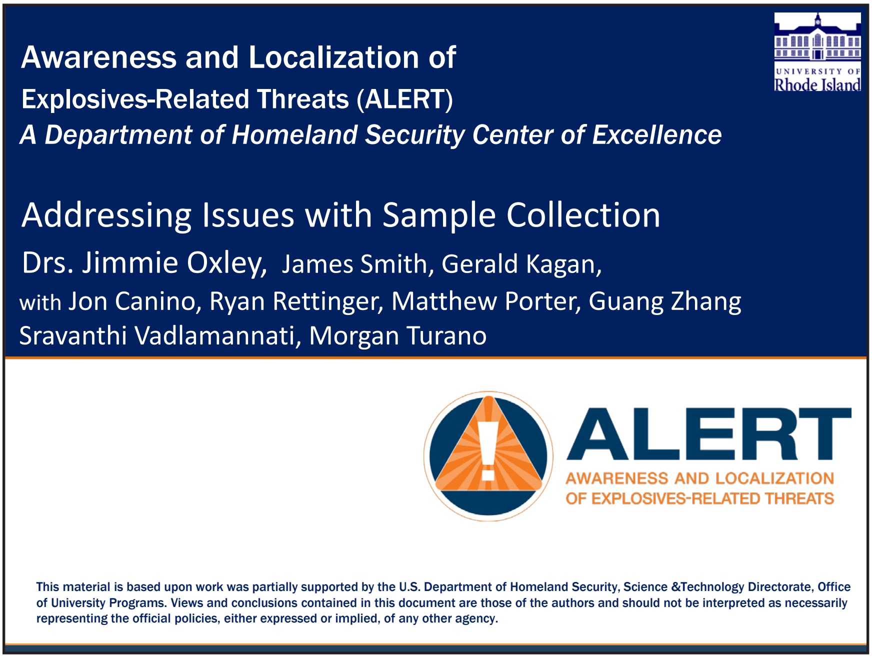
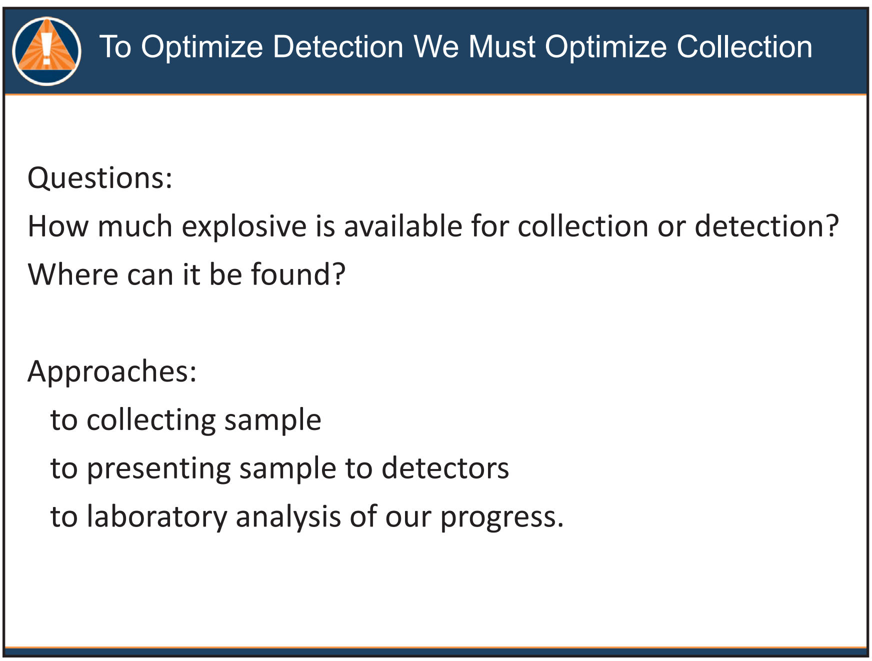
17.12 Jimmie Oxley: Addressing Issues with Sample Collection

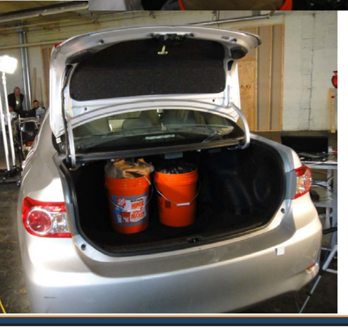





Volunteers put together "pipe bombs" with fluorescent dye filler
Fingerprints were on the device
Residue was on bench & floor
Attempts to clean up mess generally scattered more residue


Residue was found wherever hands touch

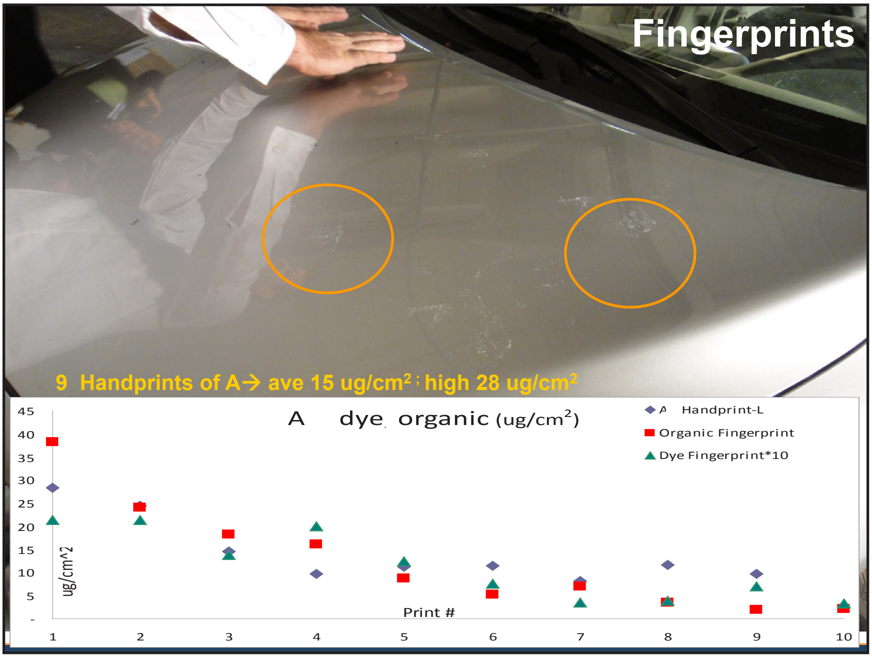
Chemical A (50 lb) was ground, loaded in a vehicle, & driven a short distance. This was repeated on two consecutive days.



Residue was where hands touched

	Day 1		Day 2	
	area cm^2	**A** **ug/cm^2**	area cm^2	**A** **ug/cm^2**
INTERIOR				
gear shift	9	**355**	9	**4848**
steering wheel	1218	**5.5**	1218	**80**
door frame driver	6	**0.87**	2	**358**
door handle driver	45	**11**	45	**112**
door handle passenger	45	**49**	45	**162**
EXTERIOR				
door handle driver	10	**15**	23	**90**
door handle passenger	8	**0.13**	2	**458**
truck by plate, right	70	**0.48**	85	**78**
truck by plate, right	70	**7.9**	35	**35**
CAR BLANK	98	**0.024**	16	**0.064**

Typical amount chemical A
0.1 to 0.4 mg/cm^2 on interior
30-90 ug/cm^2 on exterior



Lessons Learned

- Plasticized "explosive" left cleaner assembly area but adhered to hands longer than powdered material.
- Contamination of handlers' clothes was minor; < 20% of time was contamination found.
- Dye on clothing was usually on right, front side where hands touch, e.g. pocket
- Amount dye ranged from 10^{-1} to 10^{2} ug/cm,^{2}
  mode: 2 to 4 ug/cm^{2} & median: 4.7 ug/cm.^{2}
  68% of samples < 16 μg/cm^{2}.
- Size residue spot: 0.15 to 268 cm^{2} 70% samples < 3 cm^{2}

Explosive Residue on Hair

Explosives easily adhere to hair within minutes of exposure.

Even those just observing others handling explosives were contaminated.

Particle of explosive on hair observed under magnification

Generally, explosives contaminate hair by particle transfer, not by their vapor (which is minor).

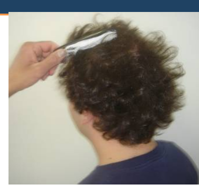
Explosives in cut hair persist for days despite washing.

Persistence: % explosive remaining on hair after standing 5 days or 2 washing

	TATP	EGDN	TNT	PETN
hair standing	20%	20%	100%	not done
hair washed	70%	30%	50%	3%

Sampling Hair on Heads of Explosive Handlers & Suspects

Hair of those working with explosive was combed. Even Monday AM, explosive residue was found in hair of some. At end of week, despite evening showers, all were contaminated. Example is shown for tests at AP Hill (2003)



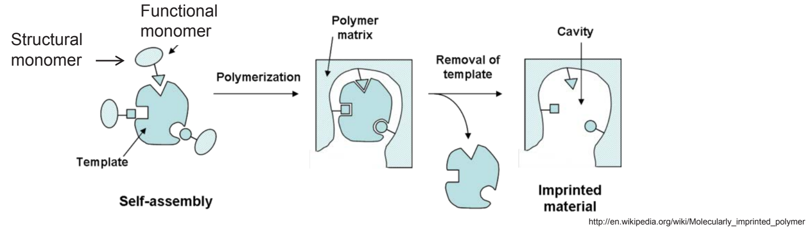
% of people (30) with detectable amounts of indicated explosive combed from hair

	Monday		Tuesday		Wednesday		Thursday	
	Start day	End day	Start day	End day	Start day	End day	Start day	End day
PETN	3%	67%	26%	75%	0%	90%	60%	100%
RDX	3%	17%	4%	40%	6%	20%	0%	54%

In 2009 ~600 combs were sent to theater & used on suspects. About 1/3 showed TNT, RDX, or PETN residue, but no immediate feedback was available to the warfighter.

Future studies will seek for in-field analysis to provide immediate results.

Molecularly Imprinted Polymers (MIP)-Selective for Explosives



Can this "selectivity" be exploited to collect explosives?

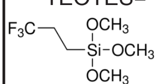
The variables
a backbone -- the structural monomer
a binding site – the functional monomer
a template
a polymerizing agent & method
the ratio of structural and functional monomers & their ratio to the template

MIP Results

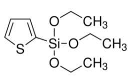
MIP mg TNT	Control Polymer mg TNT	TNT uptake over control	Functional Monomer	Structural Monomer	Ratio TNT: F:S
2.3	1.8	128%	PTMS	TriEOS	1:4:20
7.1	6.0	118%	PTMS	TEOS	1:8:36
7.7	8	96%	PTMS	TEOS	1:8:18
4.9	3.7	132%	PTMS	TEOS	1:4:27
4.9	3.7	134%	PTMS	TEOS	1:10:50
6.7	2.9	231%	PTMS	TEOS	1:8:40
2	2	100%	TMOTFS	TEOS	1:4:20
5.7	4.8	119%	TEOTES	TEOS	1:4:20

Functional PTMS= phenyltrimethoxysilane
TMOTFS= trimethoxytrifluoropropyl silane
TEOTES= Triethoxy-2-thenylsilane

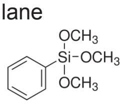
TEOS= tetraethoxysilane
TriEOS =methyltriethoxysilane



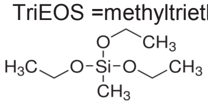
TMOTFS



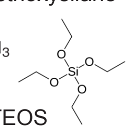
TEOTES



PTMS

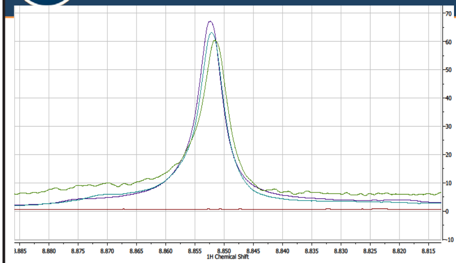


TriEOS

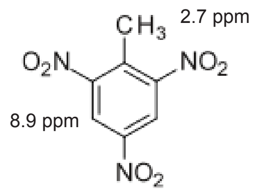


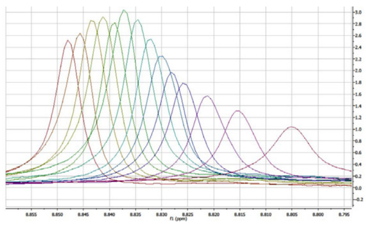
TEOS

Analysis Metric-NMR Titration TNT & Methacrylic Acid

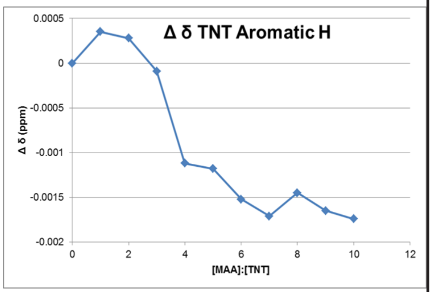


Chemical Shift of Aromatic Protons on TNT. **Red – no TNT**, **Green – 1:10 TNT:MAA**, **Blue – 7:10 TNT:MAA**, **Purple – 1:1 TNT:MAA**

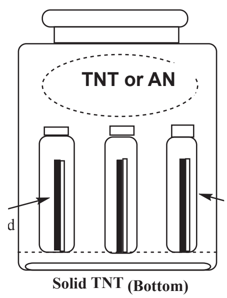




Aromatic TNT with addition of **PTMS**



Testing Method
Static Vapor Jars TNT or AN



5 uncoated & 7 coated samples Al foil or cardboard were stored with 500 mg TNT or AN at 60°C & then extracted-- TNT by 10 mL ACN & analyzed by GC/µECD or AN 5 mL DI water & analyzed by IC/ECD

Substance/Matrix	Target Explosive	Test Time	Average (µg/mL)
Polymer Powder in 1 L Container			
Empty 50mL Vial	TNT	3 days	0.139
PMAA (polymethacrylic acid)	TNT	3 days	0.179
Graphite	TNT	3 days	0.287
PS2DVB (polystyrene 2%Divinylbenzene)	TNT	3 days	0.328
Sand (SiO2)	TNT	3 days	0.343
Polypyrrole	TNT	3 days	0.389
PTMS (polyphenyl(trimethoxy)silane)	TNT	3 days	0.412
Tenax	TNT	3 days	0.477
Polyaniline (sulfate salt)	TNT	3 days	0.499
Polymer Coating on Cardboard in 1L/200 mL Container			
Polyaniline sulfate salt PVA (1g/1g)	TNT	1 hour	1.1
Uncoated Cardboard 1.5X1.5cm	TNT	1 hour	0.284
Polyaniline sulfate salt/Graphite (1g/2g)	AN	2 days	4.45
Uncoated Cardboard 3X3cm	AN	2 days	0.401

Polymer/Swab Evaluation by Pickup & Release

Sorption of TNT vapor
(60 min, 60C)(ng/mg matrix)

Substrate Type	Average TNT/Polymer (ng/mg)
Teflon	0.90
FLIR Nomex	0.90
1 PVA: 1 PANI Al Foil	0.97
1 PVA : 1 PANi	1.5
Uncoat SSW	2.7
2.5g PVA/2.5g PANi (CB)	3.9
2.5g PVA/ 2.5g graphite (CB)	4.5
2.5g graphite/ 0.5g PAA/ 2.0g PVA (CB)	4.8
Beta-Cyclodextrin	5.4
Cardboard (CB)	5.9
Polystyrene	5.9
Montmorillonite	6.6
Bentonite	7.1
Alpha-Cyclodextrin	7.3
Graphite	8.8
Tenax	10.3

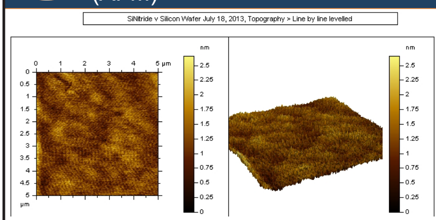
Sorption of vapor TNT is judged by exhaustive extraction by solvent.

Release is from a heated vial into GC.

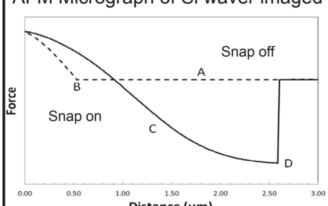
TNT vapor 60°C, 60 min sorption & release

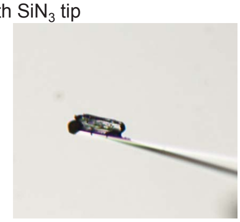
Polymer	Solution TNT/Polymer (ng/mg)	Headspace TNT/Polymer (ng/mg)	% TNT released
Tenax	16.4	0.16	1%
"	13.3	0.13	1%
"	14.9	0.20	1%
"	10.8	0.12	1%
"	10.9	0.08	1%
"	9.27	0.13	1%
"	8.76	0.11	1%
Poly(2,6-dimethyl-1,4-phenylene oxide)	4.50	0.21	5%
"	5.76	0.18	3%
"	5.59	0.17	3%
"	4.51	0.16	4%
"	5.62	0.16	3%
"	4.93	0.13	3%
"	4.92	0.19	4%
"	2.09	0.11	5%
Polystyrene	4.64	0.36	8%
"	4.05	0.31	8%
"	5.27	0.87	16%
"	6.33	0.49	8%
"	7.88	0.68	9%
"	9.78	1.58	16%
"	5.84	0.62	11%
Nomex	2.4	1.1	47%
"	2.5	2.3	92%
"	2.0	2.04	104%
"	2.6	2.37	91%

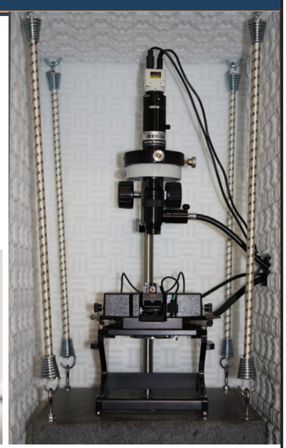
Metric of Adhesion of Explosive to Polymer: Atomic Force Microscopy (AFM)



AFM Micrograph of Si waver imaged with SiN_3 tip



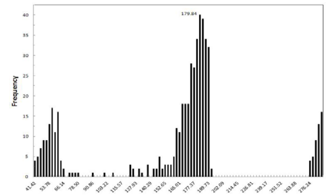




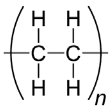
(1) 500 force curves are obtained in 3 separate static locations.
(2) 500 force curves are obtained in roaming area (25 µm^2 traveling at 1 µm/s).

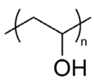
Force curves deemed unusable are discarded from data set, leaving 1000 to 2000 curves.

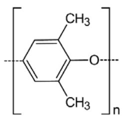
Metric for Matrix Pickup: AFM (snap-off)



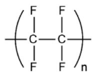
Force histogram of KClO3 v. Tenax.

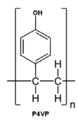

Polyethylene (PE)

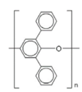

Polyvinyl alcohol (PVA)

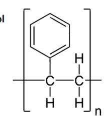

Polydimethylphenylene oxide
PMPO (PPO)

nN	TNT	PETN	RDX	HMX	KClO3
Teflon	17	N/A	N/A	61	19
PE	51	169	196	226	74
P4VP	54	133	203	188	109
PVA	256	132	270	335	179
PS	256	N/A	379	281	67
PMPO	329	160	332	256	105
Tenax	342	175	210	357	180


Teflon


P4VP
Poly 4-vinyl phenol


Tenax (PPPO)


Polystyrene (PS)

Better Pickup and Release

Conducting Polymers

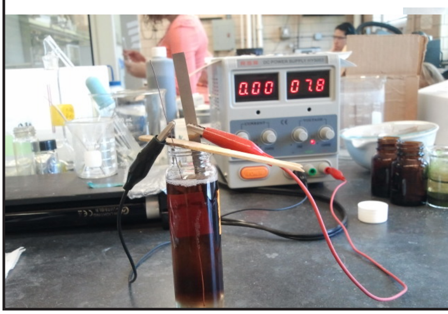
Attract (or repel) explosives with electrostatics

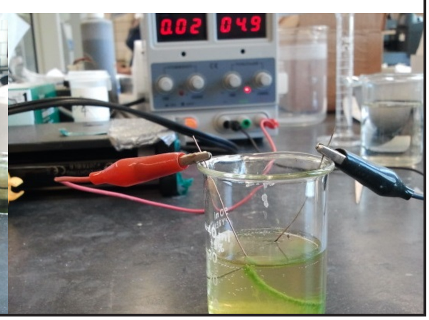
Switchable state (conducting/non-conducting) may allow easy release of explosive

NMR titration studies demonstrated aromatic compounds have affinity for TNT

Aromatics are common in conducting polymers

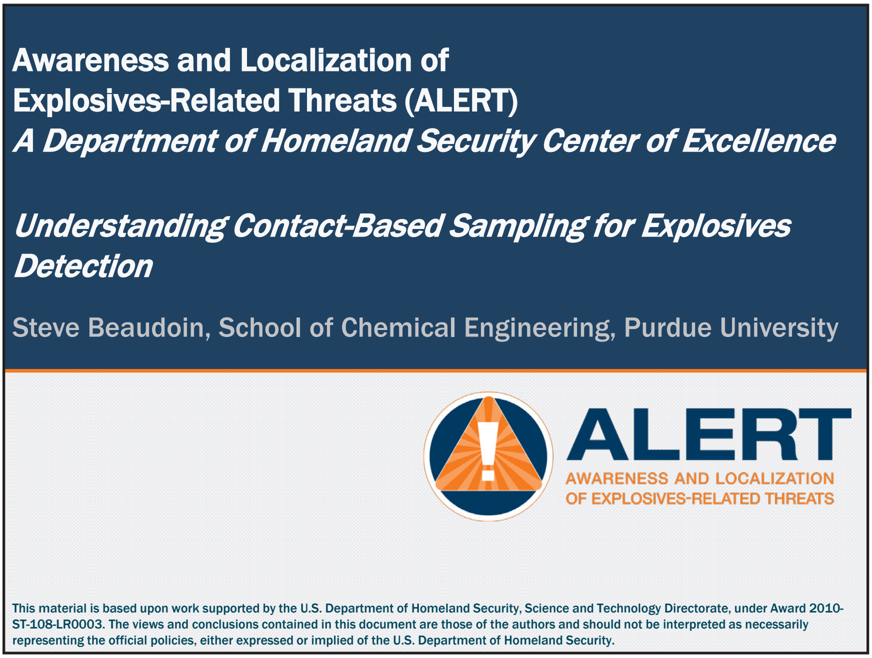
May allow for high sorption combined with high release efficiency

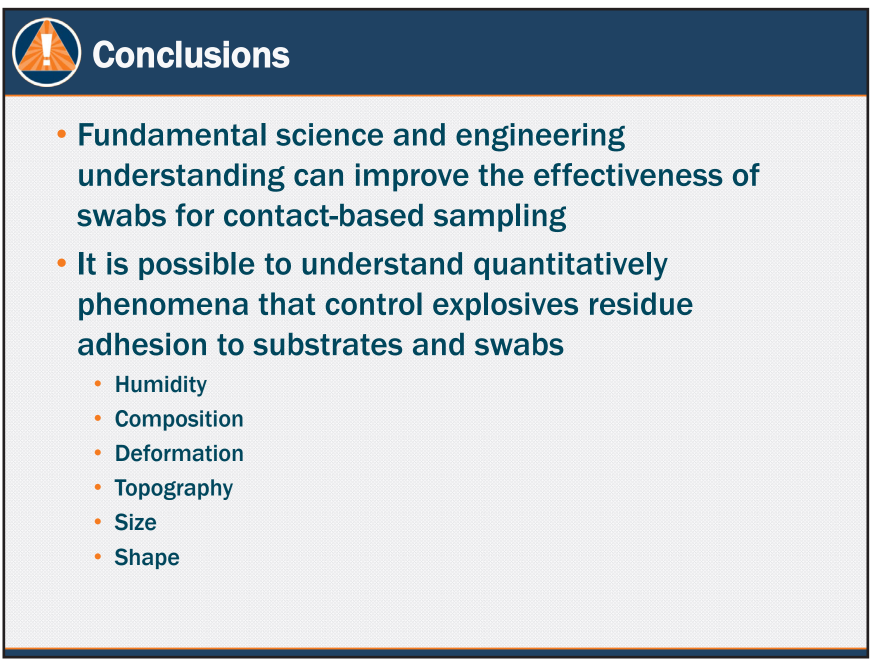





UNIVERSITY OF
Rhode Island

17.13 Stephen Beaudoin: An Engineering Basis for Improved Swab Technology



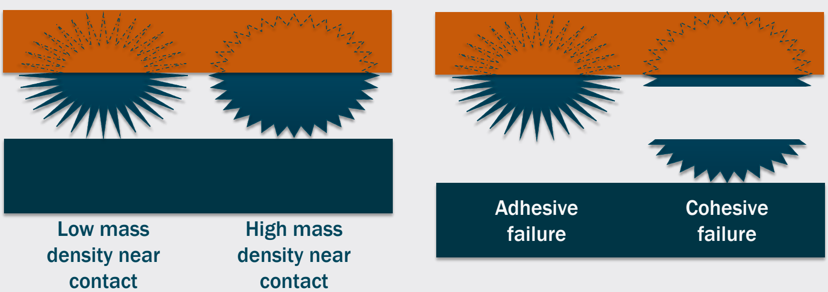


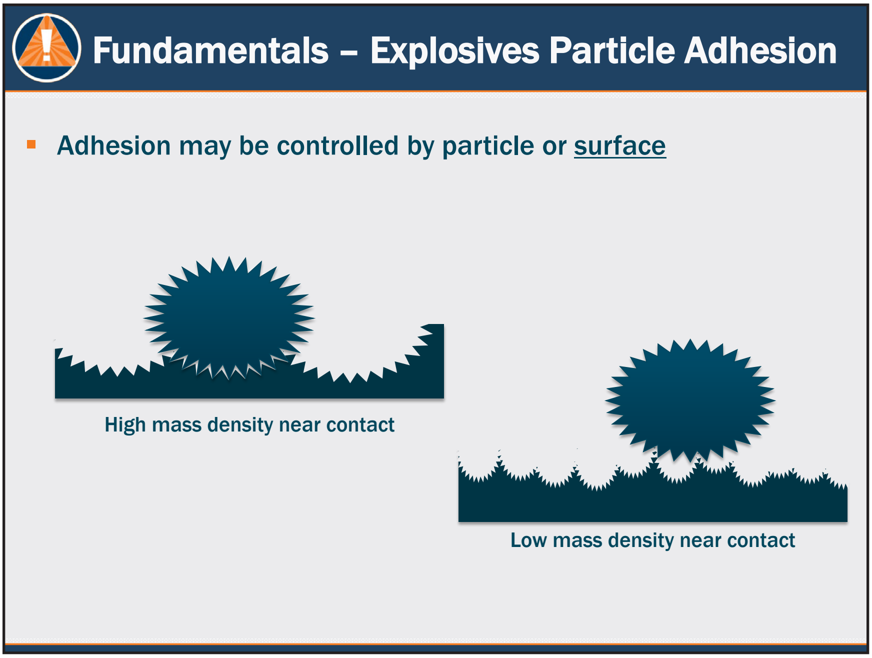
Research Goals

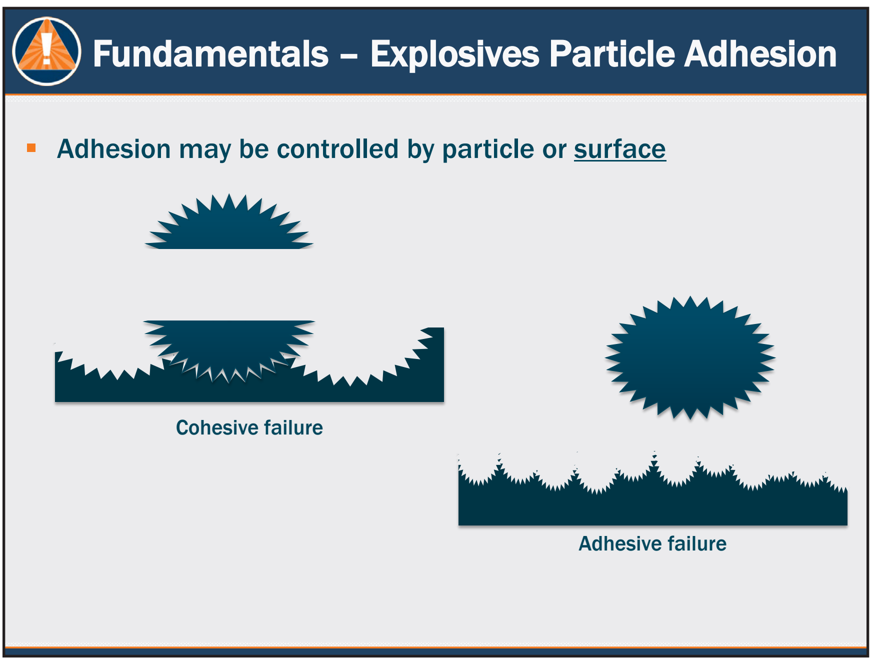
- Understand adhesion between explosives residues and swabs or substrates
- Use understanding to help guide development of improved swabbing methods/materials
- Parameters considered
  - Residue composition
    - Composites, pure explosives
  - Substrate composition
    - 6 representative surfaces provided by DHS
  - Swab composition
    - 4 common swab types provided by DHS
  - Ambient conditions
    - Primarily relative humidity (RH)

Fundamentals – Explosives Particle Adhesion

- Mass density within ~25 nm of point of contact controls adhesion
  - Higher mass density = higher adhesion
- Adhesion may be controlled by particle or surface

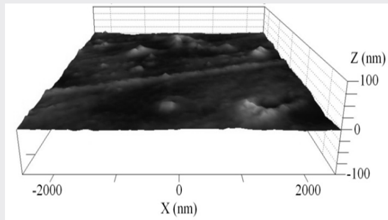



Fundamentals – Explosives Particle Adhesion
Adhesion may be controlled by particle or surface
High mass density near contact
Low mass density near contact

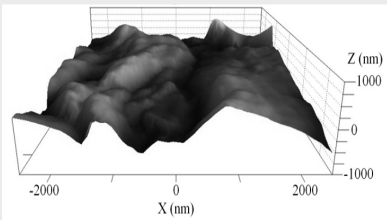

Fundamentals – Explosives Particle Adhesion
Adhesion may be controlled by particle or surface
Cohesive failure
Adhesive failure

Adhesion between Explosives and Aluminum

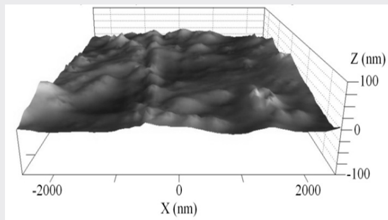
1. Micron-scale particles of PETN, RDX, and TNT mounted on AFM cantilevers
2. AFM used to measure adhesion against aluminum coated with clear-coat (acrylic melamine), white–coat (polyester acrylic melamine), and military coating



Clear-coated aluminum

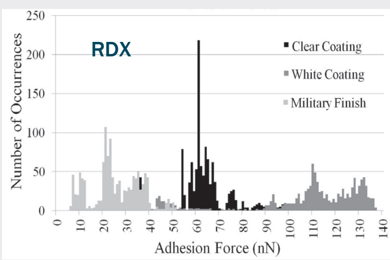


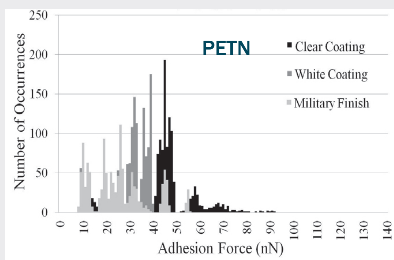
Military coating

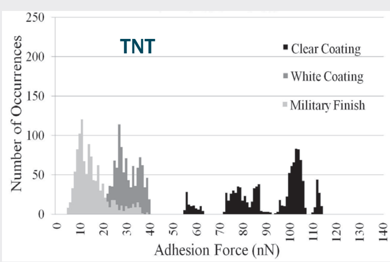


White paint with clear-coated aluminum

Adhesion between Explosives and Aluminum



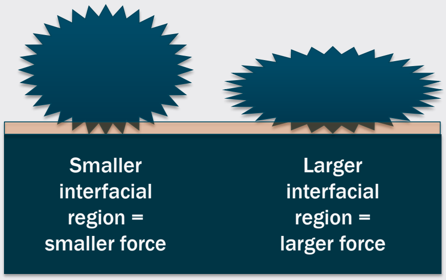




	Force (nN)		
	RDX	PETN	TNT
Clear Coating	63 ± 11	47 ± 12	91 ± 15
White Coating	110 ± 24	32 ± 8	31 ± 5
Military Finish	26 ± 10	26 ± 12	16 ± 7

Adhesion Influenced by Particle Size

- For a given mass density at interface, increasing the interface size increases the adhesion force



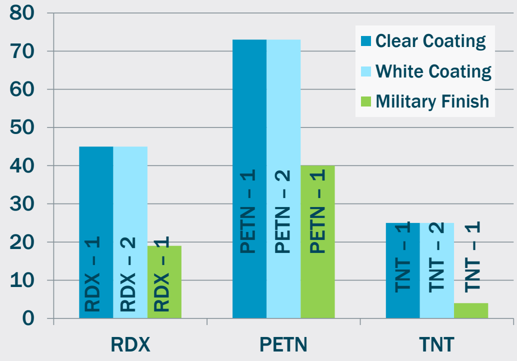
- We eliminate effect of particle size (i.e., to see the intrinsic adhesion force)
  - Evaluate force/(particle radius) for spheroids

Normalized Adhesion Forces

- Explosives particles modeled as 'effective spheroids' with measured roughness on surface

Surface	Particle	Radius of Curvature of 'Effective' Spheroid (µm)
Clear coated Al	RDX – 1	1.4
	PETN – 1	0.6
	TNT – 1	3.6
White-coated Al	RDX – 2	2.5
	PETN – 2	0.4
	TNT – 2	1.3
Military	RDX – 1	1.4
	PETN – 1	0.6
	TNT – 1	3.6

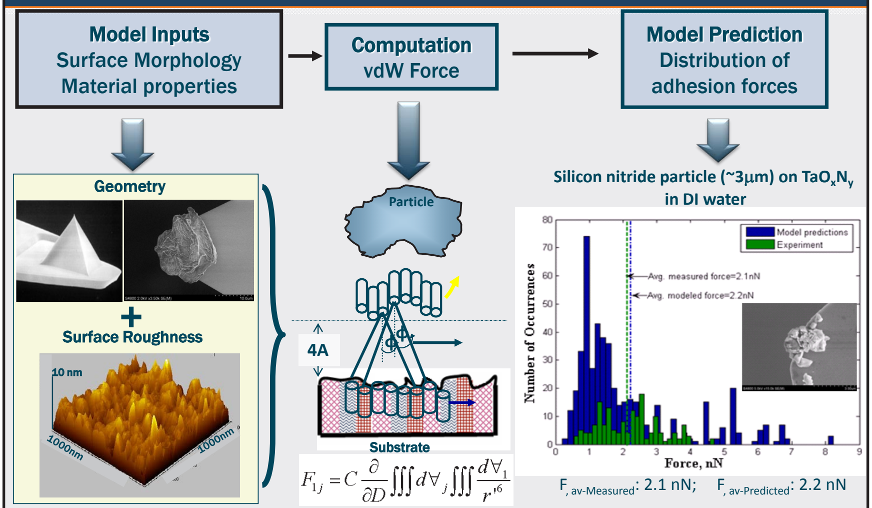
Normalized Adhesion Forces



Particle	R.O.C. Ratio (ROC 1)/(ROC 2)	Length Scale
RDX	0.6	0.5 to 3.5 μm
PETN	1.5	
TNT	2.8	

- Clear-coat and White-coat
  - Characteristics of particle surface control the interaction
  - Particles very rough on nano-scale
- Military finish
  - Topography (micron-scale) of the military finish controls the interaction

Describing Roughness Effects



- Measured forces in range of model prediction in nearly all cases

Describing Roughness Effects

- Classical models for van der Waals forces between a cylinder and a plate

$$F_{vdW} = -\frac{A_{132}R^2}{6D^3}$$

  - A_{132} = Hamaker constant (fcn of composition of materials and medium)
  - R = cylinder radius
  - D = cylinder-plate separation distance
- In Beaudoin model, when roughness added to equivalent spheroids, Hamaker constant is adjusted to predict distributions

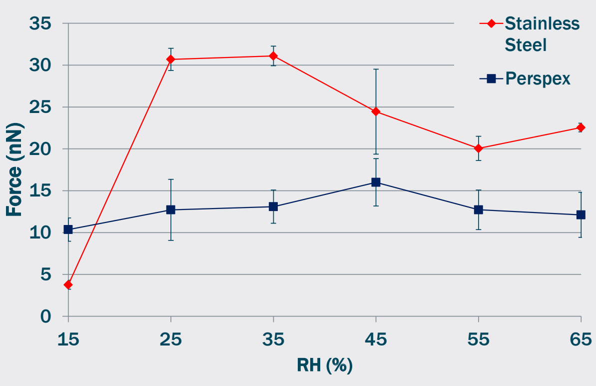
	A_c^{eff}x10^{21} (J)		
	RDX	PETN	TNT
Clear Coating	400	300	225
White Coating	425	300	225
Military Finish	800	800	450

Clear and white coatings have similar composition effects

When present, military finish topography dominates interactions

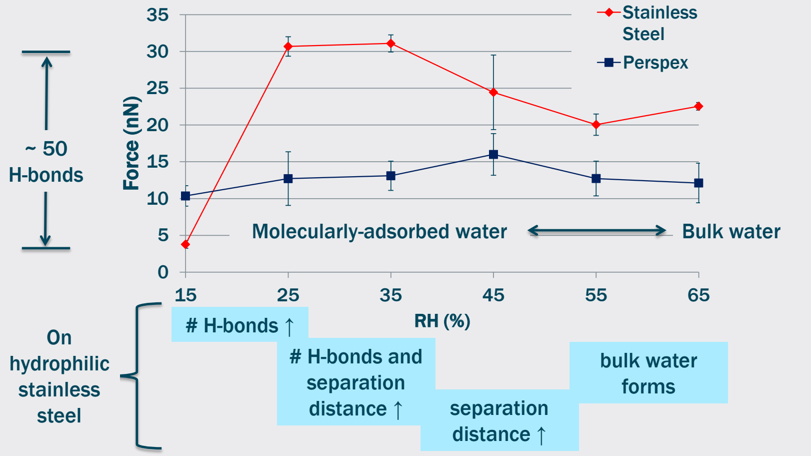
Effect of Humidity on Adhesion

Measured adhesion between silicon nitride cantilever and surfaces



Effect of Humidity on Adhesion

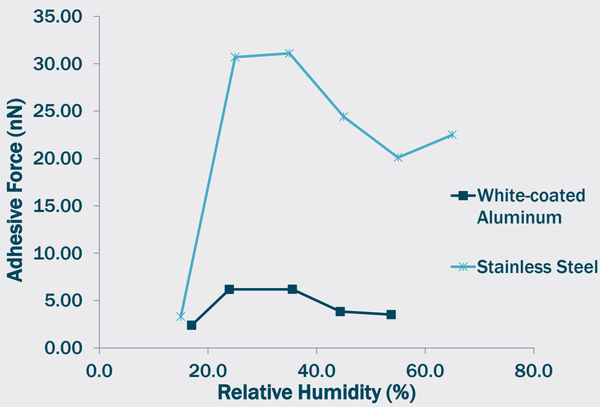
- At most RH levels, ‘bulk’ water on a surface does not exist
- Water at lower RH (< 50 - 55%) levels is molecularly-adsorbed, sub-continuum
  - No surface tension, but does support H-bonding



Effect of Humidity on Adhesion

- Metal, hydrophilic surfaces show adhesivity increase as RH rises below 35%
  - Due to adsorbed molecular water
- Show a decrease from ~35 - ~55%
  - Due to water forming a barrier to close contact
- Adhesion increases again as RH rises above 55%
  - Due to bulk water drops on surface

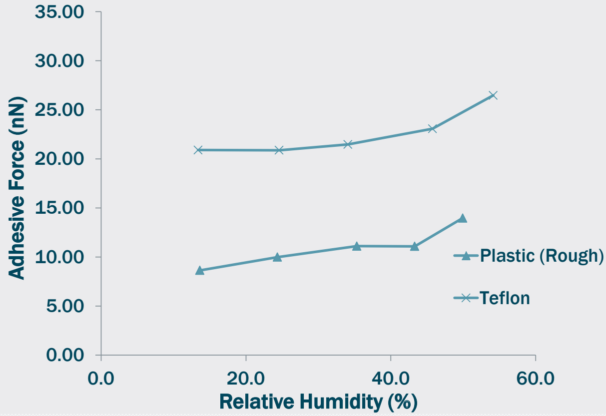
For hydrophilic surfaces, one would expect significant changes in adhesion when RH changes at low levels



Effect of Humidity on Adhesion

- Hydrophobic surfaces show minor changes in adhesivity RH < ~50%
  - Due to minimal tendency to adsorb molecular water
- Show larger increases above 55%
  - Due to bulk water drops on surface

For hydrophobic surfaces, one would expect insignificant changes in adhesion when RH changes at low levels



Ongoing Work

- Extend current studies to describe composite explosive materials
  - C4, SEMTEX, ANFO
  - Deformation during residue removal key to overall process
- Develop improved swab materials based on mechanical properties of swabs and residues

Acknowledgements

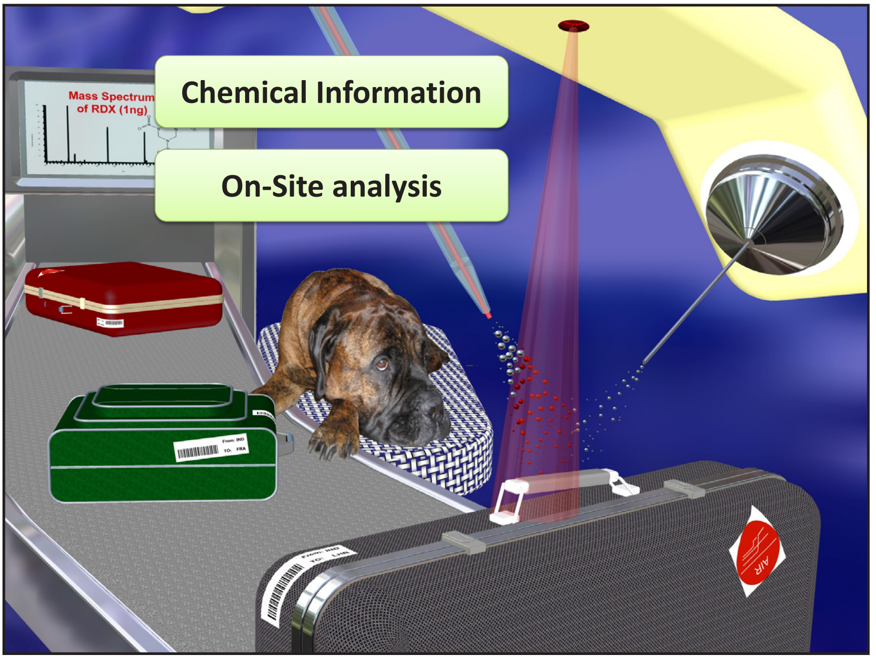
- U.S. Department of Homeland Security, Science and Technology Directorate sponsored this work under agreement 2010-ST-108-LR0003

17.14 Ryan Espy: Trace in Situ Explosives Analysis Using a Miniature Mass Spectrometer

Ambient Ionization & Miniature Mass Spectrometers for Trace Analysis of Explosives

Graham Cooks,
Chemistry Dept., Purdue University
cooks@purdue.edu

Presented by Ryan D. Espy



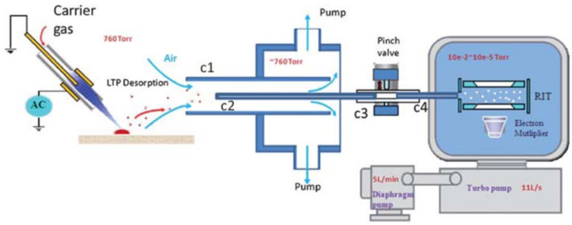
In-situ Analysis of Complex Materials

Ambient Ionization

1. No sample preparation
2. Ionization in open air
3. Rapid *in-situ* analysis

Miniature Mass Spectrometer

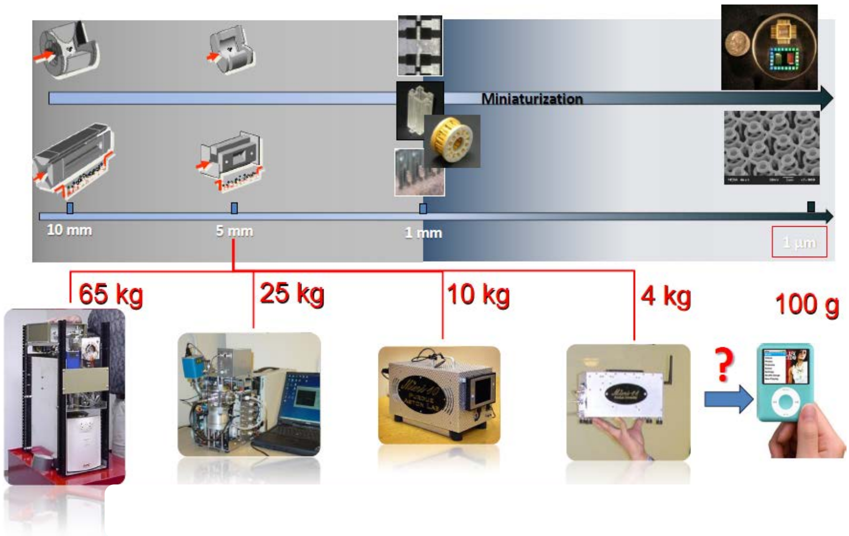
1. Mini fitted with ambient ionization
2. MS/MS capabilities
3. Small & large molecules



Miniaturization Mass Spectrometers

System	Self-sustainable Portable Systems						Portable Systems without rough pumping	
	Mini 10/11/12	ChemCube™ /ChemPack	Suitcase TOF	Griffin™ 824	Guardion-7™	IonCam™	Palm-portable MS	HAPSITE®
Developer	Purdue University	Microsaic Systems	Johns Hopkins Applied Physics Lab	Griffin Analytical Technologies , Inc.	Torion Technologies	OI Analytical	Samyang Chemical Co.	Inficon
Weight	10kg/4kg/15kg	9kg/14.9kg	N/A	22.7kg	11kg	19kg	1..5kg	18kg
Power	70W/30W/65W	45W	N/A	N/A	75W	150W	5W	<150W
Mass Analyzer	Rectilinear ion trap	Quadrupole mass filter	TOF	Cylindrical ion trap	Toroidal ion trap	Mattauch-Herzog sector	Cylindrical ion trap	Quadrupole mass filter
MS/MS	Yes	No	No	Yes	Yes	No	No	No
Sampling /Ionization	MIMS, direct leak, GDEI, APCI, ESI, DESI, LTP, PS, LS	SPME, EI	MALDI	SPME, MIMS, EI	SPME, mini GCEI	Direct gas leak EI, mini GCEI	Pulsed gas leak EI	GCEI
Mass range /Resolution	*m/z* 700, R = 700; *m/z* 1500, R = 750	*m/z* 600, R = 400; *m/z* 400, R = 200	*m/z* 70,000, R = 70	*m/z* 425, R = 400	*m/z* 500, R = 500	*m/z* 300, R = 300	*m/z* 300, R = 150	*m/z* 300, R = 300
System Photo								

Miniaturization of Ion Trap Mass Spectrometers



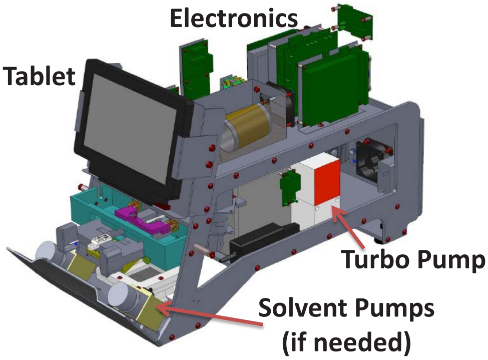
Tandem Mass Spectrometry

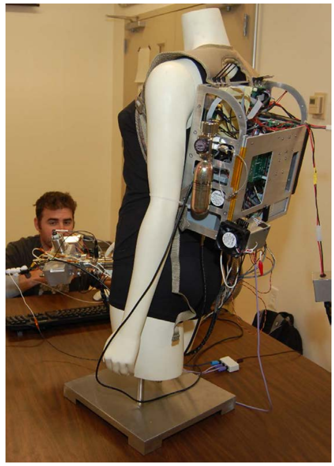
Structural information for enhanced selectivity = reducing false positives

MS1	Full m/z screen	Anything worth looking at?
MS2	Isolate, fragment specific m/z	Molecular confirmation
MS3	Isolate and fragment the fragment	Are you really, really sure?

1 to 2 Seconds

Instrumentation: Mini/Portable MS for in-situ analysis





Multiple instrument configurations

-Wearable backpack w/ sampling head unit

11.3 kg (25 lbs)

-Desktop portable

15 kg (33 lbs)

Power consumption

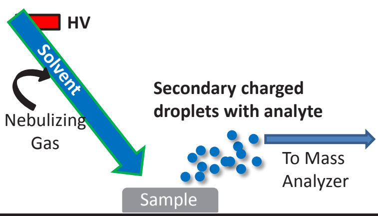
-65 W average; 144 W peak

-1.5 hrs on battery power

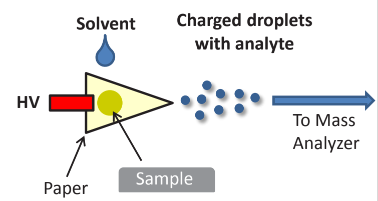
Four Ambient Ionization Methods

Ambient Ionization: Ionization of sample in its native state with transfer of ions not whole sample into MS

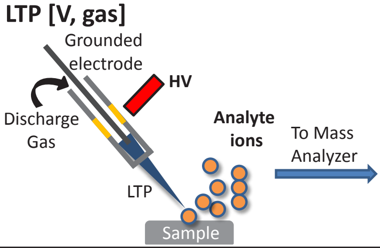
DESI [V, pneumatic, solvent]



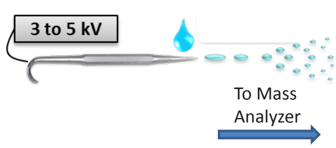
PAPER SPRAY [V, solvent]



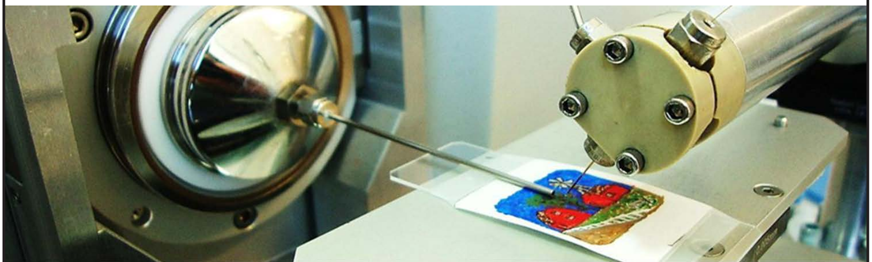
LTP [V, gas]

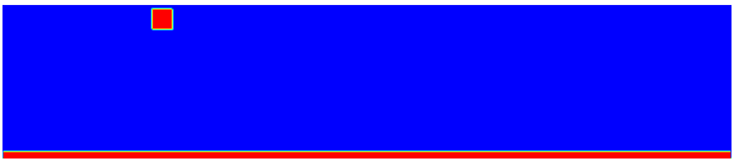


Touch SPRAY [V, solvent]

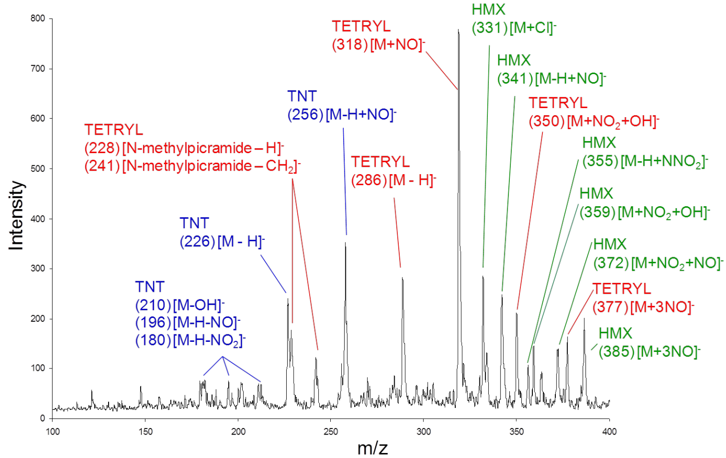


Desorption Electrospray Ionization





Explosives mixture analysis: DESI

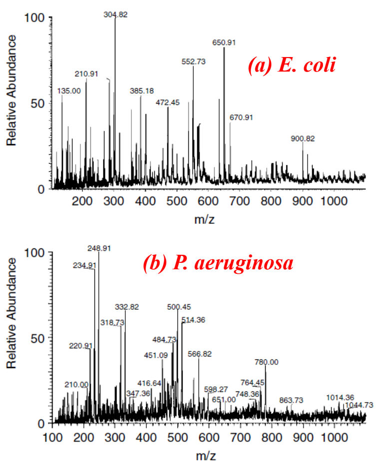


Mini 10 (10 scan average; 1 μg total amount, on 1cm^2 area)

Nathan Sanders, Sameer Kothari, and Gary Salazar

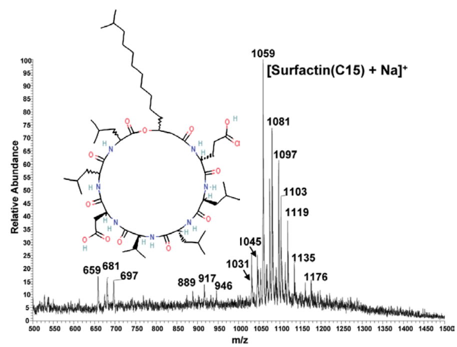
Real-Time Microorganism Analysis by DESI

DESI-MS of freshly harvested cells dried on PTFE



J. Mass Spectrom. 2005, 40, 1261-1275

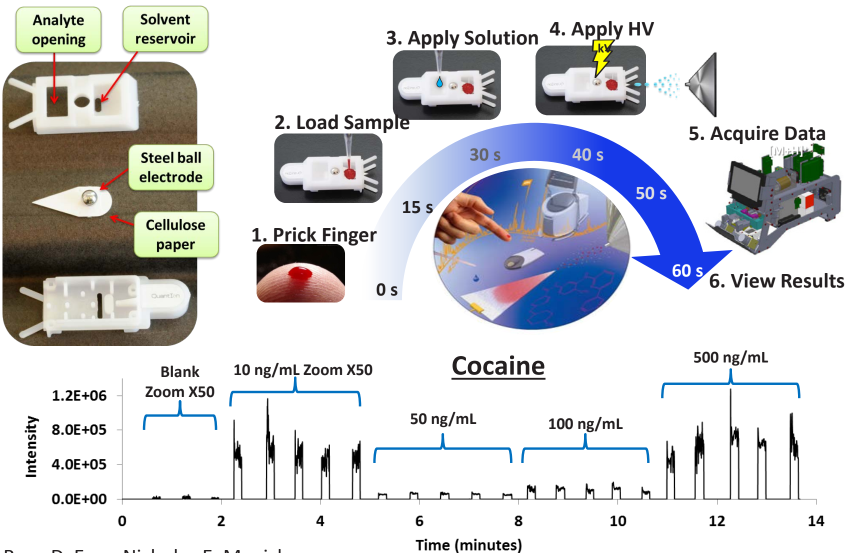
In vivo recognition of *Bacillus subtilis* by DESI-MS



Bacillus subtilis as a biofilm growing on agar nutrient: simple, high quality mass spectra dominated in both the positive and negative ion modes by signals due to the cyclic lipopeptide, Surfactin.

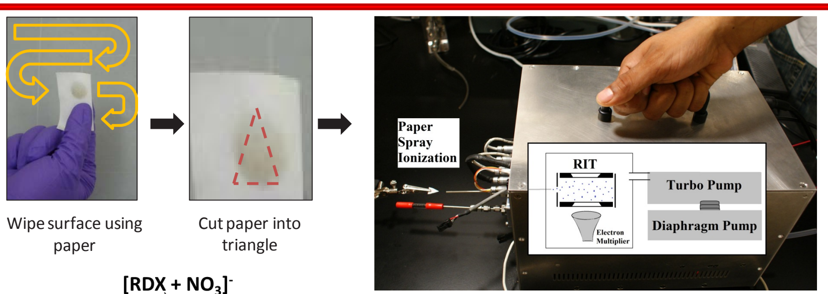
Analyst. 2009, 134, 838-841

Paper Spray: Immediate Point-of-Care Analysis



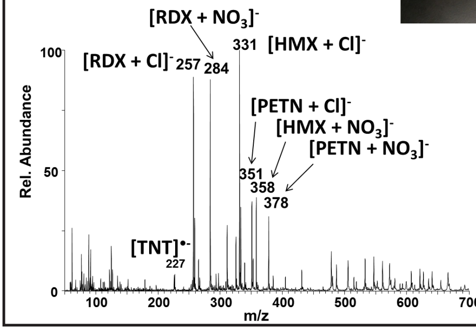
Ryan D. Espy, Nicholas E. Manicke

Paper Spray Surface Wiping



Wipe surface using paper

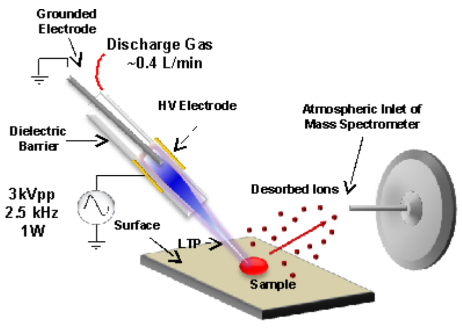
Cut paper into triangle



Paper Spray Mass Spectrometry of 50 ng each RDX, TNT, HMX, and PETN on Whatman filter paper with MeOH as a spray solvent at -5.0 kV.

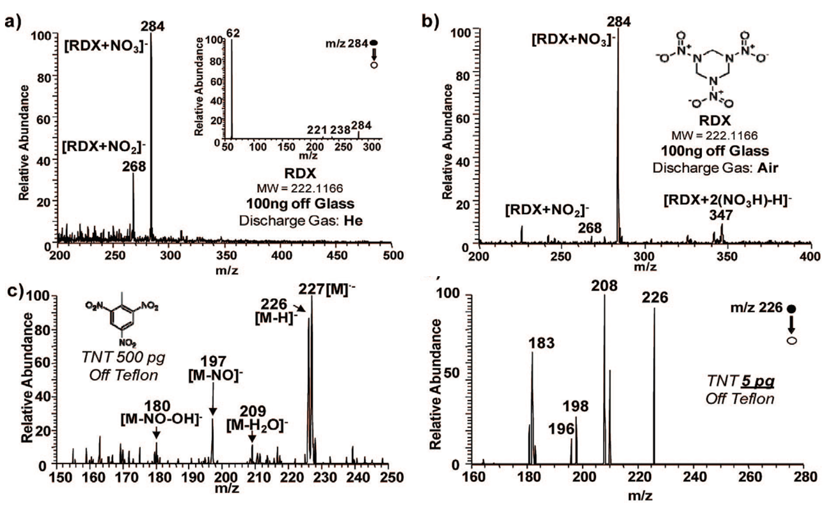
Ryan D. Espy

LTP Handheld Unit



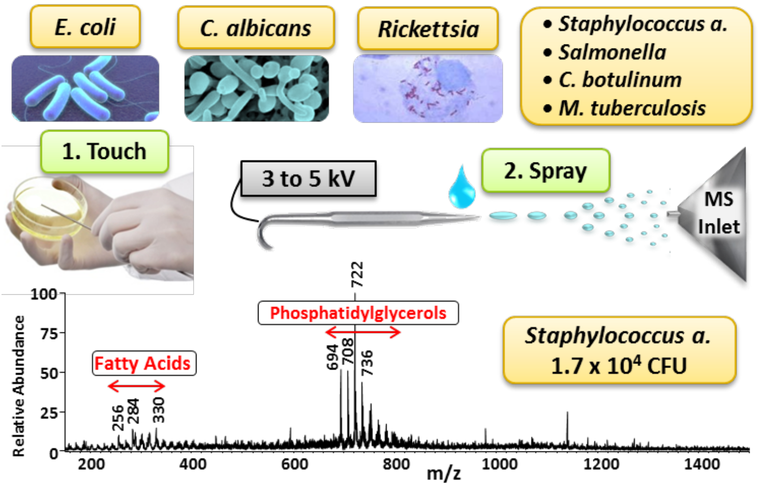
JS Wiley, JT Shelley, RG Cooks, *Anal. Chem.* **2013**, 85, 6545–6552

LTP Analysis of Explosives



JD Harper et al., *Anal. Chem.* **2008**, 80, 9097–9104

Touch Spray of Biologicals



Ahmed Hamid, Alan K. Jarmusch, Kevin Kerian

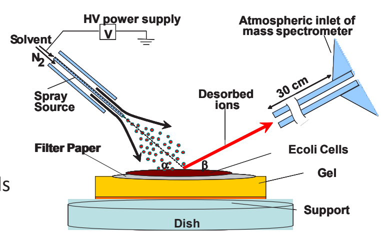
17

Summary

Instrumentation

- Miniature/portable mass spectrometers
  - Backpack MS
  - Portable benchtop MS
- Ambient Ionization
  - Desorption Electrospray Ionization (DESI)
  - Low Temperature Plasma (LTP)
  - Paper Spray (PS)
  - Touch Spray (TS)

✓ No sample preparation
✓ Ionization in open air
✓ Rapid in-situ analysis



Applications

- In-situ, on-site analysis
  - Explosives
  - Microorganisms
  - Drugs in blood, urine, & other biofluids
  - Fingerprints
  - Cloth, skin, tissue, all surfaces!
- All varieties of molecules (small vs. large, polar vs. nonpolar)
- **Mini's not commercially available, but 20 are out for testing**

17.15 Jerry Schmitt: An IMS with a Resolution of 1,000 and Parts Per Trillion Sensitivity for Ambient Vapors

NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...

Yale University

SEADM

An IMS with a resolution of 1,000
and parts per trillion sensitivity for ambient vapors

Jerome J. Schmitt, NanoEngineering Corp.
Juan Fernandez de la Mora, Yale University
Gonzalo Fernandez de la Mora, SEADM S.L.

Workshop Presentation
New Methods for Explosive Detection for Aviation Security
Northeastern University, Boston MA - October 22, 2013

DHS Center of Excellence for Awareness and Localization of Explosives-Related Threats (ALERT)

NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...

Conclusion

Tandem DMA - CCD

The DMA^2–CCD System Concept offers potential capabilities necessary to address 21st Century Aviation Security Challenges

1. **General Purpose – *ion mobility measurement***
2. **High Resolution (≥ 1000) – *500 analytes***
3. **High Sensitivity (≤ parts-per-trillion) – *plastic explosives***
4. **High Sample Flow Rate (>10 L/min) – *direct vapor sampling***
5. **Low Cost – *No High Vacuum***
6. **Related applications in Chem-Bio Threat Detection**

Mass Spec Performance – IMS Cost – Sniffer Dog Aspiration

Slide 2

NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...

Outline

**An IMS with a resolution of 1,000
and parts per trillion sensitivity for ambient vapor**

1. Detection of Airborne Trace Volatiles
2. DMA-DMA-CCD Technology for Ambient Vapor Detection
3. Development Plans / Related Applications
4. Commercialization, Collaboration and Sponsorship
5. Conclusions and Acknowledgements

Slide 3

NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...

Airborne Vapor Sensors

Definition:

Point Sensors detect with rapid response the presence of threat in immediate vicinity usually by sampling and detecting volatile vapors of explosives and chemical weapons

Key Examples:

1. Canine Olfaction (Sniffer Dogs)
2. Mass Spectrometers
3. Ion Mobility Spectrometers

Slide 4

NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...

Airborne Vapor Sensors

Performance Criteria –Threat Sensors

1. General Purpose – Detects all threat analytes
   - 500-analyte capability desired by DHS
2. Power of Discrimination – Resolution
   - Distinguish threat "A" from interferant "B"
   - Affects occurrence of false positives
3. Limits of Detection – Sensitivity
   - Threshold analyte concentration needed to trip sensor
   - Affects occurrence of false negatives
4. Response Time – Sound alarm
   - ~ 2 Seconds in aviation security
   - Affects passenger throughput
5. Low Costs – Capital and Operating

Slide 5

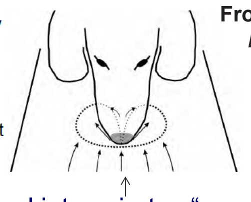
NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...

Sniffer Dogs

"About 2,000 of these working [sniffer] dogs confront danger alongside U.S. soldiers, largely in the Middle East. **Able to detect scents up to a third of a mile away**, **many sniff for explosives in Iraq**." [emphasis added]

Washington Post, August 12, 2007

- Inhaled air enters the upper airway (*dorsal meatus)* of the dog's nose
- Exhaled air is vectored down and sideways by the midlateral slit
- The dog's nostril is thus a variable-geometry inlet and exhaust flow diverter



From: "*Airborne Trace Sampling: Lessons from the Dog's Nose"*
Prof Gary Settles
Penn State University
TED Workshop 2010

Unidirectional jet aspirates "smells" into nose

Flow rate: Q ~ 10 – 100 L/min

Slide 6

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Mass Spectrometers

Pro: "Gold Standard" for general analytical chemistry

- High mass resolution (2000 – 10,000)
- High sensitivity (~ parts-per-quadrillion)

Con: High vacuum inherently limits practicality in airports

- High-vac. pumps are complex, costly, fragile, maintenance-intensive
- Low sample flow rates (< 1 L/ min)
  - higher air flow must be balanced with much bigger pumps

Slide 7

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Ion Mobility Spectrometer

Pro: "Practical" - in use in airports

- General Purpose
- Lower costs – capital and operating
  - *no high vacuum*
- Rapid Response (seconds)
- Good sensitivity (parts-per-billion)

Con: Inadequate for Emerging Threats

- Low Mobility Resolution – Cannot distinguish 500-analytes
- Low Flow Rate (≤ 0.1 L/min)
- Sensitivity - Inadequate for Direct Airborne Vapor Sampling
  - *swabbing required*

Data Points

RDX – room temp vapor pressure: < 10 parts-per trillion
Sarin – deadly at parts-per-billion concentration
HMEs –precursors ; interferants

Slide 8

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Differential Mobility Analyzer

Tandem DMA²-CCD Sensor – System Concept

Pro: Potential to Address All 21st Century Threats

- General Purpose – measures mobility
- *Promises* lower costs – *no high vacuum*
- High Mobility Resolution (≥ 1000) – 500 analytes
- Rapid Response (seconds)
- Ultra-sensitive (≤ parts-per-trillion)
- High sample flow rates (>10 L/min)
- Direct airborne vapor sampling (?) – *no swabbing*

Con: Embryonic - Developmental

- Needs development, testing and field trials
- Based on existing science demonstrated at Yale, SEADM
- Relies on proven components from SEADM, NEC and suppliers

Mass Spec performance - IMS cost – Sniffer -Dog aspiration

Slide 9

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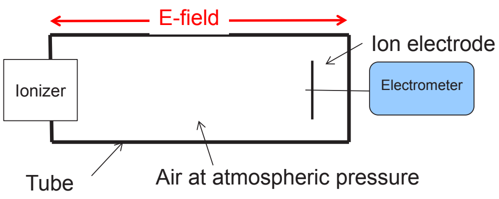
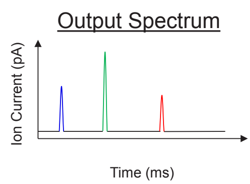
Conventional IMS

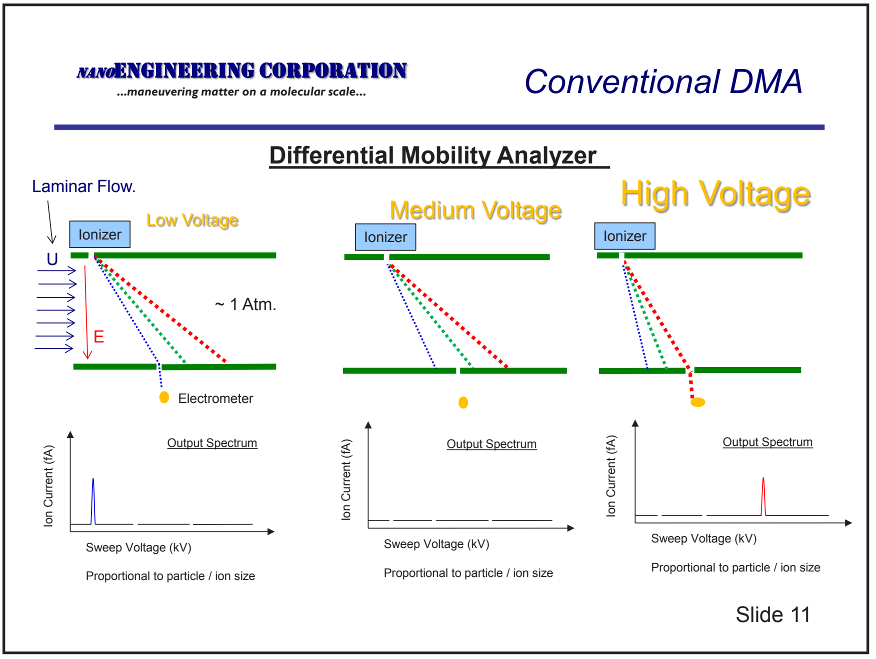
Drift-tube IMS : Time-of-Flight Measurement

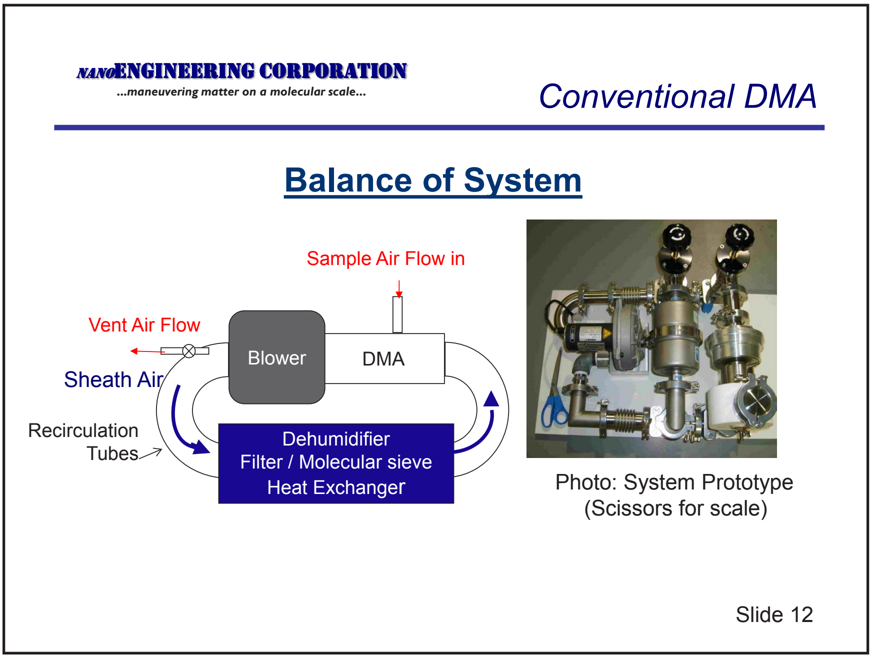




Drift time:	~20 ms
Duty cycle:	~1% - major limitation!
Detection Limits:	parts-per-billion!
Output Spectra:	Ion current (I) vs. elapsed time-of-flight (t)

Slide 10


NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...
Conventional DMA
Differential Mobility Analyzer
Laminar Flow.
Low Voltage
Medium Voltage
High Voltage
Ionizer
Ionizer
Ionizer
U
E
~ 1 Atm.
Electrometer
Output Spectrum
Output Spectrum
Output Spectrum
Ion Current (fA)
Ion Current (fA)
Ion Current (fA)
Sweep Voltage (kV)
Sweep Voltage (kV)
Sweep Voltage (kV)
Proportional to particle / ion size
Proportional to particle / ion size
Proportional to particle / ion size
Slide 11


NANOENGINEERING CORPORATION
...maneuvering matter on a molecular scale...
Conventional DMA
Balance of System
Sample Air Flow in
Vent Air Flow
Sheath Air
Blower
DMA
Recirculation
Tubes
Dehumidifier
Filter / Molecular sieve
Heat Exchanger
Photo: System Prototype
(Scissors for scale)
Slide 12

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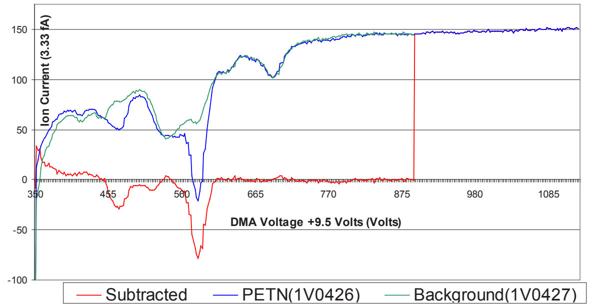
Plastic Explosive

Detection of PETN at Room Temperature



PETN Vapor Pressure* = 18 ppt @ 25 C

*B.C. Dionne, D.P. Rounbehler, E.K. Achter, J.R. Hobbs and D.H. Fine, *Vapor Pressure of Explosives* J. of Energetic Materials 4 447-472 (1986)

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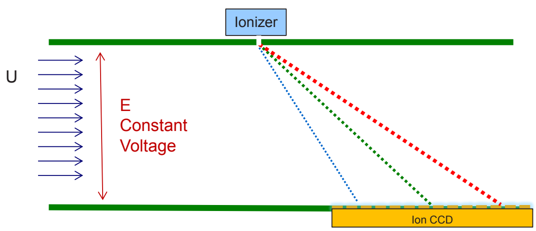
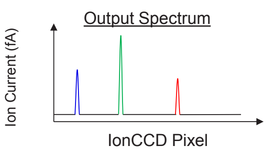
DMA + CCD



100% Duty Cycle



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Planar DMA

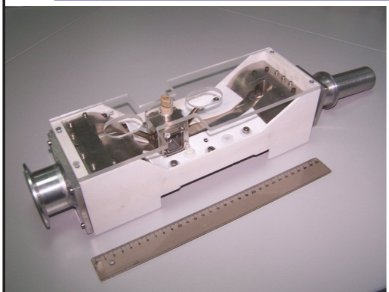
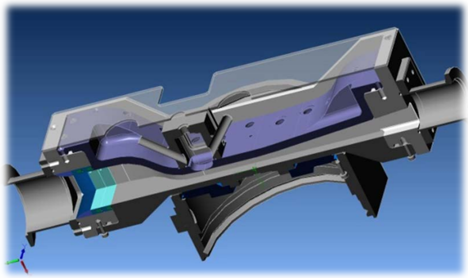


Photo: High Resolution DMA – Yale Univ.
12-inch ruler for scale



CAD drawing shows internal flow-channels

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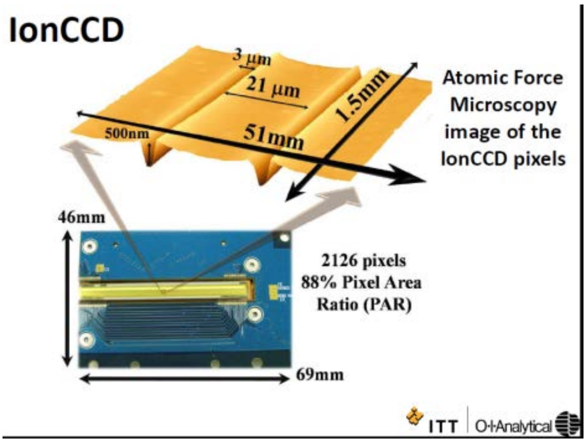
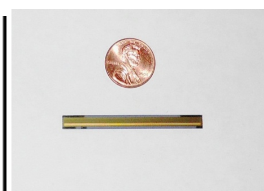
Ion CCD Detector





- < 1000 charges per pixel to detect with S/N of 3 (1 sec. integration)
- Dynamic range: 10^7

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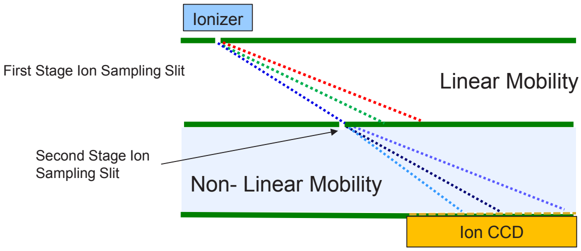
DMA^2 + CCD

Tandem DMA – DMA : Cascade



Anticipated Performance
- resolution ≥ 1000
- sensitivity ≤ parts per trillion

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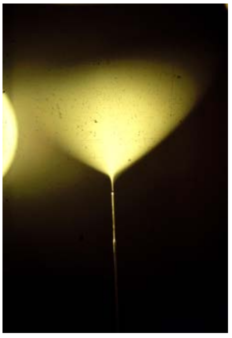
Ionizer

Secondary Electro-Spray Ionization (SESI)

Glass Capillary Tip
In-situ micrograph
OD=360 μm: ID=40μm



Dense Droplet Mist
From Taylor Cone
Back-lit Photograph

Slide 18

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R & D

Development Plans

DMA is a Platform Technology

1. ***Explosives***
2. ***Chemical Agents***
3. ***Biological Threats (No reagents)***

Slide 19

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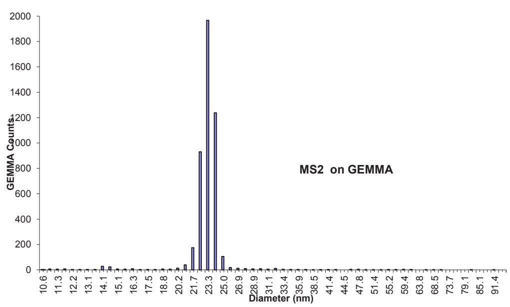
Rapid Virus Screening

ES-DMA for virus detection

Cooperative R&D with US Army Edgewood Chem-Bio Ctr.



* *Frost & Sullivan report predicts high growth in $billion / yr markets for "molecular diagnostics" targeting these viruses.*

Table 1: Human Viruses

Virus Name	Size (nm)
polio	23
rhinovirus	30
norovirus	35
hepatitis	38
encephalitis	42
dengue	45
west Nile	53
papilloma	55
rotavirus	75
hantavirus	80
rubella	85
Epstein-Barr	101
adenovirus	100
influenza	120
SARS coronvirus	130
respiratory syncytial	151
HIV	182
herpes	200
smallpox	220
And more...	

Slide 20

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Commercialization

NEC is an SBIR Company

NEC has secured key patents and patent rights w/ SEADM

NEC, Yale and SEADM have developed 30-page proprietary white-paper detailing our technology development plans

Barrier to commercialization: Lack of R&D and Exploratory Engineering Support.

We welcome:

- **Sponsorship**
- **Collaboration**
- **Development partners**
- **Commercialization partners**
- **Potential customers**
- **Investors**

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Conclusion

Tandem DMA - CCD

The DMA^2–CCD System Concept offers potential capabilities necessary to address 21st Century Aviation Security Challenges

1. **General Purpose – *ion mobility measurement***
2. **High Resolution (≥ 1000) – *500 analytes***
3. **High Sensitivity (≤ parts-per-trillion) – *plastic explosives***
4. **High Sample Flow Rate (>10 L/min) – *direct vapor sampling***
5. **Low Cost – *No High Vacuum***
6. **Related applications in Chem-Bio Threat Detection**

Mass Spec Performance – IMS Cost – Sniffer Dog Aspiration

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Conclusion

Tandem DMA – CCD Concept

- Based on solid science
- Relies on proven components
- Candidate for rapid development
- Suited for widespread deployment

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Acknowledgements

This work was sponsored in part by a US Army SBIR Grant
(Aaron LaPointe, NVL Ft. Belvoir VA)

Omar Hadjar, Ph.D. and Gottfried I, Ph.D. of ITT O-I Analytical provided useful discussions and data on the IonCCD performance

Slide 24

17.16 Juan Fernandez de la Mora: Detection of Ambient Explosive Vapors at Concentrations Below Parts Per Quadrillion

SEDET

Detection of ambient explosive vapors at concentrations below parts per quadrillion

G. Fernández de la Mora,[a,*] M. Amo,[a] G. Vidal,[a] A. Casado, D. Zamora,[a] J. Fernández de la Mora[b]

[a] *SEDET, Boecillo, Spain,*
[*] gfdelamora@SEADM.com

[b] *Yale University, New Haven, Connecticut*

1

SEDET

CONCLUSIONS on ACES

- **Product**: Air Cargo Explosives Screener (ACES), able to screen explosives while cargo is in "bulk" form, in particular complete trucks at the airport entrance,
- **Technology**: Explosives Vapour Detection (EVD) based on the integration of Differential Thermal Desorbtion (DTD), Secondary Electro Spray Ionization (SESI), Differential Mobility Analysis (DMA), and API Tandem Mass Spectrometry (API MS/MS),
- **Advantages**: ACES accomplishes two simultaneous goals: **increase security** through a higher PoD than current technologies, and **reduce screening costs and delays** to values well below present operations,
- **Development stage**: Equipment in the certification process in EU Nations,
- **Present performance**: Minimum RDX detectable alarm: 0.03 ppq (parts per quadrillion), equal to $3 \cdot 10^{-17}$ atm,
- **Company**: SEADM, Morpho and CARTIF created in 2008 a Joint venture (SEDET), aimed at development of explosive detection equipments.

2

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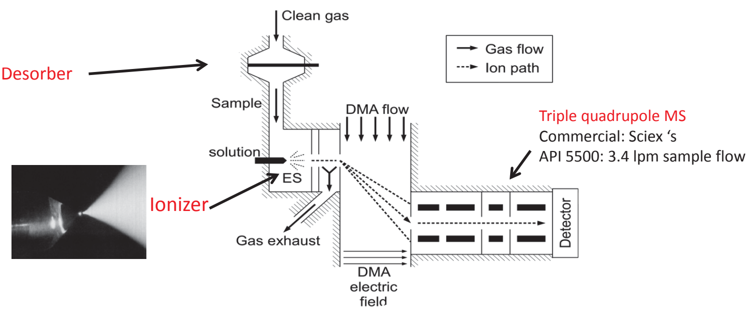
Phenomenology being exploited for explosive detection

- Direct ambient vapor detection (Sniffing) via sampling, desorbing, ionizing ambient vapor, analyzing via ion Mobility and triple quad mass filters in series
- Focusing on Air Cargo Explosives Screener (ACES), ***sniffing*** the cargo bay by sampling ~1 m^3 of cargo air into a filter, and desorbing the filter into a suitable MS detector



3

3

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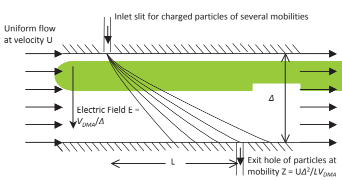
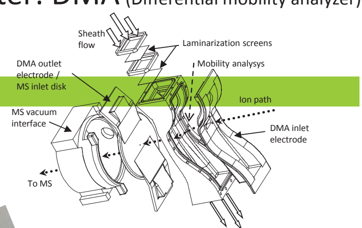
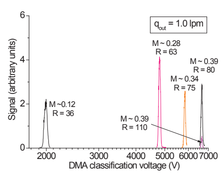
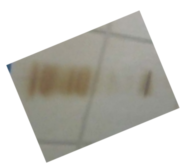
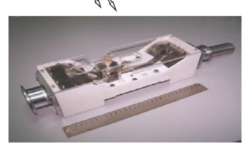
Mobility filter: DMA (Differential mobility analyzer)











•One more narrow band filter added in series to triple quadrupole: Same sensitivity and measurement speed, but 10-100 increase in resolution

•Resolution: 50-100; transmission >50%

•Since ions need to be formed at atmospheric pressure, they may as well be used in mobility separation for greater resolving power. DMA may be viewed as a fast ion chromatograph substituting slower conventional chromatographies (LC or GC).

•DMA Developed at SEADM. No alternative true mobility separation device coupled commercially to MS available

Fernández de la Mora et al. US patent 7,855,360, December 2010.
Rus et al. IMS-MS coupling a DMA to commercial API-MS systems, Int. J. Mass Spectrom, ***298****, 30,2010*

4

SEDET

Advantages of ambient vapor detection

- Sampling vapors directly from the atmosphere. No need for swabbing. No reliance on *particle events* of low probability.
- High Sensitivity (sub part per quadrillion) and specificity (low false alarm), both rapidly improving as technology develops and experience accumulates
- No alternative TSA approved method exists to **monitor the whole cargo as a unit**, without going through the lengthy and disruptive process of undoing the load and checking the packages one by one.
- Low global cost, fast analysis associated to **whole cargo monitoring, even when relying on a sophisticated detector**
- Minimizing delays and enabling 100% monitoring of all aerial cargo

5

SEDET

ACES SOLUTION

SEDET has developed an explosive screener for air cargo (ACES), whose aim is to solve problems generated by present legislation, present screening costs, and state-of-the-art technologies.

ACES delivers a radical improvement from present explosive screening procedures:

- 100% of air cargo is inspected at the airport entrance,
- Screening is done directly on the truck prior to discharge,
- Screening is completed in a single operation in a few minutes,
- Screenings costs are many times lower than present-day operations,
- PoD and FAR improve considerably over present day performances.

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SEDET

Sensitivity issues

•Broad perception that explosive detection by sniffing is not viable. YET

• Antecedents on measuring very low vapor concentrations (sub parts per trillion in 2009). Other groups are now (2013) reporting comparable results

•Sub ppq ($<10^{-15}$ atmospheres) in 2012

•Current: 0.03 ppq for RDX

•Is this enough?

•Can it be improved by orders of magnitude?

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Prior work: (ASMS conference, 2009)

20 ppq in direct ambient sampling SESI DETECTION OF EXPLOSIVE VAPORS BELOW 20 ppq ON A TRIPLE QUADRUPOLE WITH AN ATMOSPHERIC PRESSURE SOURCE; E. Mesonero; JA. Sillero; M Hernández; Juan Fernandez de La Mora

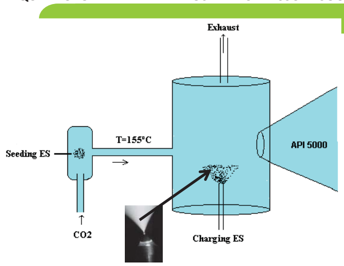
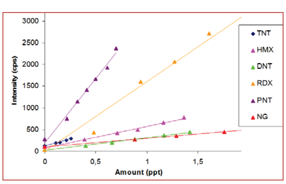


Table 1:Transitions for Explosives Detection

Explosive	Precursor Ion (m/z)	⇨ Product Ion (m/z)
TNT	226.1 (M-H)$^-$	46.1 (NO_2^-)
HMX	340.9 (M+HCOO$^-$)$^-$	45.9 (NO_2^-)
DNT	180.9 (M-H)$^-$	45.9 (NO_2^-)
RDX	267.0 (M+HCOO$^-$)$^-$	46.0 (NO_2^-)
PENT	360.8 (M+HCOO$^-$)$^-$	62.1 (NO_3^-)
NG	271.9 (M+HCOO$^-$)$^-$	62.1 (NO_3^-)

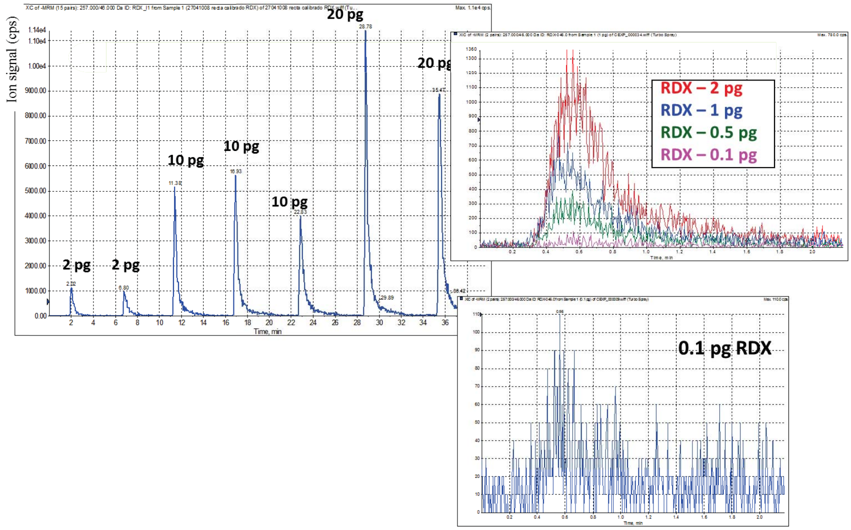
Background from clean air ~ 40-100 counts/s



Explosive	Sensitivity (ion/s/ppt)	LDL (ppt) IUPAC[1]	LDL (ppt) B-99%[2]
TNT	633	0.07	0.018
HMX	494	0.11	0.025
DNT	295	0.12	0.023
RDX	1642	0.07	0.005
PENT	2959	0.04	0.006
NG	197	0.22	0.056

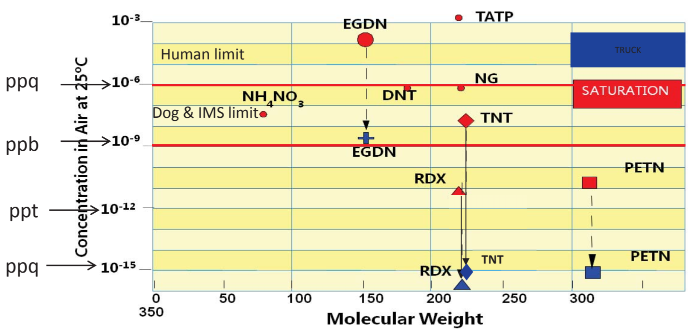
8

SEDET **RDX Calibration by desorbing sample deposited on filter**
(Gordon Conference, 2012)



Required sensitivity

SEDET tests (to be later discussed) show that explosives hidden in volumes up to 110 m^3 generate vapour pressures which are from 10^4 to 10^7 lower than the saturation value. Taking into account equilibrium vapour pressure of RDX, an effective Vapour Screener requires a sensitivity of 0.01 ppq.



10

Vapor sensitivity of contemperary triple quadrupole MS

- 1000 lit atmospheric air ~ 2.7 10^{25} molecules
- 0.001ppq (10^{-18} atmospheres) in that air volume ~ 2.7 10^7 molecules. **This is a very large number**
- Even allowing for limitations of sampling (10% vapor capture efficiency in collector filter), vapor ionization efficiency (0.1%) current triple quadrupole MS performance, (1% ion transmission and detection efficiency in MS), still 27 counts!
- Therefore, 0.001-0.01 ppq should be detectable today!
- NO SENSITIVITY PROBLEM at this concentration level

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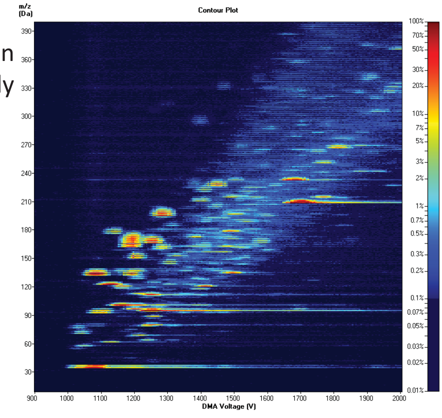
False alarms: The resolution problem

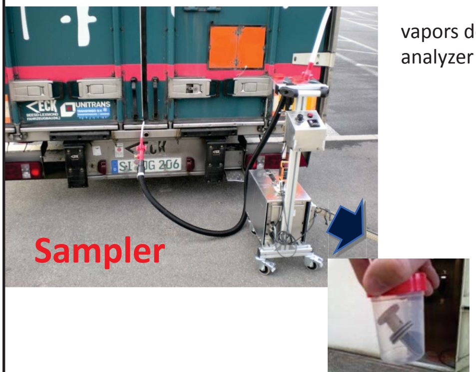
- The real challenge is background noise from zillions of competing species in the atmospheric background. The larger the sensitivity, the greater the number of species with the same mass and the same primary fragment masses as the explosive monitored.
- Our approach to deal with this challenge is the use of multiple ion filters in series, all having relatively high transmission and resolution, all shifting in synchrony from one explosive to the next:
- Mobility filter (DMA)→triple quadrupole filter
- Substantial effort needs to be invested in minimizing internal noise and multiple sources of contamination.



SEDET

- Operations

Cargo→Sample gas → vapors trapped in filter

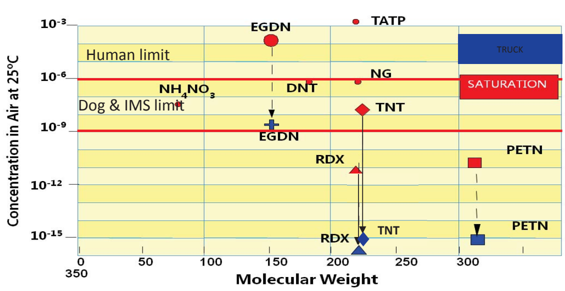


vapors desorbed from filter → ionization (SESI)→ analyzer (Ion mobility filter+triple quad MS filter)

13

Limitations based on concealment, containment, explosive type, minimum mass and other factors: A study of the dilution effect in real cargo loads

Our sensitive instrument permits detecting small masses of explosives hidden in cargo loads under a broad range of operational conditions. A large experience has been gathered in precertification tests in the UK the Netherlands, Germany, France and Spain. **The data to be discussed today have been obtained in the port of Vigo (NW Spain) in collaboration with the Spanish Guardia Civil**. The information to be presented is unique.



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Dilution effects for vapor signal

The dilution effect: $p_v/p_{eq}(T)$, is a function of the following variables

1. Truck cargo bay volume,
2. Explosive confinement (packaging),
3. Cargo itself (stuff inside boxes),
4. Temperature,
5. Soaking time,
6. Distance from the explosive to the sampling point,

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Container or truck volume

Volume effect	EGDN	Nitroglycerin	TNT
Saturation pressure (ppq)	10^{11}	10^{9}	10^{6}
Partial pressure in 76 m^3 truck (ppq)	$5\ 10^{5}$	250	50
Dilution factor	$2\ 10^{4}$	$4\ 10^{6}$	$2\ 10^{4}$

The vapor's partial pressure within a large volume such as a truck cargo bay is typically well below saturation. For EGDN and TNT, the dilution is ~ 20,000.

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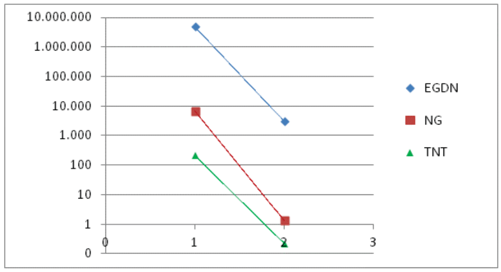
Concealment effect

Explosive confinement in a carefully sealed box reduces vapor pressure by a factor of 1,000

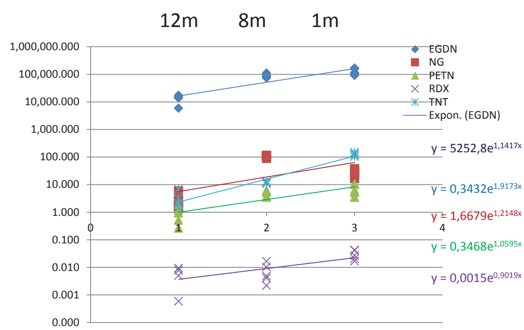


EGDN, NG and TNT vapour pressure. Point 1 shows an open box, and point 2 shows a sealed box

17

Distance

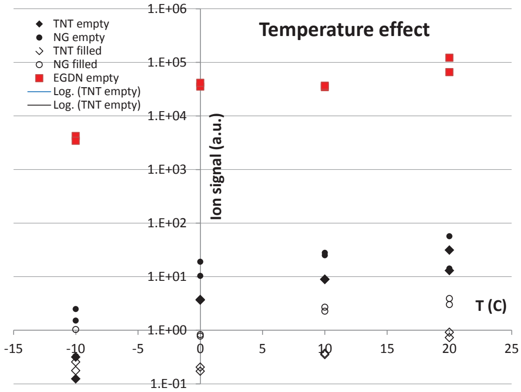
Distance between the sampling point and the explosive in a closed truck bay modifies vapour pressure ~ TENFOLD. This rule applies to all explosives.



EGDN, NG, TNT, PETN and vapour pressure plotted in 3 cases: sampling point at 12 m, sampling point at 8 m, sampling point at 1m

18

Temperature and cargo effect: EGDN, NG and TNT



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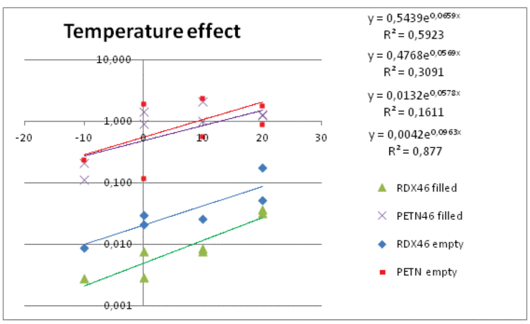
Temperature and cargo effect: RDX and PETN

Large refrigerated cargo container



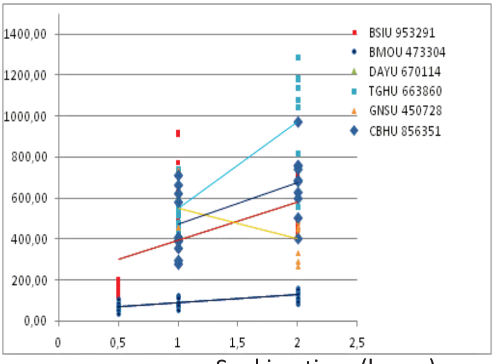
Vapor pressure increase for every 10ºC varies from a minimum factor of 1.6 to a maximum of 4.3.
Cargo reduces vapor pressure between one and two orders of magnitude

20

Soaking time: EGDN

In the short run (between 30 minutes and 2 hours), soaking time effect is unpredictable. In some experiments, vapour pressure increased by a factor of 3, while in other experiments it decreased by a factor of 2. If we average, vapour pressure at 2 hours is about 50% higher than at 0.5 hours.

It follows at first sight that the characteristic time for the vapor to spread over the volume is tens of minutes rather than tens of hours

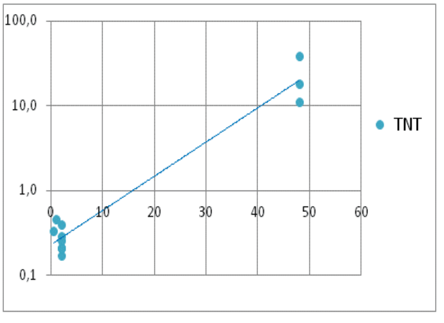


Soaking time (hours)

21

Soaking time: TNT

In the long run, soaking time can have dramatic effects. In the Figure at right, successive samplings made at 0.5, 1 and 2 hours gave similar values. However, two days latter, vapour pressure had increased by a factor of 100. This shows that there are at least two rather different characteristic times for the vapor to spread over the volume



TNT partial pressure versus time (hours)

22

Conclusions on factors affecting signal

- **The most relevant "loss factor" is the volume effect**. Vapour pressure within a truck cargo bay is typically 20,000 times lower than saturation pressure,
- **Second relevant loss factor is explosive confinement**. Although difficult to implement, since explosive handling always leaves traces, if explosive is well confined, vapour pressure drops by a factor of 1,000 (few molecules are able to cross carton/film),
- **Third relevant loss factor is the cargo itself.** Vapour pressure in a loaded truck bay is typically between 10 and 100 times lower than an empty cargo bay,
- **Fourth relevant factor is temperature**: Vapour pressure at -10ºC is typically 20 times lower than at 20ºC,
- **Fifth relevant factor is distance between the sampling point and the explosive**. Vapour pressure at 1 m from the explosive is typically 10 times lower than vapour pressure at 12m,
- **Soaking time is the less relevant loss factor**. A soaking time on the order of 2 days is needed in order for vapour pressure to increase by one order of magnitude.

23

Overal picture of the vapor molecules in the cargo volume

- Small (~20 g) condensed source releases vapors according to usual diffusive release aided by thermal convection. The rapidity with which the vapor spreads through the volume is as surprising as the long term permanence of the explosive signature even under extremely cold conditions
- Large area adsorbs vapors acting as sink
- partial pressure of vapor in the gas determined as much by adsorption-desorption from these surfaces as by the release process from the source. Hence the unexpected weak dependence on temperature found
- The fact that the *sticky* explosive *stick*s to the carton and is lost is well known, but the favorable effects of the long term desorption of the vapor *stuck* had not been observed. We have found explosive contamination in containers after several months of navigation following the introduction of a small explosive sample. The surface adsorption effect is similar to that taking place in ultrahigh vacuum surface experiments, with comparable residual pressure levels.

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SEDET

Timeframe and barriers for commercialization

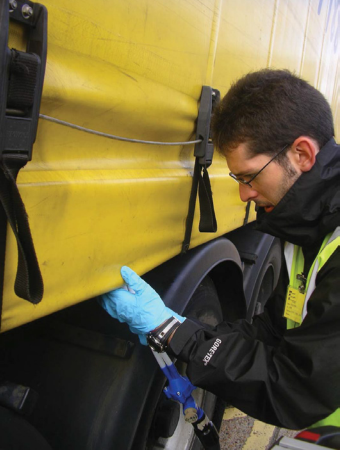
- The ACES instrument has been operational for over one year, with performance improving continuously
- Detector has been evaluated and continues to be evaluated at various European facilities in the UK, Holland, France, Germany and Spain
- Certification is the only pending barrier for commercialization, and is slowly proceeding in UK, Holland, France, Germany, Spain
- Estimated time frame for deployment ~ 1 year

25

SEDET

End

- Gonzalo Fernandez de la Mora <gfdelamora@seadm.com>
- SEDET
- Parque Tecnologico de Boecillo, parcela 205
- 47151 Boecillo
- Spain
- info@sedet.com
- www.sedet.com



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17.17 Carl Crawford: ADSA10 Topics

Ninth Algorithm Development for Security Applications Workshop (ADSA09):

New Methods for Explosive Detection for Aviation Security

Call To Order
Day 2

Carl R. Crawford

1

Reminders

- Fill out questionnaire
  - Key element of deliverable to DHS
- End at 4:00 PM today
  - Please stay to end if possible
- Comments welcome after conclusion

2

Reminders (II)

- Reconstruction project meeting here 4:15-5:15
- ATR project meeting here 5:15 – 6:15
- Reconstruction project program review tomorrow

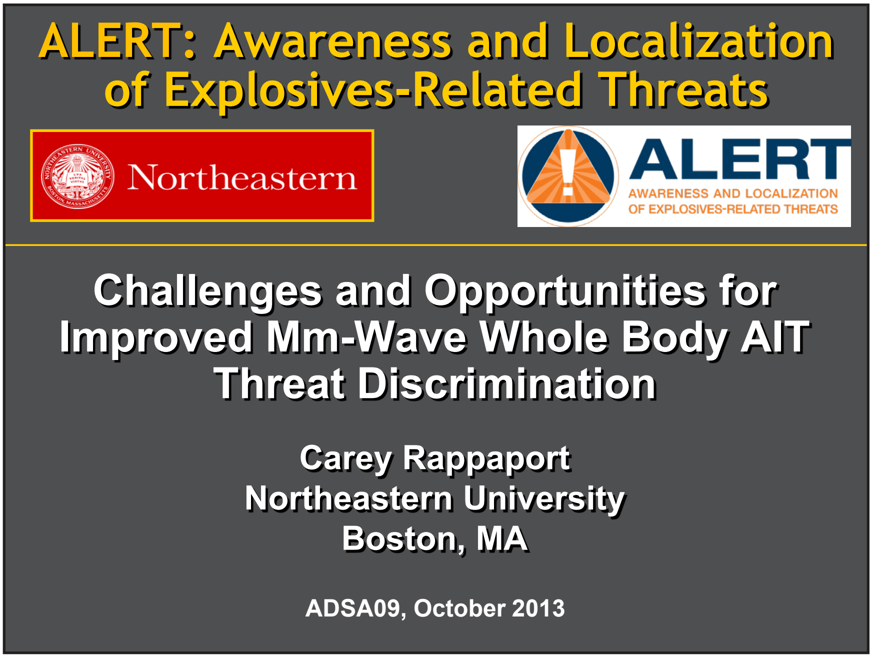
3

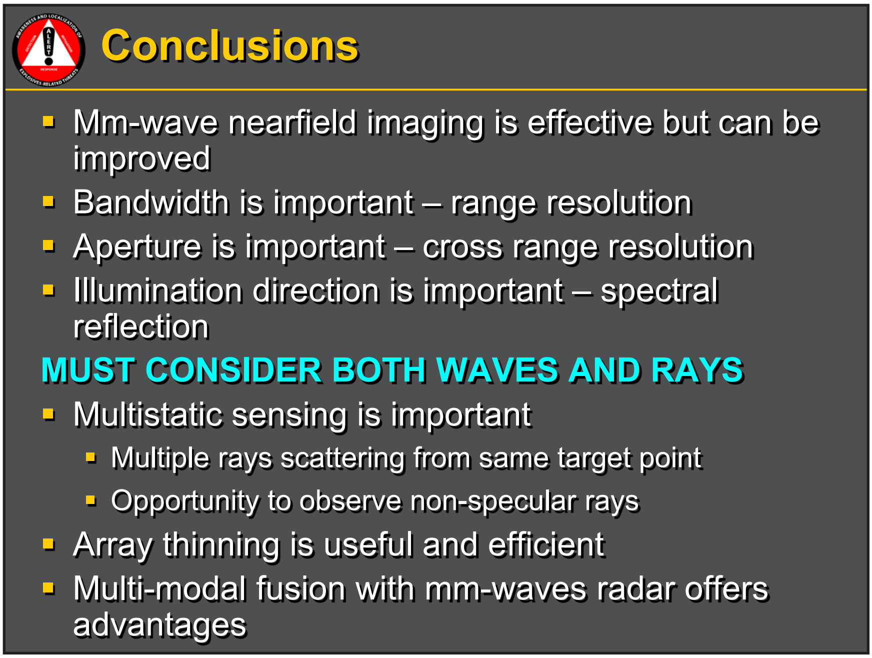
ADSA10 Possible Topics

- Computer simulations
  - X-ray transmission, back-scatter, diffraction
  - MMW
  - Standardized phantoms
- Cargo
- Application of micro-CT
  - Training/testing
  - Scanner transfer functions
- Improving statistical significance of testing
- Video analytics
- Risk-based screening & gaming theory

4

17.18 Carey Rappaport: Challenges and Opportunities for Improved Mm-Wave Whole Body AIT Threat Discrimination



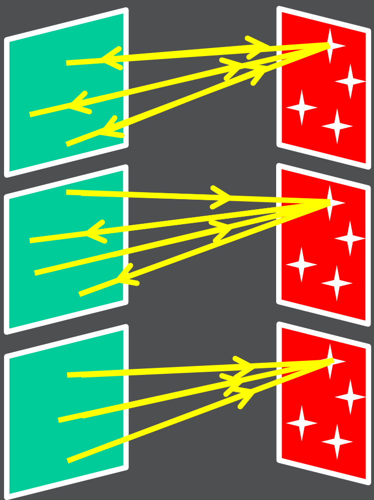


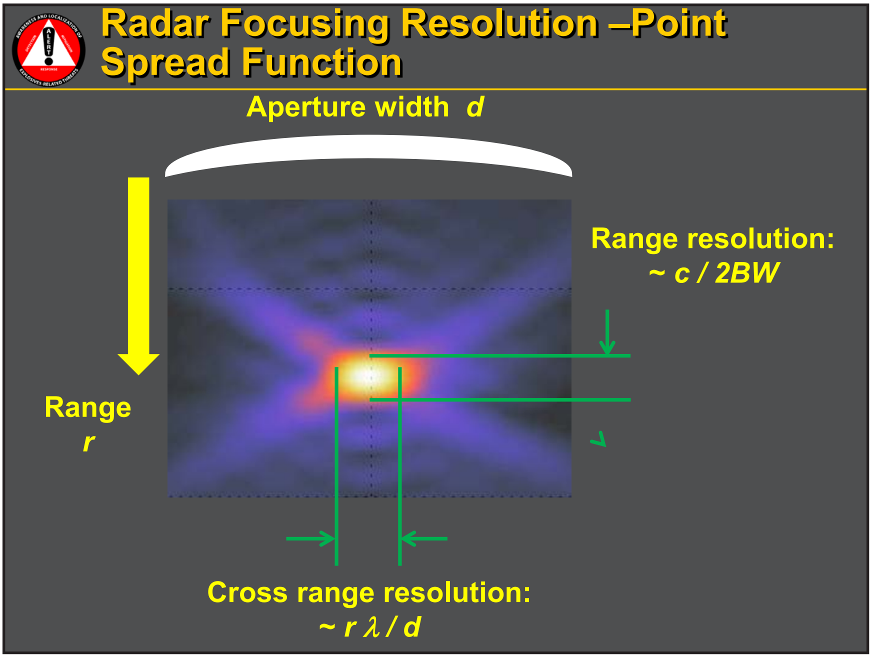
Portal-Based Mm-Wave Security Screening (AIT)

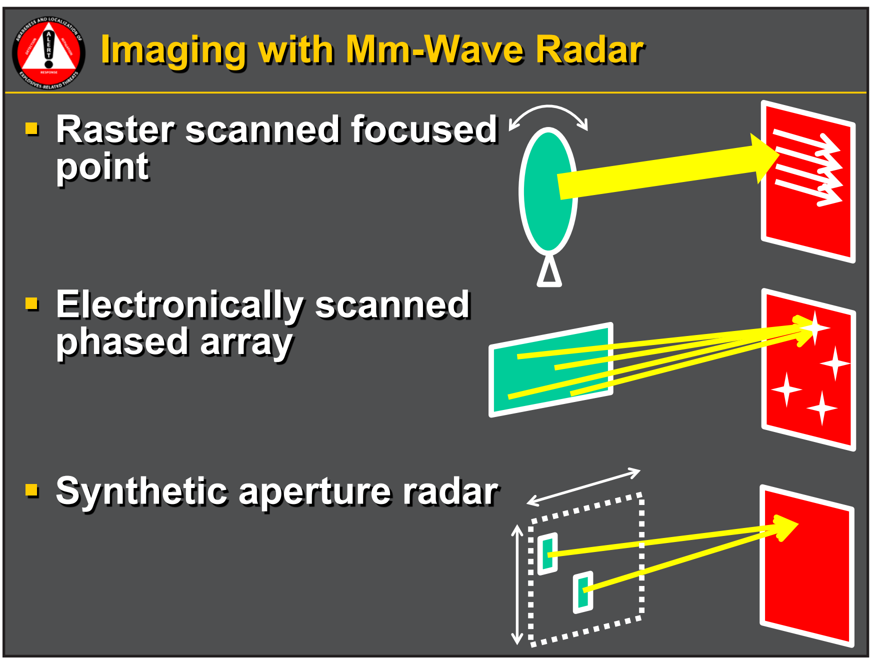
- Goal: Detect concealed man-made objects under clothing
- Portal-based broadband mm-wave radar
  - 26-33 GHz (15-45 GHz)
  - 56-64 GHz
  - 70-77 GHz
  - 91-98 GHz
- Advantages:
  - Non-ionizing, eye-safe
  - Reasonable resolution ~ 0.25-2.5 cm
  - Sensitive to metal and low-permittivity explosives
  - Commercially available RF modules
  - Many algorithms for shape reconstruction
- Disadvanages
  - Huge amounts of data
  - No chemical information
  - Limited time to acquire / process
  - Poor non-specular focusing / SAR imaging

Monostatic / Multistatic Radar

- **Monostatic**
  - **Multi-monostatic**
- **Bistatic**
  - **Multi-bistatic**
- **Multistatic**



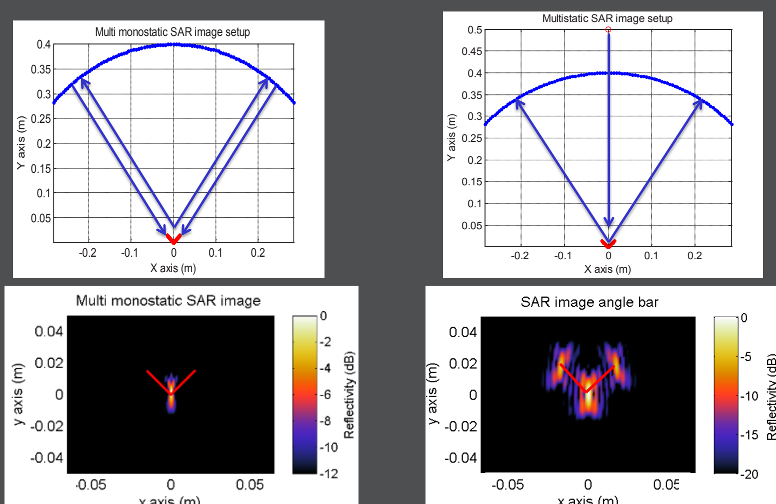

Radar Focusing Resolution –Point Spread Function
Aperture width d
Range resolution:
~ c / 2BW
Range
r
Cross range resolution:
~ r λ / d


Imaging with Mm-Wave Radar
Raster scanned focused point
Electronically scanned phased array
Synthetic aperture radar

AIT Systems

Raster scanned focused point	Cost	Perf.	Developer
Moving antenna / mirror	$$	★★	JPL, PNNL
Electronically scanned reflect-array	$	★	Smiths
Electronically scanned phased array			
Multi-monostatic	$$$	★★★	
Multi-bistatic	$$$$	★★★★	
Multistatic	$$$$	★★★★	Rohde & Schwarz
Synthetic aperture radar			
Moving mast of multiple monostatic	$	★★	L3
Moving focusing multistatic system	$	★★★	NEU

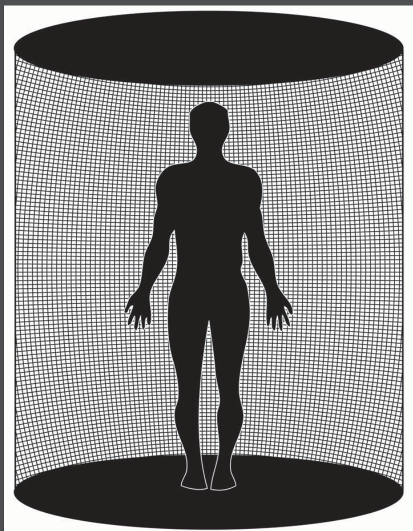
Monostatic vs. multistatic



Monostatic: Dihedral images to a point

Multistatic: Dihedral images to correct corner scatterer

Portal Provides the Possibility for Full Aperture Sensing



Huge 360 deg. Aperture

•Almost perfect body surface reconstruction
•No motion artifacts

However:
•Very expensive
•Long acquisition time
•Long computation time and massive storage
$(200 \times 300)^2$ Tx/Rx
10,000 (cm^2) body pts.
= $3.6 \; 10^{13}$ focusing calculations

9

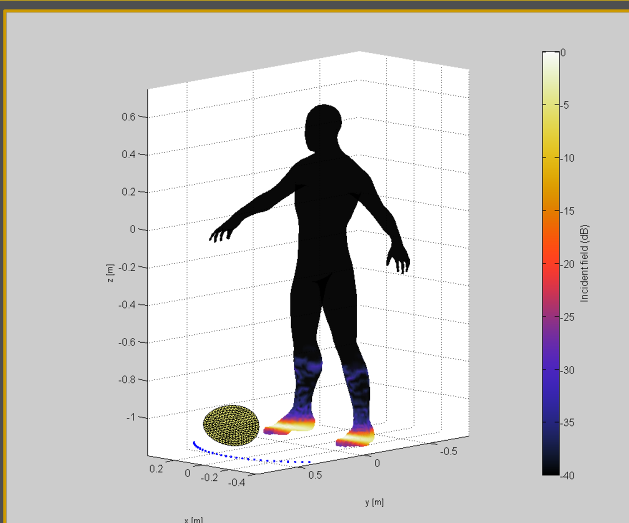
Current State-of-the-Practice Example: L3 ProVision Mm-Wave Imager

- TSA qualified AIT system
- Detects many types of materials based on shape (metallic and non-metallic): liquids, gels, plastics, metals, ceramics
- Uses two linear antenna arrays, scans through 240 degrees
- Quick acquisition, processing
- Mm-wave Limitations
  - Poor non-spectral imaging
  - Limited views
  - No spectroscopic info
  - Poor penetration through wet or metallic clothing
  - No penetration through skin or into body cavities

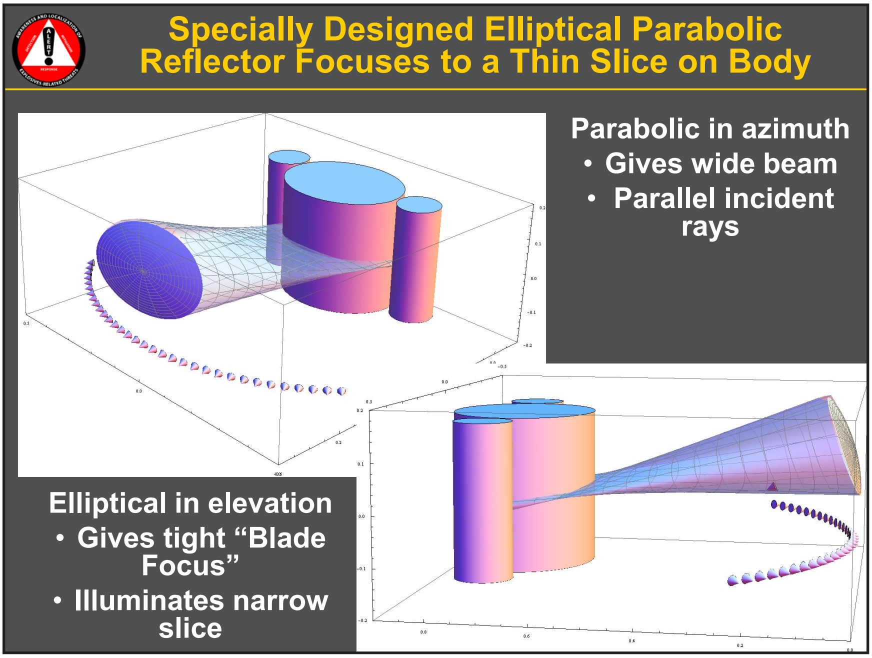
Current State-of-the-Practice Example: Smiths eqo Mm-Wave Imager

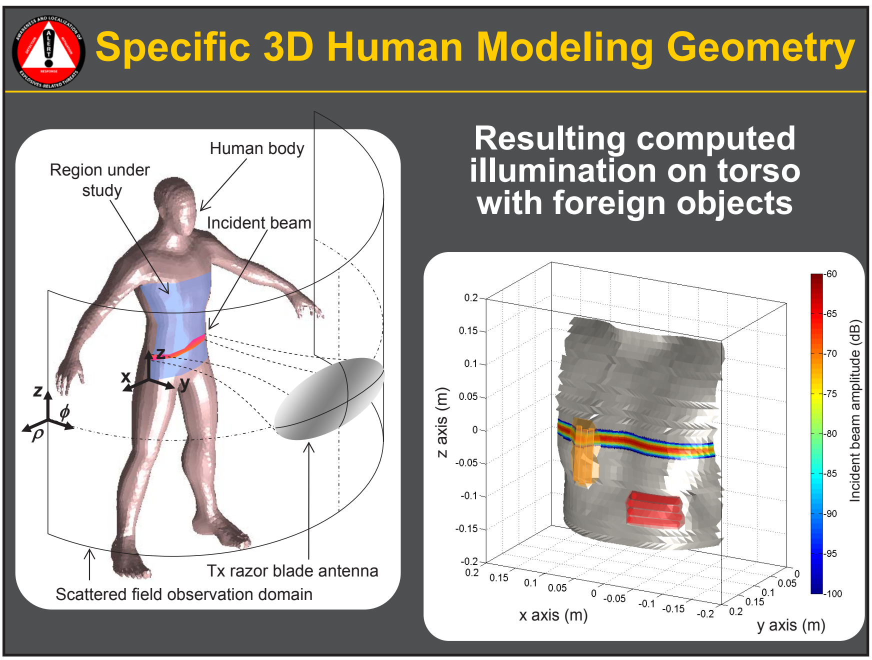
- ECAC Std. 2 qualified AIT system
- CW – 26 GHz
- Detects shape anomalies
- Uses reflect-array with single antenna: 45 deg. view (360 deg. with subject rotation)
- Extremely quick acquisition, processing (> 10 frames/s)
- Mm-wave Limitations
  - Requires subject rotation

NEU System Simulated Scanning Protocol



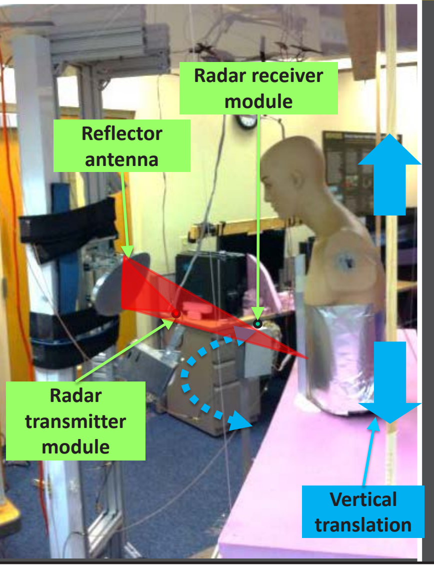
12


Specially Designed Elliptical Parabolic Reflector Focuses to a Thin Slice on Body
Parabolic in azimuth
• Gives wide beam
• Parallel incident rays
Elliptical in elevation
• Gives tight "Blade Focus"
• Illuminates narrow slice


Specific 3D Human Modeling Geometry
Human body
Region under study
Incident beam
z
ϕ
ρ
x
y
Tx razor blade antenna
Scattered field observation domain
Resulting computed illumination on torso with foreign objects
z axis (m)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
x axis (m)
y axis (m)
Incident beam amplitude (dB)
-60
-65
-70
-75
-80
-85
-90
-95
-100

NEU Portal Security System Concept – Multistatic, Narrow Slice Illumination

- Lab prototype AIT system
- 56-63 GHz
- Detects shape anomalies
- Uses blade beam and 120 deg. receiver arc
- Second transmitter necessary for more than +/- 30 deg. field of view
- Quick acquisition, processing
- Mm-wave Limitations



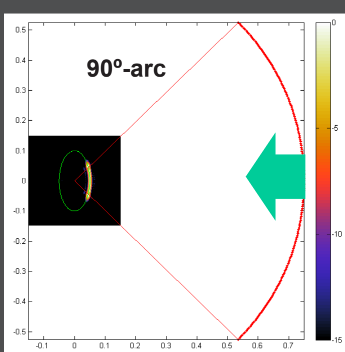
Importance of Large Aperture

- Electrically large aperture provides narrow beam and high resolution (wave effect)
- As center frequency increases, for same physical aperture, resolution increases
- As distance to target increases, resolution decreases
- For given aperture, higher frequency demands more elements, more closely spaced
  - Grating lobes for uniform sparse aperture
  - Non-uniform element spacing avoids lobes

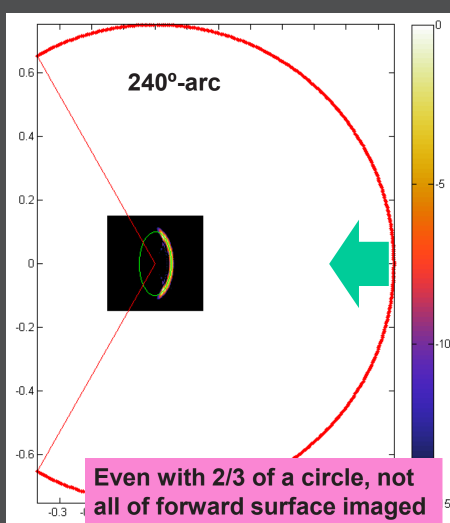
Importance of Specular Sensing

- At high frequencies, waves behave like rays
- Rays reflect from piecewise planar boundaries specularly
- Extreme focusing or ultra large bandwidth cannot compensate for specular reflection
- If reflected rays leave subject away from source, the detector must be on the other side of the subject from the source
- Ray analysis is often overlooked, but crucial for effective design

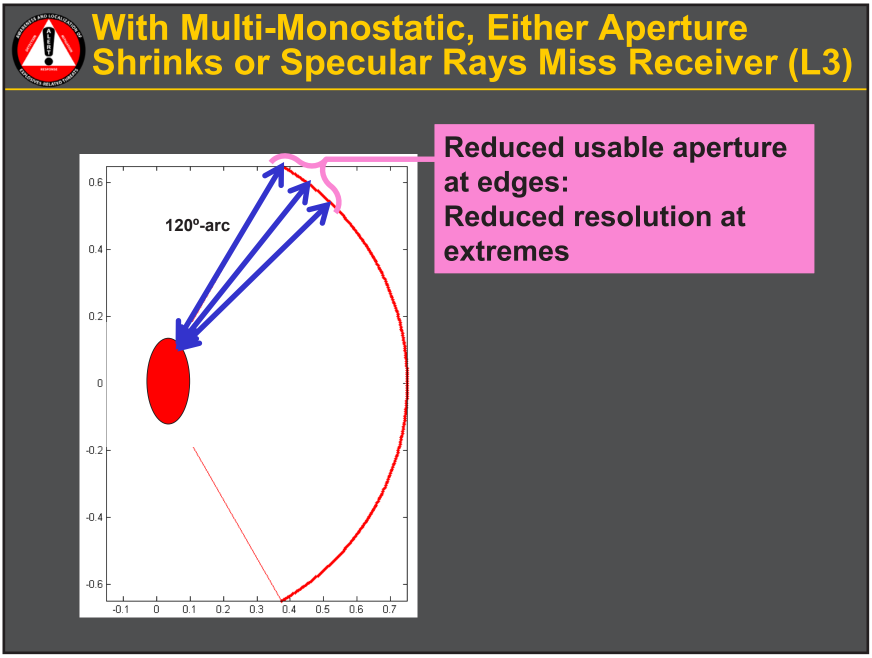
With Single Plane Wave Illumination, Receiving Array Must be Oversized (NEU)

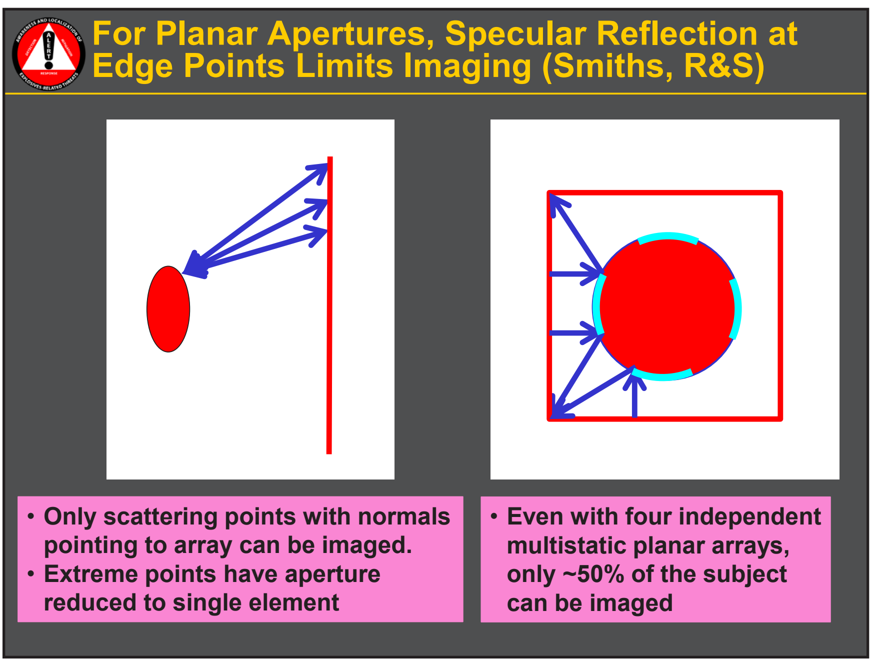


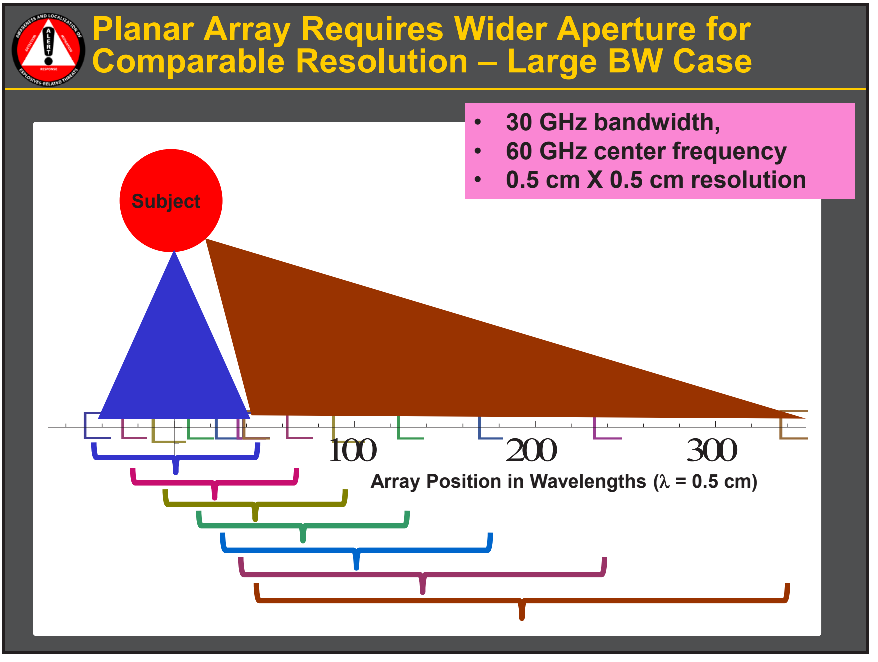
Only front surface (normals < 22.5 deg.) imaged

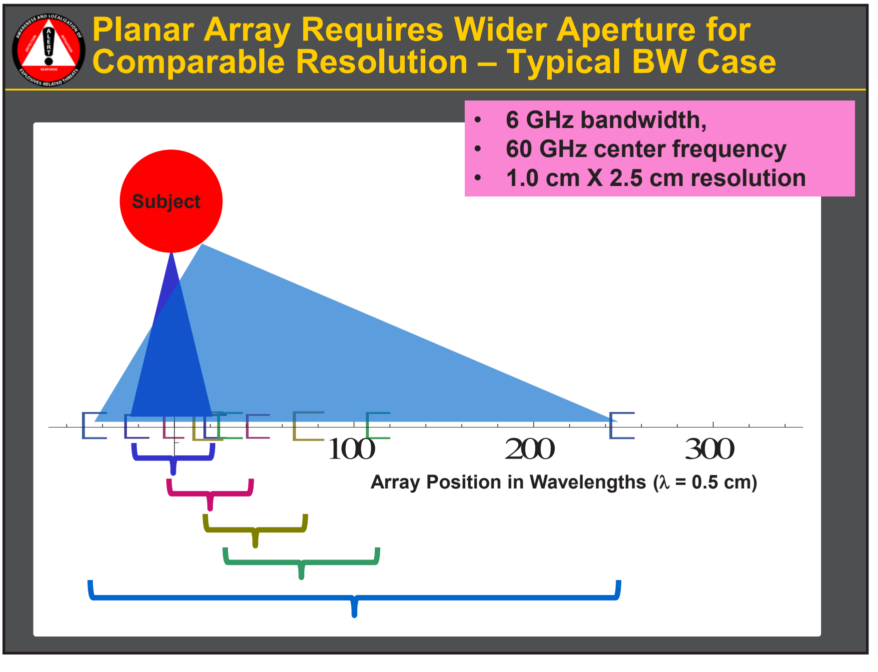


Even with 2/3 of a circle, not all of forward surface imaged


With Multi-Monostatic, Either Aperture Shrinks or Specular Rays Miss Receiver (L3)
Reduced usable aperture at edges:
Reduced resolution at extremes
120°-arc

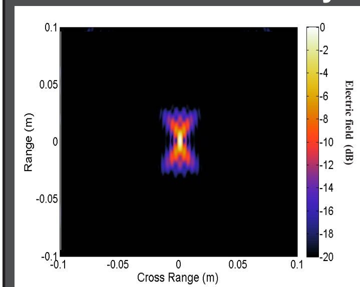

For Planar Apertures, Specular Reflection at Edge Points Limits Imaging (Smiths, R&S)
• Only scattering points with normals pointing to array can be imaged.
• Extreme points have aperture reduced to single element
• Even with four independent multistatic planar arrays, only ~50% of the subject can be imaged

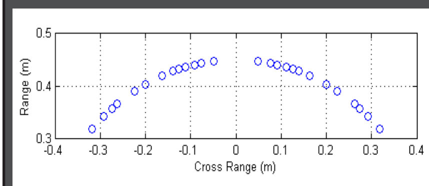

Planar Array Requires Wider Aperture for Comparable Resolution – Large BW Case
30 GHz bandwidth,
60 GHz center frequency
0.5 cm X 0.5 cm resolution
Subject
100
200
300
Array Position in Wavelengths (λ = 0.5 cm)


Planar Array Requires Wider Aperture for Comparable Resolution – Typical BW Case
6 GHz bandwidth,
60 GHz center frequency
1.0 cm X 2.5 cm resolution
Subject
100
200
300
Array Position in Wavelengths (λ = 0.5 cm)

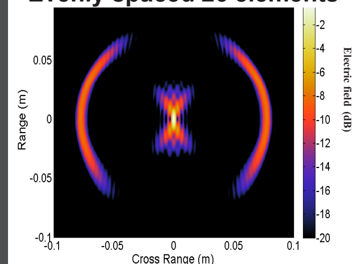
Effect of 83% Element Thinning and Optimization

Full 151 element array

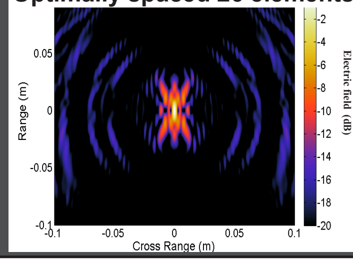




Evenly spaced 26 elements



Optimally spaced 26 elements



Considerations for Fusing Technologies with Mm-Wave Sensing

- Compensate for deficiencies of mm-wave sensing
  - Low resolution
  - No skin penetration
  - Limited material identification
  - Heavy computation burden
- Establish minimum desired sensing requirements
  - Resolution
  - Material classification
- Consider completely orthogonal sensor
  - No joint inversion – simple union of sensor info
- Consider front-end fusion – joint inversion
  - Initial guess
  - Regions of particular interest

Conclusions

- Mm-wave nearfield imaging is effective but can be improved
- Bandwidth is important – range resolution
- Aperture is important – cross range resolution
- Illumination direction is important – spectral reflection

MUST CONSIDER BOTH WAVES AND RAYS

- Multistatic sensing is important
  - Multiple rays scattering from same target point
  - Opportunity to observe non-specular rays
- Array thinning is useful and efficient
- Multi-modal fusion with mm-waves radar offers advantages

People Who Actually Did the Work…

Prof. Jose Martinez
Prof. Yuri Alvarez
Dr. Borja Gonzalez Valdes
Spiros Mantzavinos
Kathryn Williams
Galia Ghazi
Luis Tirado
Dan Busioc
James Rooney
Nathan Dunn
Matt Nickerson
Jenna Czeck
Greg Allan
Nigil Lee
Richard Moore

17.19 Kate Williams: GPU Accelerated Ray Tracer for Simulating a Portal Based Security System

Ray Tracing Simulation Tool for Portal-Based Millimeter-Wave Security Systems using the NVIDIA OptiX Ray Tracing Engine

Kathryn Williams

ALERT Center of Excellence

Northeastern University, Boston, MA

Northeastern

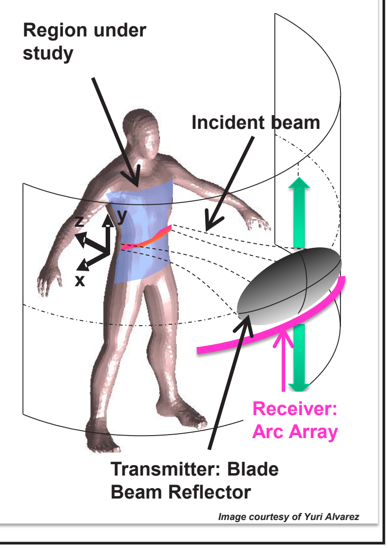
ALERT
AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

Algorithm Development for Security Applications
October 23, 2013

Project Background

2

- Create a next generation system to improve detection capabilities of whole-body imaging systems
  - Novel hardware designs
  - Novel algorithms
- This talk: GPU Ray Tracing (RT) Simulation Tool



So what, who cares?

3

- Why develop computational models?
  - Predict the scattering behavior of objects to mm-waves
  - Model optimal sensor configurations at minimal cost
  - Develop model-based inversion methods
- Why ray tracing?
  - Inherently parallelizable (GPUs!)
  - Can be an effective forward model for inversion

Outline

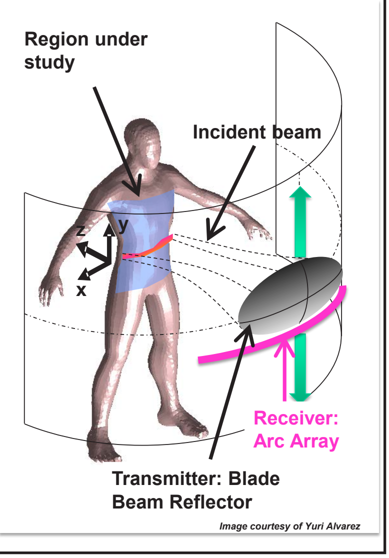
4

- **Algorithm development**
  - Modeling of scanner components
  - Implementation
- **Computational Results**
  - Validation
  - Performance

Components to Model

5

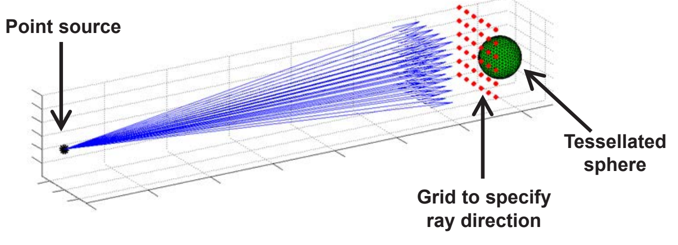
- Transmitter
- Human Body
- Ray-Body Intersection
- Receiver Arc Array



Components to Model

6

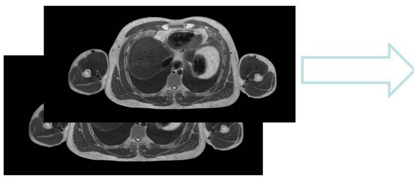
- Transmitter
  - Electromagnetic wavefronts are approximated by a collection of rays
  - Propagation direction of rays governed by a virtual grid
  - Rays are traced from the transmitting source to the mesh (“scene”)



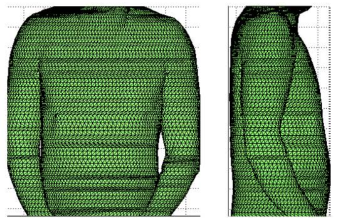
Components to Model

7

- Human Body
  - Triangular faceted mesh
  - User control over triangle size and uniformity
  - Can extract and correlate 2D slices



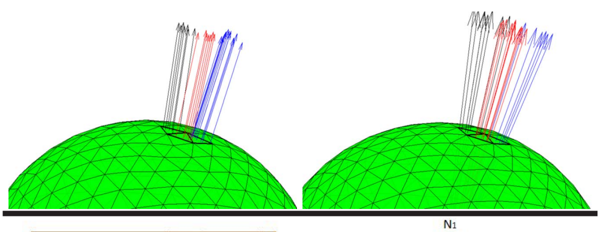
Images courtesy of Visible Human Project



Components to Model

8

- Intersection
  - Perfect electric conductor
  - Interpolation of surface normals
  - Acceleration
  - "Scene epsilon"



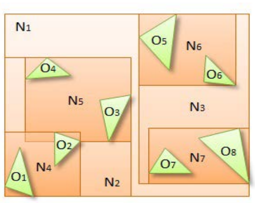


Image courtesy of NVIDIA

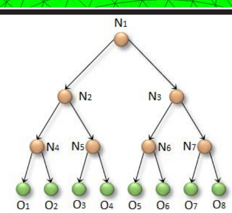
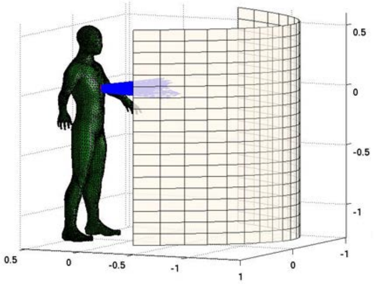


Image courtesy of NVIDIA

9

Components to Model

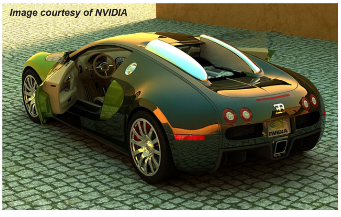
- Receivers
  - Receiver array is discretized into patches ("bins")
  - Field of each ray is computed, including path length phase: e^{-jkl}
  - If rays land within the same bin, their field values are summed ("ray aggregation")



10

Implementation

- Goal: All rays and all fields (bins) in parallel
- OptiX Ray Tracing Engine
  - Free SDK, released in 2009
  - By NVIDIA for NVIDIA GPUs
  - Uses CUDA C based device (GPU) programs
  - Optimized
  - Used for many applications



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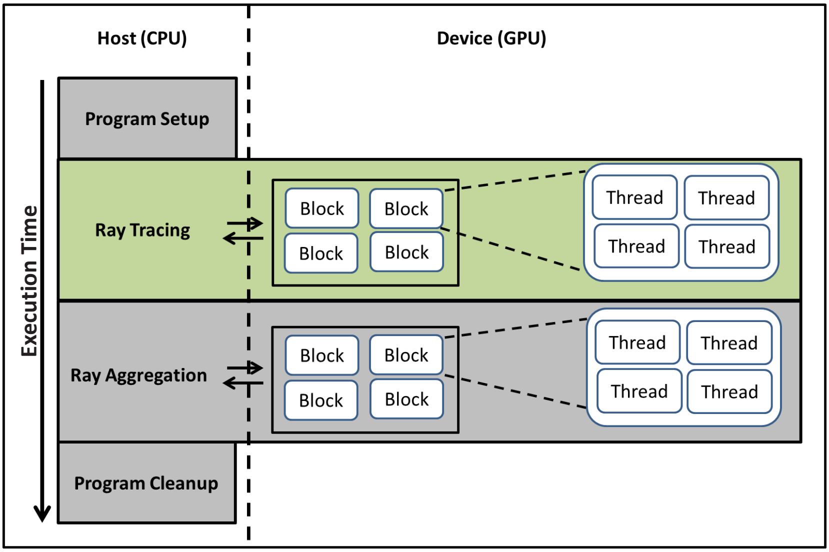
High Level Implementation



12

Implementation

- Platform Configuration
  - OptiX 3.0
  - CUDA 4.2
  - Ubuntu 12.04
  - 3.2 GHz Intel Core i7
  - NVIDIA GTX 670 (1344 CUDA Cores; 2 GB memory)
  - PCI Express 3.0

13

Computational Results: Validation

- 4 cases presented here:
  - 2D cylinder to approximate the torso
  - 2D torso with arms
  - 2D torso with arms and pipes
  - 2D torso with realistic features
- RT field values and SAR images are compared with 2D Method of Moments (MOM) solutions

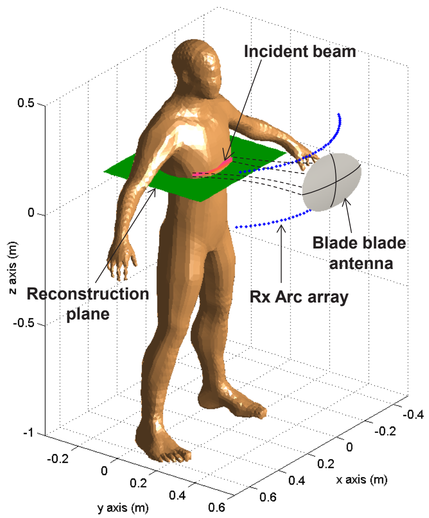
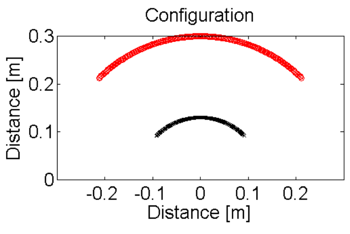
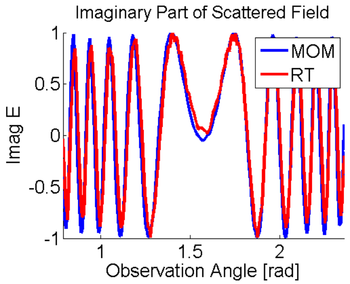


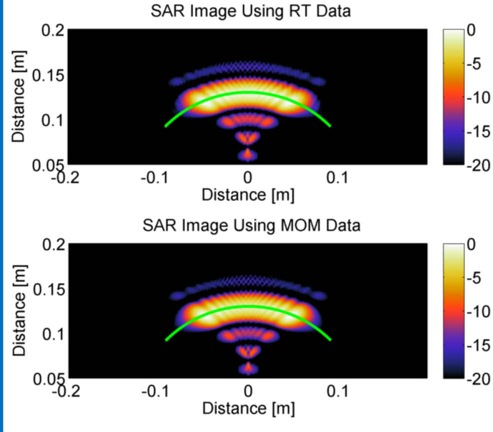
Image courtesy of Borja Gonzalez Valdes

14

Computational Results: 2D Cylinder

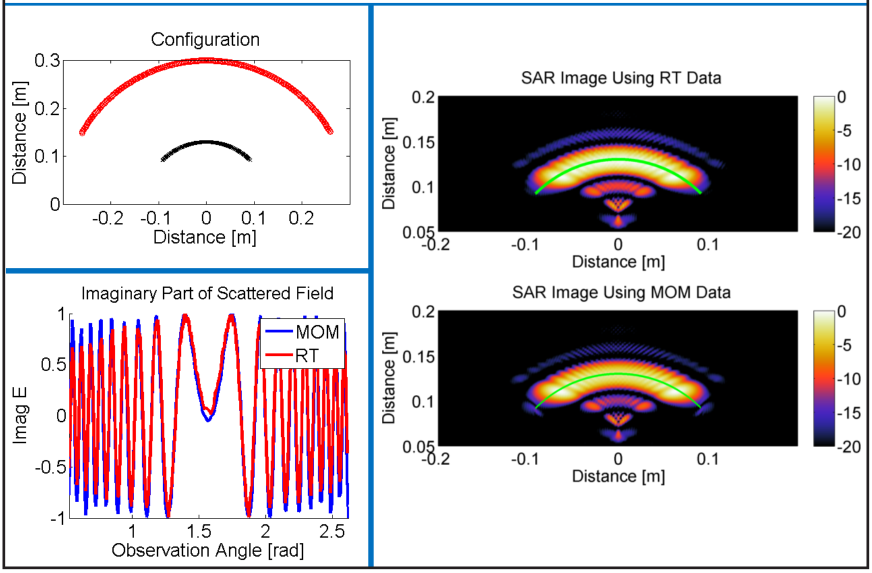






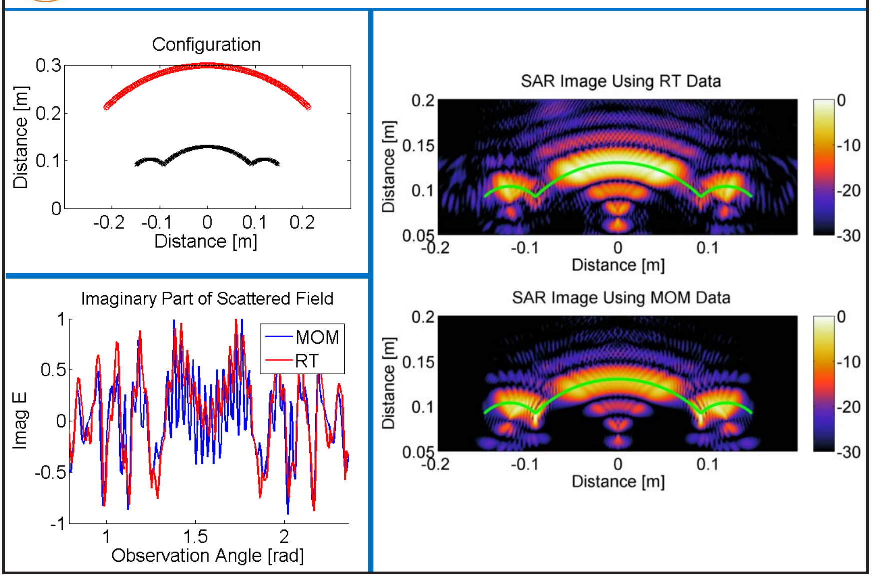
15

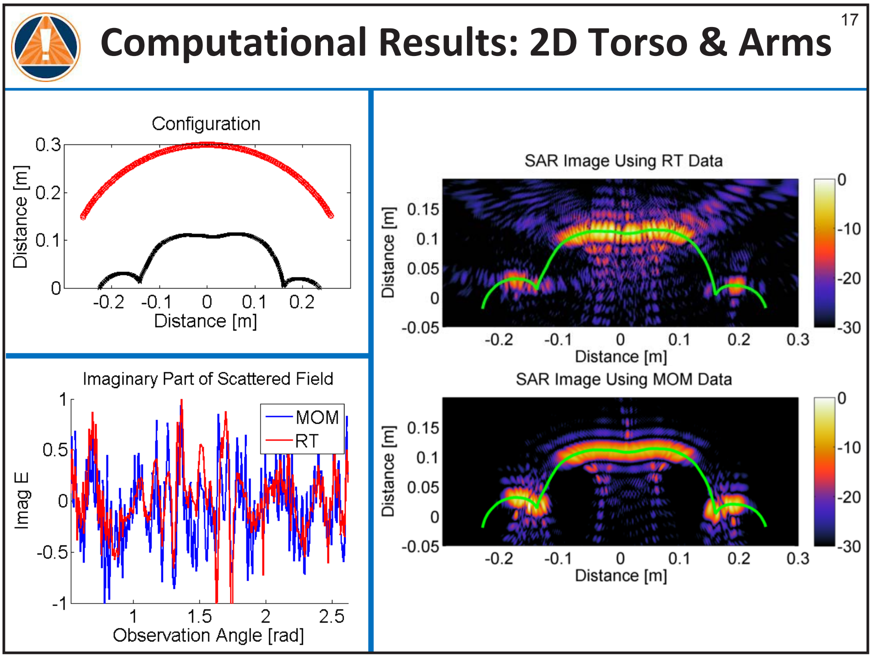
Computational Results: 2D Cylinder

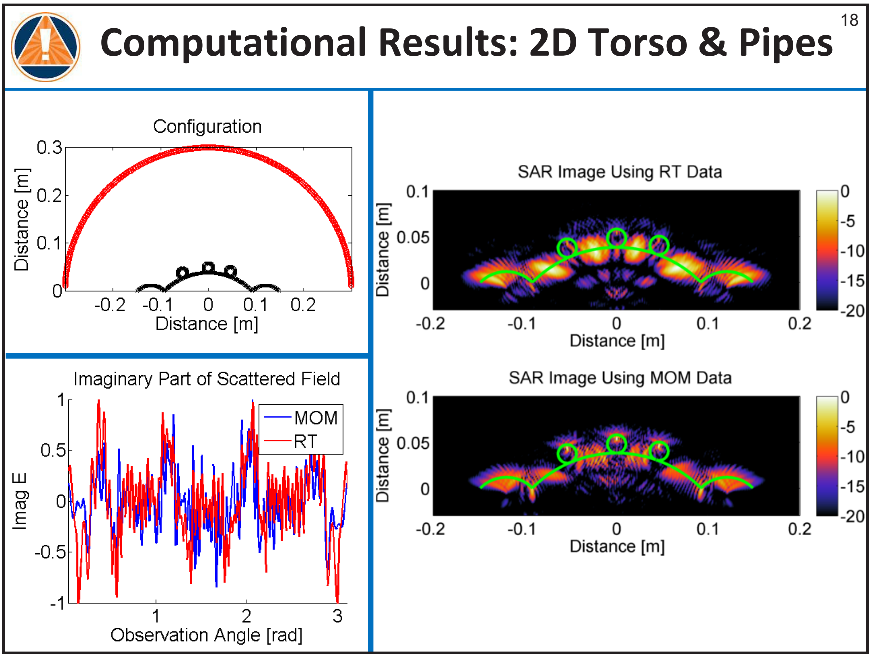


16

Computational Results: 2D Torso & Arms




17
Computational Results: 2D Torso & Arms
Configuration
Distance [m]
Distance [m]
Imaginary Part of Scattered Field
MOM
RT
Imag E
Observation Angle [rad]
SAR Image Using RT Data
Distance [m]
Distance [m]
SAR Image Using MOM Data
Distance [m]
Distance [m]


18
Computational Results: 2D Torso & Pipes
Configuration
Distance [m]
Distance [m]
Imaginary Part of Scattered Field
MOM
RT
Imag E
Observation Angle [rad]
SAR Image Using RT Data
Distance [m]
Distance [m]
SAR Image Using MOM Data
Distance [m]
Distance [m]

Computational Results: Performance

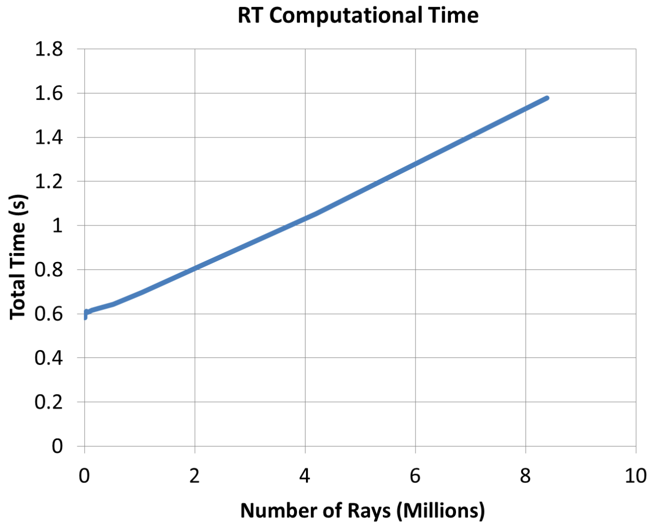
19

- Factors affecting performance
  - # of rays
  - # facets
  - # receiver bins
  - # of frequencies
- Results performed for a faceted plate
- Computation time is compared, if applicable, with 3D GPU implementation of the Modified Equivalent Current Approximation (MECA) [1]

[1] *L. Tirado, . Martinez-Lorenzo, B. Gonzalez-Valdes, C. Rappaport, O. Rubinos-Lopez, H. Gomez-Sousa, "GPU Implementation of the Modified Equivalent Current Approximation," ACES Journal, vol 27, pp. 726-733, Sep. 2012.*

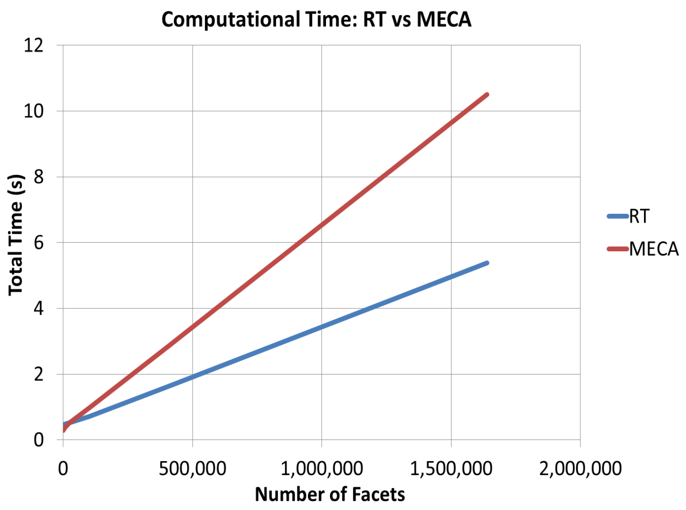
Computational Results

20



21

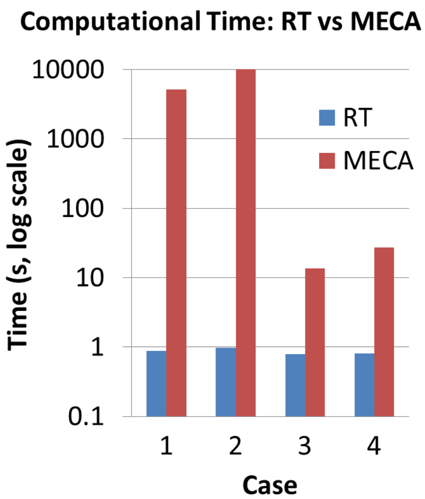
Computational Results



22

Computational Results

	Parameters			Result
Case	# Freq	# Bins (Azimuth)	# Bins (Height)	Factor Speedup
1	16	654	417	**5808**
2	32	654	417	**10581**
3	16	654	1	**17**
4	32	654	1	**33**



Summary

23

- Developed ray tracer simulation tool that takes advantage of free software available in the computer graphics community, modified for this application
- Computational modeling leads to better hardware designs, insight into scattering
- Ray tracing produces accurate field values and speed-ups when compared to other methods
- Fast forward models can lead to fast model-based inversion algorithms
- Future work: testing on additional geometries, additional speed-ups, ray tracing-based inversion method

Acknowledgements

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Professor Carey Rappaport, Professor Jose Martinez, Professor Yuri Alvarez, Borja Gonzalez-Valdes, Luis Tirado, Chen Zhongliang

ALERT
AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

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Useful Resources

25

- CUDA Tutorials
  - udacity.com
  - "CUDA Handbook", Nicholas Wilt

- GPU Technology Conference On-Demand OptiX Tutorials
  - gputechconf.com:
    - Online tutorial: "GPU Ray Tracing Exposed: Under the Hood of the NVIDIA OptiX Ray Tracing Engine," A. Robison, P. Miller, S. Parker
    - Online tutorial: "Advanced OptiX Programming and Optimization", D. McAllister
    - Online tutorial: "GPU Ray Tracing Using OptiX," D. McAllister

BACKUPS

26

Project Background: Motivation

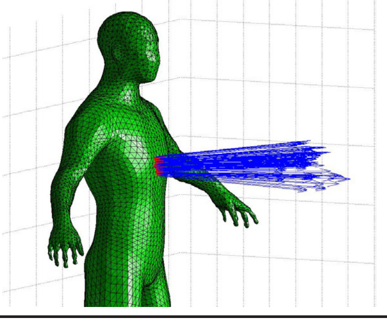
27

- Accurate & quick detection of person-borne threats in highly secure areas
- Millimeter-wave portal-based scanning systems are currently used to meet this need
- Millimeter-waves
  - Penetrate clothing, reflect off skin
  - Can detect nonmetal and metal objects
  - Enable high resolution images
  - Multiple views give depth information
  - Non-ionizing radiation
  - More publicly accepted than x-ray

Ray Tracing Basics

28

- Electromagnetic wavefronts are approximated by a collection of rays
- Rays are traced from a transmitting source to a surface or scene
  - (i.e., a 3D triangle mesh of a human body)
- Rays reflected from a surface are calculated with Snell's law
- Reflected rays are traced until they reach a receiving surface
- All ray contributions, including path length phase, are added at the receiving surface



Advantages of Ray Tracing over Other Methods

- Simple formulation
- Inherently parallelizable
- Has potential for real-time computation
- Reasonably accurate for mm-waves for objects of interest

- MoM, Finite Difference Frequency Domain (FDFD) are more accurate but slow, and not readily as parallelizable
- Includes mutual interactions (multiple bounces) much more readily than Physical Optics (PO)
- Uses the object 2nd-order normal at every surface point, instead of just the center of each triangular facet for PO

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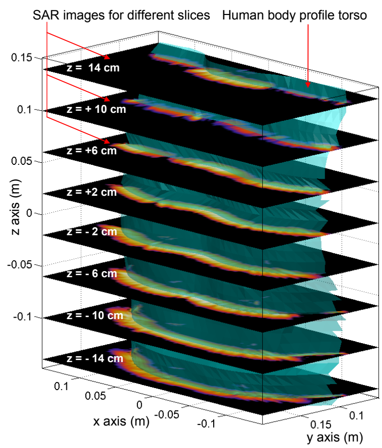
- Can be effective forward model for inversion
  - May give 3D (i.e., height) response to supplement 2D stacked reconstructions
  - May be used for iterative reconstruction
  - May be used as part of a novel multiple bounce SAR inversion scheme
  - May be useful for focusing in on details (i.e., a possible threat)

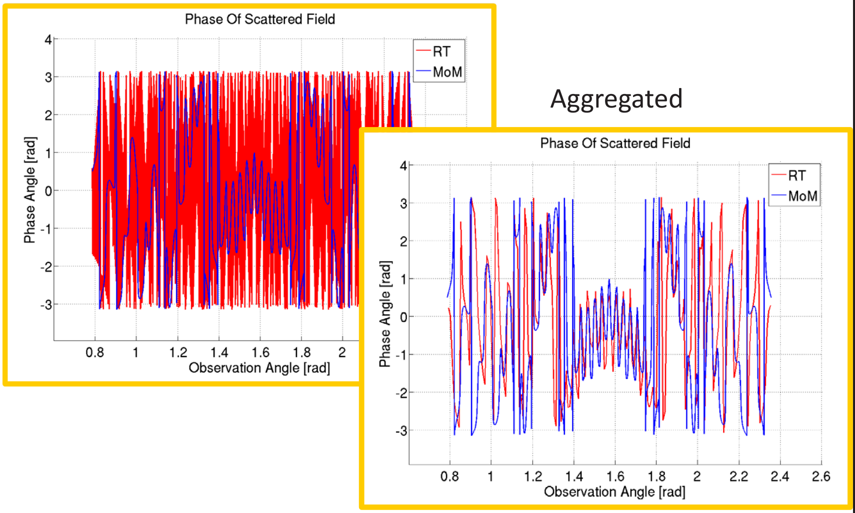


31

Ray Aggregation: Sample Data

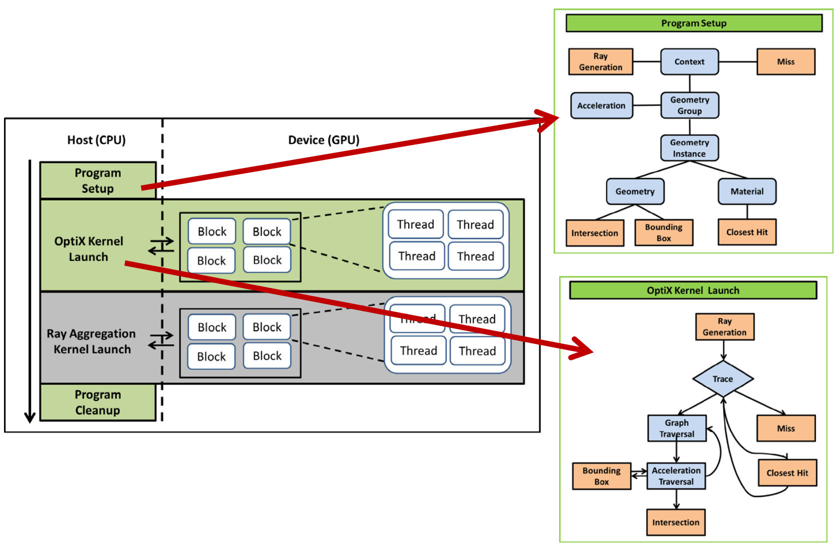
Not aggregated

Aggregated



32

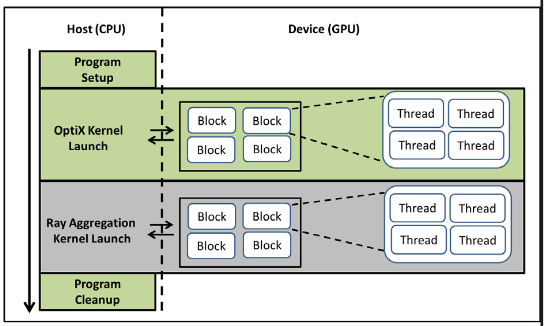
Implementation



33

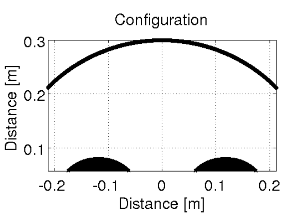
Computational Results: Performance

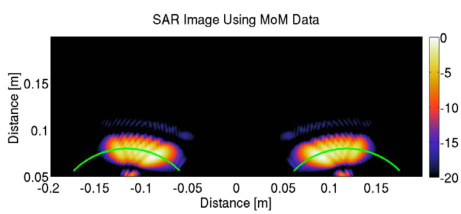
- RT execution time breakdown:
  - Program setup
  - OptiX validation
  - OptiX kernel
  - Ray aggregation
  - Saving fields

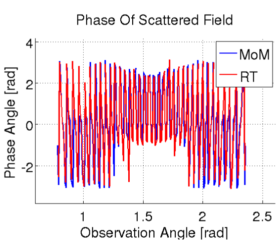


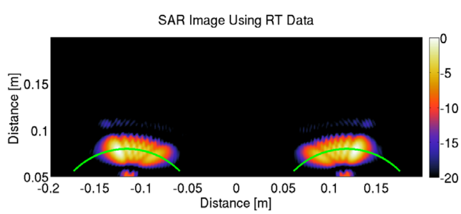
34

Computational Results: 2D Legs



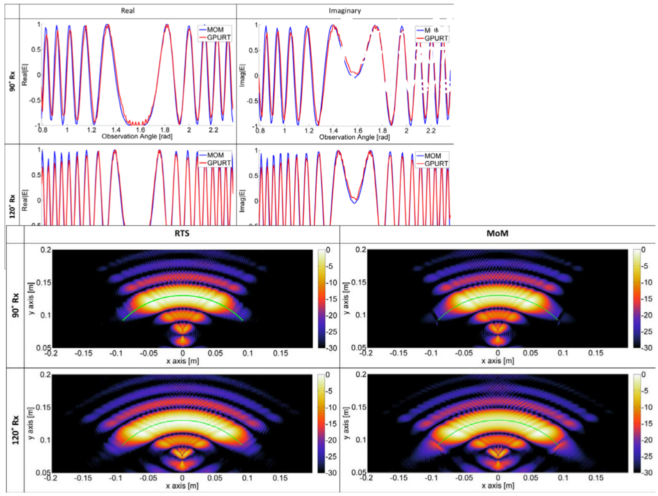






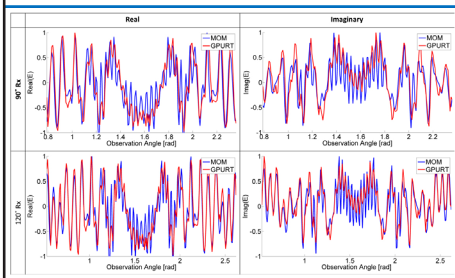
35

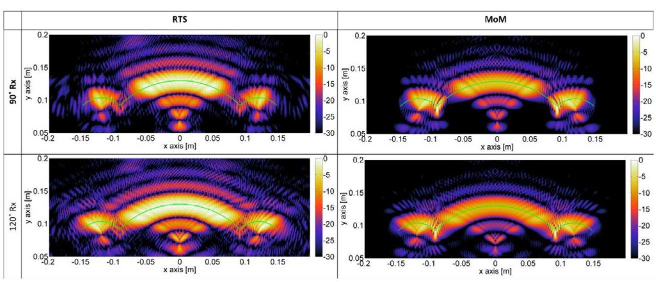
Computational Results



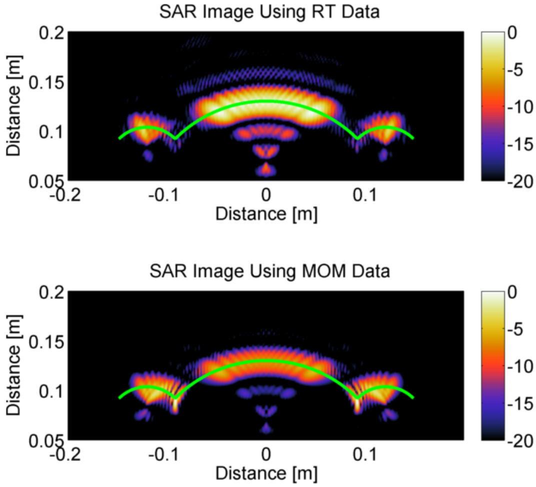
36

Computational Results



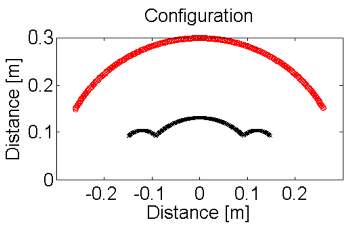


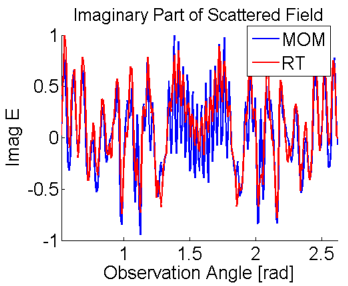
37

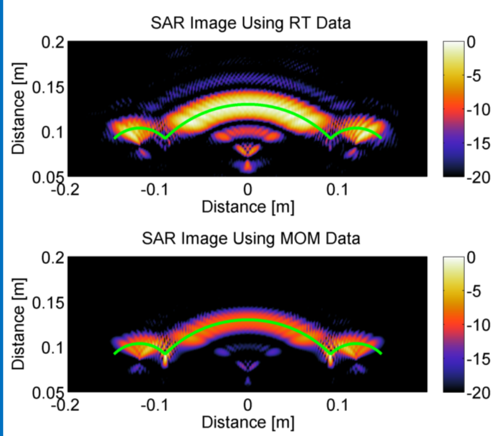


38

Computational Results

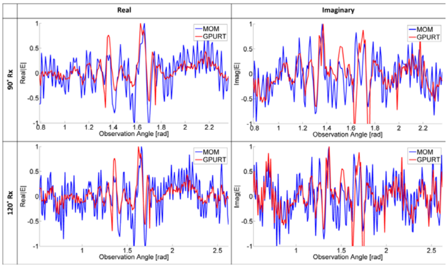


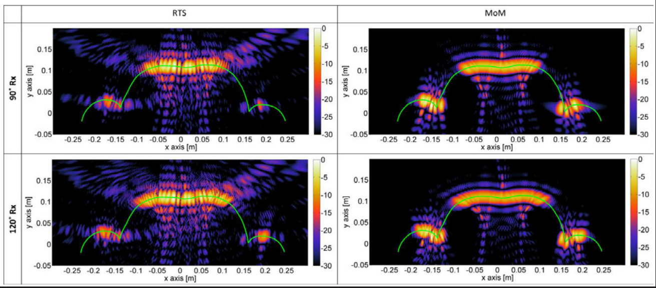




39

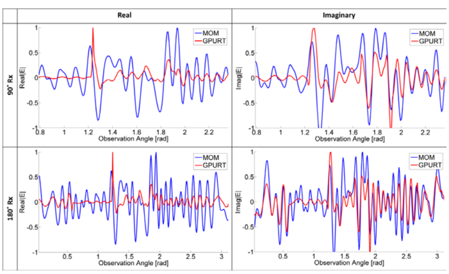
Computational Results

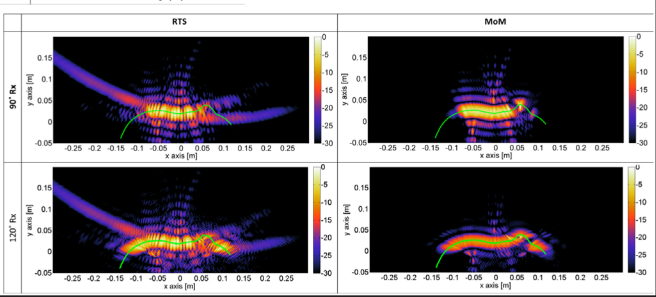




40

Computational Results





41

Computational Time

	Parameters			Time		
	# Freq	# Bins in Azimuth	# Bins in Height	RT Time (s)	MECA Time (s)	Factor Speedup (for these case only)
Case A	16	654	417	**0.8843**	**5136**	**5808**
Case B	32	654	417	**0.9707**	**10272**	**10581**
Case C	16	654	1	**0.7970**	**13.68**	**17**
Case D	32	654	1	**0.8117**	**27.36**	**33**

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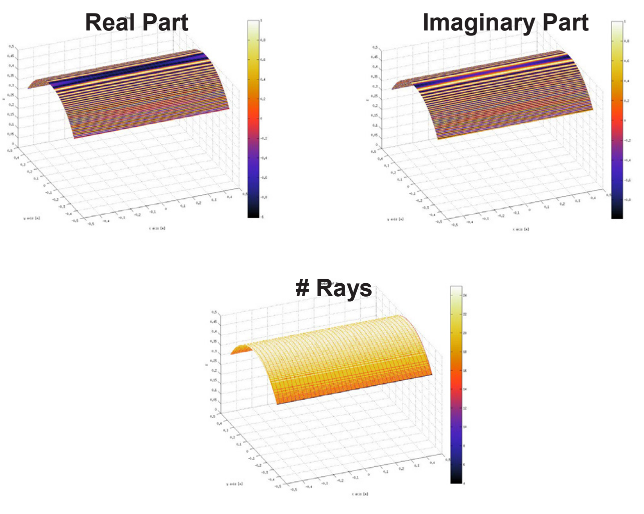
Visualization of Results: 1cm Plate



Computational Results: Template

43

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44

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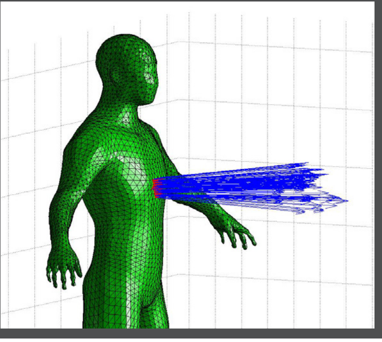

45

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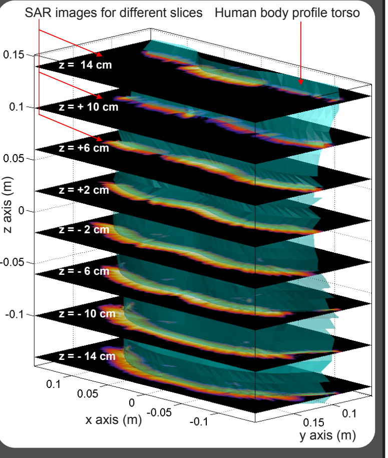
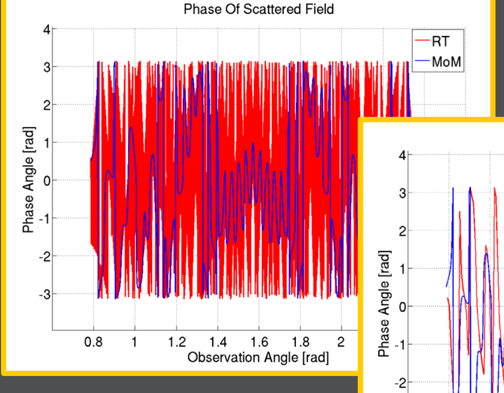


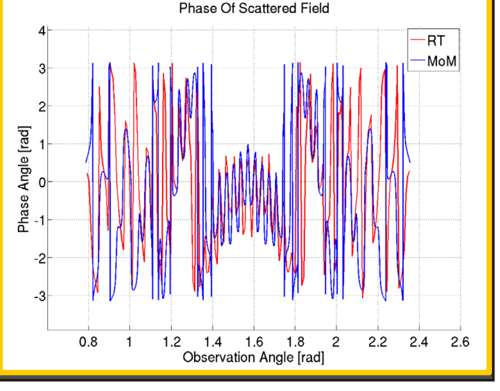
48

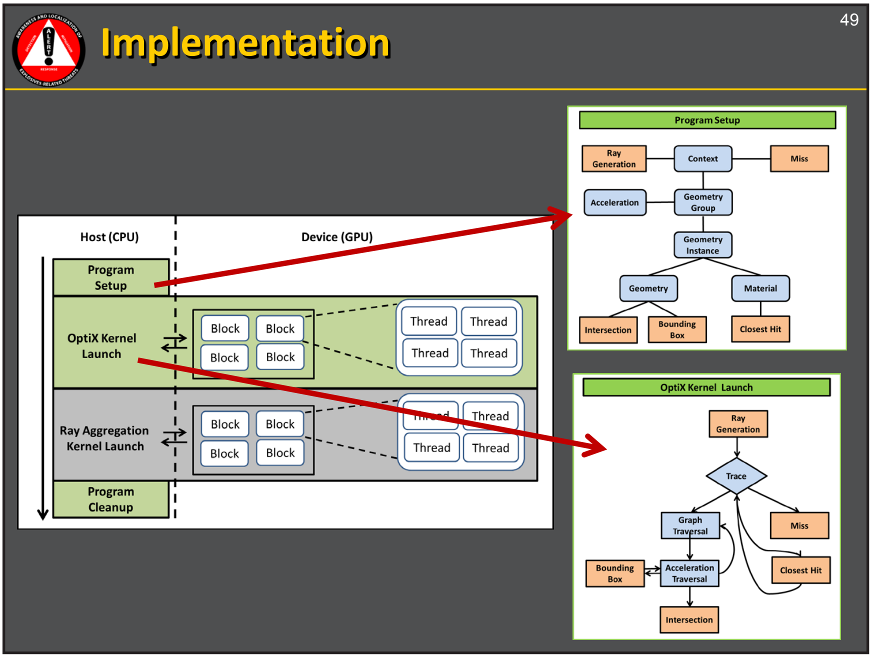
Ray Aggregation: Sample Data

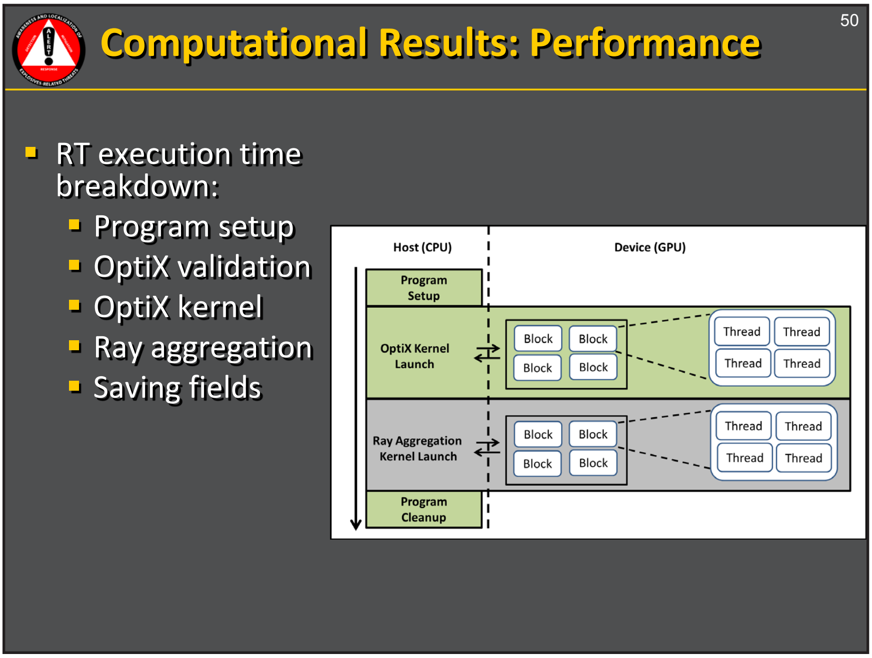
Not aggregated



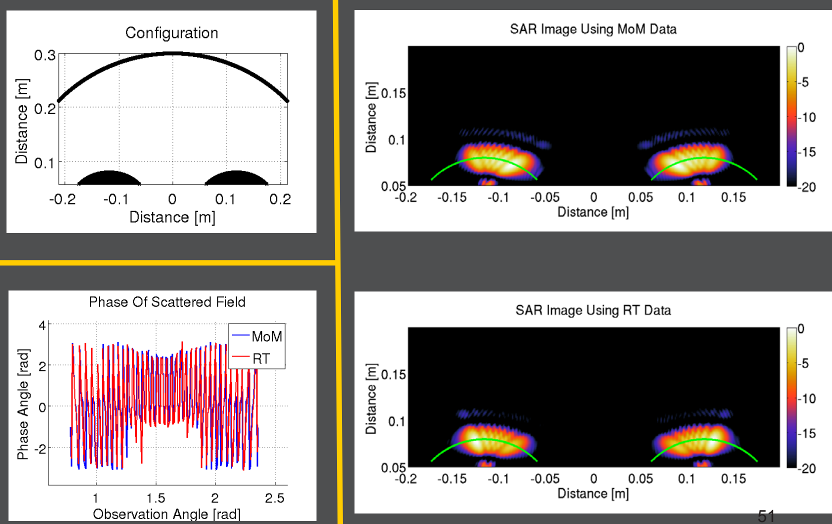
Aggregated




49
Implementation
Host (CPU)
Device (GPU)
Program Setup
OptiX Kernel Launch
Block
Block
Block
Block
Thread
Thread
Thread
Thread
Ray Aggregation Kernel Launch
Program Cleanup
Program Setup
Ray Generation
Context
Miss
Acceleration
Geometry Group
Geometry Instance
Geometry
Material
Intersection
Bounding Box
Closest Hit
OptiX Kernel Launch
Ray Generation
Trace
Graph Traversal
Miss
Bounding Box
Acceleration Traversal
Closest Hit
Intersection

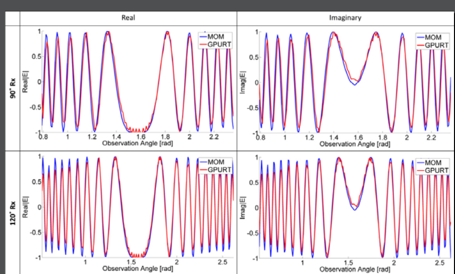

50
Computational Results: Performance
RT execution time breakdown:
Program setup
OptiX validation
OptiX kernel
Ray aggregation
Saving fields
Host (CPU)
Device (GPU)
Program Setup
OptiX Kernel Launch
Block
Block
Block
Block
Thread
Thread
Thread
Thread
Ray Aggregation Kernel Launch
Program Cleanup

Computational Results: 2D Legs

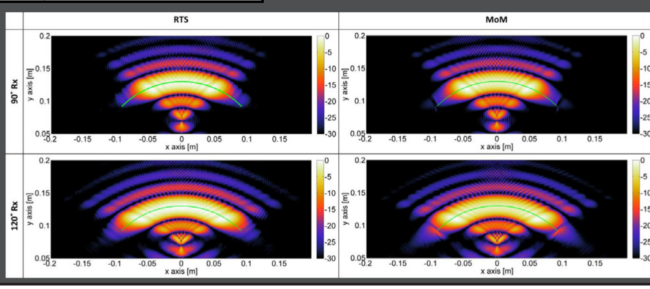


Computational Results

52

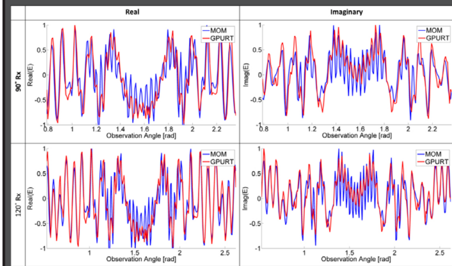


Facets: 80
Rays: 3072
Receivers Bins: 199/266

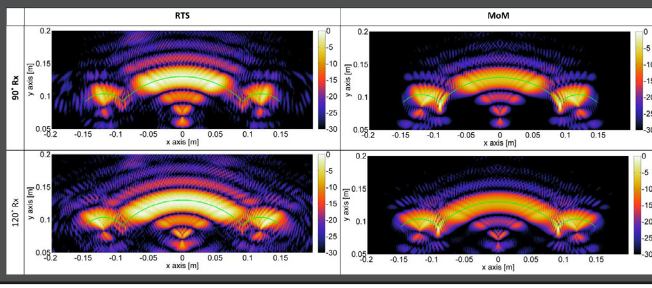


53

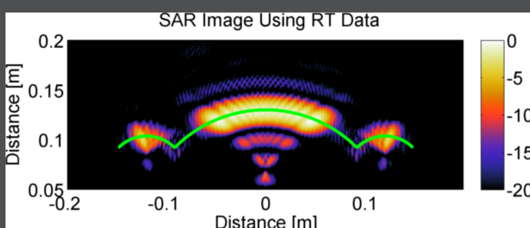
Computational Results

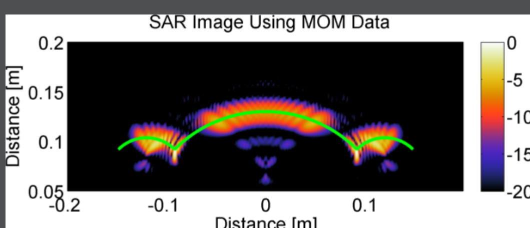


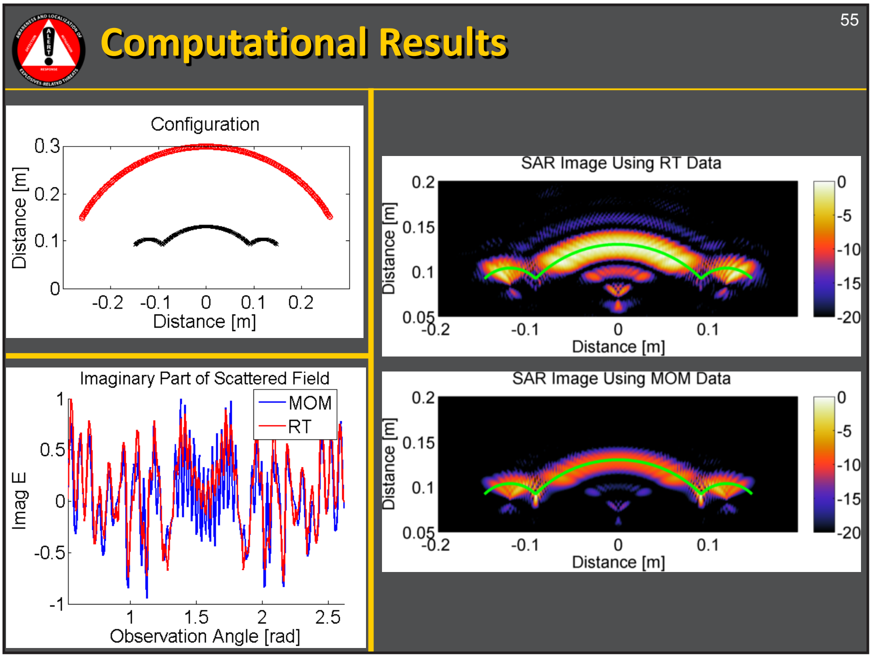
Facets: 134/134
Rays: 3072
Receivers Bins: 199/266

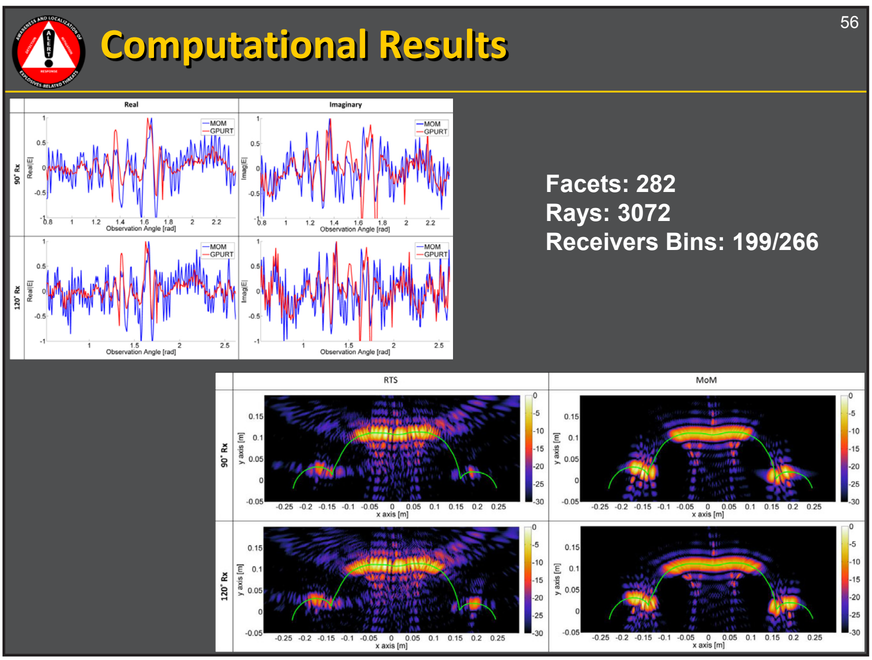


54






55
Computational Results
Configuration
Distance [m]
Distance [m]
Imaginary Part of Scattered Field
MOM
RT
Imag E
Observation Angle [rad]
SAR Image Using RT Data
Distance [m]
Distance [m]
SAR Image Using MOM Data
Distance [m]
Distance [m]


56
Computational Results
Real
Imaginary
MOM
GPURT
Observation Angle [rad]
90° Rx
120° Rx
Facets: 282
Rays: 3072
Receivers Bins: 199/266
RTS
MoM
y axis [m]
x axis [m]

Computational Results

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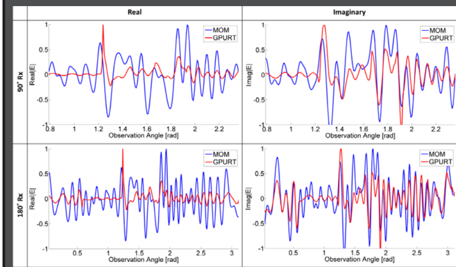
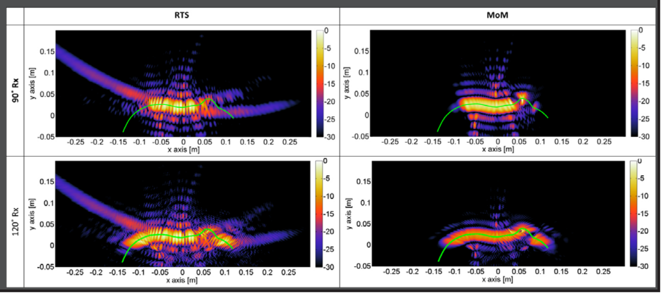


Facets: 126
Rays: 131,072
Receivers Bins: 199/389



Computational Time

58

	Parameters			Time		
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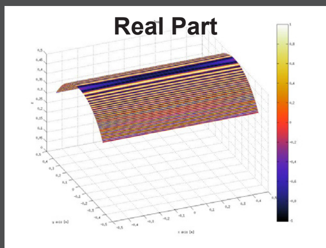
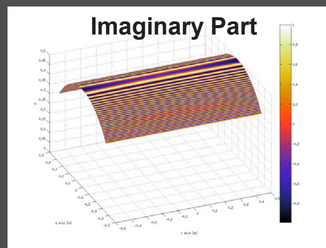
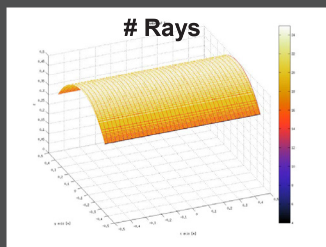
Visualization of Results: 1cm Plate





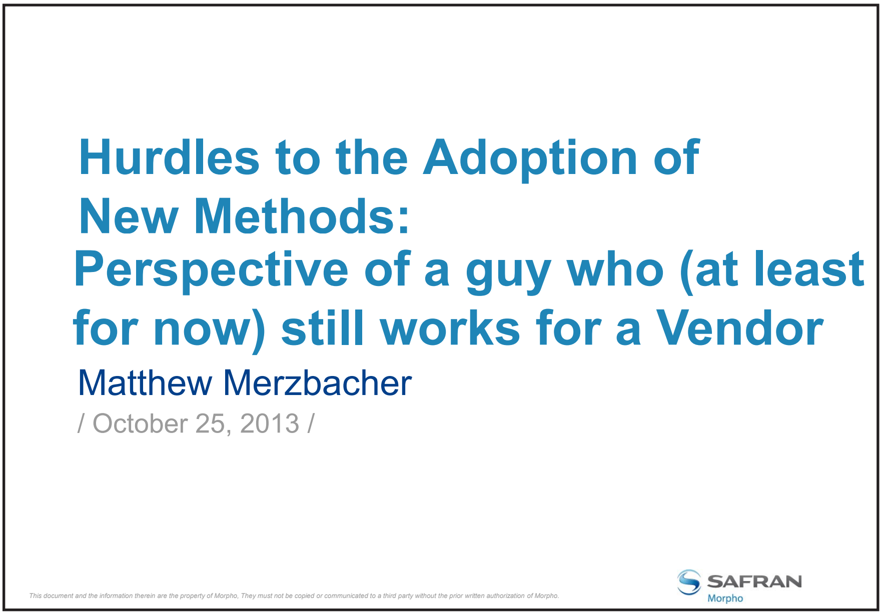
Facets: 80,000
Rays: 2048 x 2048
Receivers:

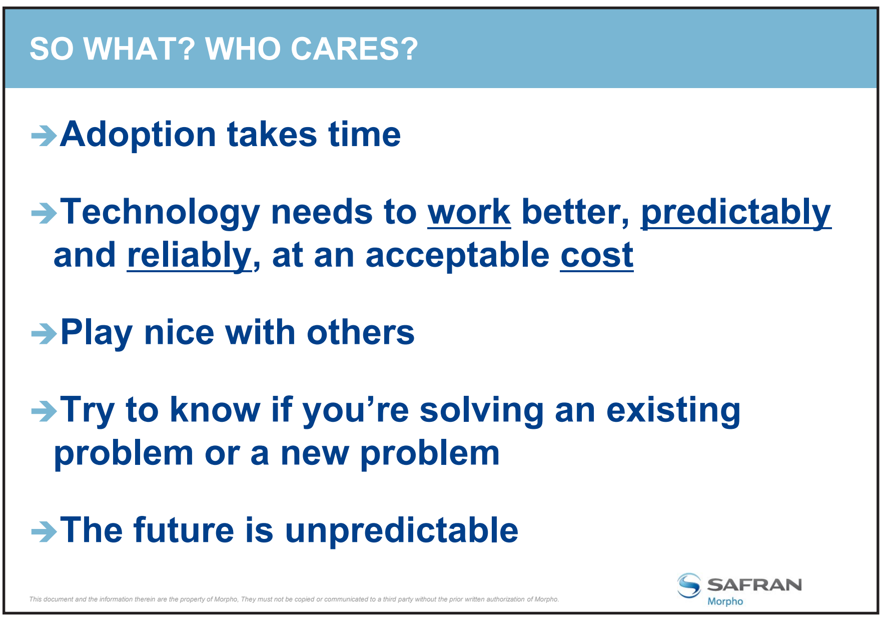


60

Computational Results: Template

17.20 Matthew Merzbacher: Hurdles to the Adoption of New Methods





QUESTIONS THAT CARL SUGGESTED

- Why is transmission x-ray (CT + TRX) the primary mode of inspecting checked baggage a[illegible]d items at the check point?
- Why is XRD not more widely deployed in the United States?
- What happened to NQR?
- What is wrong with XBS AIT?
- How does testing (e.g., cert, CRT, qualificati[illegible]nology?
- How to address marketing (ie, po[illegible] vendors?
- How can technologies b[illegible] cycle to determine if they have value?
- What happen[illegible]e detection requirement specs?
- Wh[illegible]s it work?
- [illegible]deployment of new technologies?
- Is [illegible]
- How [illegible]A procurement strategies affect which technologies are chosen?
- Are life-cycle costs a factor?
- How should new technologies be fused with extant technologies?

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ADAM SMITH'S OCTANT

- **Academia**
  - Educate Students
  - Publish Research
  - Drive knowledge frontier
- **Vendors**
  - Make Improvements
  - Sell Products
  - Drive technological frontier
- **Customers**
  - Use
  - Buy
  - Avoid all frontiers

To Understand the Future, Study the Past

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CASE HISTORIES

- **Mouse**
  - Early adoption in 1984
  - Full adoption in 1995
  - Introduced in 1963
- **Tablet**
  - Early adoption in 2007
  - Full adoption in 2010
  - Introduced in in 1984
- **Internet**
  - Early adoption in 1979
  - Broad adoption in 1995
  - Introduced in in 1969
- **Fax Machine**
  - Invented in 1843
- **Internal Combustion Engine**
  - Broad adoption in 1913
  - Invented in 1870
- **Phonograph**
  - Invented in 1877
  - Mass wax cylinders in 1880s
  - Improved to platters in 1910s
  - Broad adoption in 1940s
  - Cassettes/8-Tracs/CDs in 1960s
  - Digital "MP3" invented in 1970s
  - Broad adoption in late 1990s
- **Velcro**
  - Invented in 1941

MORE CASE HISTORIES

- **Doorknob**
  - 1878
- **Magnetic (**
  - 1600 (G
  - 1040 (C
- **Timezone**
  - 1880 - [
- **Self-Servi**
  - 1916
  - Benefit
- **Bag Balm**
  - For soo
  - For mal

WHY DOES TECHNOLOGY GET ADOPTED? "THE BIG 10 REASONS"

- **It doesn't cost too much**
  - Procurement
  - Operation
  - Maintenance
  - Replacement
- **It doesn't break**
- **It works**
  - Better than what was before (in both reality & perception)
  - Testable & understandable
  - For multiple environments
- **It plays nice with existing systems**
  - Space & Performance
- **It does no harm**
  - No added corner cases
  - No new costs, training, expertise
  - Health
  - Privacy
  - Operational
  - In both reality & perception
- **It should work (better) in the future**
- **It doesn't cost too much**
- **It works**
- **It doesn't cost too much**

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BUILD A REALISTIC SCORECARD

Technology	Cost	Reliability	Play Nice	Works	Future	Do No Harm
CT (HBS)						
CT (CBS)						
SV X-Ray						
MV X-Ray						
XRD						
QR						
mmW (AIT)						
XBS (AIT)						
Neutron						
Your Solution						
Doing Nothing						

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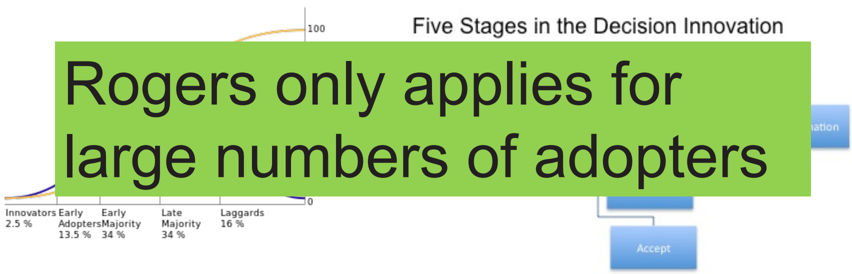
A WORD ABOUT THE "ROGERS CURVE"



Rogers only applies for large numbers of adopters

Five Intrinsic characteristics of innovations that influence decision to adopt or reject:
Relative Advantage, Compatibility, Complexity/Simplicity, Trialability, Observability

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WHAT CAN BE DONE TO PAVE THE WAY?

→ **Adoption of new technology takes time**
- Maybe 30 years

→ **Worry about the "Big Ten" early**
- It needs to work better, predictably and reliably, at an acceptable cost

→ **Try to know if you're solving an existing problem or a new problem**
- But be flexible in your answer – you may solve a problem that you don't even know exists

→ **Unless you're in a new game, play nice with others**
- If you're in a new game, play nice with others

→ **Lastly, a word about the future…**
- Good luck predicting it

Engineering is Science… that works

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17.21 Harry Martz: What's the Problem with Neutrons for Explosive Detection?

Using Neutrons to Screen for Explosives

Presented to
ADSA09

on October 22, 2013

Harry E. Martz, Jr., Ph.D.

Lawrence Livermore National Laboratory

LLNL-PRES-645175

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Summary

- Several neutron-based explosives screening systems (many of which I do not have time to discuss) have been investigated
- They have major technical limitations in either
  - Depth of penetration in large cargo and/or
  - Ability to detect a particular explosive class
- Furthermore most have practical limitations including
  - Large size and weight for accelerator/large radiation shielding
  - Regulatory and safety issues associated with neutron-based technologies
- Given this they have not been able to compete with X-ray-based technologies

P. Griffin, et al., Assessment of the Practicality of Pulsed Fast Neutron Analysis for Aviation Security, NAP, 2002.

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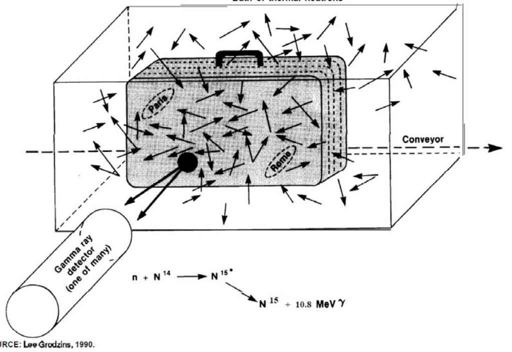
Agenda

- Summary
- Neutron physics and operation of
  - TNA
  - FNA
  - PFNA
- Summary

Thermal Neutron Analysis—TNA Physics

Figure A-I—Sketch of Apparatus for Thermal Neutron Analysis of Nitrogen



SOURCE: Lee Grodzins, 1990.

TNA measures nitrogen via thermal neutron capture gamma rays

Summary of SAIC TNA machine airport deployments

- Under a contract awarded to SAIC in 1985, the FAA purchased six TNA machines to detect plastic explosives
- The six TNA machines needed to be combined with X-ray unit and were called XENIS—X-ray Enhanced Neutron Interrogation System
- Four were installed at
  - JFK
  - Dulles
  - Miami
  - Gatwick

Report to the President by the President's Commission on Aviation Security and Terrorism May 15, 1990*

- Commission began November 1989
- Charges
  - Evaluate existing aviation security systems
  - Options for handling terrorists threats
  - Treatment of families of victims of terrorists acts
  - Pan Am 103 tragedy (Dec 1988) was a point of reference
  - Findings with respect to the deployment of Thermal Neutron Analysis (TNA)
- Report completed May 1990

* http://books.google.com/books?id=PU2gl3TwFQ4C&pg=PA65&lpg=PA65&dq=Why+did+TNA+failed+to+detect+explosives+at+JFK&source=bl&ots=-3SBh9eqMi&sig=Yg13YThvRbXAZL9wud_XE4xwb5o&hl=en&sa=X&ei=cfdSUq-nl8mCygH4gYHgCw&ved=0CCsQ6AEwAA#v=onepage&q=Why%20did%20TNA%20failed%20to%20detect%20explosives%20at%20JFK&f=false

Commission's TNA machine findings and recommendations

- Findings
  - Under a contract awarded to SAIC in 1985, the FAA purchased six TNA machines to detect plastic explosives
  - These machines by design and performance detected only amounts far greater than the weight used by terrorists
    - For example the bomb that destroyed Pan Am 103 is believed to have weighed half or less than the amount than the TNA machine would reliably detect
  - They were not fully automated
  - The TNA/XENIS machine is massive, weighing close to 14 tons and a footprint for the TNA alone is about 12 m^2, and an additional equivalent area would be needed to add an x-ray system and baggage diverter* NAP: TNA weighted 28,000 lbs., required 41-m^2 and cost $1.4M & $0.7M operational cost/yr.
  - For threat masses of concern the false alarm rates are too high
- Recommendation
  - The program to require US airlines to purchase and deploy ~150 existing TNA machines should be deferred.
  - The FAA should create an R&D program to detect small amounts of plastic explosives.

Given the large false alarms for TNA machines other neutron based methods were explored

* http://www.skyjack.co.il/pdf/Thermal-Neutron-Analysis.pdf

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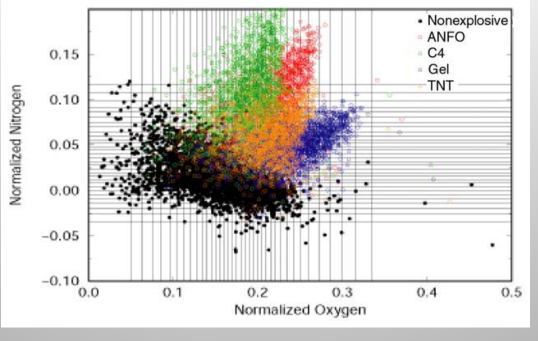
Oxygen vs. Nitrogen signatures

38,000 Pulsed Fast Neutron Transmission Spectroscopy (PFNTS) measurements from actual airline suitcases, with and without explosives



From Chmelik, et al., Analysis of Blind Tests for Explosives in Luggage Through Fast-Neutron Transmission Spectroscopy, 1997.

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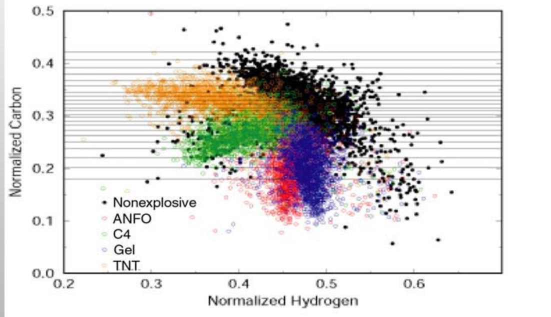
Hydrogen vs. Carbon signatures

38,000 Pulsed Fast Neutron Transmission Spectroscopy (PFNTS) measurements from actual airline suitcases, with and without explosives



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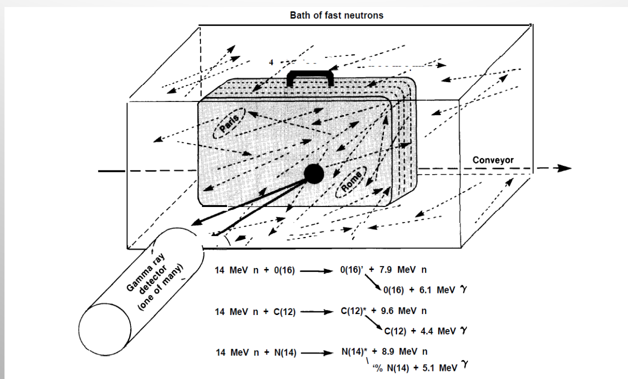
Fast Neutron Analysis–FNA Physics



SOURCE: Lee Grodzins, 1990.

FNA measures gamma rays via fast neutrons inelastically scattered off of C, O and N

Summary of Fast Neutron Analysis—FNA

- FNA can measure more than just N so it should improve detection while reducing false alarms
- FNA is physically similar to TNA but there are significant differences in the neutron source, shielding requirements and gamma-ray detector resulting in an increase in cost size and weight
  - A fast neutron source requires an accelerator, e.g., $^{2}H(d,n)^{4}He$
  - Requires more shielding
- The fast neutrons create a lot of background in the gamma detectors
- 2D images were generated by collimation of the neutron beam
- 2D image is not good enough to sort threats from non-threats just using the atomic ratio features

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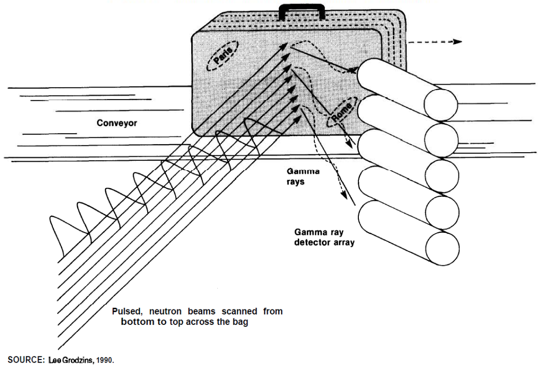
Pulsed Fast Neutron Analysis—PFNA

Figure A-3-Sketch of Apparatus for Pulsed Neutron Beam Analysis



SOURCE: Lee Grodzins, 1990.

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Summary of Pulsed Fast Neutron Analysis—PFNA

- PFNA concept is similar to the FNA concept except that a focused collimated, pulsed beam of neutrons is used
- A lower energy neutron beam accelerator, $^{2}H(d,n)3H,e$ is used since it generates less background in gamma detectors
- The collimated neutron beam provides two-dimensional position
- Timing and image reconstruction provides the third dimension
- The 3D image provides an improvement over the FNA data but with large isotropic voxels 5 cm x 5 cm x 5 cm
- A prototype system to look at LD-3 containers was not very promising it had PD and PFA issues*:
  - Can't see zone
  - Cannot detect a particular class of explosives
- An SAIC system built to screen cargos for large threat masses in cargo
- The system is much larger than a TNA system

* C. Bell and D. Green, Pulsed Fast Neutron Analysis (PFNA) October 2000 Test Overview, viewgraphs presented to NAS PFNA study Panel, Jan, 2001.

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Schematic of PFNA for cargo inspection

D.R. Brown, T. Gozani / Nucl. Instr. and Meth. in Phys. Res. B 99 (1995) 753–756

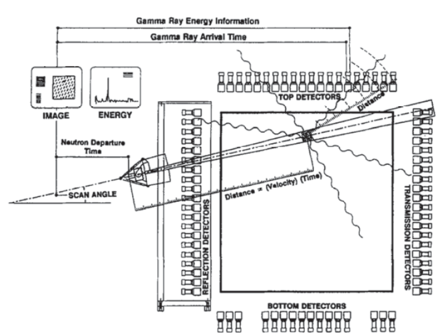

Fig. 1. Schematic view of the cargo inspection system based on PFNA.

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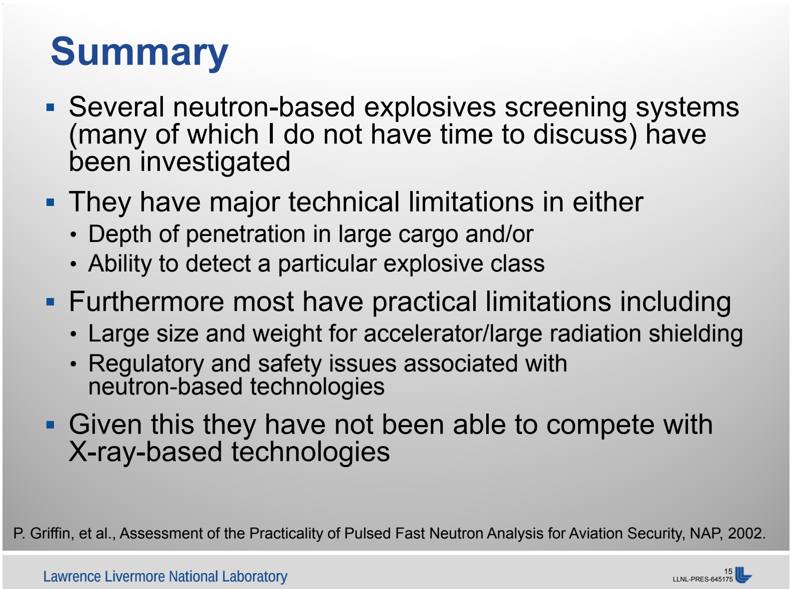
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Furthermore most have practical limitations including
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17.22 George Zarur: Apples to Apples Discussion of Emerging Technologies

1

AVIATION SECURITY
EMERGING TECHNOLOGIES

DRIVERS FOR INNOVATION

DYNAMIC THREAT SPACE

EARLY STAGES MILITARY AND COMMERCIAL EXPLOSIVES

SUBSEQUENT INTRODUCTION

HOME MADE EXPLOSIVES, SOLIDS AND LIQUIDS

DYNAMIC CONCEALMENT

PAN AM 103 CHECKED LUGGAGE

PERSON BORNE THREATS (CHECHEN WIDOWS)
SHOE BOMBER
UNDERWEAR BOMBER
PRINTER CARTRIDGE

DETECTION TECHNOLOGY ACQIUISITION AND DEPLOYMENT

POST INCIDENT

DIFFICULT TO PREDICT FUTURE INCIDENTS

SPECIAL CASE WHERE AN EFFECTIVE SOLUTION WAS DEVELOPED AND SUCCESSFULLY DEPLOYED USED TO DETECT INGESTED NARCOTICS BASED ON TRANSMISSION XRAYS

VERY EFFECTIVE AGAINST INTERNAL THREAT CONCELAMENT BUT UNLIKELY TO BE DEPOYED EXCEPT FOR EXTREME CONDITIONS- CONSIDERABLE HEALTH AND SAFETY AND PRIVACY OPPOSITION. DEPLOYED IN OTHER COUNTRIES.

THE SECOND CRITICAL DRIVER FOR NEW TECHNOLOGY

ECONOMICS AND TOTAL COST OF OWNERSHIP.

ONLY RECENTLY HAS ATTENTION BEEN FOCUSED ON EXTENSIVE LABOR COSTS

CONSUMABLES SUCH AS SWABS FOR TRACE, NOT A SGINIFICANT FACTOR BUT LABOR IS.

2

EXAMPLE OF LABOR COSTS

TSA DATA FEDERAL REGISTER

Year	Passenger Opt Outs	Industry Utilities	TSA Costs				Total
			Personnel	Training	Equipment	Utilities	
2008	$7.0	$5.7	$14,689.1	$389.5	$37,425.2	$18.8	$52,535.3
2009	$32.2	$5.7	$15,618.6	$88.0	$42,563.6	$20.4	$58328.5
2010	$262.2	$158.2	$247,566.7	$5,332.8	$119,105.4	$241.4	$372,666.6
2011	$1,384.2	$186.7	$284,938.7	$15,354.4	$55,567.2	$269.1	$357,700.2
Total	**$1,685.6**	**$356.3**	**$562,813.0**	**$21,164.7**	**$254,661.3**	**$549.6**	**$841,230.6**

LABOR COSTS ASSOCIATED WITH RESOLVING FALSE ALARMS AT CHECKPOINT AND FOR CHECKED LUGGAGE ARE ESTIMATED TO BE SIMILAR IF NOT EXCEED.

AT SEVERAL HUNDRED MILLION DOLLARS PER YEAR IN LABOR COSTS, THE PROMISE OF SAVINGS THRU IMPROVED OR INNOVATIVE TECHNOLOGY IS CONSIDERABLE

3

TECHNOLOGY INNOVATIONS

CHECKED LUGGAGE EDS

ALTERNATIVE DESIGN NON ROTATING GANTRY MADE POSSIBLE BY RECENT ADVANCES IN ITERATIVE RECONSTRUCTION WHEREAS THE CONVENTIONAL WISDOM CALLED FOR 700 TO 1000 VIEWS, IT SEEMS THE LESS THAN 100 WOULD BE ADEQUATE. SYSTEMS WITH NOVELIGNS ARE VERY PROMSING AND NEAR CERTIFICATION.
THIS IS A TRANSFER FROM MEDICAL APPLICATIONS

NOVEL XRAY SOURCES ALLOW FOR NEW EDS DESIGNS
TRIPLE RING SOURCES, XINRAY CARBON NANOTUBE SOURCES

NOVEL COHERENT SCATTER SYSTEMS AND NON ROTATING GANTRY EDS HOLD PROMISE FOR CONSIDERABLY LOWER FALSE ALARM RATES, HIGH TRHOUGHPUT AND LOWER MAINTENACE COSTS OVER TRADITIONAL ROTATING GANTRY SYSTEMS.

MULTI ENERGY DETECTORS HAVE YET TO PROVE VALUE BUT CAN SEE INCREASING USE (REDLEN AND MULTIX)

TIME FRAME 1 TO 3 YEARS.

CHECKPOINT SYSTEMS.

SLOWLY DESKTOP CT SYSTEMS ARE BECOMING COMERCIALLY AVAILABLE AND MAY FIND A REPALCEMENT NICHE TO DEPLOYED TRACE SYSTEMS. THESE SYSTEMS ARE NOW DEPLOYED IN EUROPE AND ARE VERY EFFECTIVE FOR LIQUID SCREENING AND
4

APPLICABLE TO FALSE ALARM RESOLUTION AT CHECKED LUGGAGE AS WELL.
S&T HAS AN ACTIVE PROGRAM IN THIS AREA.

ALTHOUGH BACKSCATTER XRAY HAS FAR BETTER RESOLUTION

THAN COMPETING MMWAVE PORTALS, BACKSCATTER FAILED

DUE TO LACK OF EFFECTIVE AUTOMATED ALGORTIHM

CAUSED BY THE PUBLIC PRESSURE OF THE RAW BACKSCATTER

IMAGES PUBLICIZED IN EARLY STAGES.

BACKSCATTER IS BY NO MEANS RULED OUT, THERE MIGHT BE SOME DEPLOYMENT IN THE FUTURE.

HIGHER FREQUENCY MMWAVE AND THZ SYSTEMS ARE BEING DEVELOPED WITH PROMISE OF HIGHER RESOLUTION, SHARPER IMAGES AND GREATER ATR ACCURACY (RHODES AND SCHWARTZ IN GERMANY, NOVATRANS IN ISRAEL)

DESIRABLE FEARTURES, FASTER THROUGHPUT (240 PASSENGERS PER HOUR) WALK THRU INSTEAD OF STOP AND IMAGE.

AT XRAY SYSTEMS WERE ACQUIIRED AND DEPLOYED AS A RESPONSE TO THE LIQUID PLOT IN THE UK, THE PREVIOUSLY DEPLOYED SINGLE VIEW TRX SYSTEMS WERE UNABLE TO PROVIDE SUFFICIENT INFORMATION TO DETERMINE DENSITY
5

WITH ACCURACY ENOUGH TO DISTINGUISH LIQUID THREATS FROM COMMON ITEMS.
THE initial SELCTION WAS FOR THE 4 VIEW STEM BUT EVENTUALLY 2 AND 3 VIEW SYSTEMS WERE DEPLOYED.
THE DRAWBACK WAS THE CONTINUED REQUIREMETNS TO DIVEST, LIQUIDS AND LAPTOPS.

NOVEL XRAY SOURCES MAY EXPLOIT THE NEW XRAY SOURCES TO DEVELOP AT ARCHITECTURE WITH MANY VIEWS, 100 OR HIGHER RESULTING IN SUFFICIENT INFORMATION WHICH WHEN COUPLED WITH ITERATIVE RECONSTRUCTION CAN PROVIDE CT QUALITY SCREENING (XINRAY HAS DEVELOPED PROTOTYPES UNDER DHS SPONSORSHIP
OTHER SMALL FOOTPRINT CT SYSTEMS WHICH FIT IN THE HEIGHT, WEIGHT AND FOORTPRINT REQUIREMETNS ARE BEING DEVELOPOED BY IDSS.
THESE NOVEL CT EDS SYSTREMS WOULD PERMIT PASSENGERS TO STOP DIVESTING LIQUIDS AND LAPTOPS AT CONSIDETRABLE SAVINGS IN LABOR.

STANDOFF SCREENING AT MASS TRANSIT OR AIRPORT ENTRY CONTINUES TO BE A CHALLENGE.

EFFECTIVE SHOE SCANNERS TO ALLOW PASSENGERS TO KEEP

SHOES ON REMAINS ELUSIVE.
STANDLONE IS NOT DESIRABLE BUT HAS TO BE INTEGRATED AT the CHECKPOINT WITH AIT PORTALS.

TSA PREFERS INTEGRATED SOLUTIONS RATHER THAN STANDALONE SYSTEMS.

6

THIN PLASTIC THREATS PLACED ON THE BODY IN SELECTED LOCATIONS REMAIN A CHALLENGE TO BE RESOLVED. THIS IS TRUE FOR BOTH BACKSCATTER AND MMWAVE

TRACE SYSTEMS

A NEGATIVE RESPONSE FROM A TRACE SYSTEM IS NOT AN ABSOLUTE INDICATION OF ABSENCE OF A THREAT.
A POSITIVE RESULT HOWEVER IS A CONSIDERABLE CAUSE FOR ALARM. TRACE FALSE ALARMS ARE RELATIVELY LOW AND MOST OFTEN ASSOCIATED WITH NITRATE RESIDUE FROM AGRICULTURAL ACTIVITY.

IT IS NOT ASSURED THAT TRACE WOULD CONTINUE TO BE EFFECTIVE IN AVIATION SECURITY. MOST LIKELY IS THE SOPHISTICATION OF THE NEWER DEVICES AND THE ABILITY TO HERMETICALLY SEALED THE THREAT TO ELIMINATE EXTERNAL RESIDUE OR CONTAMINATION.

IT IS DIFFICULT TO ASSESS THE LEVEL OF CONTAMINATION THAT MIGHT BE EXPECTED, GIVEN THIS FACT, TRACE SYSTEMS WITH MUCH HIGHER RESOLUTION AND LEVELS OF DETECTION ARE BEGINNING TO APPEAR AND MAY REACH DEPLOYMENT IN THE NEAR FUTURE.

IN ADDITION, TWO OTHER DEVELOPMENTS, THE MIGRATION OF MASS SPECTROSCOPY FROM THE LAB TO THE FIELD. AS A DEFINITIVE METHOD MS IS THE GOLD STANDARD OF ANALYTICAL WORK (SYSTEMS BASD ON TIME OF FLIGHT TOF FROM MORPHO AND QUADRUPOLE TRAPS FROM FLIR ARE

7

REACHING CERTIFICATION)

THE OTHER MAJOR AREA OF INNOVATION IS SAMPLE PRESENTATION TO THE INSTRUMENT.
IDEALLY NON CONTACT TRACE IS DESIRABLE, THIS AVOIDS THE SUBJECTIVE METHOD OF MANUAL SWABS AND MANUAL HARVESTING OF RESIDUES.

COSTS ARE MOSTLY LABOR RATHER THAN THE CONSUMABLES.

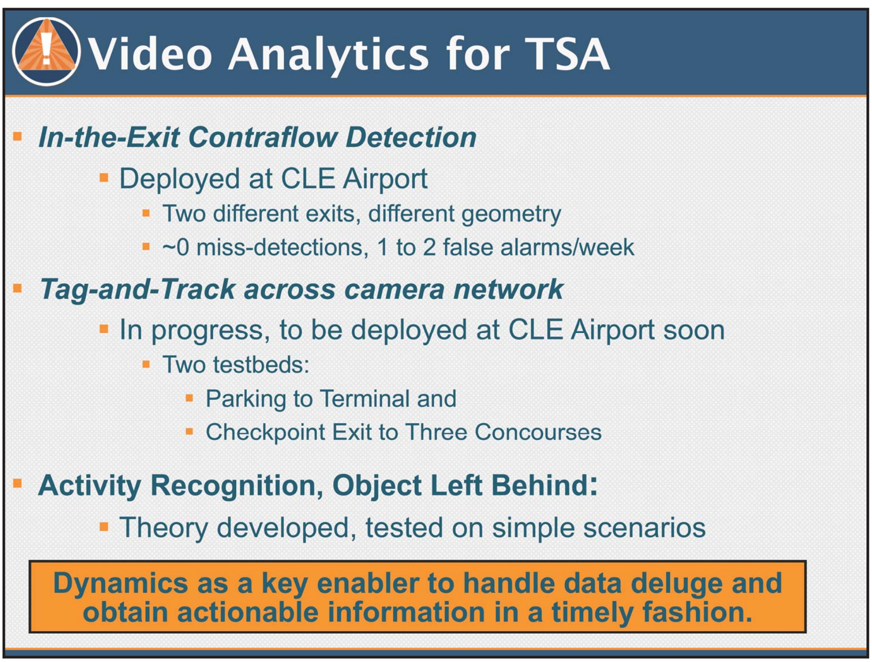
ON THE FAR FIELD DOMAIN, OPTICAL METHODS SHOW PROMISE, THE ABILITY TO SCAN OBJECTS FROM A DISTANCE OF 10 FEET OR HIGHER AND BE SENSITIVE AND SELECTIVE EVEN IN THE PRESENCE OF A LARGE NUMBER OF AMBIENT NUISANCE CHEMICALS.

ISSUES SUCH AS INSPECTION AREA AND RASTER FREQUENCY ARE MAIN OBSTACLES. EYE SAFE LASERS ARE CRITICAL.

THESE SYSTEMS ARE PREFERABLE TO CURRENT METHODS OF SCREENING CARS AND PASSENGERS FROM A DISTANCE. THIS MAYBE A MILITARY AND LAW ENFORCEMENT RATHER THAN AVIATION

IT IS NOT THE ACQUISITION COST, IT IS THE OPERATIONAL AND ASSOCIATED LABOR COSTS.

17.23 Octavia Camps: Where Does Video Analytics Go Next for TSA



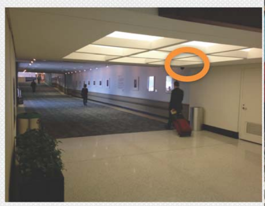
Goals

Image from http://iware.pk/CCTVSystems.aspx

- **Detect Potential Threats & Track Suspects:**
  - Security breaches at portals
  - Track across cameras
  - Disruptive, suspicious behaviors
  - Objects left behind
- **Detect Other Emergencies:**
  - Person falling or hurt
  - Lost child
  - Stolen property
- **Customers:**
  - TSA
  - Law enforcement agencies
  - Sport venues, theme parks, etc.

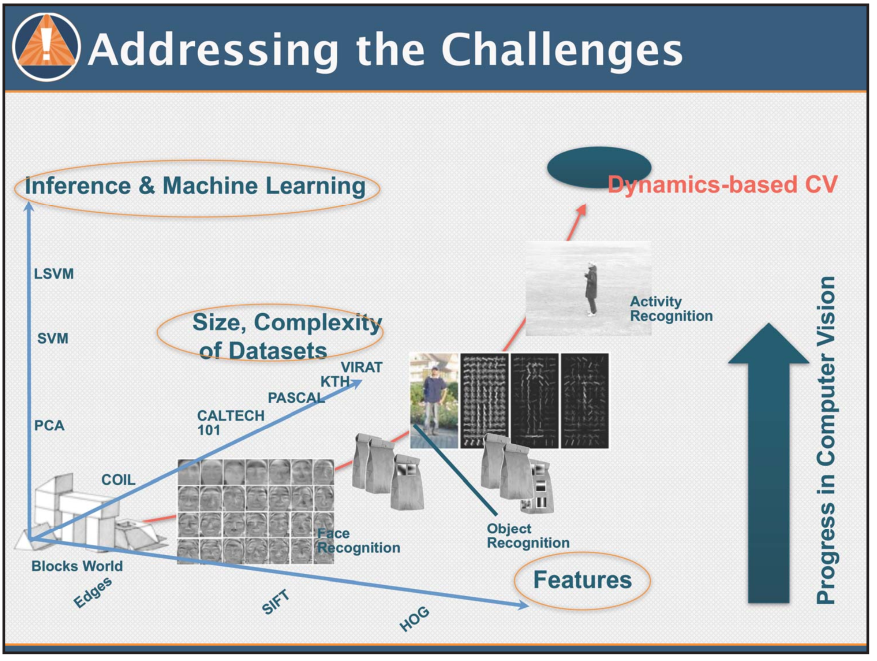
Requirements and Challenges

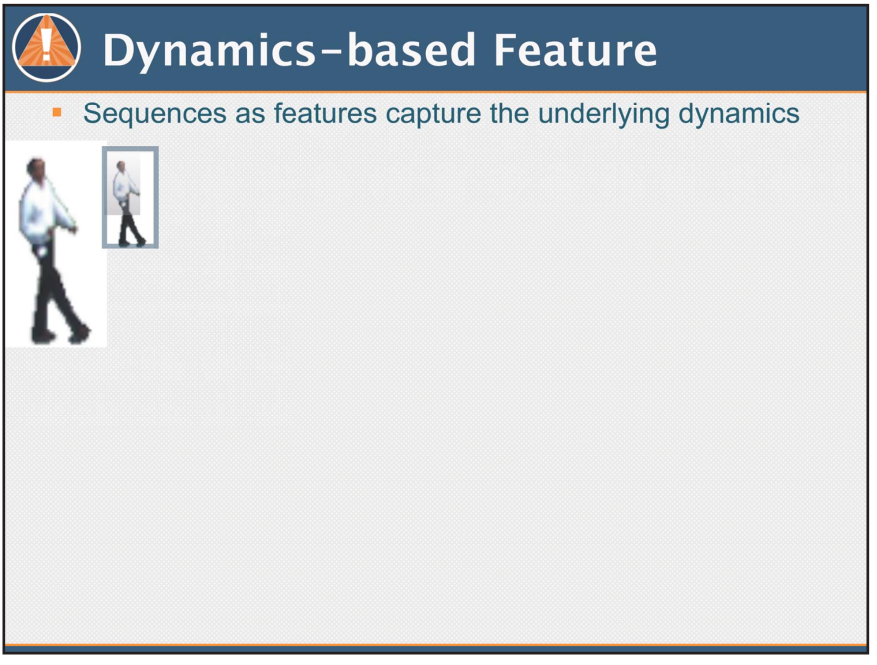
- Infrastructure:
  - Cameras already deployed
    - Security surveillance cameras
    - Citizen's cell phones
  - Video is recorded, not processed
- Performance:
  - 0 misdetections, ~0 false alarms
  - Timely detection: real time processing
- Data Deluge Challenge:
  - Need to process vast amounts of highly complex data
  - Cope with environment, viewpoint, appearance changes
  - Ignore nuisance/clutter data
  - Find actionable/relevant information
  - ➡ Dynamics as key enabler

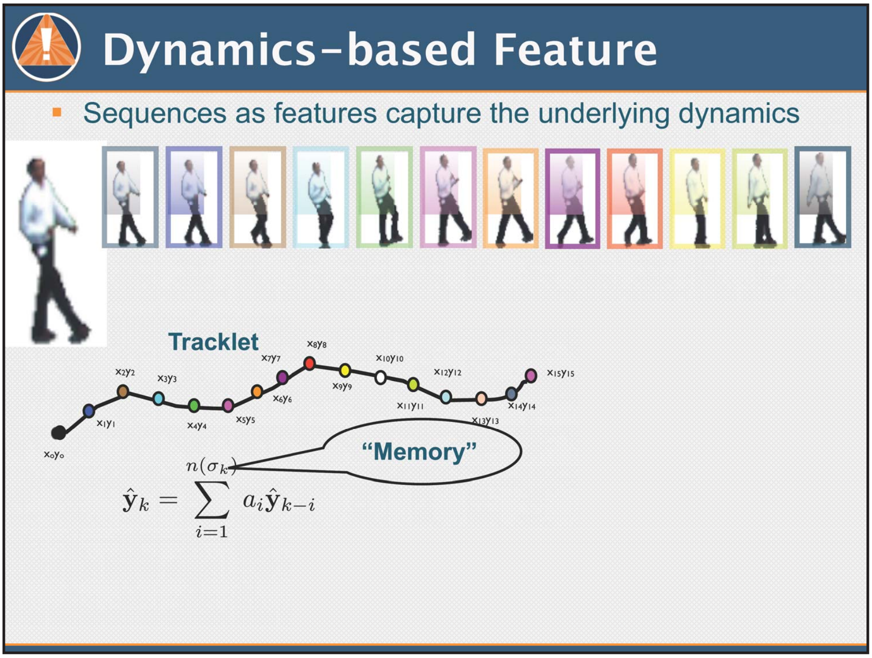


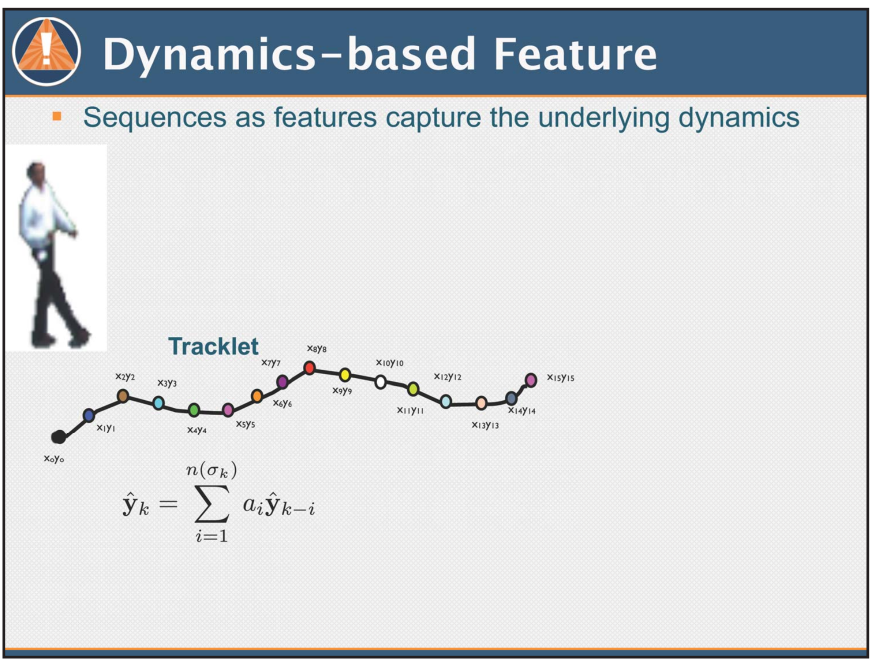
Surveillance camera in an airport.

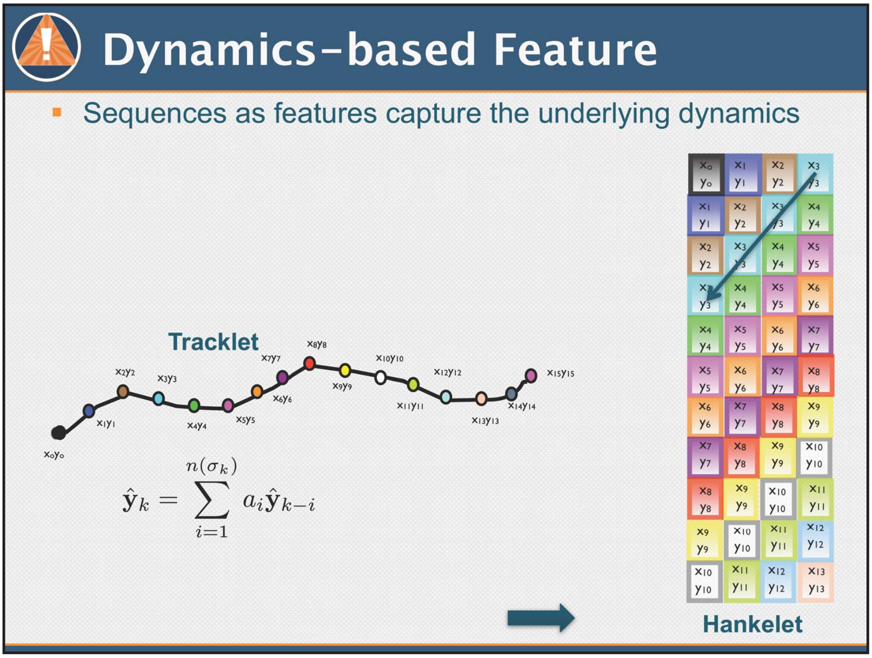
Cell video showed the Boston Marathon Suspect(s)

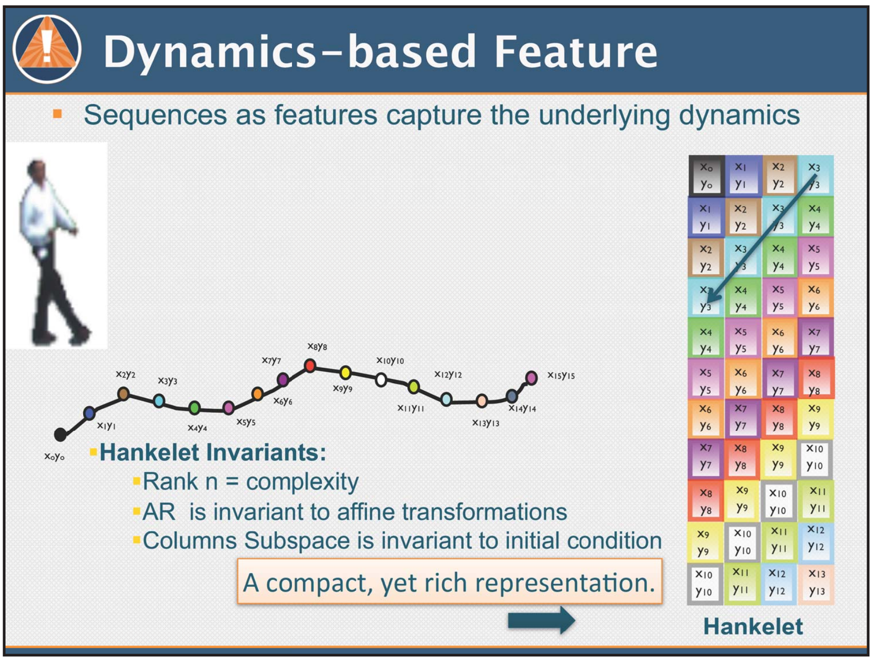

Addressing the Challenges
Inference & Machine Learning
Dynamics-based CV
LSVM
SVM
PCA
Size, Complexity of Datasets
VIRAT
KTH
PASCAL
CALTECH 101
COIL
Activity Recognition
Face Recognition
Object Recognition
Blocks World
Edges
SIFT
HOG
Features
Progress in Computer Vision


Dynamics-based Feature
Sequences as features capture the underlying dynamics


Dynamics-based Feature
Sequences as features capture the underlying dynamics
Tracklet
"Memory"
$\hat{\mathbf{y}}_k = \sum_{i=1}^{n(\sigma_k)} a_i \hat{\mathbf{y}}_{k-i}$

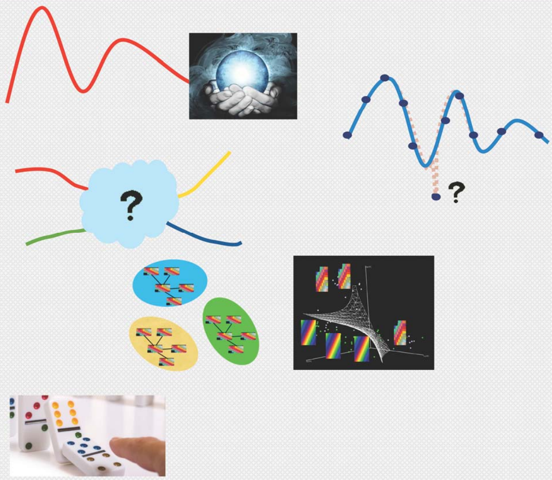

Dynamics-based Feature
Sequences as features capture the underlying dynamics
Tracklet
$\hat{\mathbf{y}}_k = \sum_{i=1}^{n(\sigma_k)} a_i \hat{\mathbf{y}}_{k-i}$


Dynamics-based Feature
Sequences as features capture the underlying dynamics
Tracklet
$\hat{\mathbf{y}}_k = \sum_{i=1}^{n(\sigma_k)} a_i \hat{\mathbf{y}}_{k-i}$
Hankelet


Dynamics-based Feature
Sequences as features capture the underlying dynamics
Hankelet Invariants:
Rank n = complexity
AR is invariant to affine transformations
Columns Subspace is invariant to initial condition
A compact, yet rich representation.
Hankelet

Dynamics-based Inference Methods

- Predict
- Denoise
- Associate data
- Classify data
  - Unsupervised
  - Supervised
- Detect Causality



Rank minimization of a structured Hankelet matrices

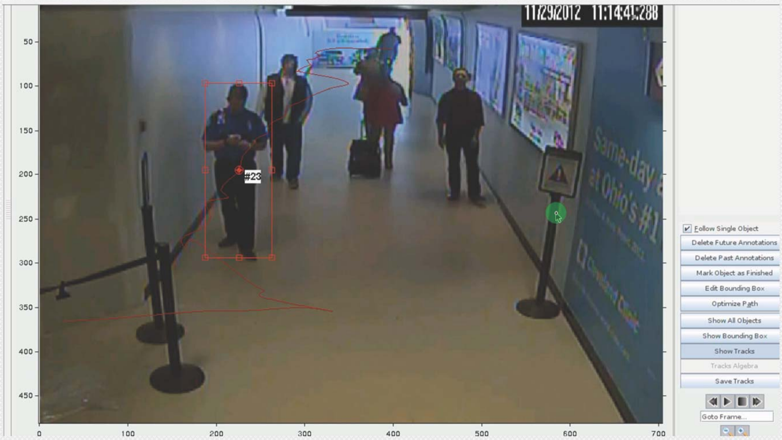
Real Surveillance Data

Partnership with TSA and CLE Airport
- Access to live video:
  - 3 and 2 cameras at two exit lanes
  - 5 cameras from Parking structure to terminal
  - More to come

Collaboration with Siemens Research
- Support recording and accessing video
- Support transition technology to commercial surveillance systems

Semi-automated annotation
- Ease ground-truth annotation of data
  - Location, attributes, Id-across cameras
- Facilitate both training and testing of algorithms

Anchovy



In-The-Exit Contraflow Detection

In-the-exit contraflow:

- Entrance through an airport exit:
  - Security-breach
  - Terminal(s) must be evacuated
  - Flights cancelled, millions of dollars cost

In-The-Exit Contraflow Detection

In-the-exit contraflow:

- Entrance through an airport exit:
  - Security-breach
  - Terminal(s) must be evacuated
  - Flights cancelled, millions of dollars cost

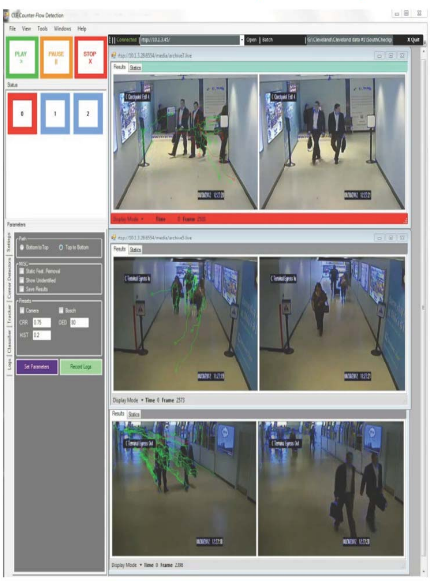
In-The-Exit Contraflow Detection

- Bank of trackers + detection of contraflow motion
  - Real time GPU-based implementation
  - Currently deployed at CLE Airport, running 24/7, two exit lanes
  - Statistics on 10 weeks of video:
    - **628 detections; 0 Miss-detections, 12 False alarms**

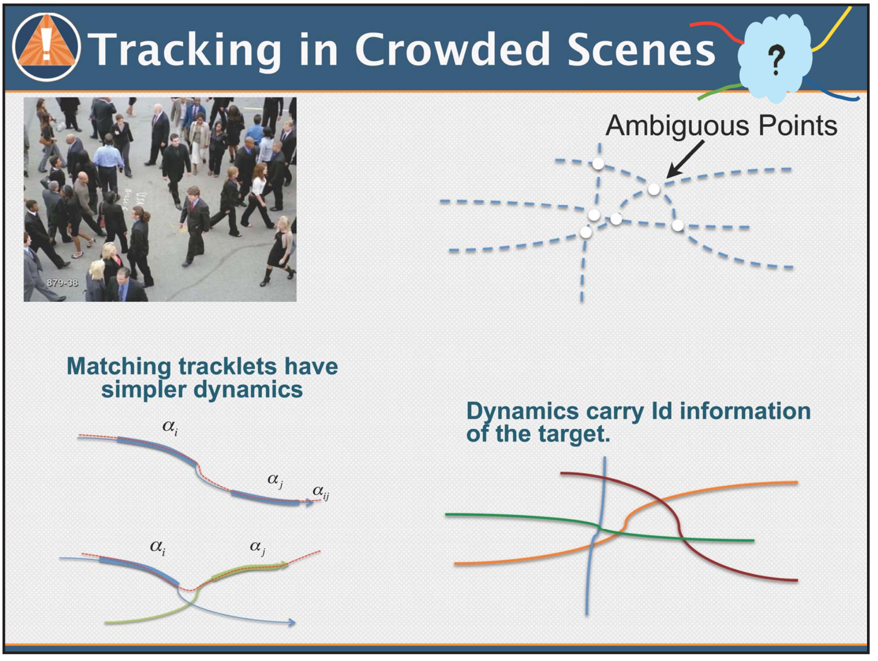
In-The-Exit Contraflow Detection

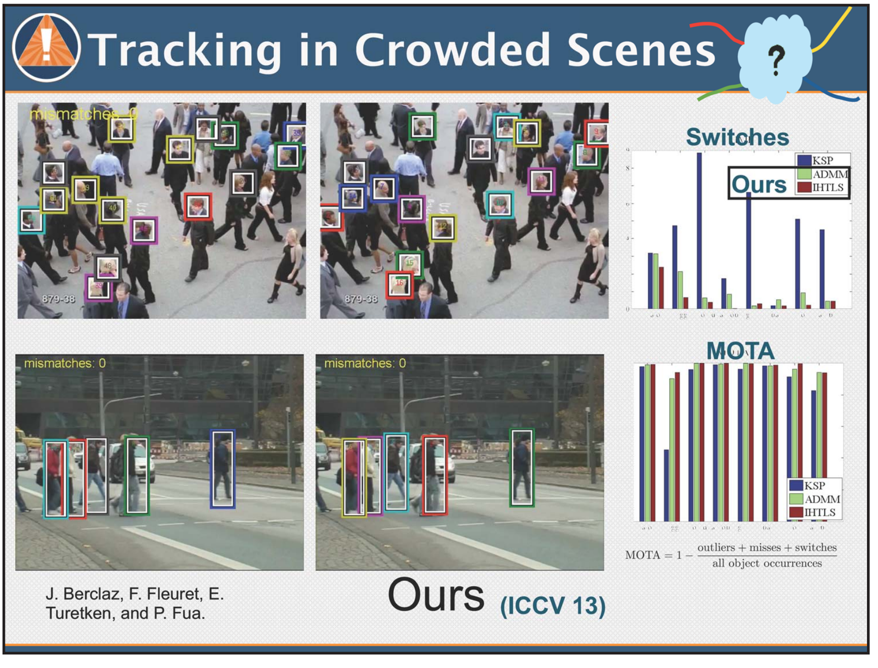
- Bank of trackers + detection of contraflow motion
  - Real time GPU-based implementation
  - Currently deployed at CLE Airport, running 24/7, two exit lanes
  - Statistics on 10 weeks of video:
    - **628 detections; 0 Miss-detections, 12 False alarms**

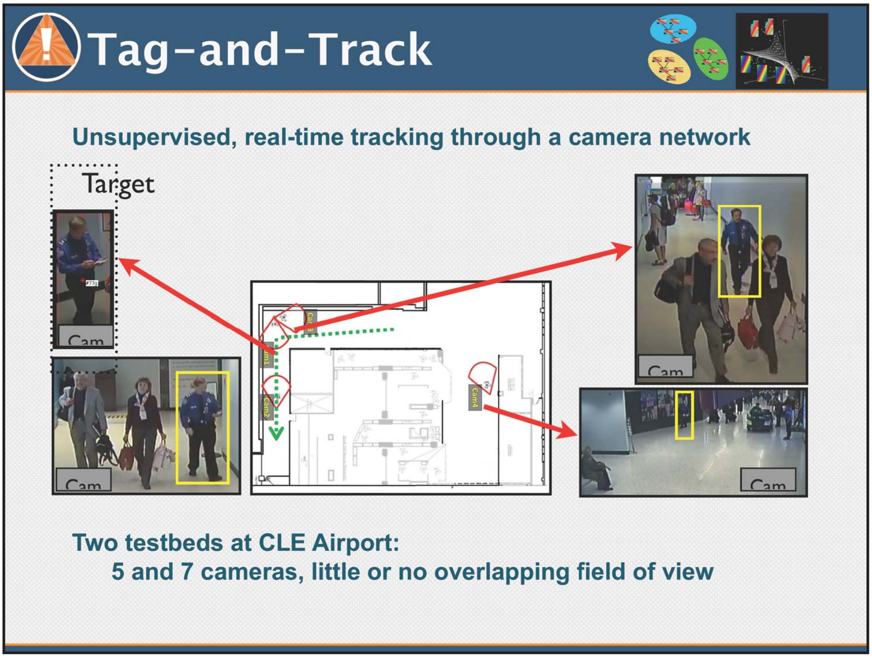
RPI In-the-Exit (R. Radke)

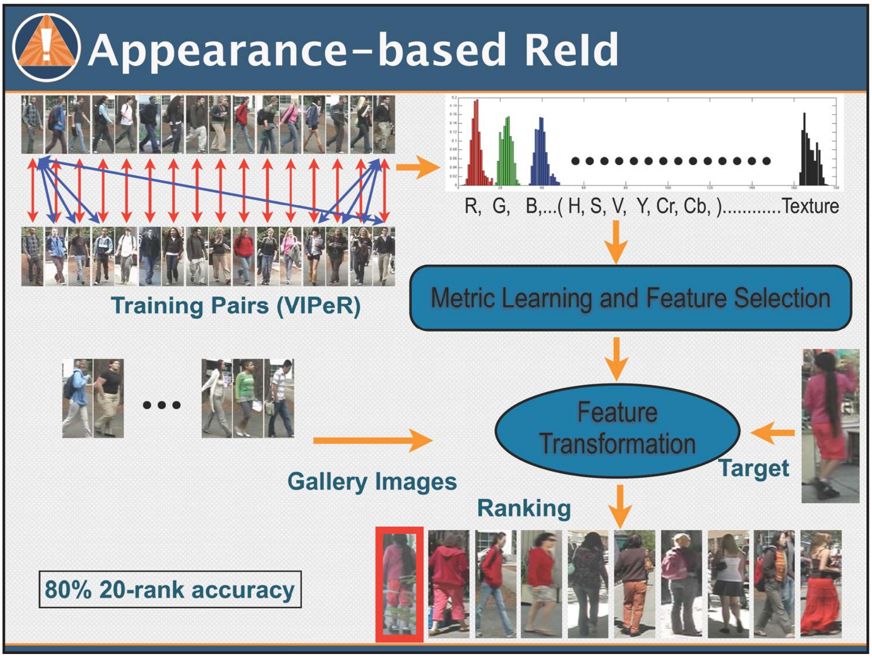


BU In-the-Exit (V. Saligrama)


Tracking in Crowded Scenes
Ambiguous Points
Matching tracklets have simpler dynamics
Dynamics carry Id information of the target.


Tracking in Crowded Scenes
Switches
Ours
KSP
ADMM
IHTLS
mismatches: 0
mismatches: 0
MOTA
KSP
ADMM
IHTLS
MOTA = 1 − outliers + misses + switches / all object occurrences
J. Berclaz, F. Fleuret, E. Turetken, and P. Fua.
Ours (ICCV 13)


Tag-and-Track
Unsupervised, real-time tracking through a camera network
Target
Two testbeds at CLE Airport:
5 and 7 cameras, little or no overlapping field of view


Appearance-based ReId
R, G, B,...(H, S, V, Y, Cr, Cb,)...........Texture
Training Pairs (VIPeR)
Metric Learning and Feature Selection
Feature Transformation
Gallery Images
Target
Ranking
80% 20-rank accuracy

Using dynamic appearance

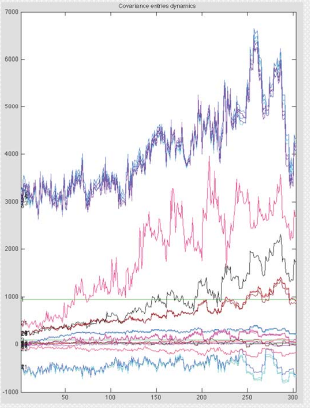
Using dynamic appearance

	x	$\lvert y-y_{0} \rvert$	R	G	B	I_{x}	$\lvert I_{y} \rvert$
x	1	2	4	7	11	16	22
$\lvert y-y_{0} \rvert$		3	5	8	12	17	23
R			6	9	13	18	24
G				10	14	19	25
B					15	20	26
I_{x}						21	27
$\lvert I_{y} \rvert$							28

- Use **Region Covariance** to model target appearance.

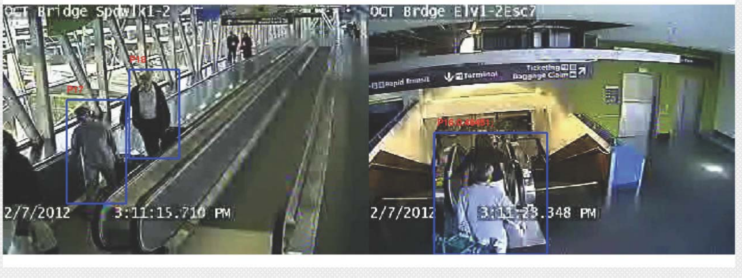
Using dynamic appearance

	x	|y-y_{0}|	R	G	B	I_{x}	|I_{y}|
x	1	2	4	7	11	16	22
|y-y_{0}|		3	5	8	12	17	23
R			6	9	13	18	24
G				10	14	19	25
B					15	20	26
I_{x}						21	27
|I_{y}|							28



- Use **Region Covariance** to model target appearance.
- Model its dynamic evolution on the Lie group of positive definite matrices.

Using dynamic appearance



- Use **Region Covariance** to model target appearance.
- Model its dynamic evolution on the Lie group of positive definite matrices.
- Compare appearances using their intrinsic distance on this manifold.

Cross-View Activity Recognition

- IXMAS dataset (5 cameras, 12 actors, 11 activities):
  - Check watch,
  - cross arms,
  - scratch head,
  - sit down,
  - get up,
  - turn around,
  - walk,
  - wave,
  - punch,
  - kick,
  - pick up

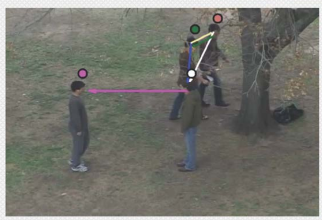
- 90.57% Average Accuracy
- Improvement of 20% over previous state of the art.

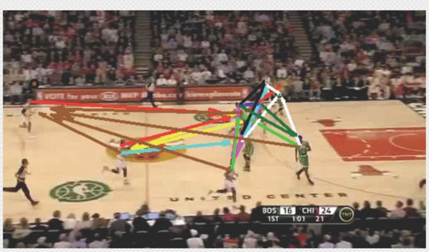
(CVPR 12)

NEXT: Crowded and clutter scenarios with multiple agents

Coordinated Activities

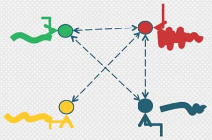
- State of the Art

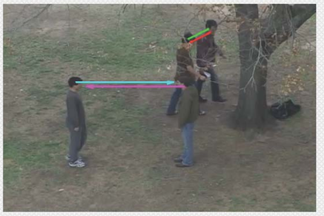


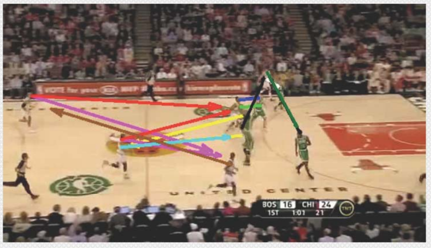


Coordinated Activities

- Using Sparse Dynamics:







(ICCV 13)

Next: From seemingly normal individual activity to suspicious collective behavior.

Who/What Where doing What

- Automatically joint segmentation and event detection
  - Uses both appearance and dynamics

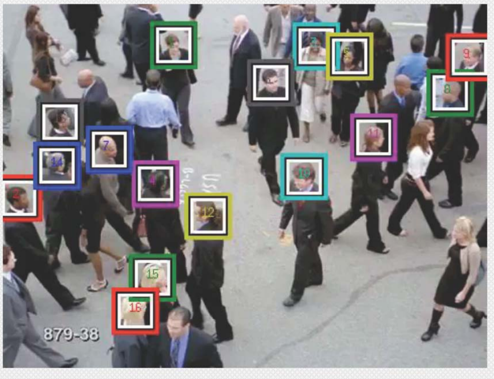
NEXT: Threats (i.e. leaving bag behind) in crowded scenarios
- Real time implementations

Video Analytics for TSA

- ***In-the-Exit Contraflow Detection***
  - Deployed at CLE Airport
    - Two different exits, different geometry
    - ~0 miss-detections, 1 to 2 false alarms/week

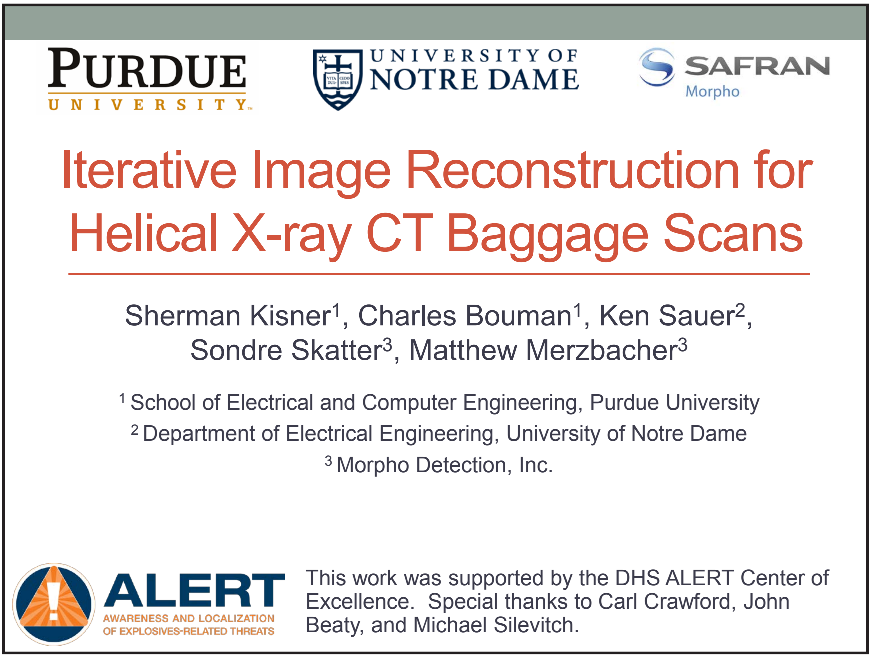
- ***Tag-and-Track across camera network***
  - In progress, to be deployed at CLE Airport soon
    - Two testbeds:
      - Parking to Terminal and
      - Checkpoint Exit to Three Concourses
- **Activity Recognition, Object Left Behind:**
  - Theory developed, tested on simple scenarios

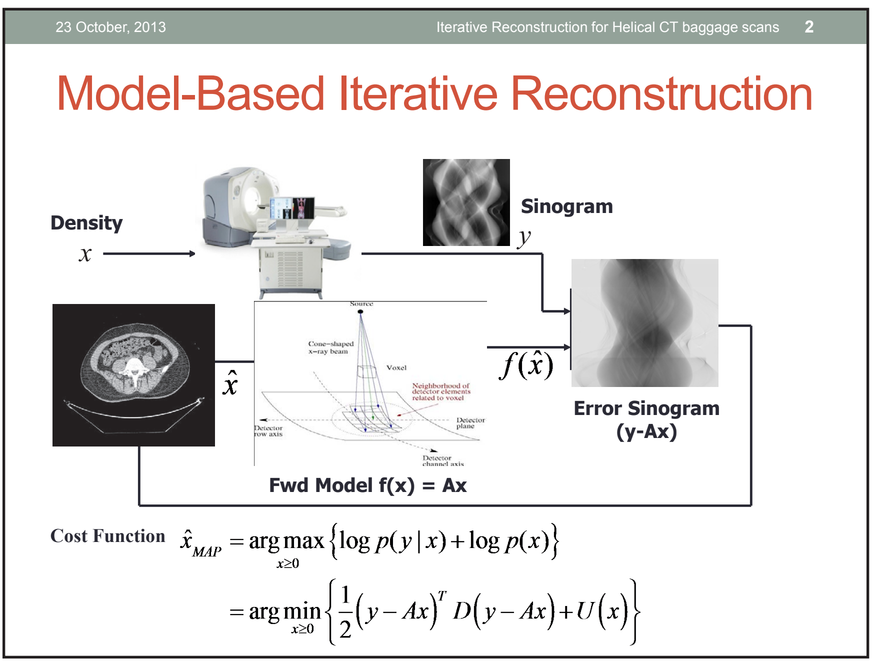
Dynamics as a key enabler to handle data deluge and obtain actionable information in a timely fashion.



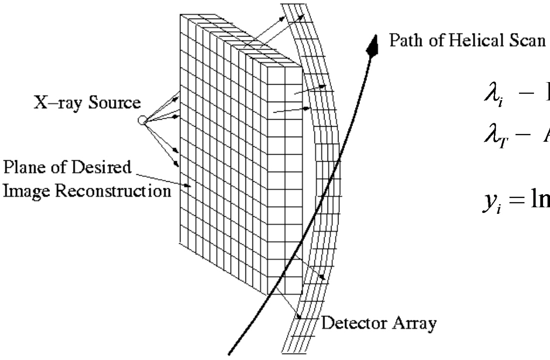
THANKS!!

17.24 Charles Bouman: Iterative Reconstruction with Vendor Participation





Scanner forward model



λ_i – Photon count at detector

λ_T – Air calibration scan

$y_i = \ln\left(\frac{\lambda_T}{\lambda_i}\right)$ – Attenuation

- Need to accurately and efficiently model the:
  - 3D forward projection geometry
  - Detector and source geometry and physics
  - Noise and distortion

Data model

- Taylor expansion of Poisson log likelihood produces

$$\log p(y|x) \cong -\frac{1}{2}(y - Ax)^t D(y - Ax)$$

- $y_i = -\log(\lambda_i / \lambda_{T,i})$ where λ_i and $\lambda_{T,i}$ are measured photon counts
- Matrix *A* is a linear projection operator
- *D* is a diagonal noise weighting matrix

$$D_{ii} = \frac{1}{\text{noise variance}} = \frac{\lambda_i^2}{\lambda_i^2 + \sigma_e^2} \cong \lambda_i$$

- **MBIR uses information that FBP throws away!**
  - Uses photon counts to estimate noise variance
  - This results in a data dependent ill-conditioned optimization problem

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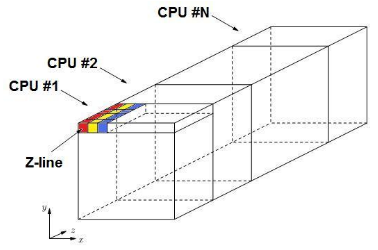
Multi-Core Parallelization of ICD

- Implemented
  - Parallel ICD on 24 core shared memory Linux machine with p-threads
  - Speedup allows for fast algorithm development
- Performance issues
  - Computation tends to be limited by memory/cashing speed, not computation
  - Memory must be organized as view, channel, row (slow to fast variables)
  - Allocation of slices to cores must balance computation/bandwidth load
- Architecture of parallel algorithm
  - Each core is responsible for updating voxels in a range of slices
  - Z-line updates:
    - A Z-line is a set of voxels along z, but at the same (x,y) position
    - Processors do ICD update along Z-lines
    - Leads to much better cash efficiency



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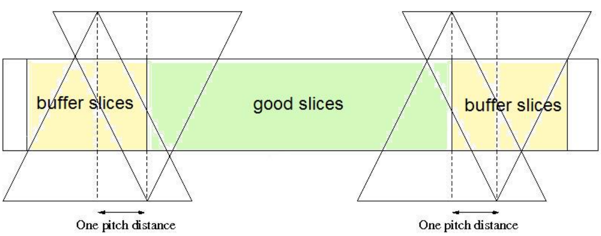
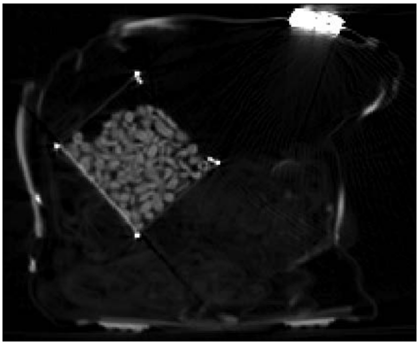
Boundary condition and buffer slices

- For helical scan reconstructions, it is necessary to reconstruct buffer slices on both sides of the ROI
  - Buffer slices are discarded, but required for accurate reconstruction
  - With of each set of buffer slices is approximately half the width of detector array
  - Computation associate with buffer slices is overhead

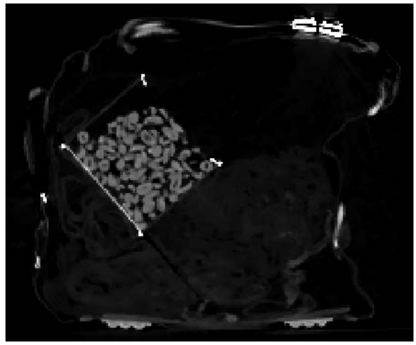


Results: resolution and object discrimination

DFM

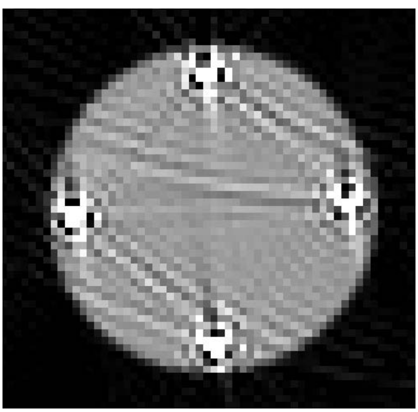


MBIR

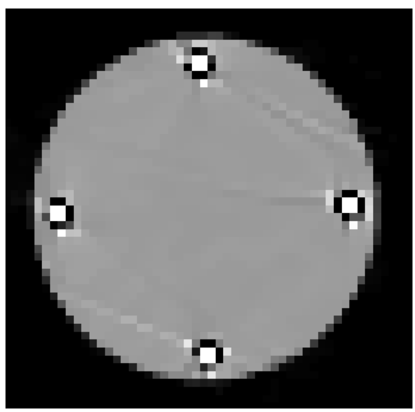


Results: metal artifact reduction

DFM



MBIR



Mixed power law data weighting

- Want to adjust the data weighting in the cost according to the suspected presence of metal in each projection measurement
- First using an initial reconstruction, $x^{(0)}$, define a metal indicator for each projection i,

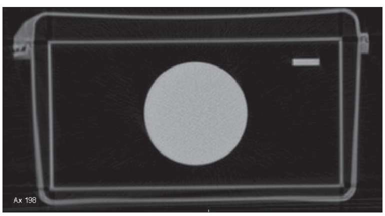
$$I_i = \begin{cases} 1, & \text{if for some voxel } j, \text{ both } A_{ij} > 0 \text{ and } x_j^{(0)} > T \\ 0, & \text{otherwise} \end{cases}$$

- Mixed data weighting: $D_{ii} = I_i\left(\lambda_i / \lambda_{T,i}\right) + \left(1 - I_i\right)\left(\lambda_i / \lambda_{T,i}\right)^{0.5}$

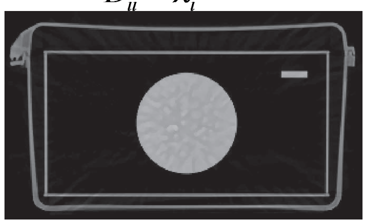
where λ_i is the target scan count and $\lambda_{T,i}$ is the air scan count

Results: power law data weighting

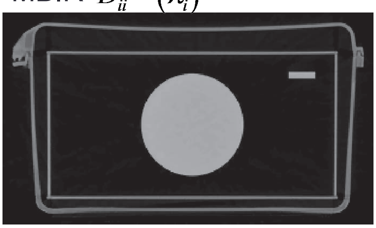
DFM



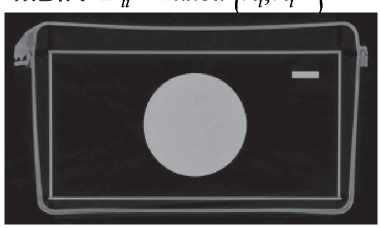
MBIR $D_{ii} = \lambda_i$



MBIR $D_{ii} = \left(\lambda_i\right)^{0.5}$



MBIR $D_{ii} = mixed\left\{\lambda_i, \lambda_i^{0.5}\right\}$



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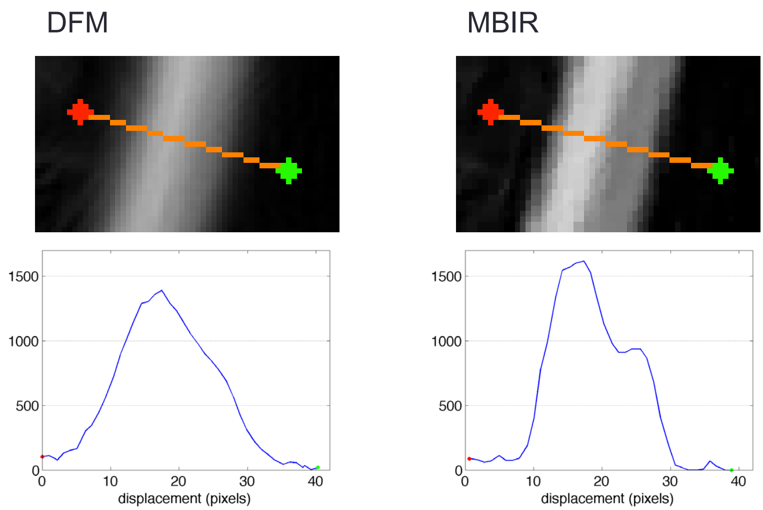
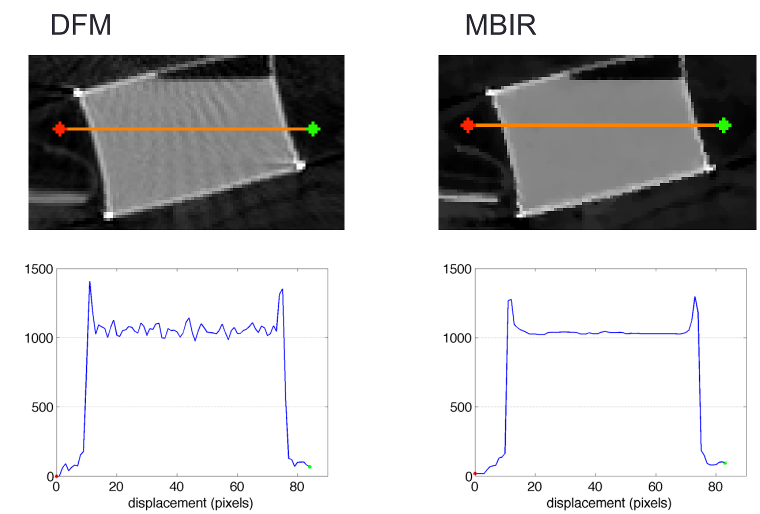
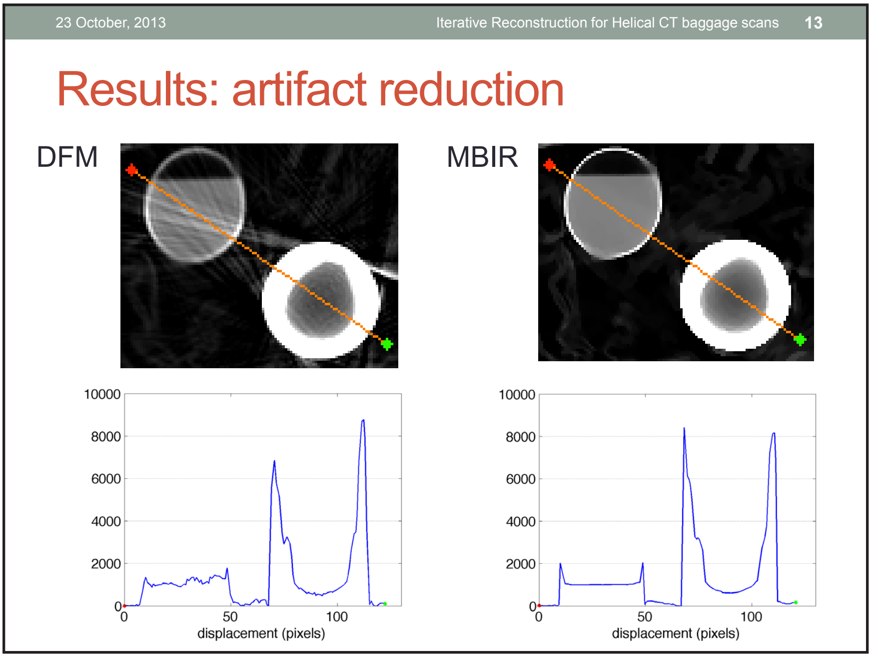
Results: object discrimination



23 October, 2013 — Iterative Reconstruction for Helical CT baggage scans — 12

Results: metal artifact reduction



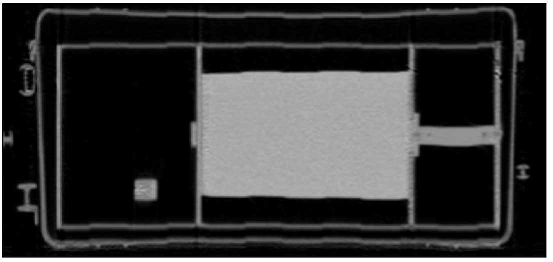

23 October, 2013
Iterative Reconstruction for Helical CT baggage scans
13
Results: artifact reduction
DFM
MBIR
10000
8000
6000
4000
2000
0
0
50
100
displacement (pixels)
10000
8000
6000
4000
2000
0
0
50
100
displacement (pixels)


23 October, 2013
Iterative Reconstruction for Helical CT baggage scans
14
Detector afterglow correction
before
after

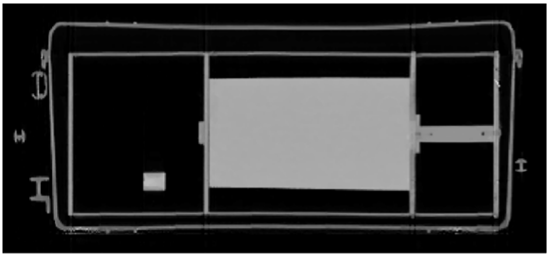
23 October, 2013 Iterative Reconstruction for Helical CT baggage scans 15

Fan angle offset correction

DFM w/out correction



MBIR with correction



Industry/University Collaboration

- My background:
  - 12 year GE relationship: *Veo* and 3T MRI
  - 20 years HP relationship: Technology in millions of printers
  - Signal Processing: Applied math, algorithms, physical models
- The opportunity:
  - Technology transfer from university to large company
  - Build on company's infrastructure
  - Provide university an efficient path to impact
- The obstacles:
  - Trust, IP, information sharing, risk
  - Understanding need to make money
  - Understanding need to publish and educate
- The keys to success:
  - Industry researcher who takes ownership
  - University researcher committed to success
  - Technology that will differentiate industry in the marketplace

Summary

- MBIR offers great potential in baggage screening
  - Improved resolution
  - Reduced artifacts
  - Increased design flexibility
- Model accuracy is important
- Computation remains a challenge

- Key's to success in industry university partnership:
  - Trust
  - Committed team of researchers on both sides
  - Tight integration of research with clear goals

MBIR/Veo Publications and Patents

- Some key publications:

K. Sauer and C. Bouman, "A Local Update Strategy for Iterative Reconstruction from Projections," *IEEE Trans. on Sig. Proc.*, vol. 41, no. 2, pp. 534-548, Feb. 1993.

C. A. Bouman and K. Sauer, "A Unified Approach to Statistical Tomography using Coordinate Descent Optimization," *IEEE Trans. on Image Processing*, vol. 5, no. 3, pp. 480-492, March 1996.

J.-B. Thibault, K. Sauer, C. Bouman, and J. Hsieh, "A Three-Dimensional Statistical Approach to Improved Image Quality for Multi-Slice Helical CT," *Medical Physics,* pp. 4526-4544, vol. 34, no. 11, November 2007.

- Issued patents:

1. J. Hsieh, J.-B. Thibault, C. A. Bouman, and K. Sauer, "An Iterative Method for Region-of-Interest Reconstruction," US Pat. 6,768,782, July 27, 2004.
2. 9. K. Sauer, C. A. Bouman, J.-B. Thibault, and J. Hsieh, "Iterative Reconstruction Methods for Multi-Slice CT," US Pat. 6,907,102, June 14, 2005.
3. K. D. Sauer, J.-B. Thibault, C. A. Bouman, and J. Hsieh, "Methods, Apparatus, and Software to Facilitate Iterative Reconstruction of Images," US Pat. 7,251,306, July 31, 2007.
4. J.-B. Thibault, K. D. Sauer, C. A. Bouman, and J. Hsieh, "Methods, Apparatus, and Software to Facilitate Computing the Elements of a Forward Projection Matrix," US Pat. 7,272,205, Sep. 18, 2007.
5. C. A. Bouman, K. D. Sauer, J. Hsieh, and J.-B. Thibault, "Methods, Apparatus, and Software for Reconstructing an Image," US Pat. 7,308,071, Dec. 11, 2007.
6. K. D. Sauer, J.-B. Thibault, C. A. Bouman, and J. Hsieh, "Method, Apparatus, and Software for Reconstructing an Image," US Pat. 7,327,822, Feb. 5, 2008.
7. J. Hsieh, C. A. Bouman, K. D. Sauer, and J.-B. Thibault, "Methods, Apparatus, and Software for Failed or Degraded Components," US Pat. 7,440,602, Oct. 21, 2008.
8. J. Hsieh, J.-B. Thibault, K. D. Sauer, and C. A. Bouman, "Method and System for Improving a Resolution of an Image," US Pat. 7,583,780, Sept. 1, 2009.
9. K. D. Sauer, C. A. Bouman, J. Hsieh, and J.-B. Thibault, "Systems and Methods for Filtering Data in Medical Imaging Systems," US Pat. 7,676,074, Mar. 9, 2010.
10. K. D. Sauer, C. A. Bouman, J. Hsieh, and J.-B. Thibault, "Method and System for Image Reconstruction," US Pat. 7,885,371, Feb. 8, 2011.
11. K. D. Sauer, C. A. Bouman, J. Hsieh, and J.-B. Thibault, "Methods and Systems for Improving Quality of an Image," United States Patent 7,983,462. July 19, 2011.
12. Charles A. Bouman, Ken D. Sauer, Jean-Baptiste Thibault, and Zhou Yu, "Methods and System for Image Reconstruction," United States Patent 8,135,186. March 13, 2012.
13. Jean-Baptiste Thibault, Jiang Hsieh, Bruno De Man, Samit Basu, Zhou Yu, C. A. Bouman, Ken D. Sauer, "Method and System for Iterative Reconstruction,", United States Patent 8,175,115. May 8, 2012.
14. Jiang Hsieh, Charles A. Bouman, Ken D. Sauer, and Jean-Baptiste Thibault, "Methods and Systems to Facilitate Correcting Gain Fluctuations in Image Reconstruction," United States Patent 8,218,715. July 10, 2012.
15. Jeffery A. Fessler, Charles A. Bouman, Jiang Hsieh, Jean-Baptiste D. M. Thibault, Ken D. Sauer, Samit K. Basu, and Bruno K. B. DeMan, "Methods and Systems for Improving Spatial and Temporal Resolution of Computed Images of Moving Objects," United States Patent 8,233,682. July 31, 2012.

Distance-Driven (DD) forward projector

- CT forward projection is modeled by a linear matrix operation.

Sinogram (Projection) → $$\begin{bmatrix} y \end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} x \end{bmatrix}$$ ← Image voxels

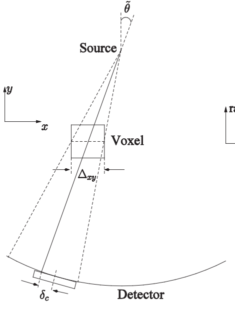
  - The j-th column of A corresponds to projection of voxel j.

- In DD model, each voxel is flattened along the dimensions parallel to detector face.
- Each column entry is calculated as a product of XY-plane projection $B_{i,j}$, and Z-direction adjustment factor $C_{i,j}$ for i-th detector element.

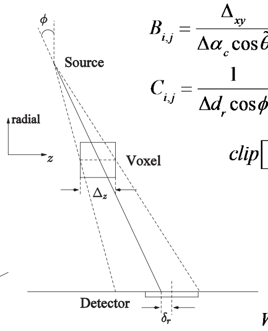
$$A_{i,j} = B_{i,j} \times C_{i,j}$$

DD forward projector calculation

- The forward projection matrix A is calculated as $A_{i,j} = B_{i,j} \times C_{i,j}$



XY-plane



Z-direction

$$B_{i,j} = \frac{\Delta_{xy}}{\Delta\alpha_c \cos\tilde{\theta}} clip\left[0, \frac{W_c + \Delta\alpha_c}{2} - |\delta_c|, \min(W_c, \Delta\alpha_c)\right]$$

$$C_{i,j} = \frac{1}{\Delta d_r \cos\phi} clip\left[0, \frac{W_r + \Delta d_r}{2} - |\delta_r|, \min(W_r, \Delta d_r)\right]$$

$$clip[a,b,c] = \min(\max(a,b),c)$$

Δ_{xy} :Voxel size

$\tilde{\theta}, \phi$:Ray angle in XY-plane and Z-direction

δ_c, δ_r :Offset from detector element center

W_c, W_r :voxel projection width in channel and row directions

$\Delta\alpha_c, \Delta d_r$:Detector width in channel and row directions

23 October, 2013 Iterative Reconstruction for Helical CT baggage scans

Poisson noise model

- Use a 2nd order Taylor series expansion of true log likelihood

$$\log p(y|x) = -\sum_{i=1}^{M}\left(\lambda_{0,i}\exp(-A_{i,*}x) + \lambda_i A_{i,*}x + \log(\lambda_i!) - \lambda_i \log(\lambda_{0,i})\right)$$

$$\approx -\frac{1}{2}(y-Ax)^t D(y-Ax) + c(\lambda)$$

where

$$A_{i,*} = i^{th} \text{ row of } A$$

$$y_i = \log\left(\frac{\lambda_{0,i}}{\lambda_i}\right)$$

$$D_{i,i} = \lambda_i$$

- *A* - forward system matrix
- *D* - *d*iagonal weighting matrix

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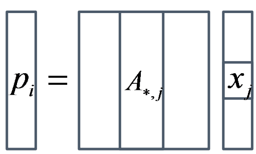
Iterative Coordinate Descent (ICD)

- Iteratively match each pixel (i.e. each column of *A*)
- Select each pixel to minimize total cost



$$x_j \leftarrow \arg\min_{x_j}\left\{\frac{1}{2}\|y-Ax\|_\Lambda^2 + U(x)\right\}$$

- Issues:
  - Efficient update by using sinogram error state
  - High spatial frequencies converge first
  - Benefits from good initial condition

*K. Sauer and C. Bouman, "A Local Update Strategy for Iterative Reconstruction from Projections," *IEEE Trans. on Sig. Proc.,* vol. 41, no. 2, pp. 534-548, Feb. 1993.

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Why ICD ?

- Advantages:
  - Fast convergence at high spatial frequencies
  - Can be initialized with FBP
  - Sequence of 1D updates provides flexibility
  - Easy to enforce positivity constraints
  - Robust to non-idealities
- Disadvantages
  - Poor low frequency convergence
  - Irregular memory access

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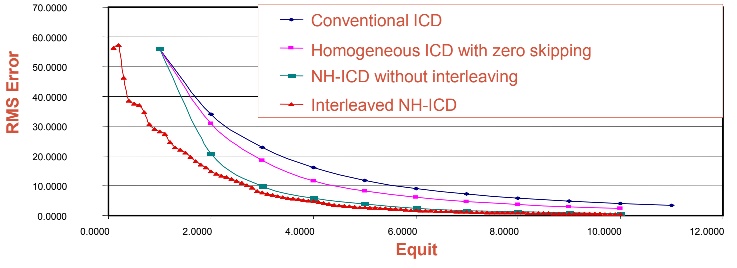
RMSE Convergence Plots for NH-ICD

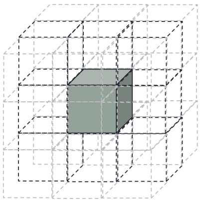


- NH-ICD
  - Reduces transients at early stage allowing faster convergence
  - Interleaving in early iterations further improves convergence speed

Zhou Yu, Jean-Baptiste Thibault, Charles A. Bouman, Ken D. Sauer, and Jiang Hsieh, "Fast Model-Based X-ray CT Reconstruction Using Spatially Non-Homogeneous ICD Optimization," to appear in the *IEEE Trans. on Image Processing*.

Image prior model

$\rho(\Delta) = \lvert\Delta\rvert$	Total Variation/Compressed Sensing
$\rho(\Delta) = \lvert\Delta\rvert^p$ where $p = 1.2$	Generalized Gaussian MRF
$\rho(\Delta) = \dfrac{\lvert\Delta\rvert^q}{1 + \lvert\Delta/50\rvert^{q-p}}$ with $p = 1.2$ and $q = 2$	Q-GGMRF



$$U(\mathbf{x}) = \frac{1}{p\sigma^p} \sum_{\{j,k\}\in C} \rho(x_j - x_k)$$

- 3D regularization using 26 neighbors
- Design to:
  - Preserve high contrast edges
  - Enhance low contrast sensitivity

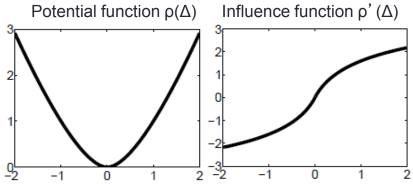
Jean-Baptiste Thibault, Ken Sauer, Charles Bouman, and Jiang Hsieh, "A Three-Dimensional Statistical Approach to Improved Image Quality for Multi-Slice Helical CT," *Medical Physics*, pp. 4526-4544, vol. 34, no. 11, November 2007.

Prior: Q-Generalized Gaussian MRF

- Define neighboring pixel difference $\Delta = x_s - x_r$. The q-GGMRF prior is defined as

$$p(x) = \frac{1}{z}\exp\left\{-\frac{1}{q\sigma_x^q}\sum_{\{s,r\}\in C} g_{s,r}\rho(\Delta)\right\}$$

where $$\rho(\Delta) = \frac{|\Delta|^p}{1 + \left|\frac{\Delta}{c}\right|^{p-q}}$$

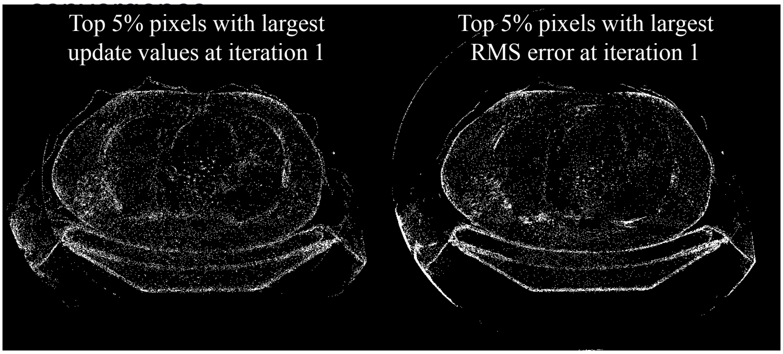


p=2.0, q=1.2, and c=1.0 case

- Controls both low and high-contrast behavior
- Parameter c is a soft transition point such that $\rho(\Delta) \approx \begin{cases} |\Delta|^p & \text{for } |\Delta| << c \\ |\Delta|^q & \text{for } |\Delta| >> c \end{cases}$
- Gaussian MRF (GMRF) prior is the special case where p=q=2, i.e. $\rho(\Delta) = \Delta^2$

Non-Homogeneous ICD (NHICD)

- Objective: find good correlation between update map and true RMS error at different stages of



Model-Based Iterative Reconstruction

- Our framework is the *maximum a posteriori* (MAP) estimate

$$\hat{x}_{MAP} = \arg\max_{x\geq 0}\{\overbrace{\log p(y\,|\,x)}^{\text{Data term}} + \overbrace{\log p(x)}^{\text{Prior term}}\}$$

  - Vector y is the projection measurements, and x is the image

- MBIR is used in GE Healthcare's *Veo* product which is sold in US and European markets since 11/2011

- We are working with Morpho Detection to investigate the use of MBIR in an EDS system for aviation security

Evaluation for EDS performance

- Evaluated qualitative impact of model-based reconstructions on proprietary automatic threat detection (ATD) algorithms
  - Improved segmentation
  - Improved object identification/classification
  - Improved separation of adjoining objects
  - Reduction in false alarms
- In addition, the improvements in reconstruction quality provide for better operator experience
- Reduced cost of additional detection

17.25 Timothy Ashenfelter: DNDO Algorithmic Needs and University Engagements

Domestic Nuclear Detection Office (DNDO)

DNDO Algorithmic Needs and University Engagements

Briefing for the 9th Algorithm Development for Security Applications Workshop

25 October 2013

Timothy Ashenfelter, PhD
Program Manager
Transformational and Applied Research
Domestic Nuclear Detection Office

Homeland Security

The Nuclear and Radiological Threat

"I continue to believe that nuclear terrorism remains one of the greatest threats to global security. That's why working to prevent nuclear terrorism is going to remain one of my top national security priorities …"
– President Obama (National Defense University, December 3, 2012)

- Types of threats:
  - Nuclear Weapon
  - Improvised Nuclear Device (IND)
  - Radiological Dispersal Device (RDD) – (also referred to as "Dirty Bomb")
  - Radiation Exposure Device (RED)

HEU intercepted by Republic of Georgia in smuggling sting

Jose Padilla – convicted of plotting RDD attack

RDD response exercise in New York

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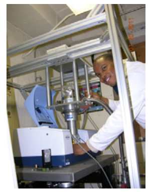
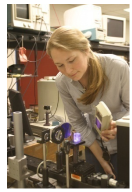
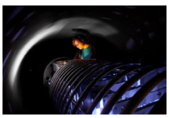
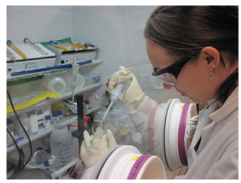
Outline

- **Mission and Objectives**
  - Domestic Nuclear Detection Office (DNDO)
  - Transformational and Applied Research (TAR)
  - Algorithm Research Role
- **Algorithm Role in Grand Challenges**
  - On Going Efforts
  - Future Needs









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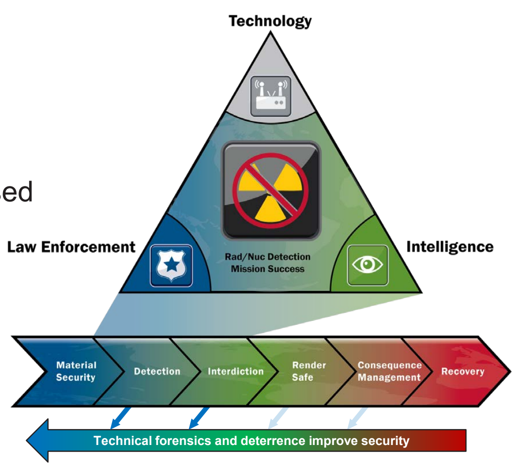
DNDO Mission

- Interagency
- Interdisciplinary
- Integration
- Interdiction-focused



Nuclear Defense Spectrum

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DNDO Transformational R&D Program

Develop break-through technologies that will have a dramatic impact on capabilities to prevent nuclear and radiological terrorism through an aggressive and expedited R&D program.

What we do …

- ***Address*** gaps in Global Nuclear Detection Architecture
- ***Improve*** performance, cost, and operational burden of nuclear detection and forensics technologies
- ***Transition*** successful technologies to system development, acquisition, and deployment or commercialization

How we do it …

- ***Include*** industry, national laboratories and academia; encourage teaming
- ***Coordinate*** with intra/interagency R&D organizations (e.g., S&T, DOE, DOD, DNI)
- ***Follow*** a sensible process that provides the transparency and agility needed for expedited R&D

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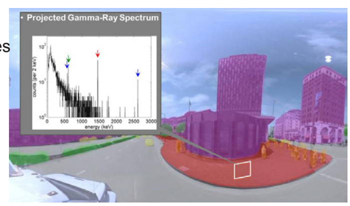
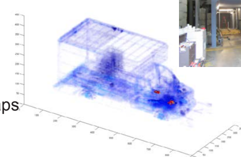
TAR Programs

- Exploratory Research Program (ERP)
  - Research by Industry, National Labs, or Universities
  - Portfolios
    - Materials
    - Neutron Replacement
    - Shielded SNM
    - Radiation Detection Techniques
    - ***Algorithms & Modeling***
    - Nuclear Forensics
- Academic Research Initiative (ARI)
  - University Grant Program coordinated through NSF
  - Create **next generation** of scientists and engineers
- Advanced Technology Demonstration (ATD)
  - Further develop technology concepts applied to GNDA gaps
  - Characterize in a **simulated operational environment**
- Small Business Innovative Research (SBIR)
  - Agile R&D to support rapid prototyping





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DNDO R&D Program Progression

Programs	Progression	Technology Readiness Level (TRL)
	Nuclear Detection Architecture Challenges	N/A
Transformational R&D: ARI, ERP	Feasibility Evaluation	TRL 1-3
Transformational R&D: ARI, ERP; SBIR, ATD	Proof of Concept (POC)	TRL 3-4
Transformational R&D: SBIR, ATD	Performance Test Unit (PTU)	TRL 5-6
SBIR, ATD; Product Acquisition or Commercial Development	Prototype	TRL 7
Product Acquisition or Commercial Development	Engineering Development Model (EDM)	TRL 7
Product Acquisition or Commercial Development	Limited Rate Initial Production (LRIP)	TRL 8
Product Acquisition or Commercial Development	Full Rate Production (FRP)	TRL 9

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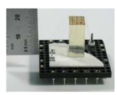
Grand R&D Challenges

- ***Cost effective equipment*** with sufficient performance to ensure wide spread deployment



- ***Detection of special nuclear material*** even when heavily shielded

- ***Enhanced wide area search*** in a variety of scenarios, to include urban and highly cluttered environment

- Monitoring along ***challenging GNDA pathways***, to include general aviation, small vessels, and in between ports of entry

- Forensic ***determination of origin*** and/or route of interdicted materials

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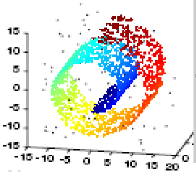
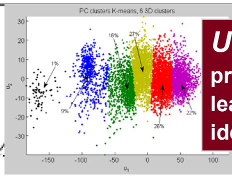
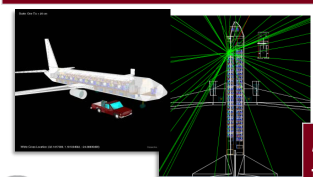
Algorithm Portfolio Mission and Overview





Utilize **cutting-edge signal processing, data fusion, and machine learning to detect, locate, track, and identify potential threats**

Develop **capability to effectively model radiation detection and environments to test algorithm performance**



Implement **advanced simulation tools to support personnel training, threat awareness, or visualization**

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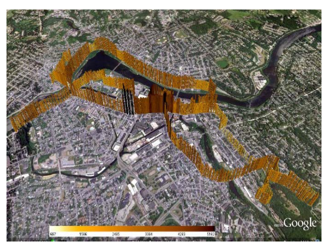
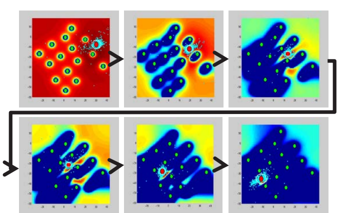
Algorithms for Detect, Locate, and Track

Goal 1: *Increase Detector Sensitivity* by capturing background uncertainty

- High Gain vs. Low Gain Tradeoff
- Detect→Locate→Track
- Track→Locate→Detect





Goal 2: *Agile Architecture* by networking, data fusion, and mobile search enhancements

- Context-Aware Systems
- Distributed Sensor Fusion
- Video-enhanced tracking

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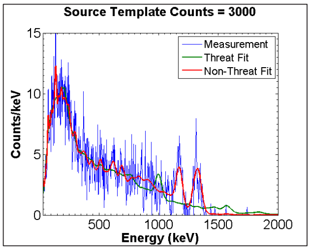
Algorithms for Identification

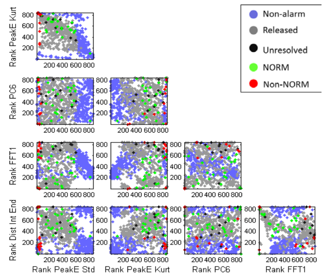


Goal 1: *Low Cost SNM Detection* by developing ID algorithms on new materials or improved threat discrimination on current systems

- Template Matching
  - Variance weighting
- Peak-Finding
- Adaptive Learning
  - Bayesian Branch and Bound

Goal 2: *Reduce Operational Burden* by screening non-threat alarms

- Adaptive Learning Algorithms
  - Random Forest best performance
- Inclusion of non-radiological information
- Augmentation with Advanced Sensors
  - Hyperspectral, LIDAR, EO/IR, & gravity



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Examples of TAR Research Efforts

- University led with National Lab support (**Machine Learning for Search**)
- Industry-led (performer) with National Lab (gov-team) (**IRSS**)
  - Follow-up to include National Lab and University support
- National Lab led with University support with Industry developed technology (**Background Estimation**)
- National Lab led with Small-business spin-off from University Research (**gravity gradiometry**)

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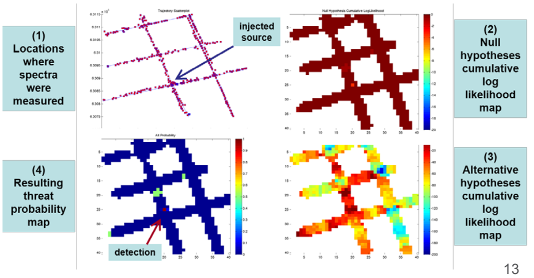
Machine Learning for Search –CMU (ARI)

- Machine Learning for Effective Nuclear Search and Broad-Area Monitoring
- Goal: Use supervised learning for detection and classification of threats for spatial/temporal/spectral information for mobile search
- Injection Study using large mobile data set
- LLNL Partnership with RNAK tool
  - Bayesian-based
  - Branch and Bound
  - Genetic Algorithm



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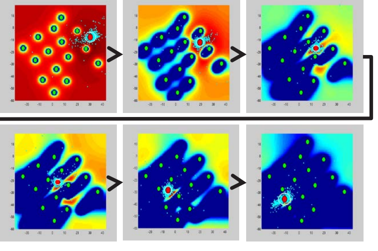
Intelligent Radiation Sensing System (IRSS)

- Advanced Technology Demonstration of 20 mobile detectors searching a wide area
  - Fuse detectors in real-time for increase ability to detect, locate, and track
  - Extensive span of independent variables including:
    - Detector (number, type, geometrical configuration)
    - Source (type, intensity, location, and vector)
    - Background (uniformity, variability)
    - Algorithms (ex. particle filter numbers)
    - Networking (method, data loss)
  - Provide data to Academic Researchers



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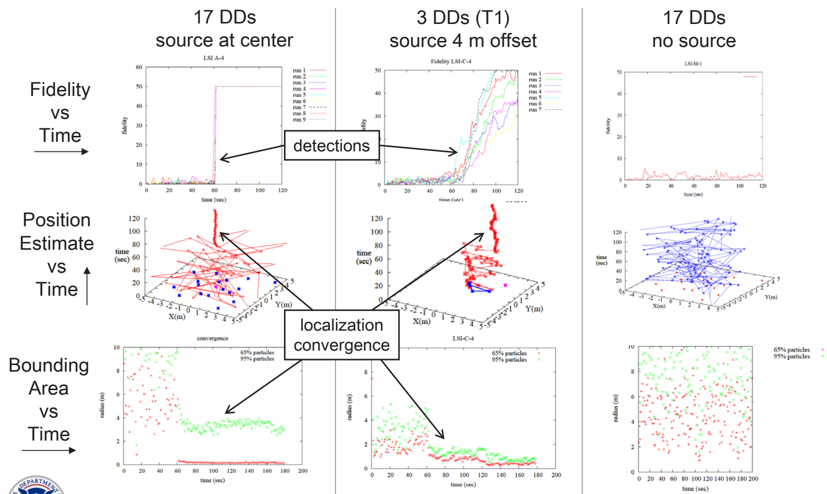
Convergence of IRSS Position Estimates



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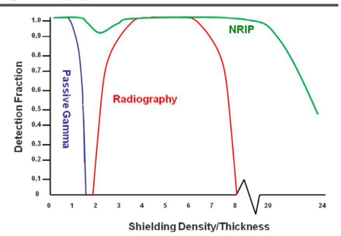
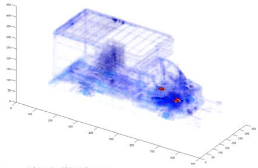
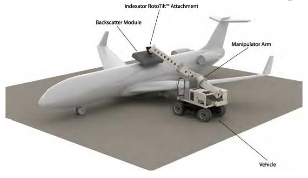
Transformational Screening Applications

- Goal is to detect Shielded Special Nuclear Material in Relevant Environments
  - Technology may also detect explosives and other materials
- Multiple (18) and Large Projects tackling the shielded SNM challenge
  - Passport NRIP (high-energy backscatter)
  - Rapiscan (high-energy backscatter)
    - Aircraft Inspection System
    - Neutron Differential Die-away
  - Algorithm Development on Novel Data
    - Telesecurity Sciences 2-energy algorithm







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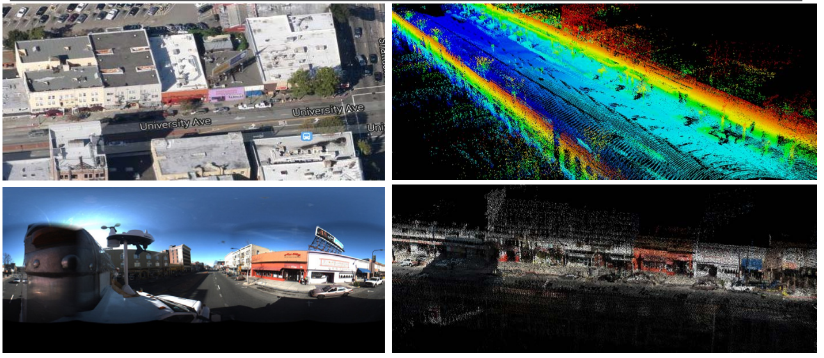
Background Estimation Algorithms



Goal is to discover and quantify the non-radiological observables that correlate to the radiation signatures and improve detection algorithms

- Potentially compare these results with existing materials databases
- Mobile EO/IR, LIDAR, & Adv. Radiation Spectral Imaging Detectors

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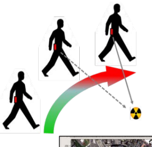
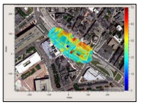
Other On-Going Effort Examples

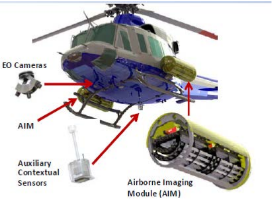
- Algorithms to Improve Discrimination of Threats and Non-threats
  - Systematic mapping of background radiation in 3D: "Nuclear Street View"
  - Algorithms to detect at low signal to background ratios
  - Advanced search techniques with low-cost detectors integrated with smartphones
- Radiation Imaging and Tracking
  - Moving and mobile choke point systems with the ability to detect, identify, locate, and track threats: Long Range Radiation Detection (LRRD) ATD
  - Airborne Radiological Enhanced-sensor System (ARES) ATD
  - Dual gamma ray and neutron imaging and spectroscopy
  - Advanced imaging technologies (electron tracking, liquid imagers)
  - Non-visible roadside tracking (different infrared wavelengths, short range radar)

Nuclear Street View





Smart Phone Integration



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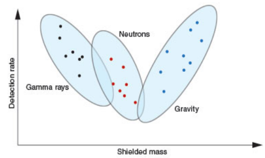
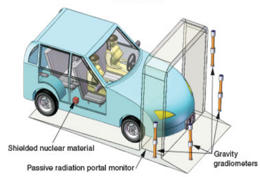
Pathforward for Aviation Algorithms

- Partnerships crucial to gather representative data
  - Operational Knowledge
  - Reasonable Threat Objects
- Leverage modeling to bootstrap data
  - Improve Algorithms as well as Visualization



- Apply novel sensors to support detection in dose-constrained pathways
  - Gravity Gradiometry or Muon Deflection
- Augment systems with low-cost sensors
  - Contextual Information (weight, size, proximity)
- Multi-threat integration with CBRNE spectrum
- Algorithms: Spatial Mapping & Adaptive Learning



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17.26 David Castañón: Algorithms and Architectures for X-ray Diffraction Tomography

Algorithms and Architectures for X-Ray Diffraction Tomography

Ke Chen and David Castañón
{ck, dac}@bu.edu

This work was sponsored by DHS S&T under the ALERT Center of Excellence

BOSTON UNIVERSITY Electrical & Computer Engineering

Summary

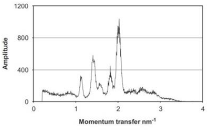
BOSTON UNIVERSITY

- Iterative reconstruction algorithms for reconstruction of XDI images
  - Good localization, characterization of materials with strong Bragg peaks
  - Harder: accurate reconstruction of liquids and other amorphous materials in the presence of stronger scatterers nearby
- XDI architectures with coded apertures and limited illumination directions leads to good reconstruction of volumetric and spectral images
  - increased scatter signal strength, better conditioned reconstruction
- Iterative reconstruction algorithms are essential in these architectures
  - Needed to mitigate artifacts from "strong" scatterers, obtain observability exploiting sparsity and spatial consistency
- Need fusion with CT or equivalent normalization for reconstruction
- Major challenges remain:
  - Computation requirements for reconstruction
  - Architecture design for improved signal/noise ratio
  - Explosives detection/classification using reconstructed signals for liquids and HME classes

Motivation

Background:

- Material identification based on conventional X-ray computed tomography (CT) images can be ambiguous
- X-ray diffraction imaging (XDI) systems identify material based on coherent-scatter form factor – New signature that depends on molecular structure



Coherent-scatter form factor of TNT
(Harding '09, Morpho)

Issues:

- Weak signals may require long collection times
- What are appropriate algorithms and architectures?

Existing XDI Commercial Product:

- Single view, direct imaging

Morpho XRD 3500 ™

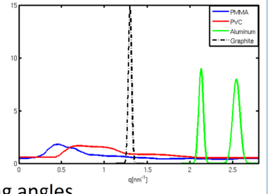
Focus of Talk: Discuss recent progress and results on algorithms for different XDI architectures

X-ray Diffraction Imaging

- Construct the *coherent-scatter form factor* $|F(q,\boldsymbol{x})|^2$ at all positions x in volume of interest: 4-dimensional function!
  - Expressed as distribution of transferred momentum q that causes the deviation of photon of wavelength λ by angle θ

$$q = \frac{1}{\lambda}\sin(\frac{\theta}{2})$$

Form factors



  - For crystalline materials, Bragg peaks reveal molecular composition for material discrimination in terms of preferred scattering angles
  - For amorphous materials, or liquids, form factor is smoother

X-ray Diffraction Principles

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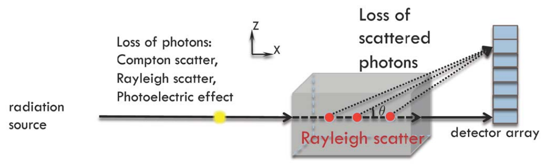

Observations:

- ❑ Fraction of photons that are scattered coherently is small – fraction decreases with increasing photon energy
- ❑ Fraction of photons that are lost to photoelectric effect also decreases with increasing photon energy
- ➔ Low energy Rayleigh scatter will be highly attenuated
- ➔ High energy Rayleigh scatter is less likely

➔ **Weak signals! Limit on effective energy band**

X-ray Diffraction Principles - 2

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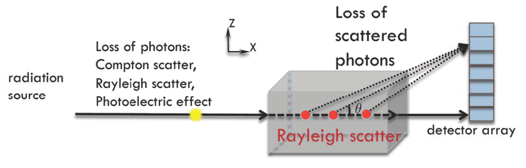

Observations 2:

- ❑ Depending on collimation scheme and source spectrum, each detector measures scatter from different locations and different energies
- ❑ Detector technology: photon counting detectors vs intensity detectors
  - ❑ Slice reconstruction: 3-D object may be easier to reconstruct from 2-D array of photon counting detectors, equivalent to 3-D measurement
  - ❑ Alternative: few views with intensity measurements (not many, though…): compressive sensing reconstruction

X-Ray Diffraction: Some Architectures

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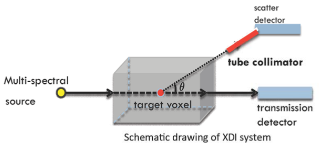
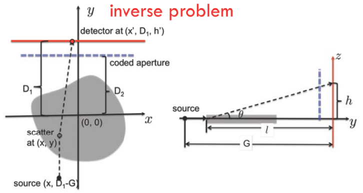
Direct imaging: tube collimators

Photon-inefficient but simple algorithms



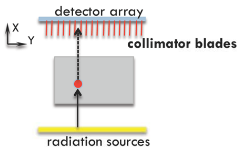
Coded aperture imaging:

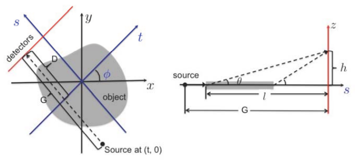
Captures more photons, complex inverse problem



Limited-angle tomography: sheet collimators

Higher SNR, often requires rotating detectors and tomography algorithms





XDI Math

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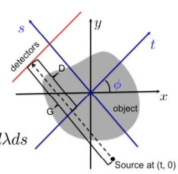
Model depends on architecture :

- Example below for intensity detectors, sheet collimators separating vertical lines of detectors



$$I_\phi(t,h) = \int_0^G \int_{\lambda_min}^{\lambda_max} I_\lambda(t,0)\mathcal{A}_\lambda(t,0,s,0)\mathcal{B}_\lambda(t,s,G,h)\frac{|F(t,s,q)|^2}{[(G-s)^2+h^2]^{3/2}} d\lambda ds$$

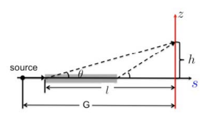
$$q = \frac{\sin(0.5\tan^{-1}(\frac{h}{G-s}))}{\lambda} \approx \frac{h}{2\lambda(G-s)}$$

$I_\lambda(t,0)$: incident x-ray intensity at λ;

$\mathcal{A}_\lambda(t,0,s,0)$:attenuation for λ along incoming ray from 0 to s;

$\mathcal{B}_\lambda(s,0,G,h)$:attenuation along the scattered ray from $(s,0)$ to (G,h).

$|F(t,s,q)|^2$:coherent scatter form factor at location (t,s)



- For photon counting detectors, model changes:

$$I_\phi(t,h,\lambda_0) = \int_0^G \int_{\lambda_0}^{\lambda_0+\Delta} I_\lambda(t,0)\mathcal{A}_\lambda(t,0,s,0)\mathcal{B}_\lambda(t,s,G,h)\frac{|F(t,s,q)|^2}{[(G-s)^2+h^2]^{3/2}} d\lambda ds$$

XDI Math 2

- Easy extensions to include other architectures
  - Different collimators or coded aperture masks, fan beams, …
- Important issue: Need to account for attenuation in both the excitation path and the scatter path
- Two approaches possible
  - Estimate attenuation using dual-energy conventional CT reconstruction and incorporate into image reconstruction process -- general
  - Normalize path loss using direct path observation
    - Small angle assumption: attenuation along the path of scattered radiation is approximately same as on transmitted path
    - More appropriate for photon-counting detectors (small energy range per measurement)

$$J_\phi(t,h) = \frac{I_\phi(t,h)}{I_\phi(t,0)} \approx \int_0^G \int_{\lambda_{m}in}^{\lambda_{m}ax} \frac{|F(t,s,q)|^2}{[(G-s)^2+h^2]^{3/2}} d\lambda ds$$

Iterative Reconstruction

- Algorithm 1 (IRL1):
  - Iterative reconstruction, slice by slice
  - Look for spatial coherence in form factor reconstructions among nearby voxels
  - Sparsity in form factors representation
- Convex optimization formulation

$$\min_{\underline{\mathbf{x}}} (\mathbf{y} - C\underline{\mathbf{x}})^T W(\underline{\mathbf{y}})(\mathbf{y} - C\underline{\mathbf{x}}) + \alpha^2 \sum_{m=1}^{M} ||D\underline{\mathbf{x}}||_1$$

  - **y** : measurements, stacked by voxels and momentum transfer
  - **x** : reconstructed form factors over voxels
  - C : Discretized observation matrix
  - D : Spatial derivative operator
  - M : Number of form factor bins
- Solve using standard convex techniques

Iterative Reconstruction

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- Algorithm 2 (IREP):
  - Iterative reconstruction, slice by slice
  - Look for spatial coherence in form factor reconstructions among
  - Simultaneous segmentation/image formation avoiding smoothing across edges (Ambrosio-Tortorelli)

$$\min_{(\mathbf{x},\mathbf{s})} ||\mathbf{y} - C\mathbf{x}||^2_{W(\mathbf{y})} + \alpha_1^2 \sum_{m=1}^{M} ||\mathbf{D}\mathbf{x}_\mathbf{m}||^2_{\mathbf{W_s}} + \varphi_S(\mathbf{s},\gamma)$$

$$W_s = \text{Diag}\left[(1-[\mathbf{s}]_i)^2\right], \quad \varphi_S(\mathbf{s},\gamma) = \gamma^2 ||\mathcal{D}\mathbf{s}||^2 + \frac{1}{\gamma^2}||\mathbf{s}||^2$$

- Solve using biquadratic iterative optimization

- Other algorithms investigated (overcomplete basis representations, …) with similar results.

Experiments

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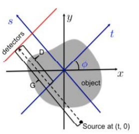
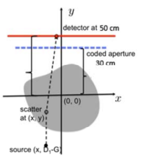
- Architecture 1: Limited angle tomography with vertical collimation
  - 7 views, from -60 to 60 degrees, 20 degrees apart
- Architecture 2: Coded aperture, single view
- Architecture 3: Coded aperture, 3 views (-60,0,60)
  - Simple coded aperture design (Brady et al '12)
  - Focus on reconstruction
- Detectors
  - Intensity detectors
  - Photon counting detectors, 6 keV resolution
- Issues:
  - 3-D slice reconstructions from very few 2-D views





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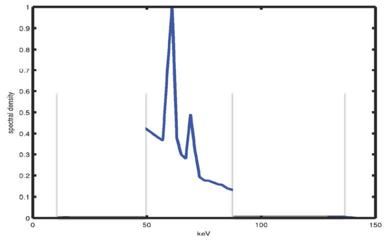
Illumination Variations

- Monochromatic source at 72 keV
- Polychromatic source from 50 keV to 80 keV with basic spectra
- Simulated Monte Carlo photon sources



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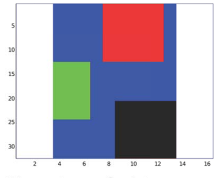
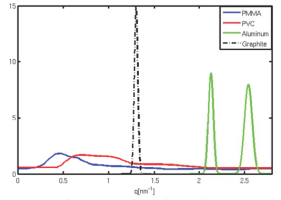
Experiment Phantom

- Object of size 8*4cm, composed of 4 elements (PMMA, PVC, Aluminum, Graphite)
- Two phantoms: a flat plate, 1 cm tall, and a tall rectangular solid, 40 cm tall
- Focus on clutter, interference, attenuation
  - Different attenuation of scatter



Plan view of object in Illumination plane



Form factors for the elements

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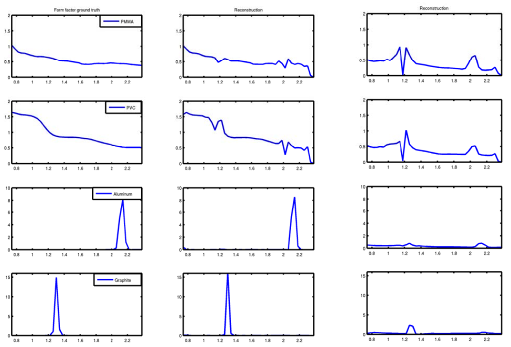
Experiment 1: Why Coded Aperture

- Phantom: Thin plate
- Architecture: with and without coded aperture, 3 views (-60, 0, 60) degrees, with intensity detectors, single energy illumination (72 keV), no noise, IRL1 algorithm



Truth   With coded aperture   Without coded aperture

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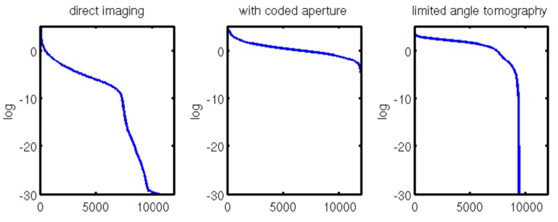
Explanation

- Without coded aperture, limited angle tomography results in ill conditioned inverse problem
  - Hard to separate different material contributions

Comparison of log of singular values for different architectures



Experiment 2: Coded aperture vs vertical collimation

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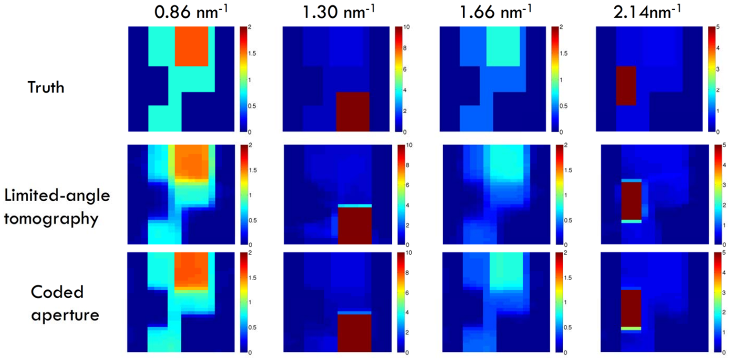
- Phantom: thin plate
- Architectures: Coded aperture, 3 views (-60, 0, 60) degrees and limited angle tomography with vertical collimators, 7 views, intensity detectors, single-energy at 72 keV, IRL1 algorithm



Main difference: More efficient collection of scattered photons in coded aperture – Increased signal strength

Form Factor Reconstructions

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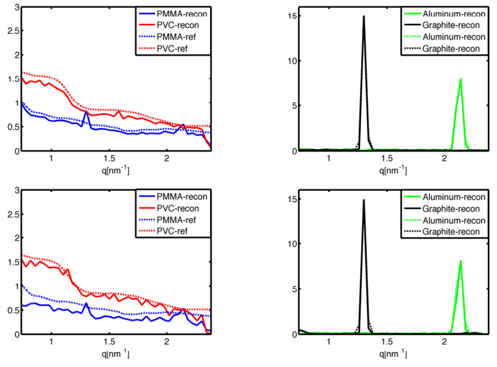
- Average over region of the materials



Experiment 3: Why Multiview?

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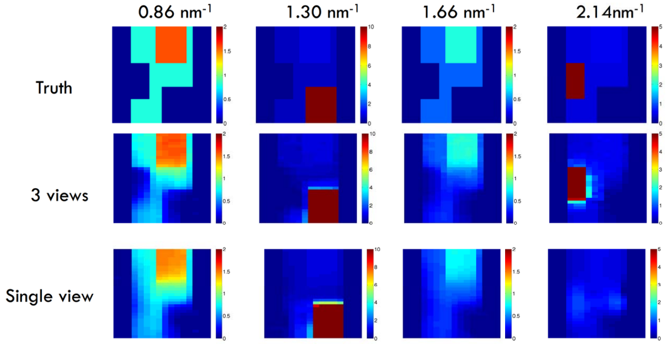
- Phantom: **Tall rectangular solid**
- Architecture: Coded aperture, 3 views (-60, 0, 60) degrees, vs single view, 0 degrees, with photon-counting detectors, multi-energy illumination, IRL1



Strong absorption from a single view can reduce scatter signal (no aluminum…)

Experiment 4: Photon-counting detectors help

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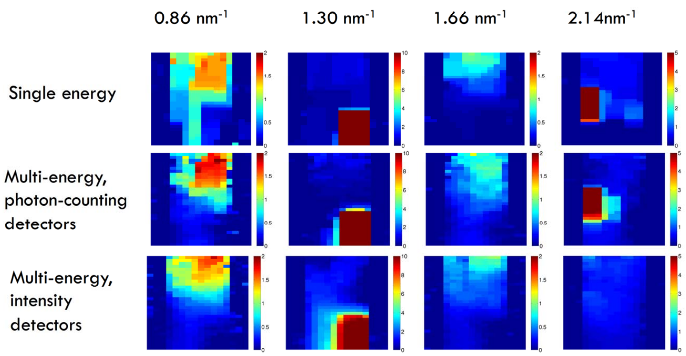
- Phantom: **Tall rectangular solid**
- Architecture: Coded aperture, 3 views (-60, 0, 60) degrees, with intensity detectors and photon-counting detectors , monochromatic vs multi-energy illumination, IRL1



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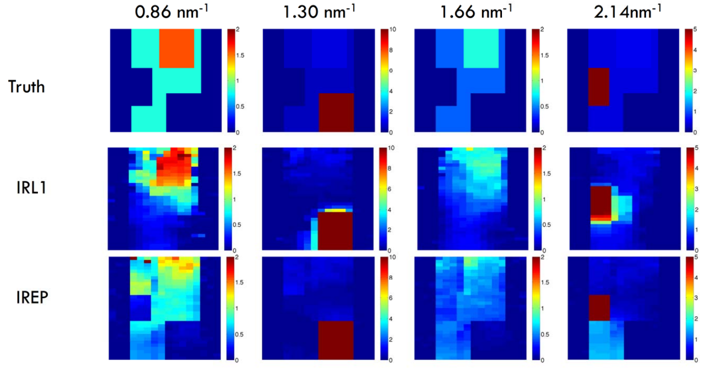
Experiment 5: Algorithm choices

- Phantom: Tall rectangular solid
- Architecture: Coded aperture, 3 views (-60, 0, 60) degrees, with photon-counting detectors, multi-energy illumination, IRL1 and IREP algorihms



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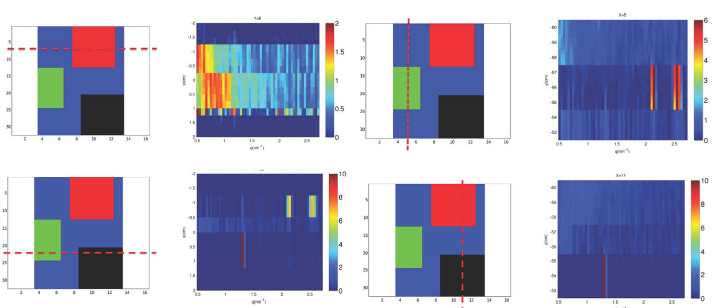
A Different View: Segmentation

- Showing form factors of X, Y slices: Can segment, approximately…



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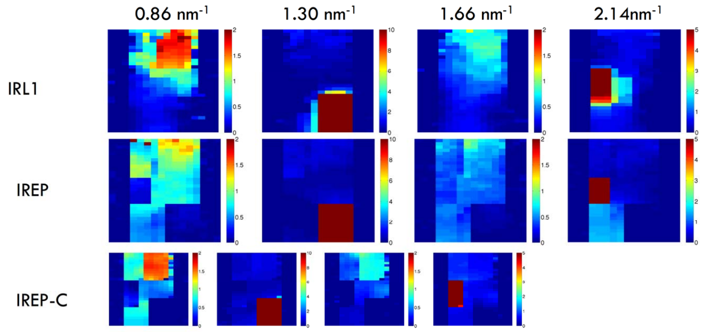
Avoiding Local Minima

- Initialize IREP after Segmentation



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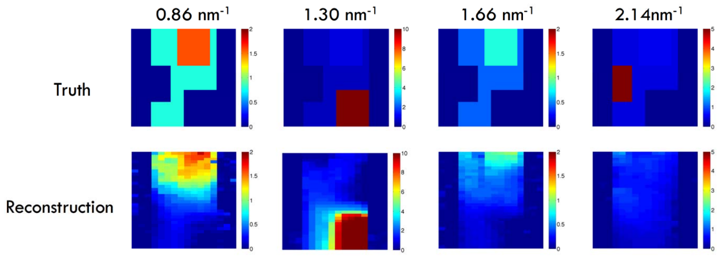
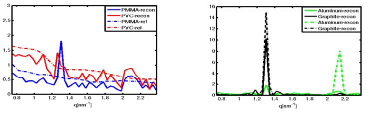
Experiment 6

- Phantom: Tall rectangular solid, reconstructing a slice
- Architecture: Coded aperture, 3 views (-60, 0, 60) degrees, with intensity detectors, multi-energy illumination, ideal noiseless case



Estimated form factors, averaged over true region



Summary

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- Iterative reconstruction algorithms are promising for reconstruction of XDI images
  - Good localization and characterization of materials with well-defined Bragg peaks
  - Harder to get accurate reconstruction of liquids and other amorphous materials in the presence of stronger scatterers nearby
- Architectures with photon-counting detectors offer improved reconstruction
  - Higher dimensional measurement, better conditioned reconstruction
- Attenuation correction requires fusion with CT or equivalent normalization for different architectures
- Major challenges remain:
  - Computation requirements for reconstruction
  - Architecture design for improved signal/noise ratio
  - Explosives detection/classification using reconstructed signals for liquids and HME classes

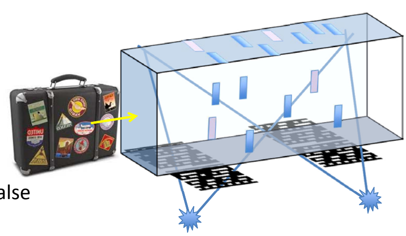
17.27 David Brady: Coding and Sampling for X-ray Molecular Imaging

Coding for X-ray Diffraction Imaging

David J. Brady and Joel Greenberg
Duke University

Introduction

- **Goal:** detect presence of threat substances in carry-on baggage
- **Primary constraints/challenges:**
  - Fast scan time (< 5s/bag) for high throughput
  - Good specificity and sensitivity to broaden threat space and reduce false alarm rate
- **Approach:** compressively acquire and combine transmission and coherent scatter signals to obtain material-specific signature at each voxel
- **Results**: structured illumination + energy-sensitive detection make real-time imaging possible



2

Background

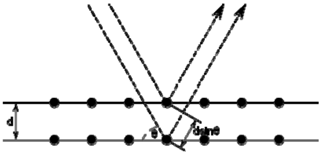
3

Coherent x-ray scatter

Bragg's law

$$q = \frac{E}{hc}\sin(\theta/2)$$

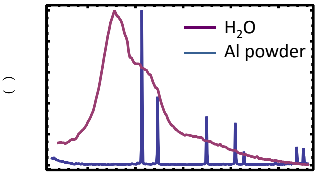
q=1/2d: momentum transfer
θ: scatter angle
E: x-ray energy



Differential cross section

$$\frac{d\sigma}{d\Omega} \propto \left[1+\cos(\theta)^2\right] f(q,\mathbf{r})$$

f(q,r): position-dependent form factor



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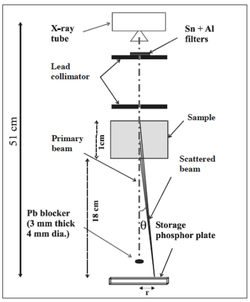
4

Techniques to measure f(q)

$$q = \frac{E}{hc}\sin(\theta/2)$$

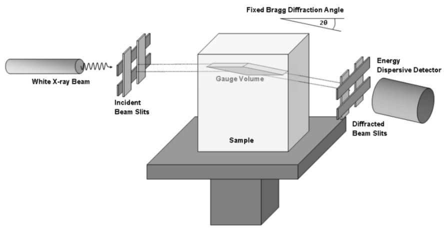
Angle-dispersive

- Study θ dependence of scatter for fixed E



Energy-dispersive

- Study energy dependence of scatter for fixed θ

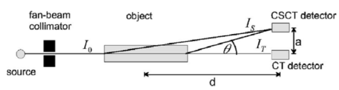


5

Coherent scatter imaging

Coherent scatter computed tomography (CSCT)

- Rotate/translate object
- Multiplexed
- State of the art: several minutes/2D slice



Delfs et al., Appl. Phys. Lett. 88, 243506 (2006)
Angew. Chem. Int. Ed. 50, 10148 (2011)
Harding et al., Phys. Med. Biol., Vol. 35, No 1, 33-41 (1990)
Dicken et al., Opt Exp. Vol 19, 6406 (2011)

6

Coherent scatter imaging

Coherent scatter computed tomography (CSCT)
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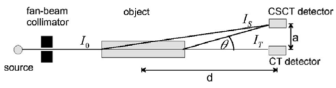
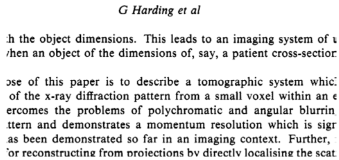


Selected volume tomography
- Scan object/collimators
- Non-multiplexed
- State of the art: several seconds/voxel


G Harding et al

:h the object dimensions. This leads to an imaging system of ι
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ɔse of this paper is to describe a tomographic system whic:
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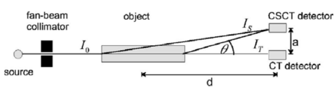
'or reconstructing from projections by directly localising the scat

Delfs et al., Appl. Phys. Lett. 88, 243506 (2006)
Angew. Chem. Int. Ed. 50, 10148 (2011)
Harding et al., Phys. Med. Biol., Vol. 35, No 1, 33-41 (1990)
Dicken et al., Opt Exp. Vol 19, 6406 (2011)

7

Coherent scatter imaging

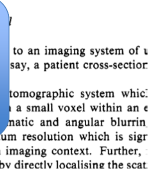
Coherent scatter computed tomography (CSCT)
- Rotate/translate object
- Multiplexed
- State of the art: several minutes/2D slice



Selected volum
- Scan ob
- Non-mu
- State o

Primary challenges:
- scatter rates are small
- attenuation effects are important

Poor photon efficiency → slow scan times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tomographic system whic:
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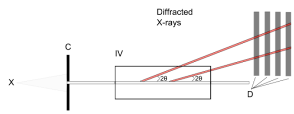
'or reconstructing from projections by directly localising the scat

Kinetic Depth Effect X-ray diffraction (KDEXRD)
- Move detector
- Multiplexed
- State of the art: 10 min/voxel

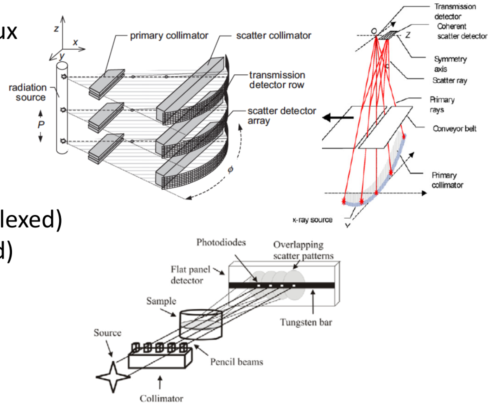


Delfs et al., Appl. Phys. Lett. 88, 243506 (2006)
Angew. Chem. Int. Ed. 50, 10148 (2011)
Harding et al., Phys. Med. Biol., Vol. 35, No 1, 33-41 (1990)
Dicken et al., Opt Exp. Vol 19, 6406 (2011)

8

Speeding things up

- Increase incident x-ray flux
  - more current
  - less filtering
- Use multiple beams
  - in series
  - in parallel (non-multiplexed)
  - in parallel (multiplexed)
- Focus scatter
  - multiple sources
  - shaped sources



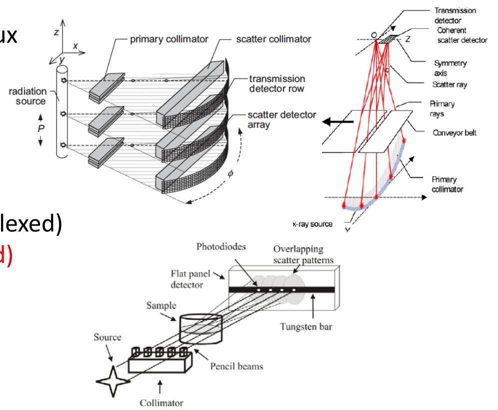
Harding et al., Applied. Rad. And Isotopes, 67, 287 (2009)

Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XIII, edited by Augustus Way Fountain III, Proc. of SPIE Vol. 8358, 83581O · © 2012 SPIE · CCC code: 0277-786X/12/$18 · doi: 10.1117/12.918666

9

Speeding things up

- Increase incident x-ray flux
  - more current
  - less filtering
- Use multiple beams
  - in series
  - in parallel (non-multiplexed)
  - in parallel (multiplexed)
- Focus scatter
  - multiple sources
  - shaped sources



Harding et al., Applied. Rad. And Isotopes, 67, 287 (2009)

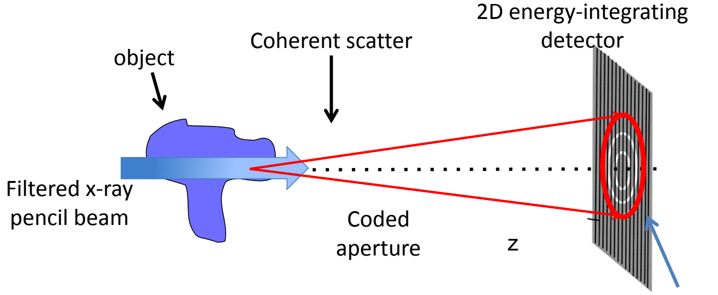
Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XIII, edited by Augustus Way Fountain III, Proc. of SPIE Vol. 8358, 83581O · © 2012 SPIE · CCC code: 0277-786X/12/$18 · doi: 10.1117/12.918666

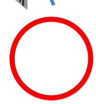
10

Coded aperture x-ray scatter imaging (CAXSI)

11

Pencil beam coded aperture x-ray scatter imaging (CAXSI)

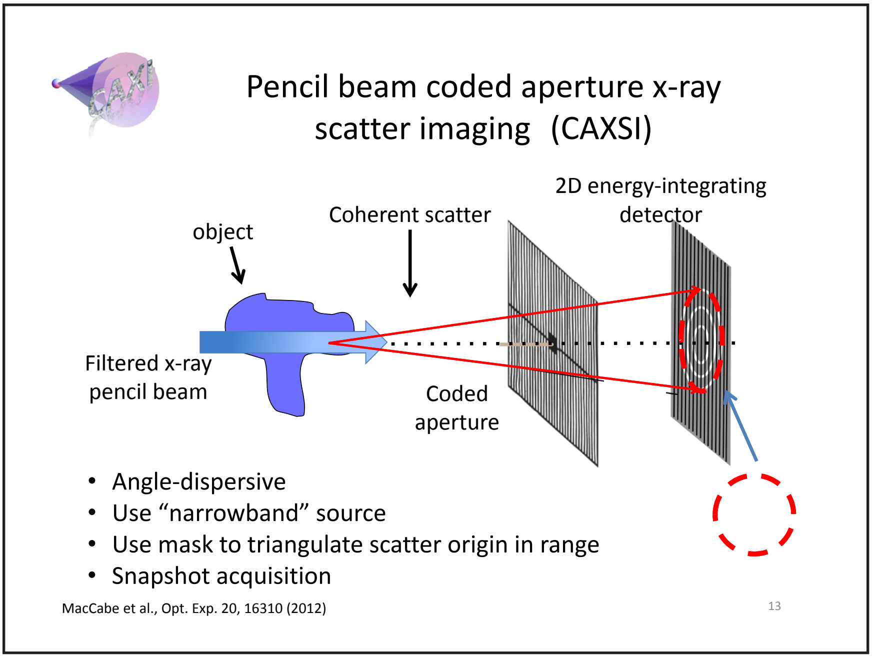


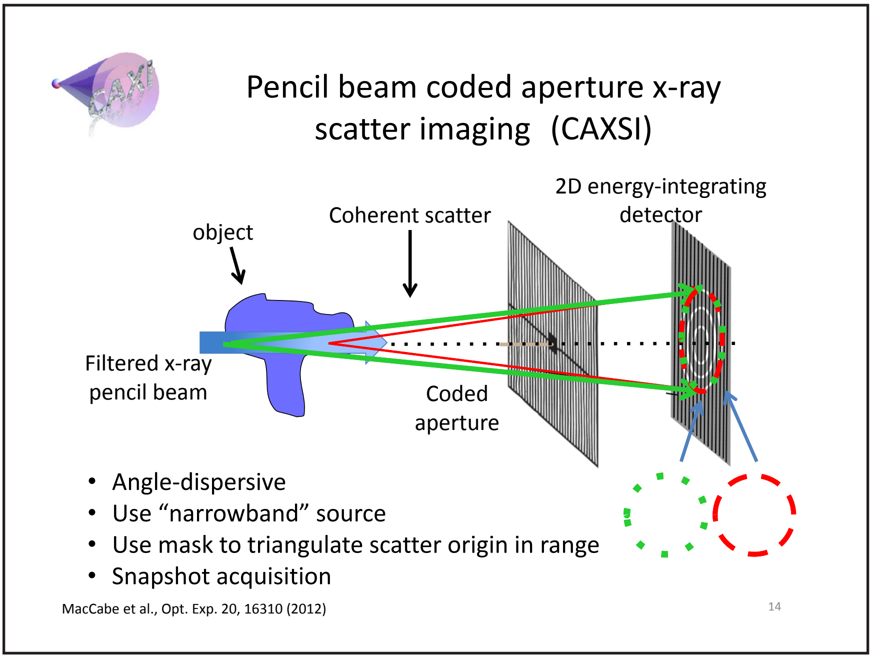


- Angle-dispersive
- Use "narrowband" source
- Use mask to triangulate scatter origin in range
- Snapshot acquisition

MacCabe et al., Opt. Exp. 20, 16310 (2012)

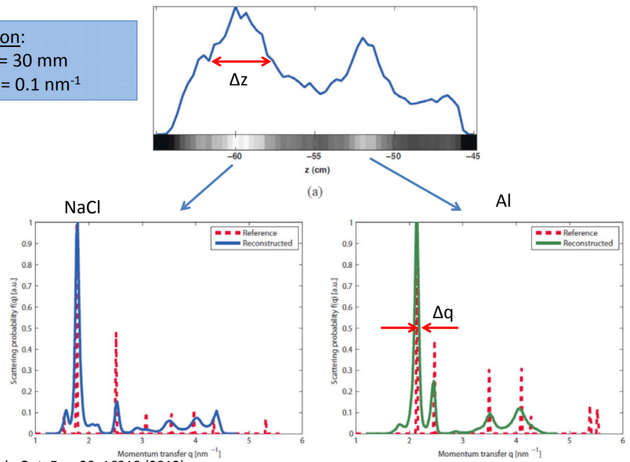
12


Pencil beam coded aperture x-ray scatter imaging (CAXSI)
object
Coherent scatter
2D energy-integrating detector
Filtered x-ray pencil beam
Coded aperture
• Angle-dispersive
• Use “narrowband” source
• Use mask to triangulate scatter origin in range
• Snapshot acquisition
MacCabe et al., Opt. Exp. 20, 16310 (2012)
13


Pencil beam coded aperture x-ray scatter imaging (CAXSI)
object
Coherent scatter
2D energy-integrating detector
Filtered x-ray pencil beam
Coded aperture
• Angle-dispersive
• Use “narrowband” source
• Use mask to triangulate scatter origin in range
• Snapshot acquisition
MacCabe et al., Opt. Exp. 20, 16310 (2012)
14

Imaging results

Resolution:
Δz = 30 mm
Δq = 0.1 nm^{-1}



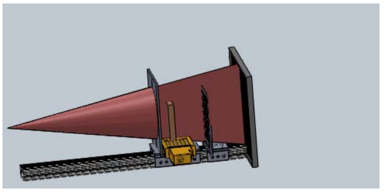
MacCabe et al., Opt. Exp. 20, 16310 (2012)

15

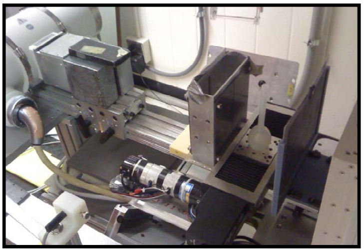
Snapshot fan-beam tomography

Extend results to fan-beam geometry
- Get range, cross-range, and angular scattering profile

Animation of experimental assembly

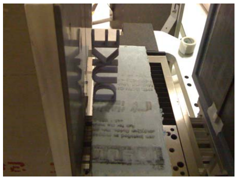


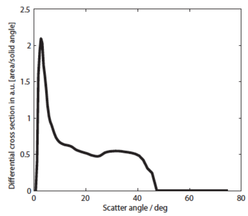
Experimental Setup at Duke MMIL



K. MacCabe, A. Holmgren, M. Tornai, and D. Brady, "Snapshot 2D tomography via coded aperture x-ray scatter imaging," Appl. Opt. 52, 4582-4589 (2013).

Snapshot fan-beam tomography



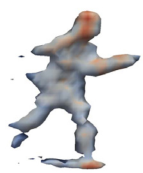
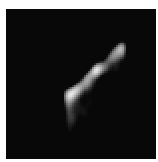


DUKE letters (plastic)
Single snapshot

K. MacCabe, A. Holmgren, M. Tornai, and D. Brady, "Snapshot 2D tomography via coded aperture x-ray scatter imaging," Appl. Opt. 52, 4582-4589 (2013).

17

Multi-shot fan-beam tomography

	Photo of object	Volume reconstruction
Toy army man (3 spatial + 1 material)		
Ticking clock (2 spatial + 1 temporal + 1 material)		

K. MacCabe, A. Holmgren, M. Tornai, and D. Brady, "Snapshot 2D tomography via coded aperture x-ray scatter imaging," Appl. Opt. 52, 4582-4589 (2013).

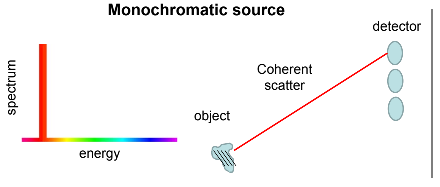
18

Coded aperture coherent scatter spectral imaging (CACSSI)

19

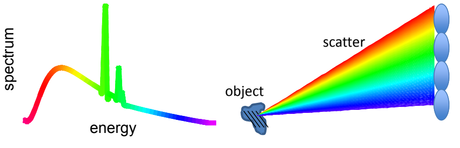
Broadband illumination

Monochromatic source



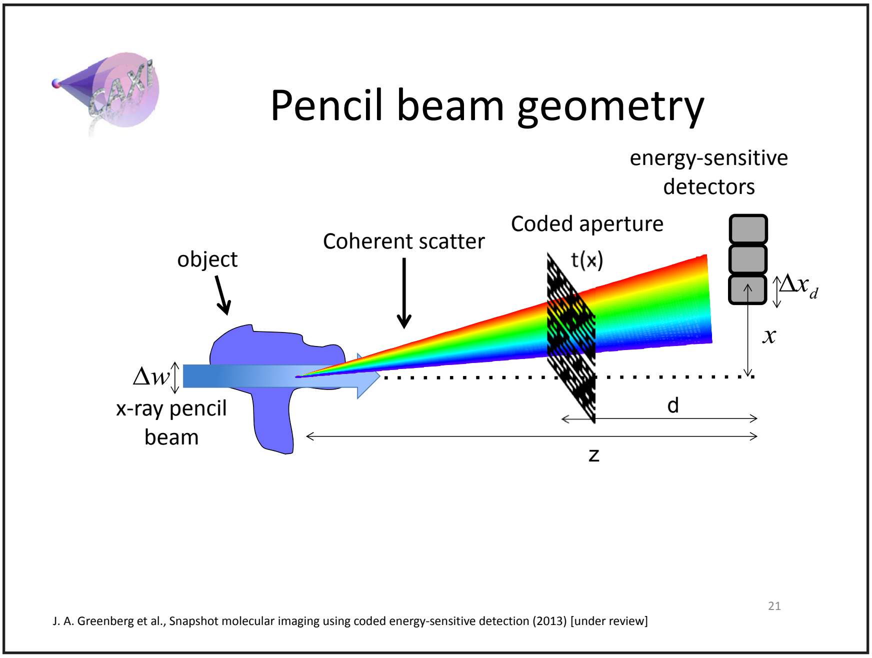
- Many photons thrown away
- Specific detector locations required

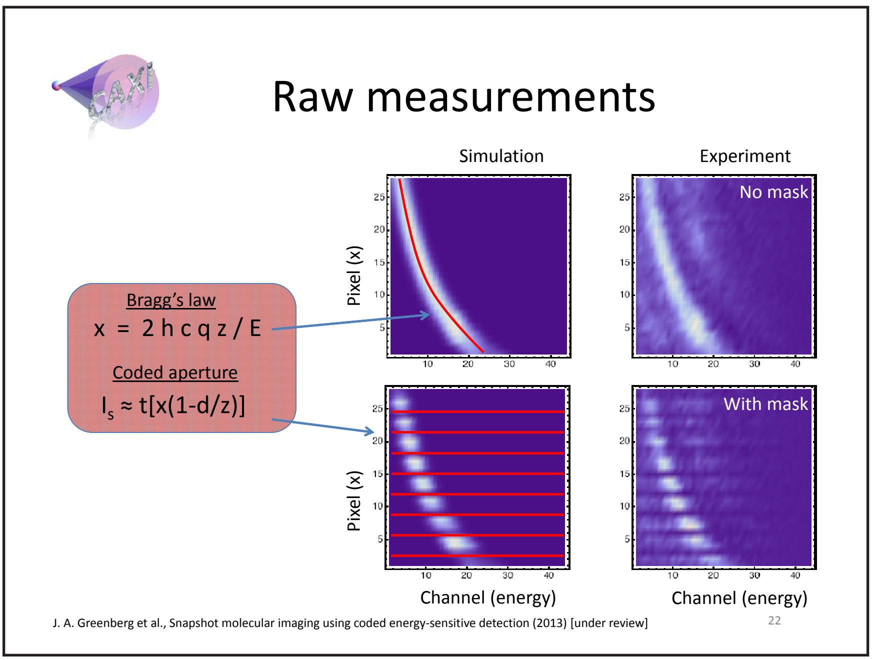
- Use all incident photons
- Range of available detector locations



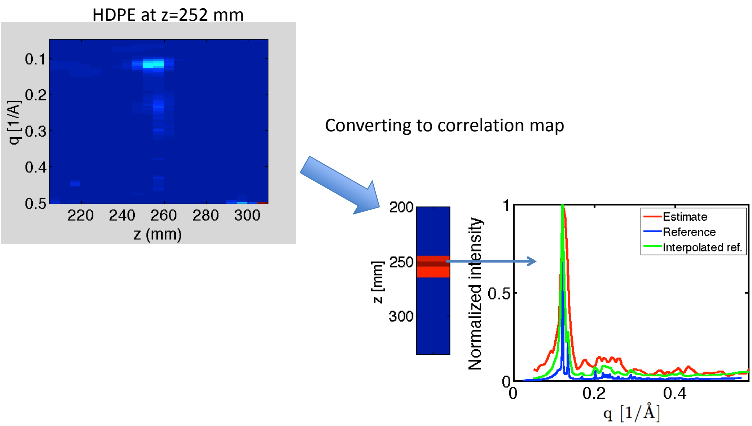
J. A. Greenberg et al., Snapshot molecular imaging using coded energy-sensitive detection (2013)

20


Pencil beam geometry
energy-sensitive detectors
Coded aperture
t(x)
Coherent scatter
object
Δw
x-ray pencil beam
Δx_d
x
d
z
J. A. Greenberg et al., Snapshot molecular imaging using coded energy-sensitive detection (2013) [under review]
21


Raw measurements
Simulation
Experiment
No mask
With mask
Pixel (x)
Bragg's law
x = 2 h c q z / E
Coded aperture
I_s ≈ t[x(1-d/z)]
Channel (energy)
Channel (energy)
J. A. Greenberg et al., Snapshot molecular imaging using coded energy-sensitive detection (2013) [under review]
22

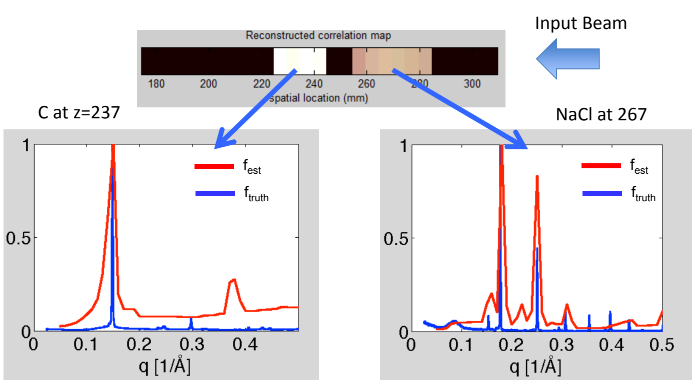
Single object reconstruction



J. A. Greenberg et al., Snapshot molecular imaging using coded energy-sensitive detection (2013)

23

Multi-object reconstruction

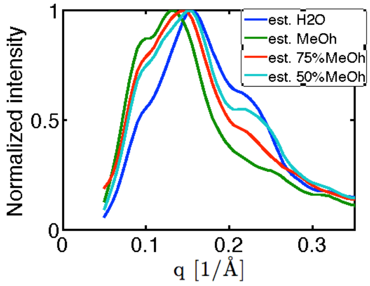


J. A. Greenberg et al., Snapshot molecular imaging using coded energy-sensitive detection (2013)

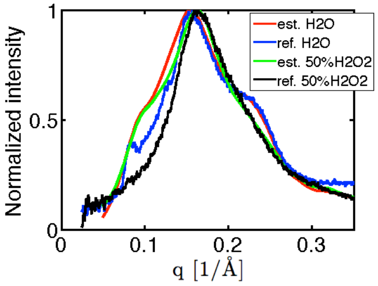
24

Water-like object discrimination

Different concentrations of H_20 + Methanol



H_20 + vs 50% H_2O_2



J. A. Greenberg et al., Snapshot molecular imaging using coded energy-sensitive detection (2013) [under review]

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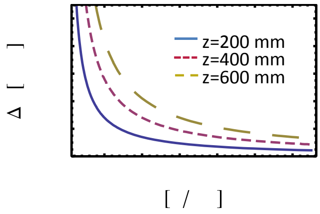
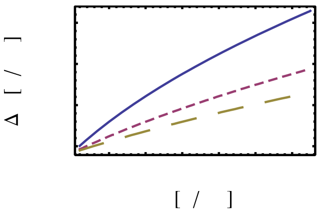
CACSSI resolution

Predictions





Observations

Δz~5 mm with
Δq<0.02 1/Å

J. A. Greenberg et al., Snapshot molecular imaging using coded energy-sensitive detection (2013) [under review]

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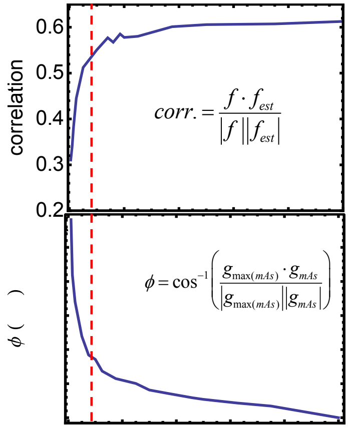
Dependence on mAs



Only ~100 mAs required to identify a range of materials with < 1% of total scatter signal collected

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Lingering issues

- Bulky
  - Detectors should be object thickness away from mask
- Difficult to scale to full 4D data cube
  - hard to code all dimensions
  - need higher-dimensional detector arrays ($)
- Bottom line: still too slow
  - Need more efficient use of source photons

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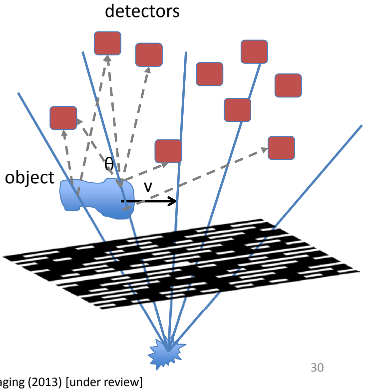
Structured illumination coherent scatter imaging (SICSI)

29

Structured illumination

Measurement strategy

- Use code to modulate illumination before object
- Object moves through beams
- Acquire many spectra at different times using energy-sensitive pixels: g(E, t, x, y)



J. A. Greenberg et al., Structured illumination for tomographic molecular imaging (2013) [under review]

30

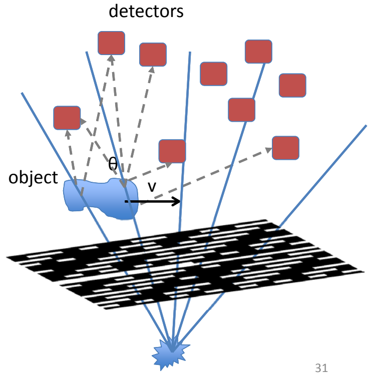
Structured illumination

Measurement strategy

- Use code to modulate illumination before object
- Object moves through beams
- Acquire many spectra at different times using energy-sensitive pixels: g(E, t, x, y)

Advantages

- Optimal use of source photons (no spectral/minimal spatial filtering)
- Scales easily up to 4D
- Fewer detectors needed (sparse array only)
- Allows for simultaneous tomosynthesis
- Compatible with multiple sources
- Allows for adaptive implementation
- Simple modification to existing machines
  - Open up collimation
  - Add scatter detectors



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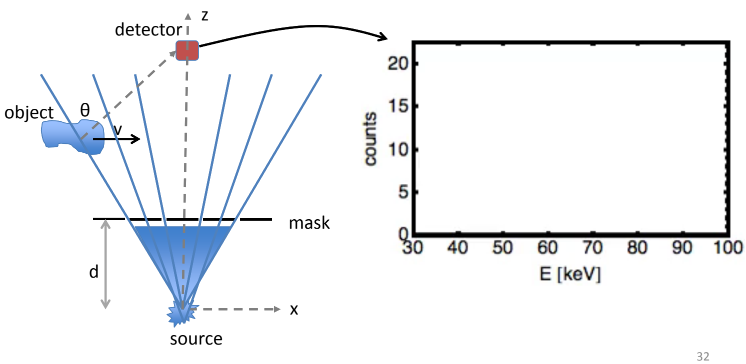
Example: modulated fan beam

- Source: conventional x-ray tube
- Mask: periodic series of holes along a line t(x) = (1+sign[sin(u x)])/2
- Detector: Single, energy sensitive pixel

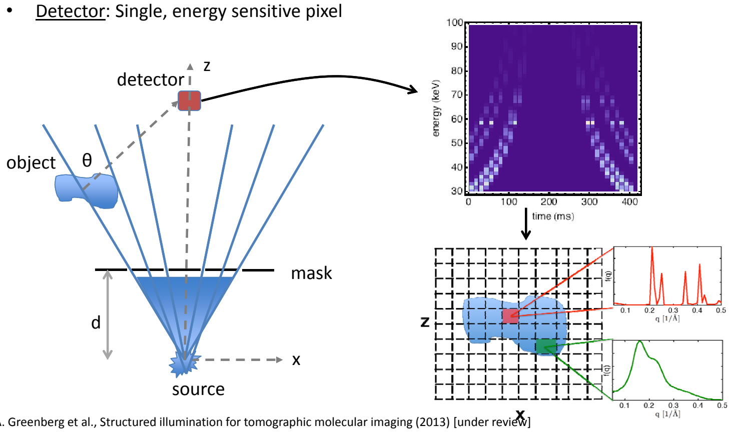


32

J. A. Greenberg et al., Structured illumination for tomographic molecular imaging (2013) [under review]

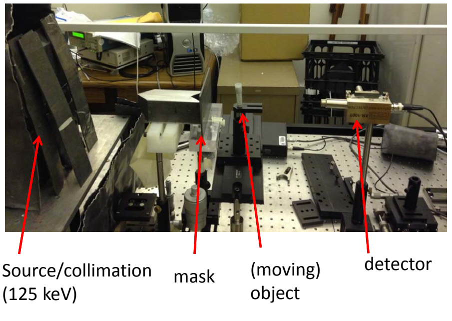
Example: modulated fan beam

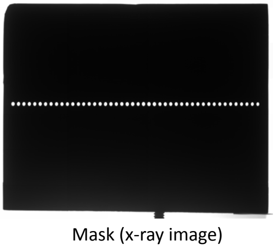
- Source: conventional x-ray tube
- Mask: periodic series of holes along a line t(x) = (1+sign[sin(u x)])/2
- Detector: Single, energy sensitive pixel



J. A. Greenberg et al., Structured illumination for tomographic molecular imaging (2013) [under review]

SICSI experiment





Mask (x-ray image)

- 3 mm thick Pb
- 1.5 mm diameter holes
- 3 mm center-to-center spacing

J. A. Greenberg et al., Structured illumination for tomographic molecular imaging (2013) [under review]

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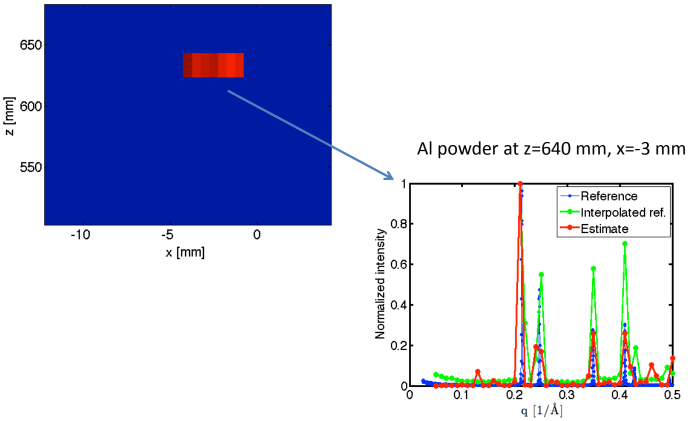
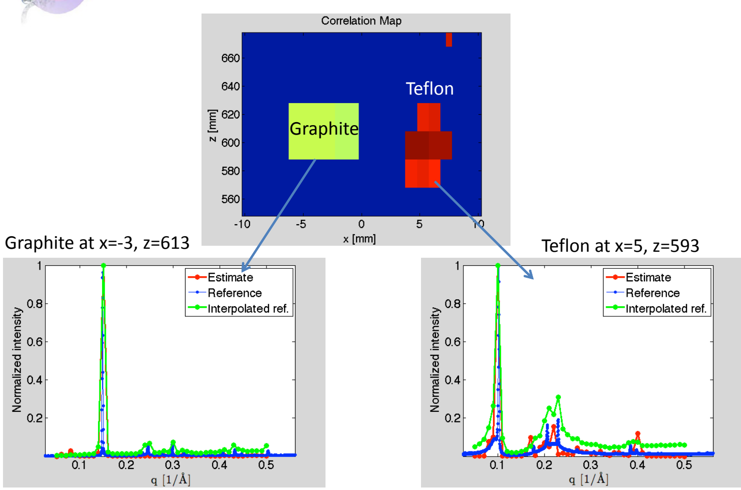
Single object reconstruction



J. A. Greenberg et al., Structured illumination for tomographic molecular imaging (2013) [under review]

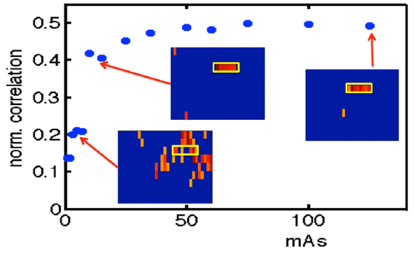
35

Multi-object classification



J. A. Greenberg et al., Structured illumination for tomographic molecular imaging (2013) [under review]

Dependence on mAs



Notes

- Only use 1 pixel
  - Collect ≈0.1% of scatter!
- Accurate results down to 5 mAs (defined per integration time)
  - Corresponds to ~1 cm/s belt speed with 10 mA source

Going forward

- Use more pixels
  - Collect more photons (e.g., 10-100x)
  - better conditioning (less compressive)
- Use higher mA/kV source (e.g., 160 kV at 90 mA)
- Combine with transmission-based tomosynthesis
- Use full cone beam

Real-time (>10 cm/s) operation with real suitcases

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Summary

- Arrays of energy-sensitive detectors are crucial for real-time operation
- Minimal source filtering with structured illumination yields a drastic speed-up in required imaging time
- Integration of scatter and transmission is necessary
- Prototype construction is currently underway!

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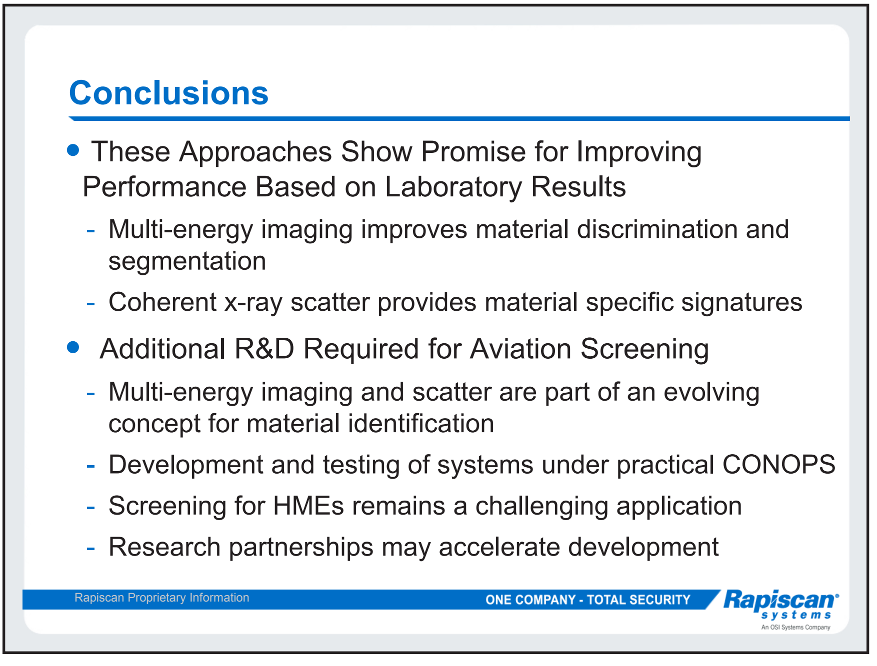
Acknowledgements

U.S. Department of Homeland Security, Science and Technology Directorate sponsored this work under contract HSHQDC-11-C-00083

CAXSI Proprietary Information 39

17.28 Ed Morton: Detection with Spectral X-ray Detectors and the Complimentary Method of X-ray Diffraction



The Challenge

- Dual-Energy Systems are Used to Screen for Aviation Threats
  - Achieves high PD with an operationally acceptable PFA
  - Commercial and military explosives are generally well separated from benign items in ρ-Zeff space
- Screening for Home Made Explosives (HMEs)
  - HMEs are variable due the way they are produced (raw materials, impurities, and manufacturing processes) and chemical effects (aging)
  - Significant overlap with benign items in ρ-Zeff space

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Rapiscan Investigating Multiple Approaches to Improve Detection and Reduce False Alarms

- Multi-Energy Imaging
  - Better measurement of ρ and Zeff
- Coherent X-Ray Scatter
  - Provides orthogonal signature related to atomic structure
- Other Approaches
  - Tomography
  - Phase contrast
  - Compressive sensing

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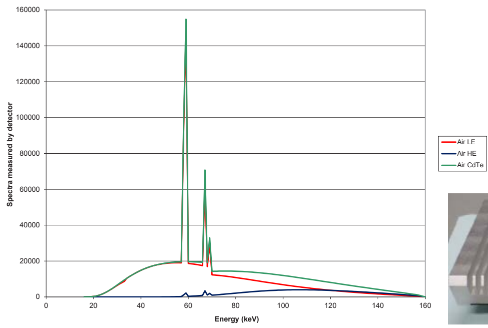
Dual-Energy (DE) vs. Multi-Energy (ME) Imaging



Calculated absorption in DE and ME detectors


DE (top) and ME (bottom) detector modules

- DE uses two broad overlapping LE and HE bands
- ME uses the entire transmitted spectrum

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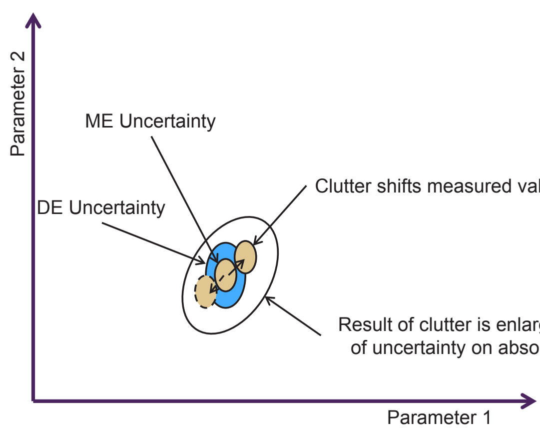
DE vs ME Accuracy



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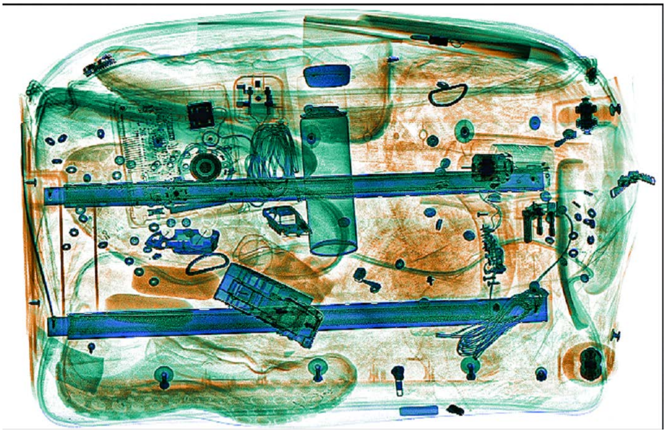
Effect of Clutter in Bags



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Multi-Energy Imaging

- Benefits
  - Improved material discrimination due to increased accuracy and precision in the measurement of Zeff and density
  - Improved segmentation due to improved resolution and image quality
- Shows promise for improved PD and PFA
- BUT clutter is a problem in quantitative imaging …
- Future efforts are focused on cargo, checkpoint, and hold-baggage applications

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Rapiscan has over 10 years experience with XRD and Coherent X-Ray Scatter

- University Collaborations
  - "Energy dispersive X-ray scatter for measurement of oil/water ratios", Luggar, R. D.; Key, M. J.; Morton, E. J.; Gilboy, W. B.; NIM, Sec A, V 422, p. 938-941 (1999).
- Bulk Explosives
  - Rapiscan XRD1000 system used XRD for alarm clearing
- Home-Made Explosives
  - Proprietary technology

XRD1000 Baggage Inspection System
Combined dual-view, dual-energy imaging with integrated XRD subsystem

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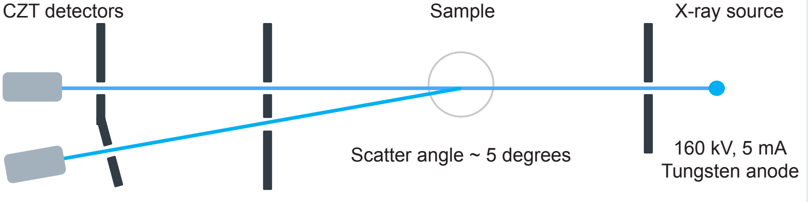
Pencil Beam Coherent X-ray Scatter Geometry



- Pencil beam geometry is very simple
  - However not very efficient
  - Probes only a single point
- Rapiscan is investigating more efficient geometries

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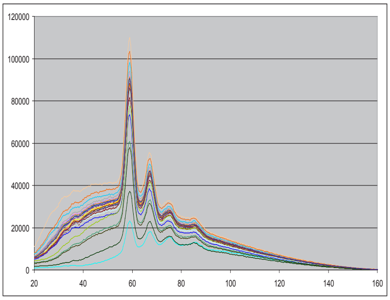
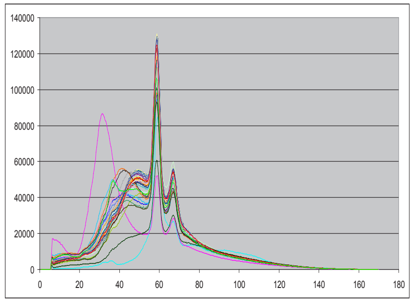
Produces Unique Material-Dependent Transmission and Scatter Signatures



Raw Transmission Spectra



Raw Coherent X-ray Scatter Spectra

- Bulk and HME explosives
- Stream-of-passenger items

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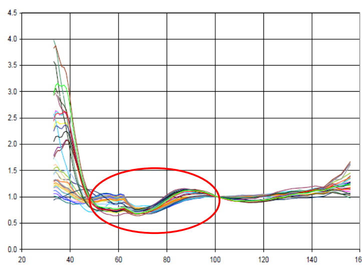
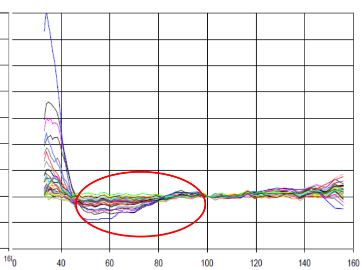
Processed and Normalized Scatter Signature



Threat Materials



Benign Substances

- Scatter signatures of threat materials distinguishable from benign materials (see red ovals)
- Can be used in automated classification algorithms

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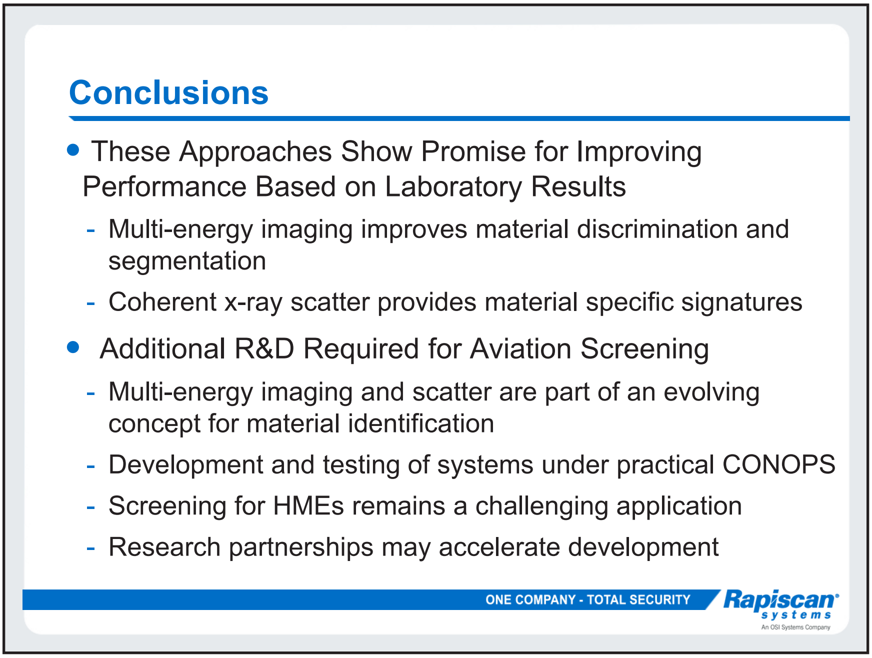
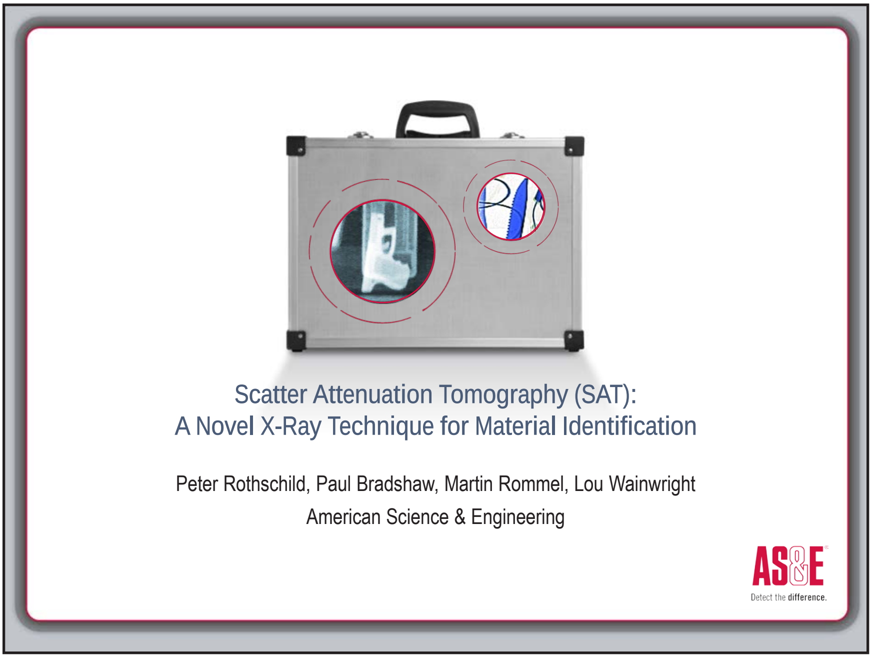
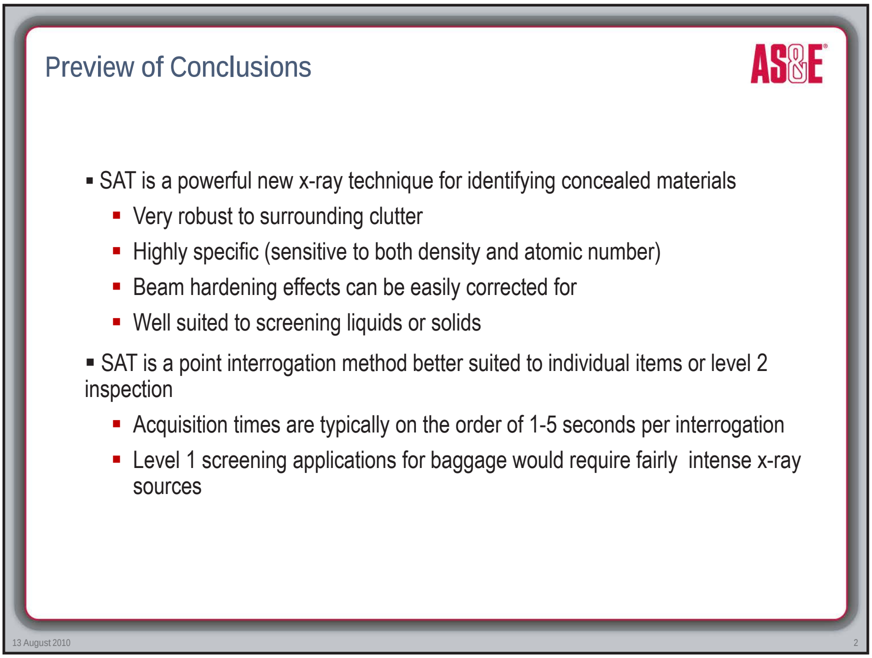

Conclusions
• These Approaches Show Promise for Improving Performance Based on Laboratory Results
- Multi-energy imaging improves material discrimination and segmentation
- Coherent x-ray scatter provides material specific signatures
• Additional R&D Required for Aviation Screening
- Multi-energy imaging and scatter are part of an evolving concept for material identification
- Development and testing of systems under practical CONOPS
- Screening for HMEs remains a challenging application
- Research partnerships may accelerate development
ONE COMPANY - TOTAL SECURITY
Rapiscan systems
An OSI Systems Company

17.29 Peter Rothschild: The Application of Scatter Attenuation Tomography (SAT) for Explosives Detection





HOW CAN WE USE INCOHERENT (COMPTON) SCATTER OF X-RAYS TO CHARACTERIZE OR IDENTIFY CONCEALED MATERIALS?

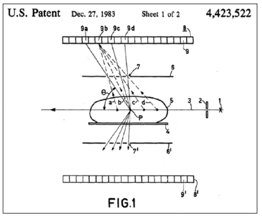
AS&E
Detect the difference.

13 August 2010 3

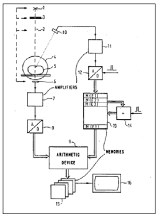
Prior Art (with Monochromatic Sources)

AS&E

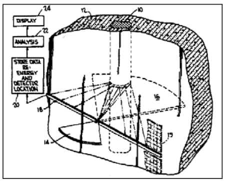
G. Harding; Philips, 1983



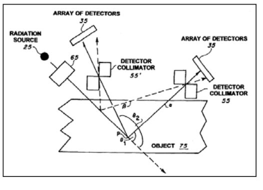
G. Harding & J.M. Kosanetzky; Philips, 1989



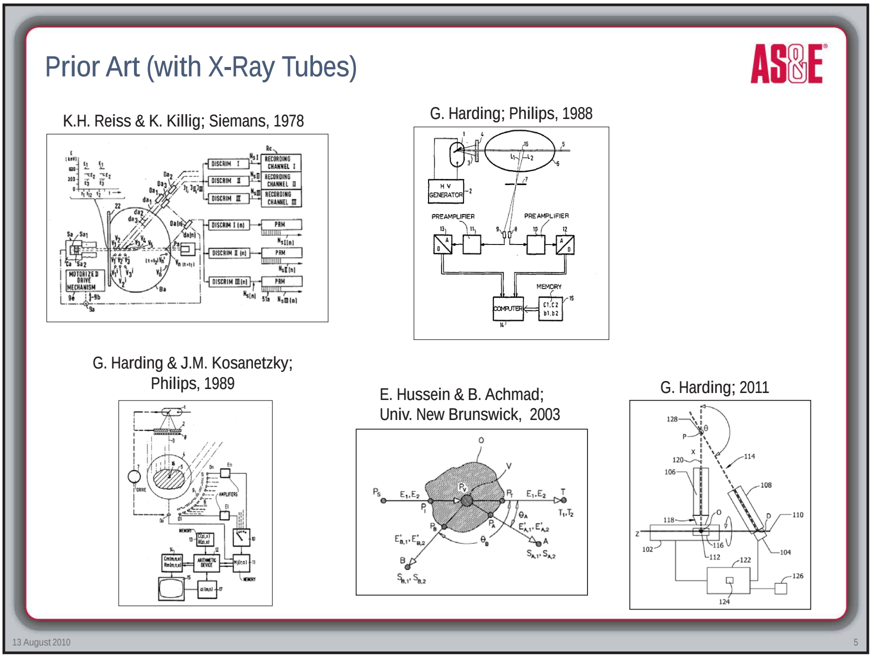
S. Norton; U.S. Dept. Commerce, 1995

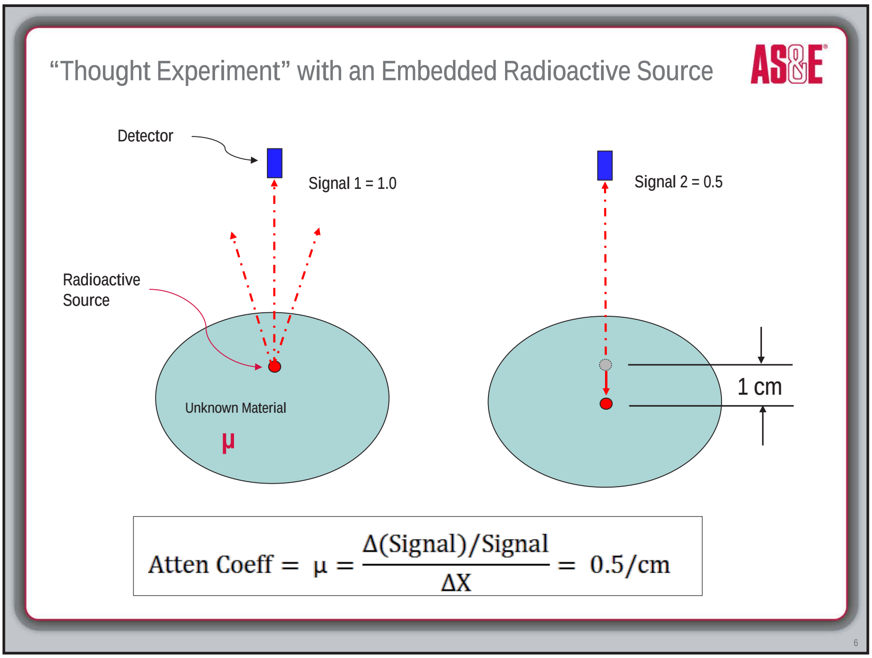


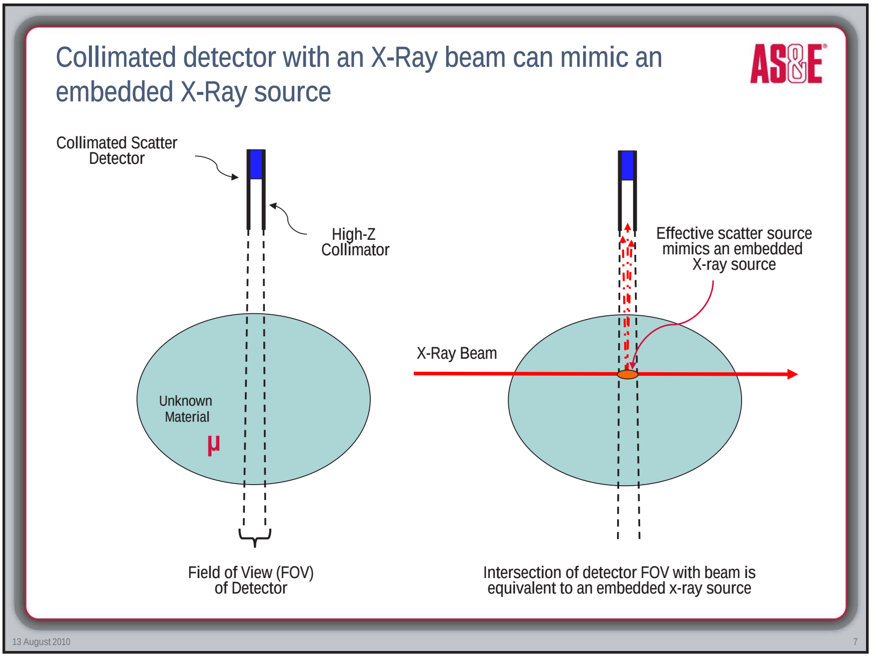
Y.S.Ham; Korean Atomic Energy R.I., 1998



13 August 2010 4


Prior Art (with X-Ray Tubes)
AS&E
K.H. Reiss & K. Killig; Siemans, 1978
G. Harding; Philips, 1988
G. Harding & J.M. Kosanetzky; Philips, 1989
E. Hussein & B. Achmad; Univ. New Brunswick, 2003
G. Harding; 2011
13 August 2010
5


"Thought Experiment" with an Embedded Radioactive Source
AS&E
Detector
Signal 1 = 1.0
Signal 2 = 0.5
Radioactive Source
Unknown Material
μ
1 cm
$\text{Atten Coeff} = \mu = \dfrac{\Delta(\text{Signal})/\text{Signal}}{\Delta X} = 0.5/\text{cm}$
6


Collimated detector with an X-Ray beam can mimic an embedded X-Ray source
AS&E
Collimated Scatter Detector
High-Z Collimator
Unknown Material
μ
Field of View (FOV) of Detector
Effective scatter source mimics an embedded X-ray source
X-Ray Beam
Intersection of detector FOV with beam is equivalent to an embedded x-ray source
13 August 2010
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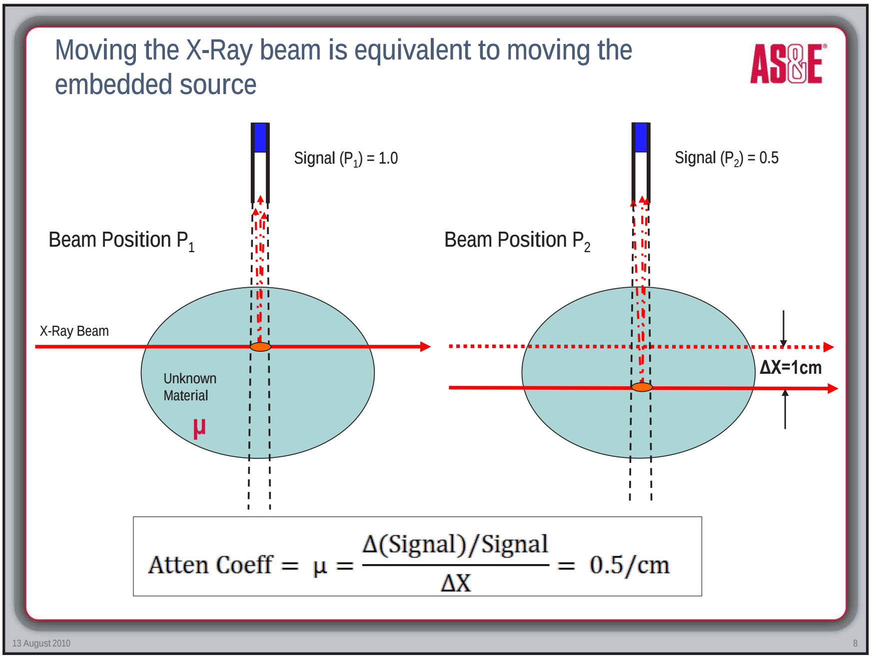
Moving the X-Ray beam is equivalent to moving the embedded source
AS&E
Signal (P1) = 1.0
Signal (P2) = 0.5
Beam Position P1
Beam Position P2
X-Ray Beam
Unknown Material
μ
ΔX=1cm
Atten Coeff = μ = Δ(Signal)/Signal / ΔX = 0.5/cm
13 August 2010
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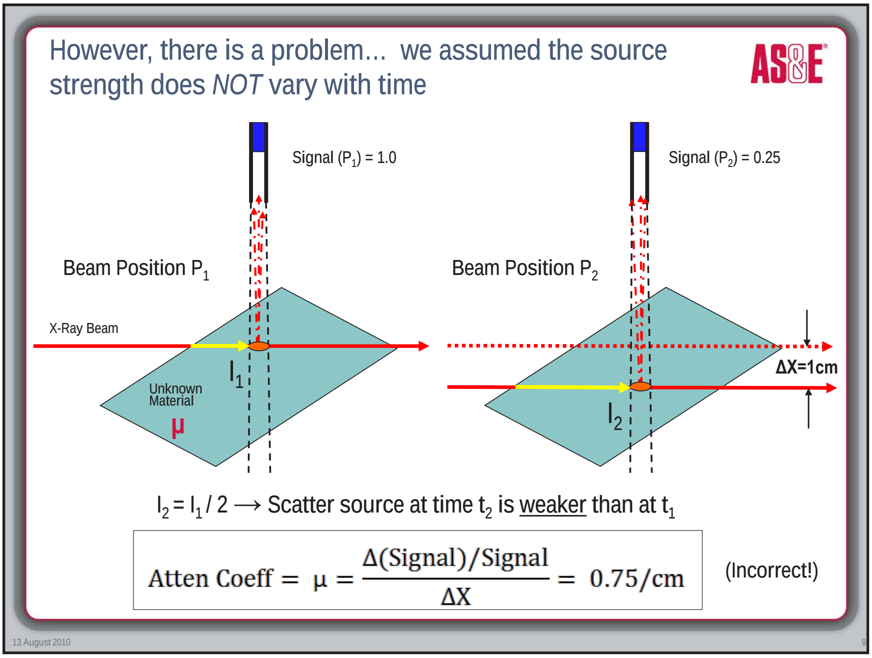
However, there is a problem… we assumed the source strength does *NOT* vary with time
AS&E
Signal (P_1) = 1.0
Signal (P_2) = 0.25
Beam Position P_1
Beam Position P_2
X-Ray Beam
I_1
I_2
Unknown Material
μ
ΔX=1cm
$I_2 = I_1 / 2$ ⟶ Scatter source at time t_2 is weaker than at t_1
$\text{Atten Coeff} = \mu = \frac{\Delta(\text{Signal})/\text{Signal}}{\Delta X} = 0.75/\text{cm}$
(Incorrect!)
13 August 2010
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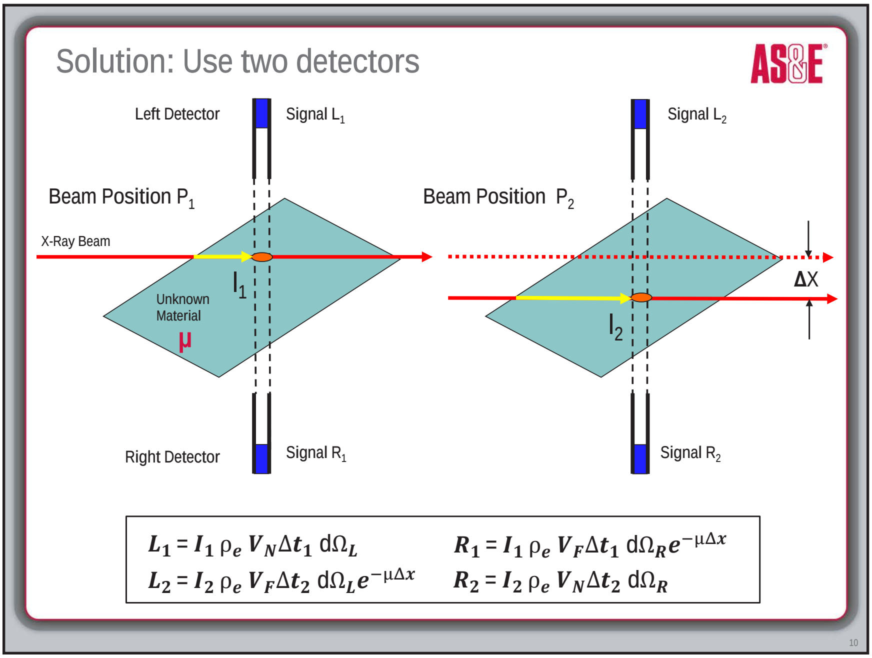

Solution: Use two detectors
AS&E
Left Detector
Signal L_1
Signal L_2
Beam Position P_1
Beam Position P_2
X-Ray Beam
I_1
I_2
Unknown Material
μ
ΔX
Right Detector
Signal R_1
Signal R_2
$L_1 = I_1 \rho_e V_N \Delta t_1 \, d\Omega_L$
$R_1 = I_1 \rho_e V_F \Delta t_1 \, d\Omega_R e^{-\mu \Delta x}$
$L_2 = I_2 \rho_e V_F \Delta t_2 \, d\Omega_L e^{-\mu \Delta x}$
$R_2 = I_2 \rho_e V_N \Delta t_2 \, d\Omega_R$
10

Take Ratios of Signals in Each Detector:

$$\frac{L_2}{L_1} = \frac{I_2}{I_1}\frac{V_F}{V_N}\frac{\Delta t_2}{\Delta t_1}e^{-\mu \Delta X}$$

$$\frac{R_1}{R_2} = \frac{I_1}{I_2}\frac{V_F}{V_N}\frac{\Delta t_1}{\Delta t_2}e^{-\mu \Delta X}$$

Multiply 2 equations and solve for μ →

I_1, I_2, Δt_1, Δt_2 disappear

$$N_{SAT}(E_s) = \mu(E_s) = \frac{1}{2\Delta X} Ln\left[\frac{L_1}{L_2}\frac{R_2}{R_1}\right] - C$$

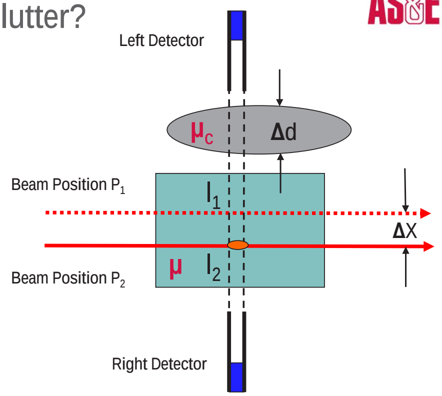
where $C = \frac{Ln\left(\frac{V_N}{V_F}\right)}{\Delta X} \sim 0$ (C can be calculated exactly from geometry, but is just an offset)

$$N_{SAT}(E_s) = \mu(E_s) = \frac{1}{2\Delta X} Ln\left[\frac{L_1}{L_2}\frac{R_2}{R_1}\right]$$

(Scatter Equivalent of the CT Number)

What about surrounding clutter?

Scattered radiation from the two voxels follows exactly the same path through the surrounding clutter, so the attenuation terms from near and far voxels cancel in the ratios



ρ_e = Electron Density
V_N, V_F = Voxel Volumes
Δt_1, Δt_2 = Integration Times

$$\frac{L_2}{L_1} = \frac{I_2}{I_1}\frac{\rho_e V_F}{\rho_e V_N}\frac{\Delta t_2}{\Delta t_1}\frac{e^{-\mu_c \Delta d}}{e^{-\mu_c \Delta d}}e^{-\mu \Delta X}$$

$$\frac{R_1}{R_2} = \frac{I_1}{I_2}\frac{\rho_e V_F}{\rho_e V_N}\frac{\Delta t_1}{\Delta t_2}e^{-\mu \Delta X}$$

$$\mu(E_s) = \frac{1}{2\Delta X} Ln\left[\frac{L_1}{L_2}\frac{R_2}{R_1}\right]$$

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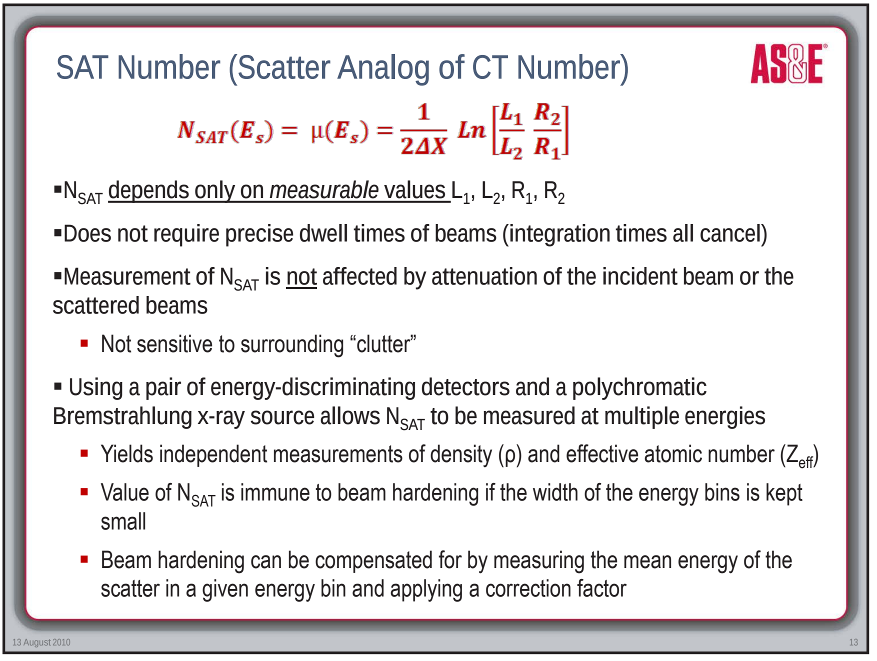
SAT Number (Scatter Analog of CT Number)
AS&E
$N_{SAT}(E_s) = \mu(E_s) = \frac{1}{2\Delta X} Ln\left[\frac{L_1}{L_2}\frac{R_2}{R_1}\right]$
▪N_{SAT} depends only on *measurable* values L_1, L_2, R_1, R_2
▪Does not require precise dwell times of beams (integration times all cancel)
▪Measurement of N_{SAT} is not affected by attenuation of the incident beam or the scattered beams
▪ Not sensitive to surrounding “clutter”
▪ Using a pair of energy-discriminating detectors and a polychromatic Bremstrahlung x-ray source allows N_{SAT} to be measured at multiple energies
▪ Yields independent measurements of density (ρ) and effective atomic number (Z_{eff})
▪ Value of N_{SAT} is immune to beam hardening if the width of the energy bins is kept small
▪ Beam hardening can be compensated for by measuring the mean energy of the scatter in a given energy bin and applying a correction factor
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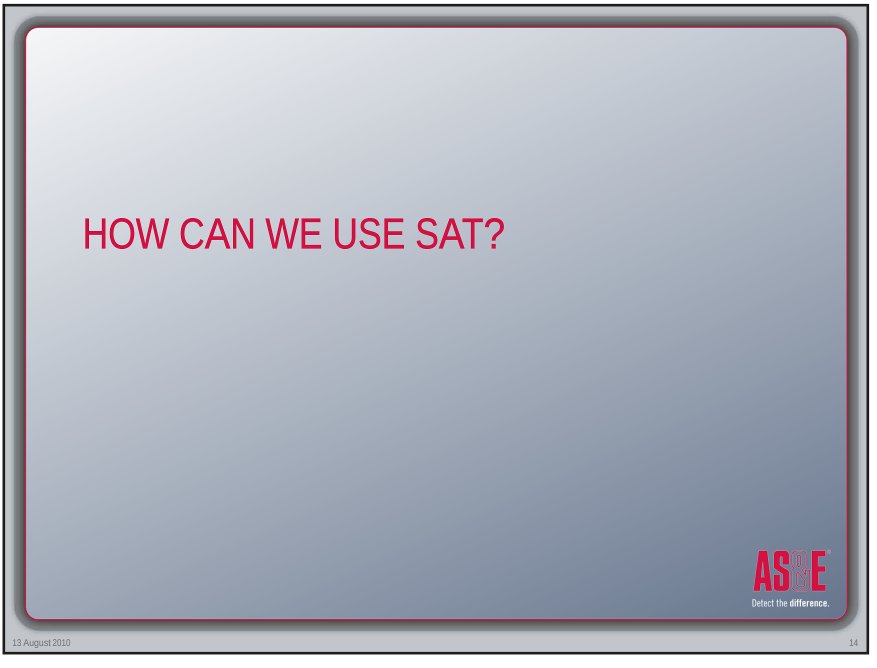
HOW CAN WE USE SAT?
AS&E
Detect the difference.
13 August 2010
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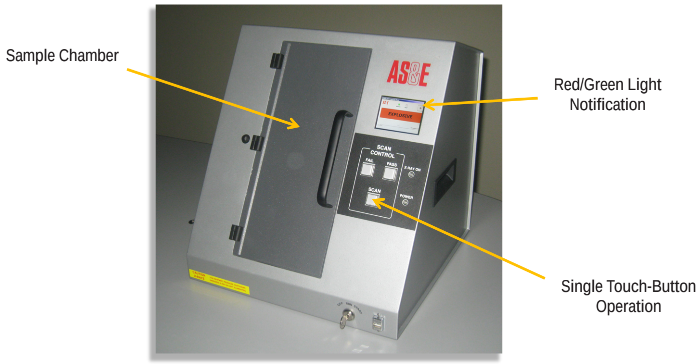
2010: 50kV SAT Bottled Liquid Scanner (BLS)

AS&E



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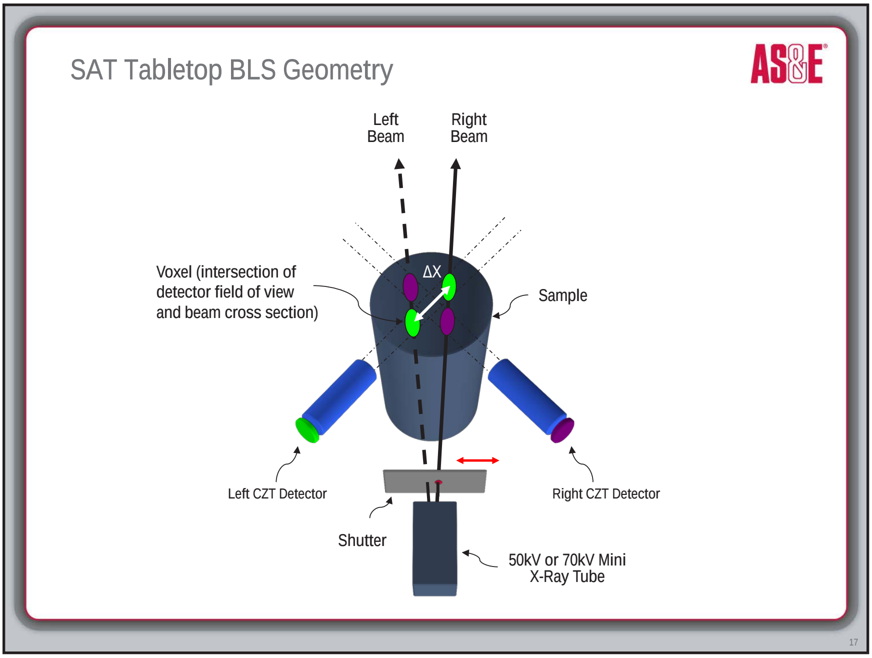
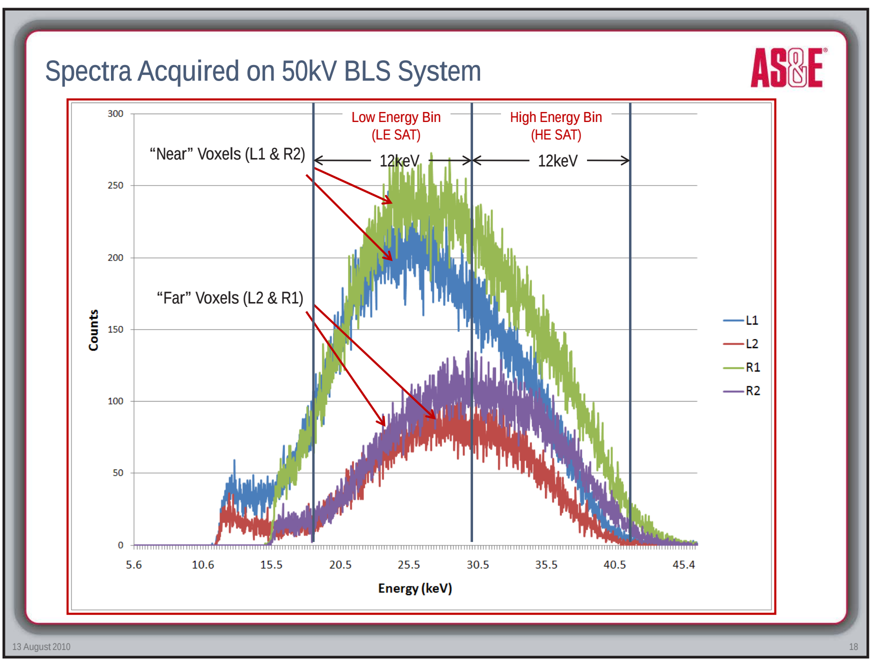
2012: 70kV SAT Bottled Liquid Scanner (BLS)

AS&E

70kV allows much wider separation of low and high energy bins
→ improved ρ and Z_{eff} determination

16


SAT Tabletop BLS Geometry
AS&E
Left Beam
Right Beam
ΔX
Voxel (intersection of detector field of view and beam cross section)
Sample
Left CZT Detector
Right CZT Detector
Shutter
50kV or 70kV Mini X-Ray Tube
17


Spectra Acquired on 50kV BLS System
AS&E
Low Energy Bin (LE SAT)
High Energy Bin (HE SAT)
12keV
12keV
"Near" Voxels (L1 & R2)
"Far" Voxels (L2 & R1)
Counts
300
250
200
150
100
50
0
5.6
10.6
15.5
20.5
25.5
30.5
35.5
40.5
45.4
Energy (keV)
L1
L2
R1
R2
13 August 2010
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System Affected by Beam Hardening

AS&E

- Energy bins are fairly wide on the 50kV BLS system due to low power x-ray source ($\Delta E \sim 12keV$)
- This means that the mean energy of the scattered x-rays in each bin can vary with container type, changing the measured SAT Numbers
  - Use a classifier algorithm that compensates for this
  - Can use measured count rate or the mean energy in each bin to determine the container type
  - Use five separate classifiers for each major container category
    - e.g. thin plastic, thick plastic, thin glass, medium glass, thick glass

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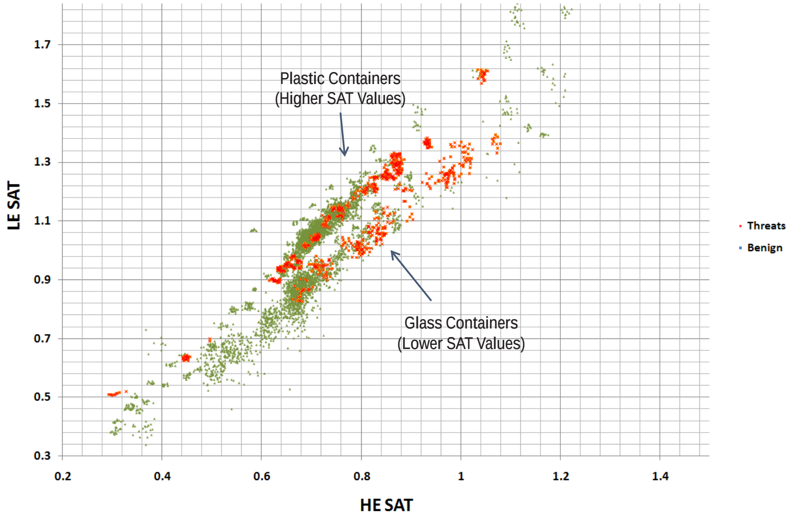
50kV Experimental SAT Data for Wide Range of Threat Liquids



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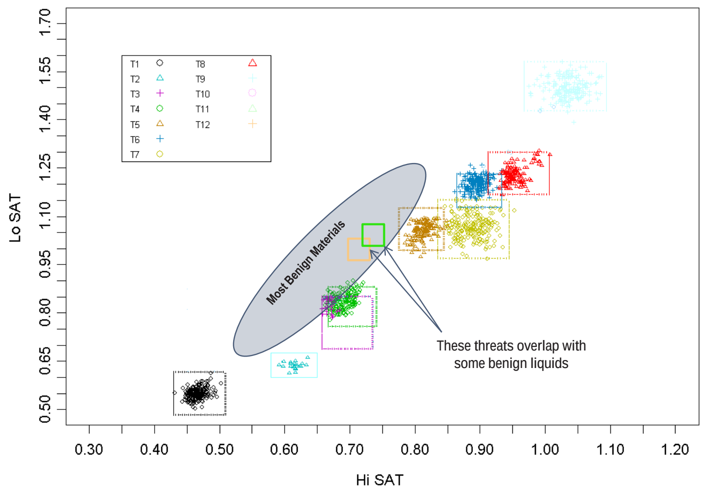
Experimental SAT Data for Some Specific Liquid Threats



ONE SOLUTION IS A VALIDATION SYSTEM THAT USES A BARCODE SCANNER

Detect the **difference.**

13 August 2010

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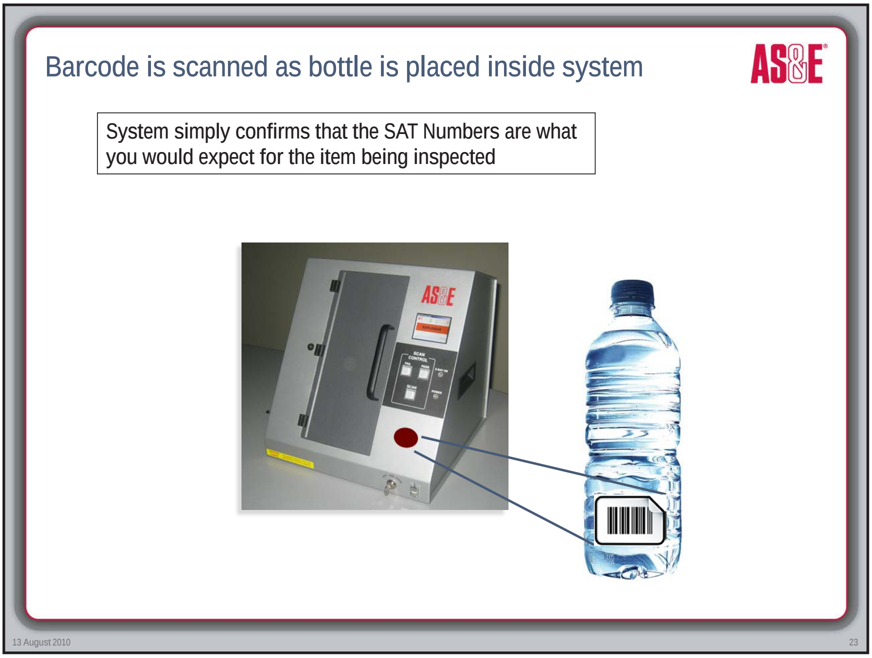
Barcode is scanned as bottle is placed inside system
AS&E
System simply confirms that the SAT Numbers are what you would expect for the item being inspected
13 August 2010
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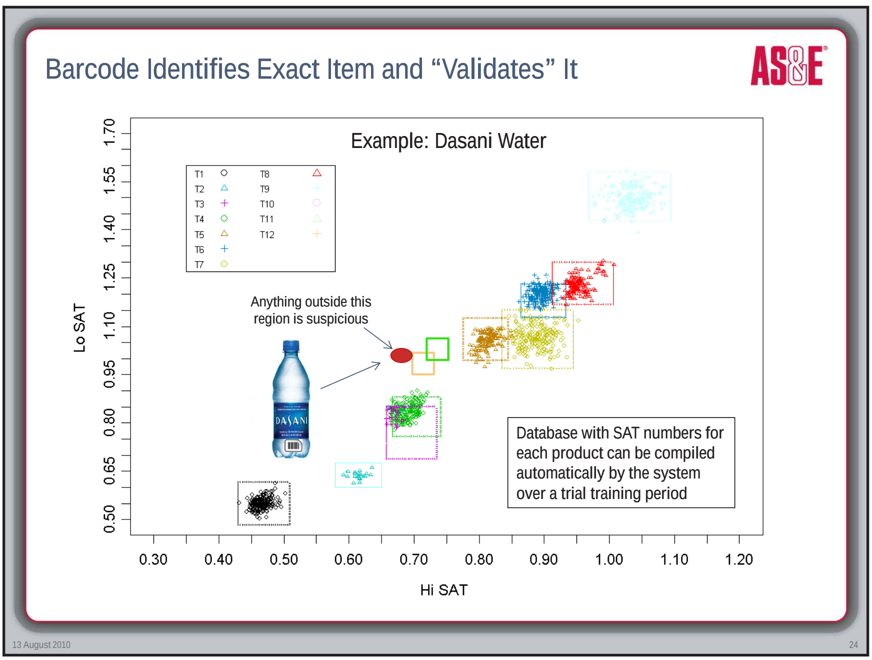
Barcode Identifies Exact Item and "Validates" It
AS&E
Example: Dasani Water
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
Anything outside this region is suspicious
DASANI
Database with SAT numbers for each product can be compiled automatically by the system over a trial training period
Lo SAT
0.50
0.65
0.80
0.95
1.10
1.25
1.40
1.55
1.70
Hi SAT
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
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Next Steps for SAT BLS

AS&E

- The 50kV SAT Tabletop system underwent testing for ECAC certification in Germany at Fraunhofer (Europe's largest application-oriented research organization)
    - 50kV system achieved Category B Standard 1 certification
    - 10 seconds/bottle (plastic) and 20 seconds bottle (thick glass)
- System was upgraded from 50kV to 70kV to attempt Standard 2 certification
    - Greatly decreased scan times (2-5 sec/bottle)
    - Approximately 1 second / bottle for a validation system with a barcode scanner
    - 70kV system has not been sent for ECAC certification testing (decision by AS&E not to pursue liquid scanning)

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SAT FOR BAGGAGE INSPECTION

AS&E
Detect the **difference.**

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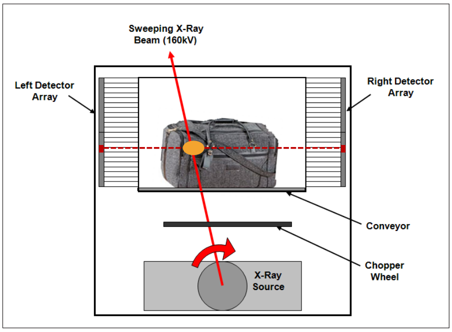
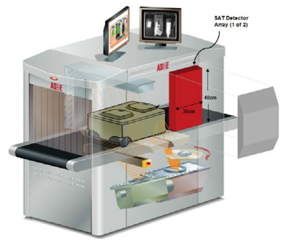
Concept for 100% Inspection of Baggage

AS&E

- In principle, a sweeping x-ray beam and two arrays of collimated scatter detectors can give 100% coverage of baggage.
- Each pair of detector elements analyzes a horizontal slice of the bag
- Detectors collimated in only one dimension are vulnerable to multiple scatter which can affect the SAT Number measurement
- The beam intensity must be very high for realistic throughput rates (10's of kWs)



AS&E Gemini ™ System
(Contains a Sweeping 160kV Beam)



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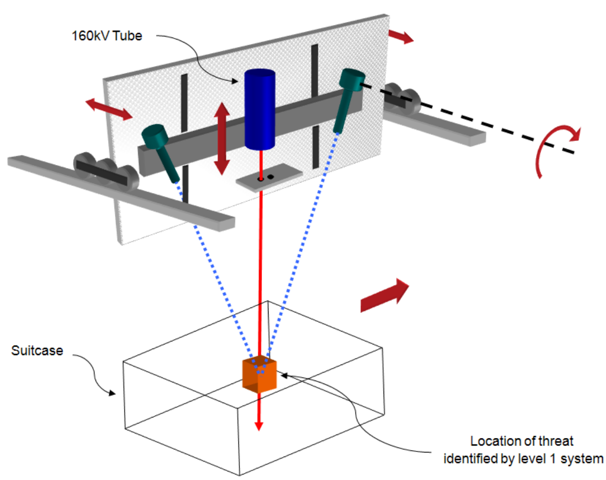
Concept for Level-2 Inspection of Baggage

AS&E



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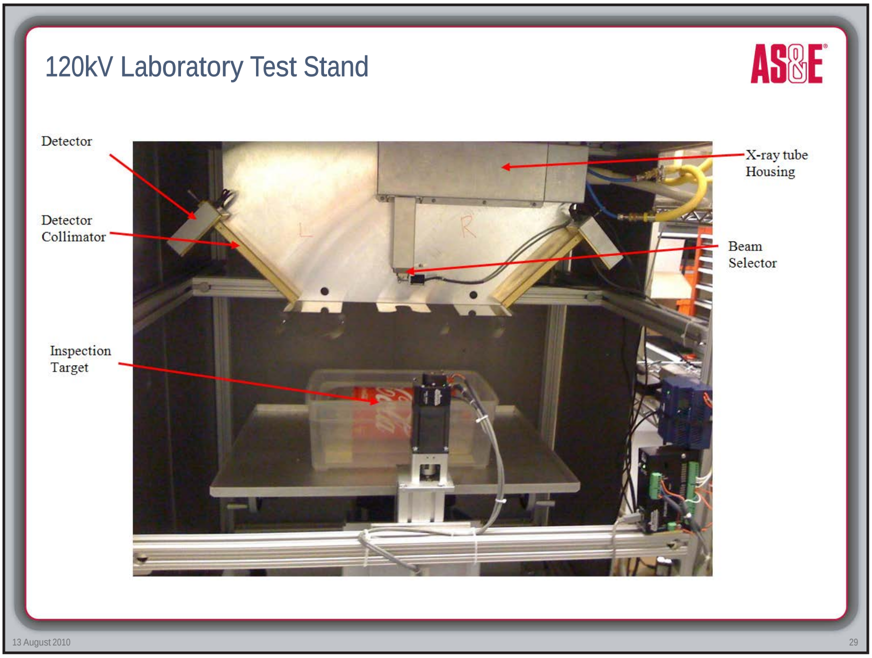
120kV Laboratory Test Stand
AS&E
Detector
Detector Collimator
Inspection Target
X-ray tube Housing
Beam Selector
13 August 2010
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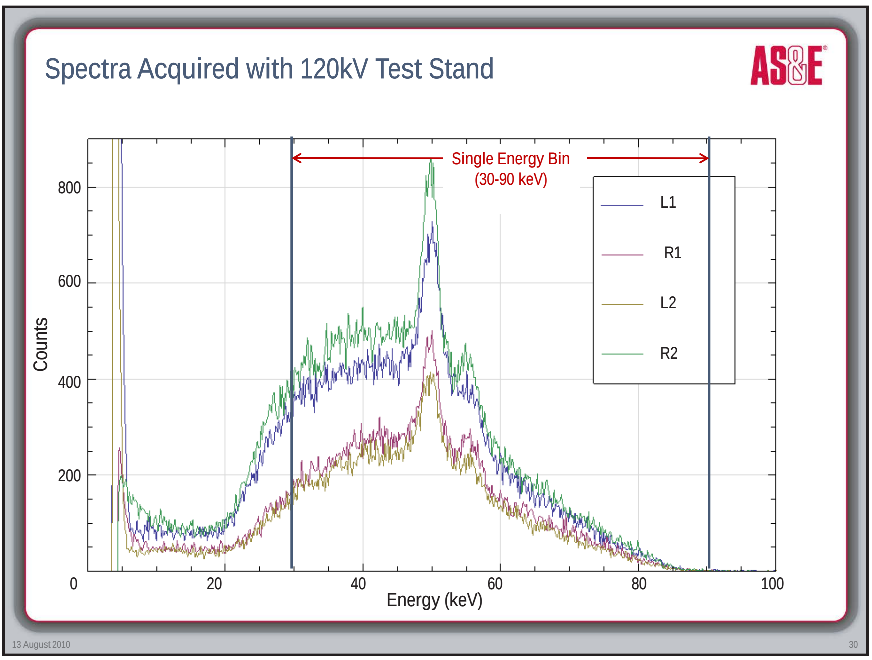
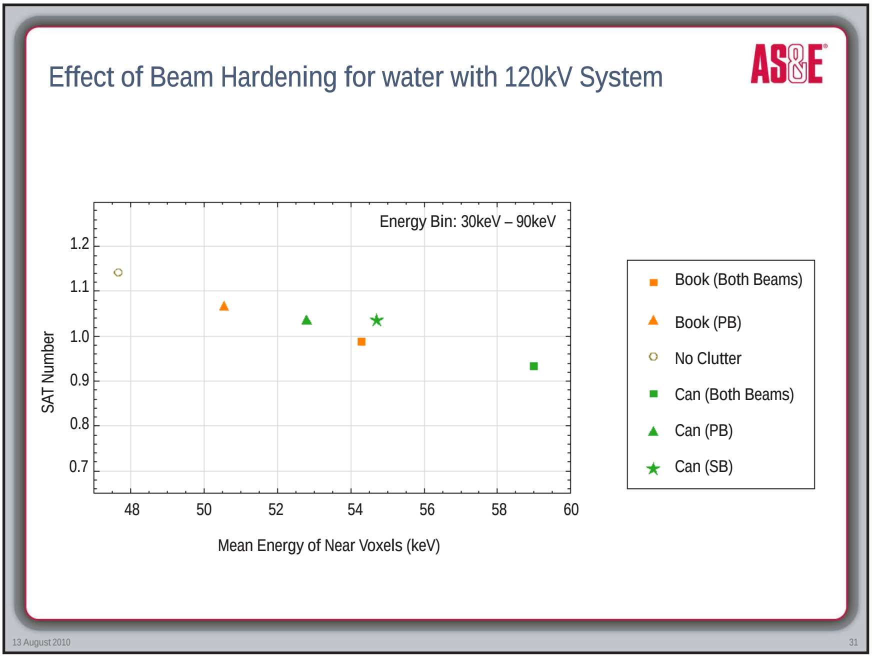

Spectra Acquired with 120kV Test Stand
AS&E
Single Energy Bin
(30-90 keV)
L1
R1
L2
R2
Counts
800
600
400
200
0
20
40
60
80
100
Energy (keV)
13 August 2010
30


Effect of Beam Hardening for water with 120kV System
AS&E
Energy Bin: 30keV – 90keV
SAT Number
1.2
1.1
1.0
0.9
0.8
0.7
48
50
52
54
56
58
60
Mean Energy of Near Voxels (keV)
Book (Both Beams)
Book (PB)
No Clutter
Can (Both Beams)
Can (PB)
Can (SB)
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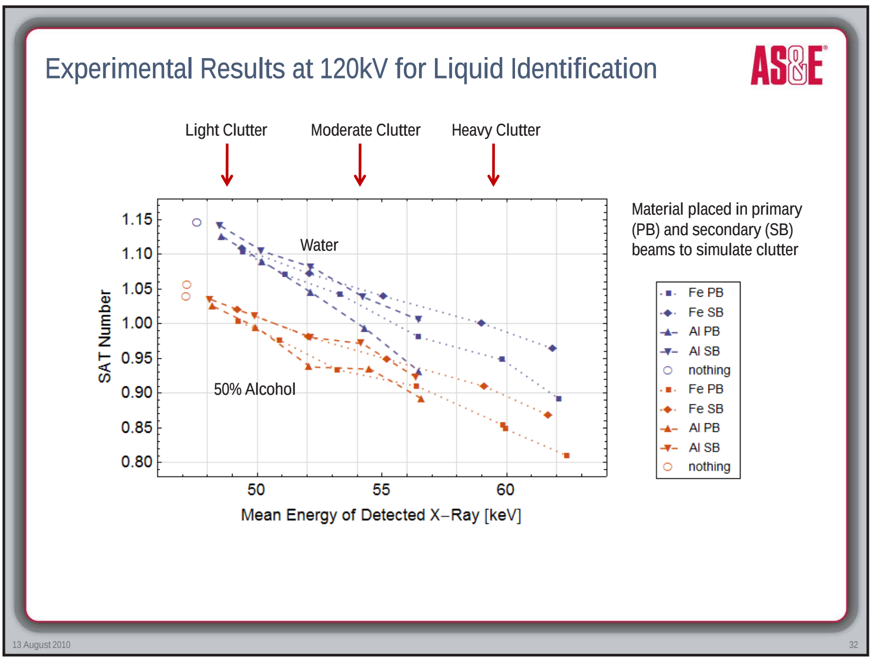
Experimental Results at 120kV for Liquid Identification
AS&E
Light Clutter
Moderate Clutter
Heavy Clutter
Water
50% Alcohol
SAT Number
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
50
55
60
Mean Energy of Detected X–Ray [keV]
Material placed in primary (PB) and secondary (SB) beams to simulate clutter
Fe PB
Fe SB
Al PB
Al SB
nothing
Fe PB
Fe SB
Al PB
Al SB
nothing
13 August 2010
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SAT FOR CARGO INSPECTION
AS&E
Detect the difference.
13 August 2010
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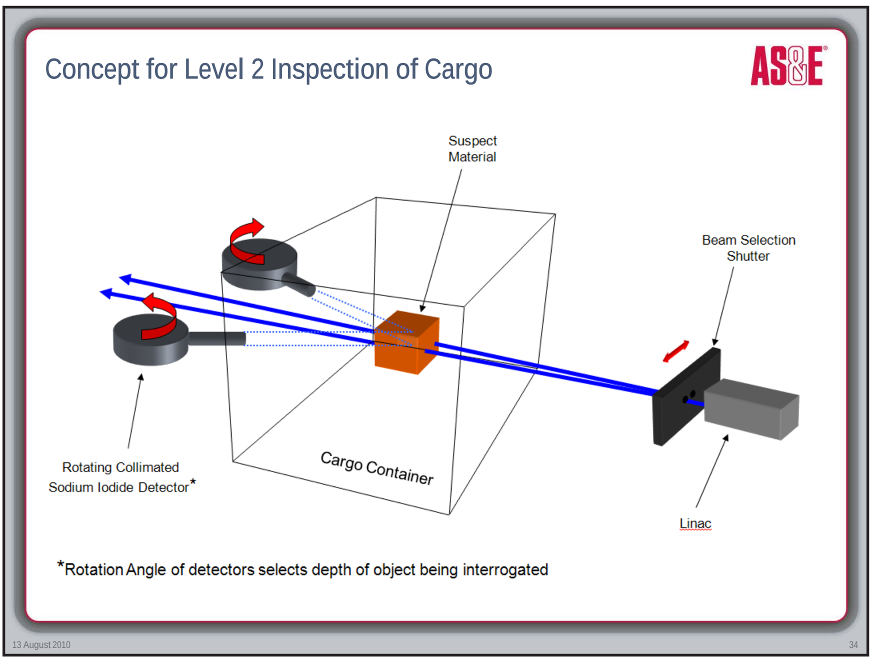
Concept for Level 2 Inspection of Cargo
AS&E
Suspect Material
Beam Selection Shutter
Rotating Collimated Sodium Iodide Detector*
Cargo Container
Linac
*Rotation Angle of detectors selects depth of object being interrogated
13 August 2010
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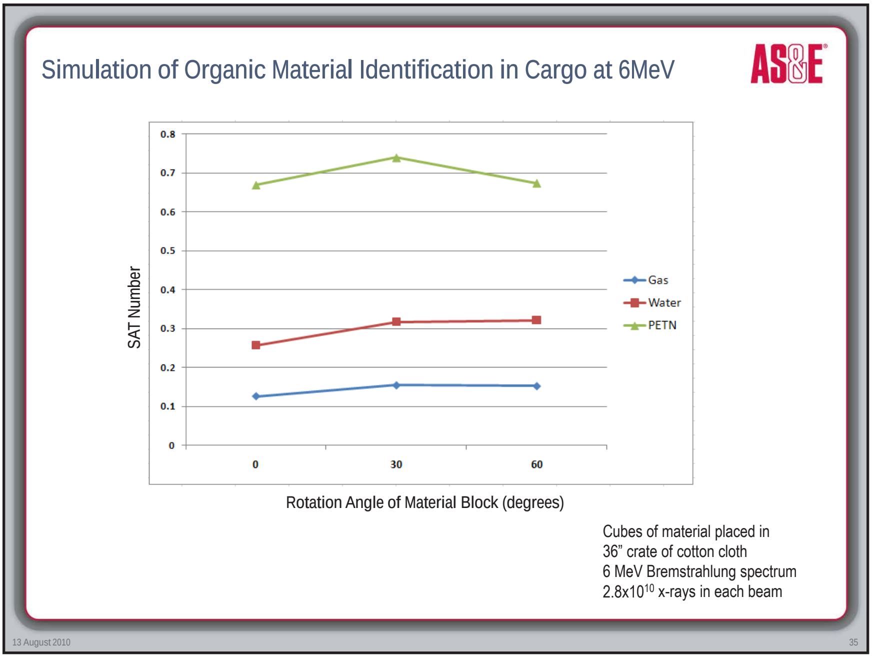
Simulation of Organic Material Identification in Cargo at 6MeV
AS&E
SAT Number
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
30
60
Gas
Water
PETN
Rotation Angle of Material Block (degrees)
Cubes of material placed in
36" crate of cotton cloth
6 MeV Bremstrahlung spectrum
2.8x10^10 x-rays in each beam
13 August 2010
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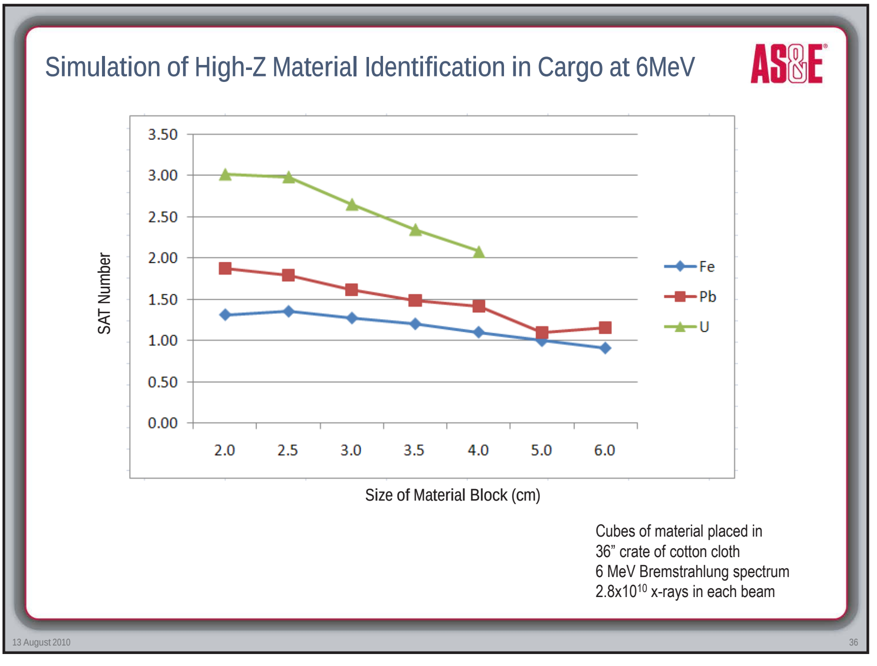
Simulation of High-Z Material Identification in Cargo at 6MeV
AS&E
SAT Number
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.0
2.5
3.0
3.5
4.0
5.0
6.0
Fe
Pb
U
Size of Material Block (cm)
Cubes of material placed in
36" crate of cotton cloth
6 MeV Bremstrahlung spectrum
2.8x10^10 x-rays in each beam
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Conclusions

AS&E

- SAT is a promising new x-ray technique for identifying materials
  - Very robust to surrounding clutter
  - Highly specific (sensitive to both density and atomic number)
  - Beam hardening effects can be easily corrected for
- SAT is a point interrogation method better suited to level 2 inspection
  - Acquisition times are typically on the order of 1-10 seconds per interrogation
  - Level 1 screening applications would require fairly intense x-ray sources
- We believe that there are many potential applications for this technology
  - Non-Destructive Testing (NDT)
    - Material characterization, void detection
  - Counterfeit pharmaceutical detection
- Selected for funding under DHS BAA 13-05 (in collaboration with LLNL, Tufts, Multix)

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AS&E

THANK YOU

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SAT WITH MONOCHROMATIC SOURCES
AS&E
Detect the difference.
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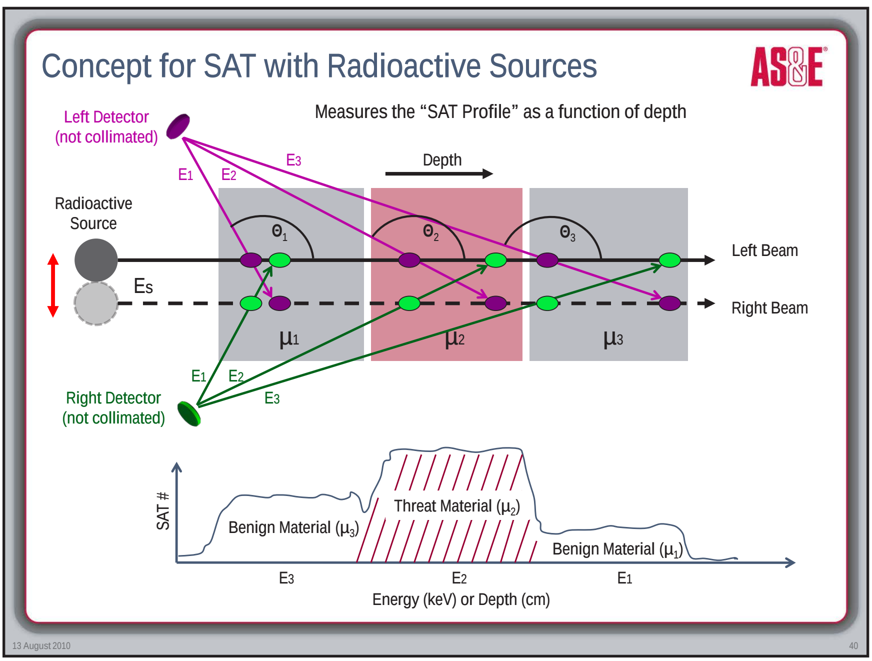
Concept for SAT with Radioactive Sources
AS&E
Measures the "SAT Profile" as a function of depth
Left Detector
(not collimated)
E1
E2
E3
Depth
Radioactive
Source
Es
Θ1
Θ2
Θ3
Left Beam
Right Beam
μ1
μ2
μ3
E1
E2
E3
Right Detector
(not collimated)
SAT #
Benign Material (μ3)
Threat Material (μ2)
Benign Material (μ1)
E3
E2
E1
Energy (keV) or Depth (cm)
13 August 2010
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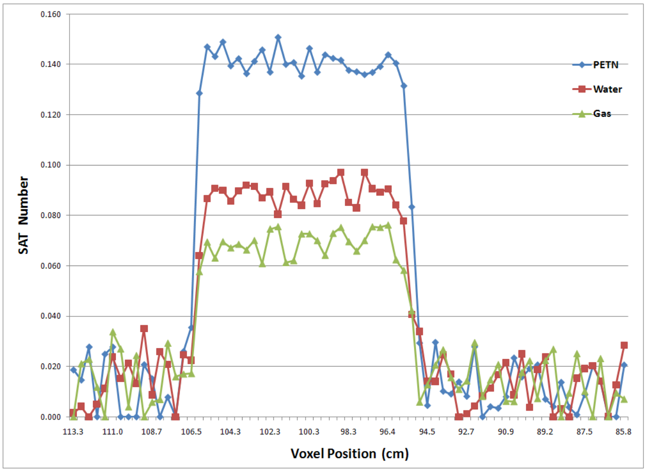
Simulation Results (10cm Cube at Center of 1m Sphere of Cotton)



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Future Developments

- Investigate Use of SAT for Non-Destructive Testing Applications
  - Material classification
    - Density Measurement
    - Effective Atomic Number Measurement
  - Void detection in Uniform Materials
  - Mining applications
    - Soil or rock classification
    - Metal content of ore
  - Counterfeit Pharmaceutical Detection
  - Quality Control

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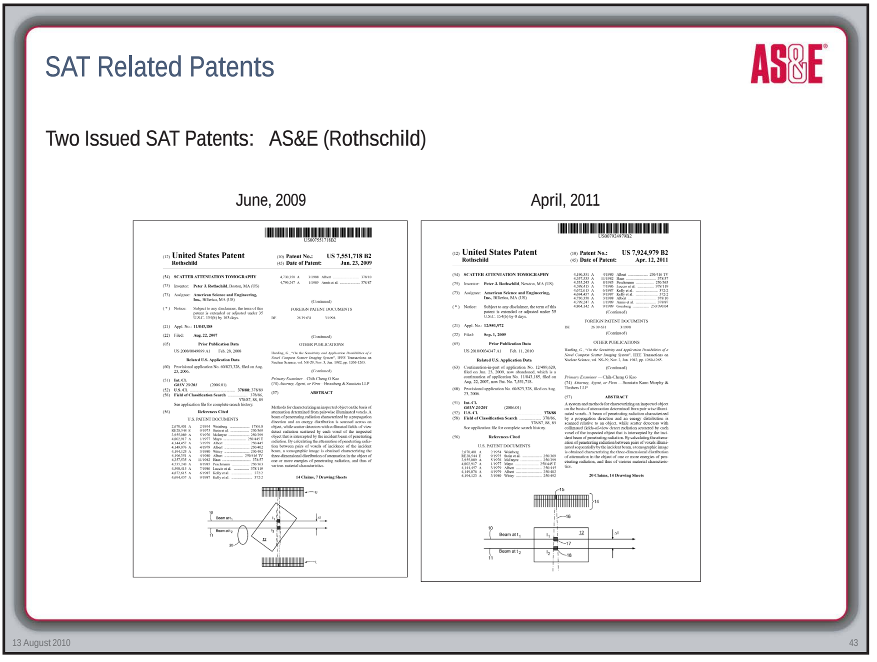
SAT Related Patents
AS&E
Two Issued SAT Patents: AS&E (Rothschild)
June, 2009
April, 2011
United States Patent
Rothschild
Patent No.: US 7,551,718 B2
Date of Patent: Jun. 23, 2009
Patent No.: US 7,924,979 B2
Date of Patent: Apr. 12, 2011
SCATTER ATTENUATION TOMOGRAPHY
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ADAPTIVE CLASSIFIER WITH A BARCODE SCANNER
AS&E
Detect the difference.
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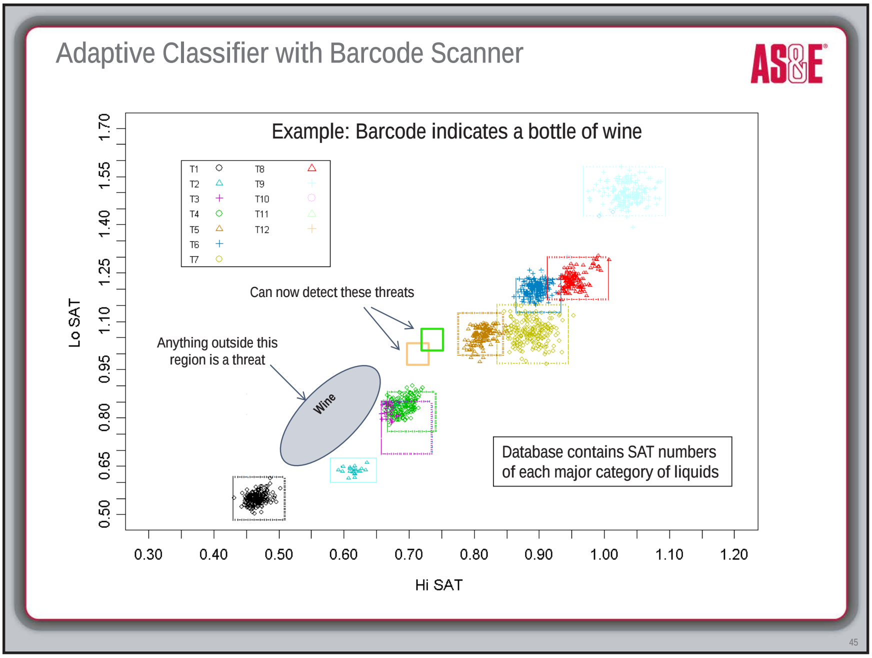
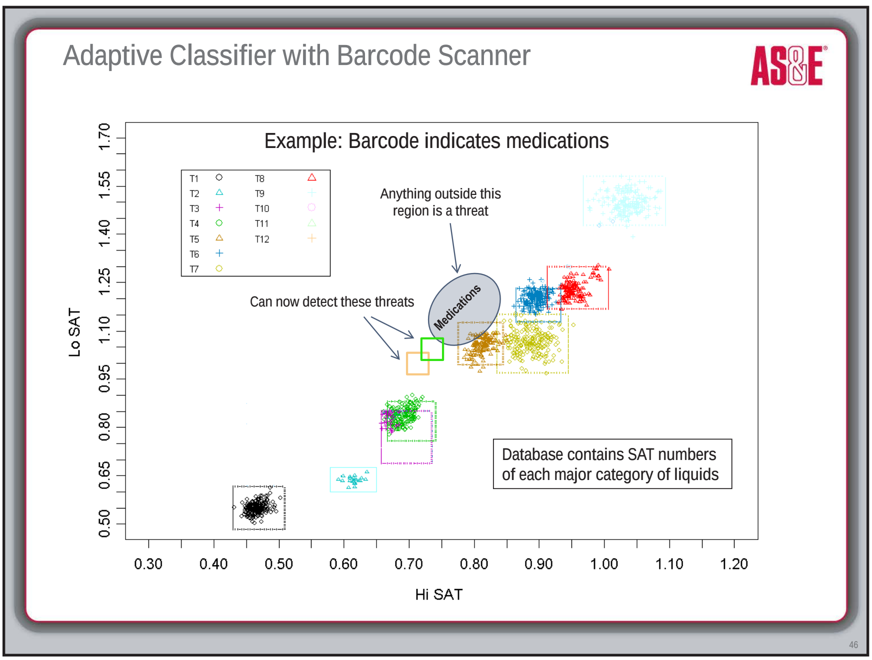
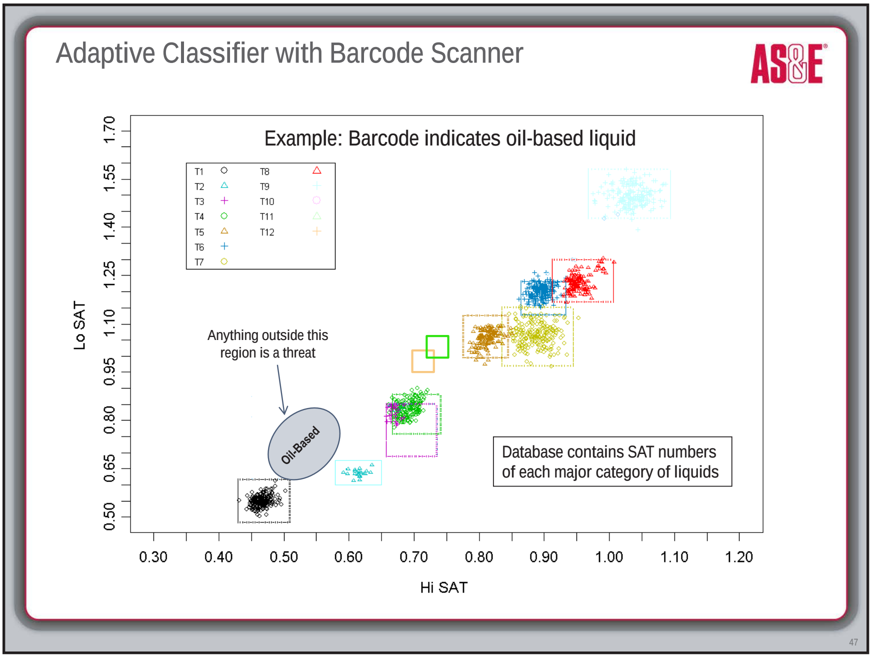
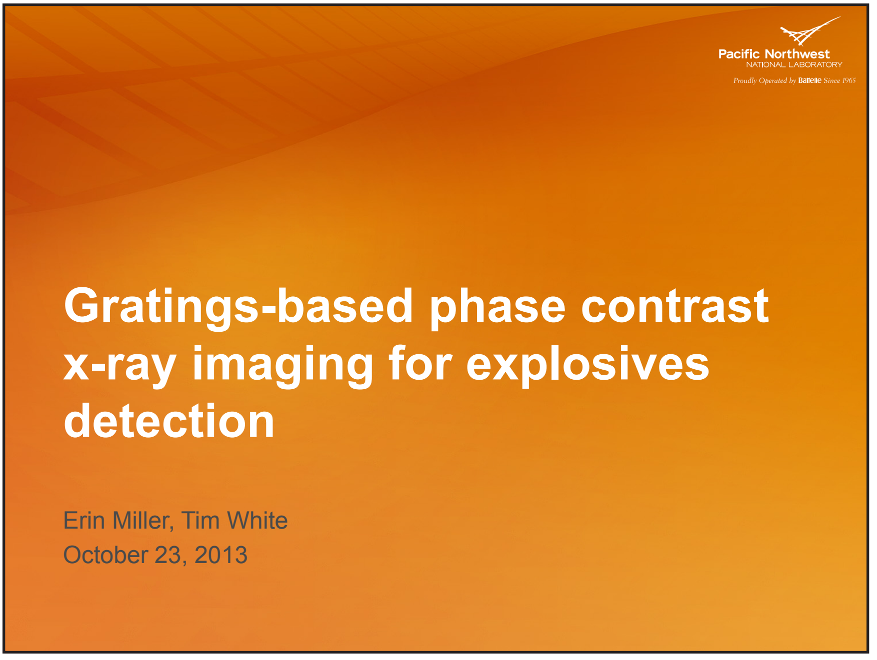
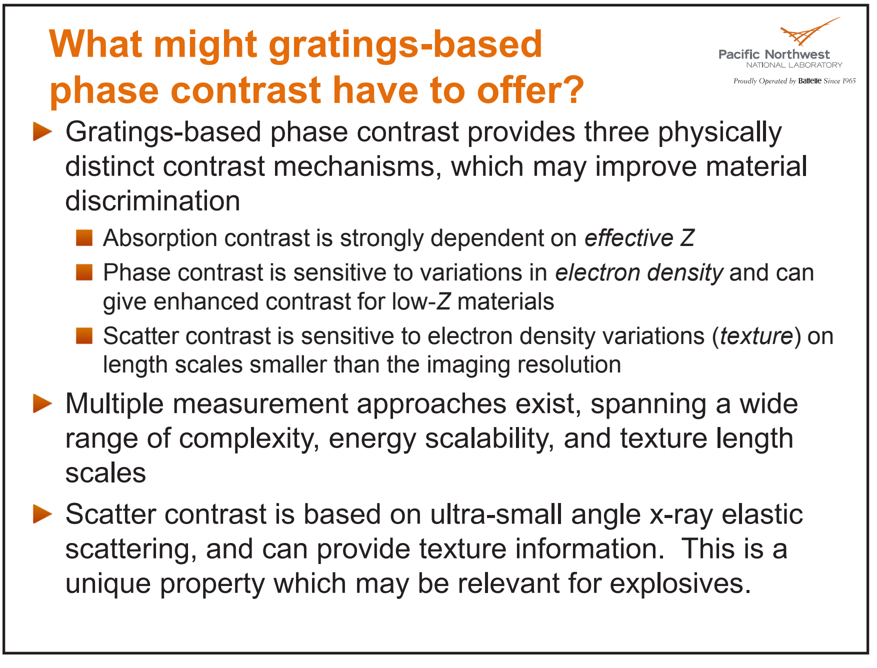

Adaptive Classifier with Barcode Scanner
AS&E
Example: Barcode indicates a bottle of wine
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
Can now detect these threats
Anything outside this region is a threat
Wine
Database contains SAT numbers of each major category of liquids
Lo SAT
0.50
0.65
0.80
0.95
1.10
1.25
1.40
1.55
1.70
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
Hi SAT
45


Adaptive Classifier with Barcode Scanner
AS&E
Example: Barcode indicates medications
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
Anything outside this region is a threat
Medications
Can now detect these threats
Database contains SAT numbers of each major category of liquids
Lo SAT
0.50
0.65
0.80
0.95
1.10
1.25
1.40
1.55
1.70
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
Hi SAT
46


Adaptive Classifier with Barcode Scanner
AS&E
Example: Barcode indicates oil-based liquid
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
Anything outside this region is a threat
Oil-Based
Database contains SAT numbers of each major category of liquids
Lo SAT
Hi SAT
0.50
0.65
0.80
0.95
1.10
1.25
1.40
1.55
1.70
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
47

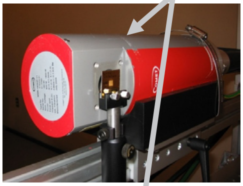
17.30 Erin Miller: Gratings-Based Phase Contrast X-ray Imaging for Improved Material Discrimination





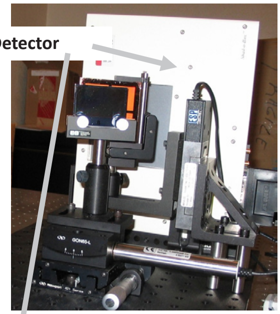
PNNL Talbot-Lau System

X-ray source



- PNNL system has been used for investigations of:
  - sensitivity to texture
  - geochemistry, fish biology
  - explosives detection
  - synchrotron version has been used to investigate biofilm structure
- Multiple iterations on gratings fabrication

Detector



Example: powdered explosives simulants

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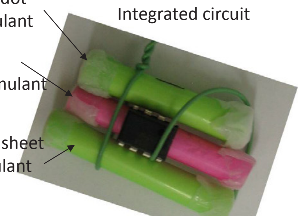
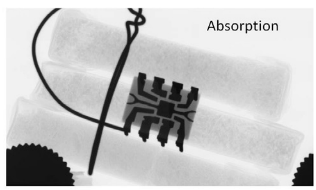
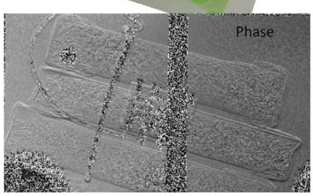
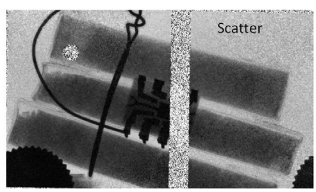
Sections 6mm in diameter









- Images are simultaneously acquired
- **Absorption** emphasizes metal components; **phase** image (differential phase) highlights fine details of low Z materials such as the parafilm endcaps; **scatter** image is sensitive to powdered simulants.

Gratings Fabrication

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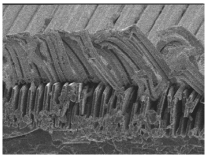
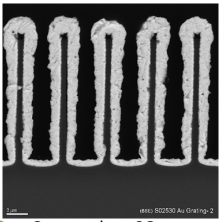
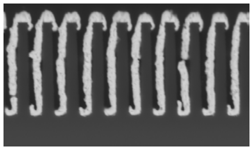


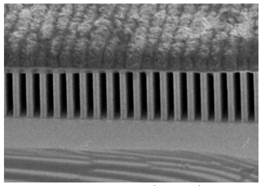
- April 07



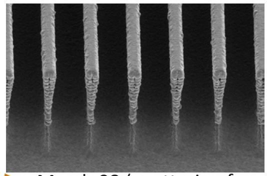
- September 08
  - deep reactive ion etch with conformal 1 µm electroplated Au



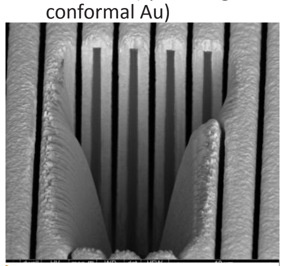
- August 07



- March 09 (LIGA)
  - built-up PMMA and Au



- March 08 (sputtering for conformal Au)



- June 11
  - Deep RIE; ALD Pt; electroplate Au

Fringe Visibility	15.4 keV	22.5 keV	40 kVp	50 kVp
Lab			15%	10%
Synchrotron	80%	40%		

Many Phase Contrast Techniques Exist

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Tradeoffs between phase sensitivity, complexity of setup and ease of energy scaling, and length scales for scattering

Number of Gratings	Grating Characteristics	Considerations
3 (Talbot-Lau)	High aspect ratio Limited to < 100kV(??)	High resolution, sensitive to small density variations. Sensitive to relatively large length scales for scatter
2 (Talbot/ Tsinghua)	(Phase or absorption) and absorption	Stronger constraint on either source size or grating period; easier alignment than 3-grating system.
1 (H. Wen)	Usually absorption; may be commercially available	Simple and inexpensive; grid pattern is imaged directly and processed image resolution is reduced to grid period. Scatter sensitive to smaller length scales.
0 (propagation based)	N/A	Simplest x-ray optics; requires very small source focal spot; works best for high resolution imaging of small objects. No scatter information.

Complexity

Single Grid Setup

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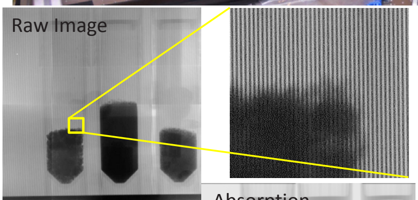
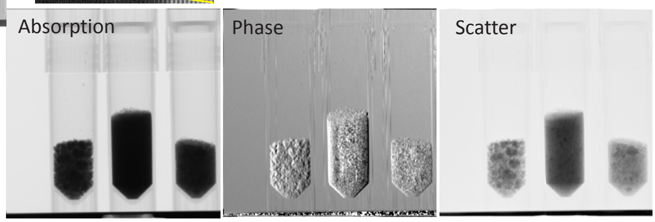


- Single exposure is processed to recover all 3 images
- Significant loss of spatial resolution
- Relatively easy to scale energy

1000 nm 30 nm 8 nm
Dry iron oxide nanoparticles



What about scatter?

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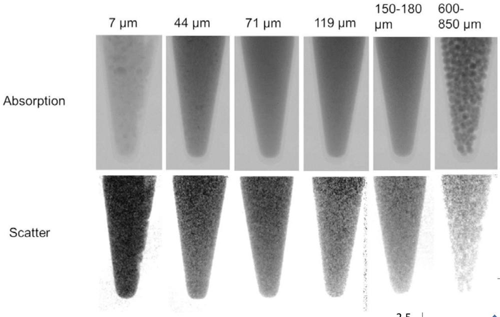
- Sensitive to texture (variations in electron density such as powders, paper, wood, bone, etc…) below the imaging resolution
- Length scale which is most visible depends on the measurement method (10's of microns down to 10's of nm)
- Some explosives have texture within this range (e.g., Lee et al., "A study on the thermal decompositions behaviors of PETN, RDX, HNS, and HMX," Thermochimica Acta v392-393, 2002). X-ray microtomography studies have been performed to characterize microstructure of explosives

PETN (particle size 100% ≤40 μm, average particle size 15 μm), RDX (particle size 100–800 μm), HMX (100% ≤60 μm, average particle size 19.8 μm), HNS (particle size 74–100 μm) and silicone rubber (Slygard 182) are the raw materials used in this work. PETN, RDX, HNS and HMX composed of silicone rubber with a weight ratio of 4:1, respectively, are also studied.

8

Scatter and Length Scales (1)



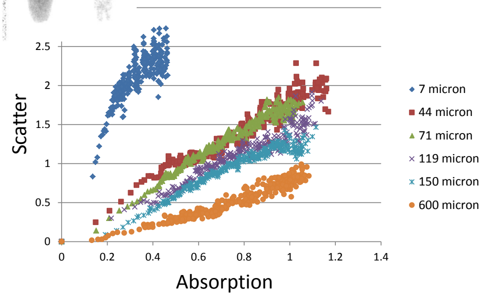
- 3-grating system; glass beads 7-850 µm (dry and wet); 40 kVp
- Scatter intensity changes with sample length scale
  - Packing fraction also varies
- Miller et al., IEEE Trans Nuc Sci 2013

- Absorption is uncorrelated with particle size
- Scatter intensity increases as particle size is reduced

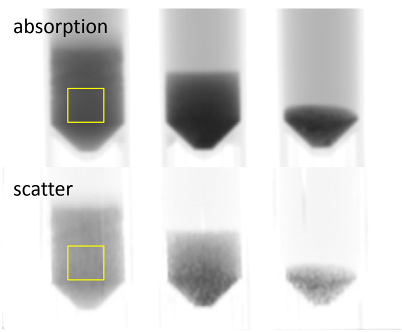
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 60, NO. 1, FEBRUARY 2013

Phase Contrast X-Ray Imaging Signatures for Security Applications

Erin A. Miller, Timothy A. White, Benjamin S. McDonald, and Allen Seifert

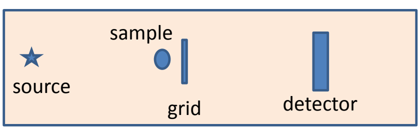


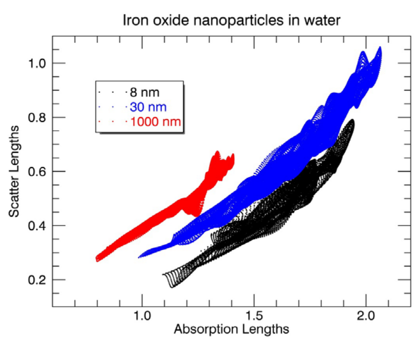
Scatter and Length Scales (2)



1000 nm 30 nm 8 nm
Iron oxide nanoparticles in water

Single grating: 2m working distance, grid and sample near center; 40 kVp
d=76 nm





Same three contrast modes, but different length scale sensitivity

Conclusions

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- Gratings-based phase contrast provides three physically distinct contrast mechanisms, which may improve material discrimination
- Multiple measurement approaches exist, spanning a wide range of complexity, energy scalability, and texture length scales
- Scatter contrast is based on ultra-small angle x-ray elastic scattering, and can provide texture information. This is a unique property which may be relevant for explosives.

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Additional Information

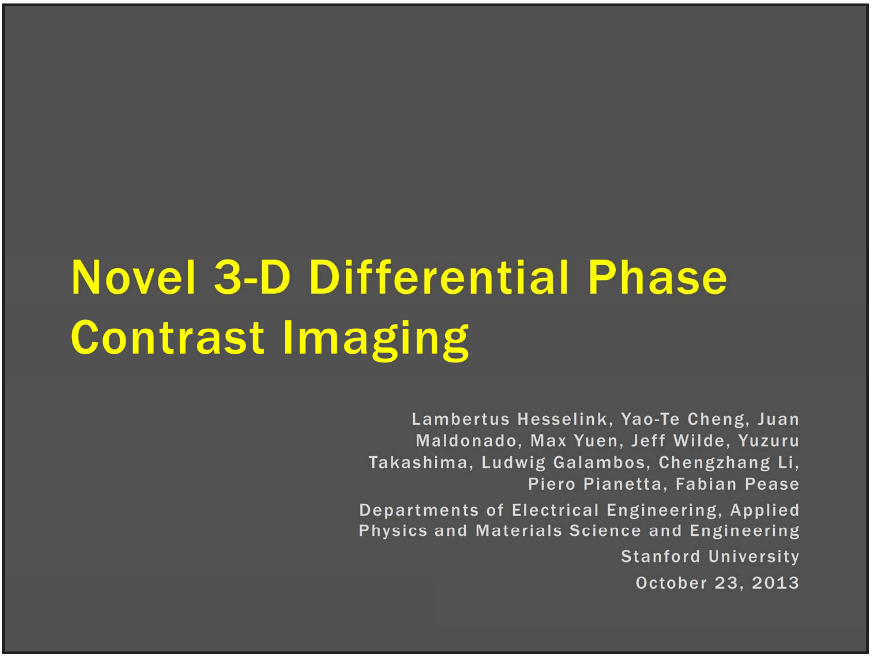
Practical considerations for explosives detection

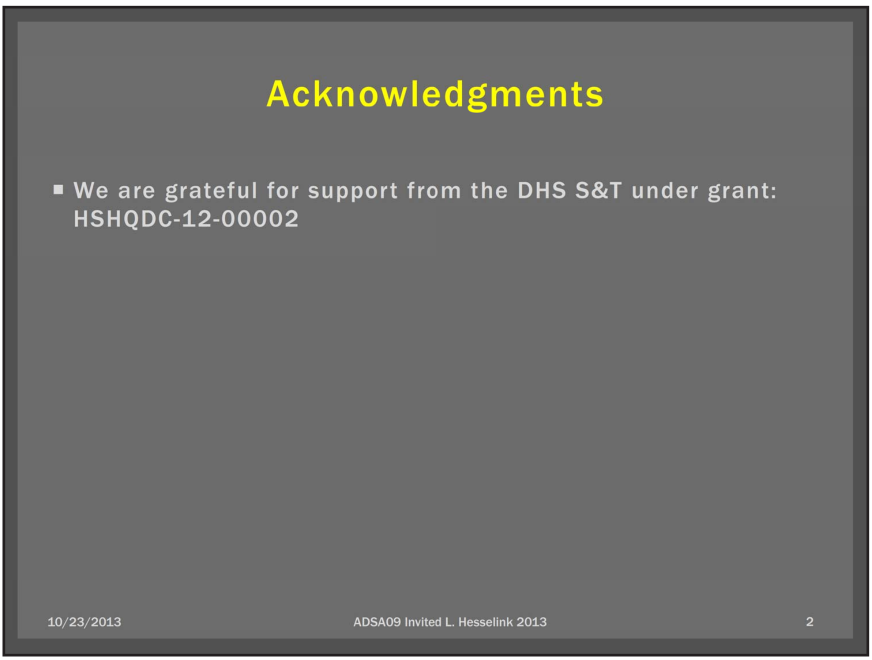
- **Scale-up to high energies**
  - Talbot-Lau has been achieved with design energy as high as 82 keV (Willner et al, TUM)
  - Easier with alternative (non Talbot-Lau) system design!
    - This will change the phase sensitivity AND scatter length scale sensitivity
- **System stability**
  - Preclinical Talbot CT with rotating gantry is being commissioned by Bruker MicroCT and may be commercially available in <5 years
- **Footprint**
  - Many setups (including ours) use about 2m src-det
  - A compact setup (32 cm) has been demonstrated, with a 6 cm field of view, using cylindrically bent gratings (Thuring, Swiss Light Source)
- **Measurement time**
  - Attenuation by gratings multiple frames for phase stepping will increase measurement time
- **Clutter**
  - The usual effects of clutter (difficulty in identifying features; reduced dynamic range) still apply
  - The 3 signals are interrelated: reduced counts due to attenuation will also affect phase and scatter; high scatter makes phase signal more difficult to extract

Gratings?

- Current set
  - source grating, 127 μm pd, electroplated through photoresist
  - phase grating, 3.94 μm pd, deep reactive ion etch
  - analyzer grating, 2 μm pd (up to 50 μm high), deep reactive ion etch (period doubled) followed by ALD platinum seed layer and electroplated 1 μm thick conformal gold layer
- Previous analyzer gratings
  - conformal gold with evaporated seed layer (period doubled etched substrate)
  - etched Si backfilled with Au
  - LIGA pattern, built up through photoresisit
    - This can do very high aspect ratio and works well; we moved away from it due to high cost and limited field of view
- Single grating parameters
  - Can be anything that you have the resolution to see; we've used a 2μm period grid at a synchrotron, and a 299μm grid with a lab source and a 50 μm/pixel detector

17.31 Bert Hesselink: Novel Differential Phase Contrast 3D X-ray Imaging for Aviation Security Applications

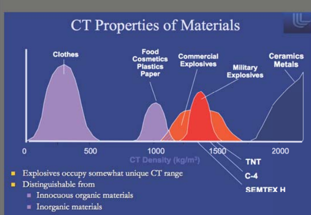




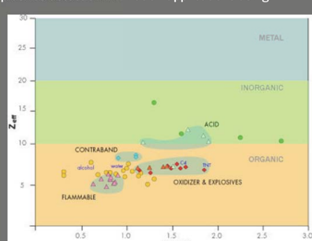
Content

- Motivation
- Differential phase contrast imaging
- Photoelectron X-Ray source array (PeXSA)
- Summary

Introduction: Problem Statement

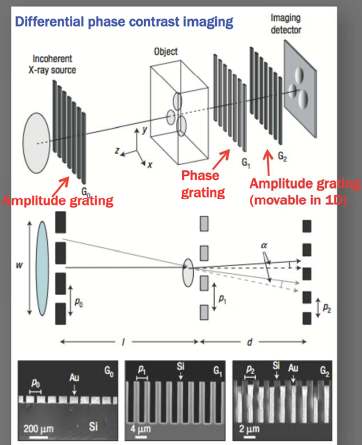


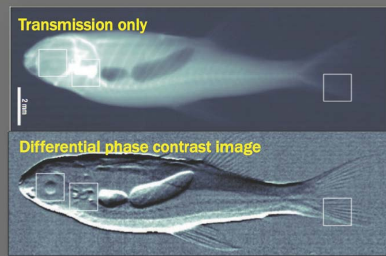
H. Martz, C. Crawford, Explosives detection in aviation applications using CT, LLNL, June 2010



- Improve discrimination through:
  - Improved data collection by measuring additional material's parameters:
    - Phase in addition to density and effective atomic number
    - Better 3-D reconstruction data

X-ray Differential Phase-Contrast Imaging





Pfeiffer et al., Nature Phys.. (2006)

Challenges:

- Need high aspect-ratio (> 100X) amplitude grating for high energy (> 100 keV) X-ray design.

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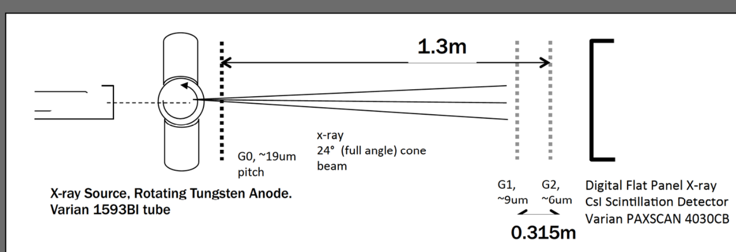
Experimental Schematic



- Incoherent, polychromatic source is made partially coherent by grating G0.
- G1 and G2 form a phase grating/amplitude grating interferometer analyzer pair.
- G0-G2 distance = 1.3m, G1-G2 distance 0.315m, G0=19um, G1=9um, G2=6um.
- Phase contrast signal is detected at the digital flat panel detector.
- X-ray parameters: 60kVp, 10mA, 7.5pps. Detector: 1x1 0.5pF Gain 2

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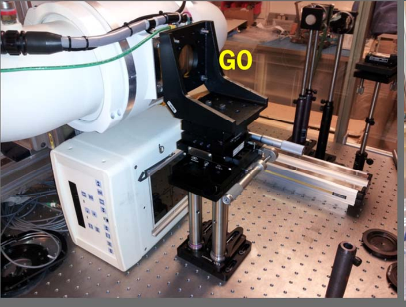
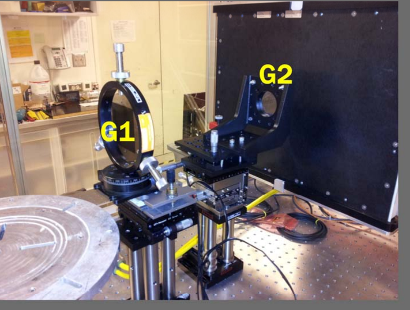
Photos of the Setup





G0, on x-y stage

G1, on x-y and tilt/rotation stage
G2, on x-y-z and tip/tilt/rotation stage+ pico motor drive

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X-ray Talbot Interferometry

- Uses Talbot effect for G1 and G2 gratings.
- Moiré Pattern detection at detector.
- Partial Coherence needed, G0 provides this via van Cittert-Zernike Theorem (Think Ducks).
- G1 can be Phase or Amplitude.
- Works with polychromatic sources.

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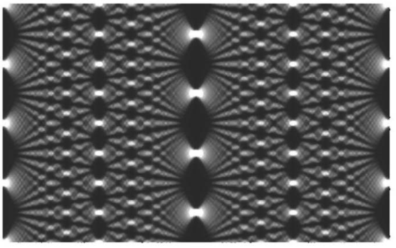
The Talbot Effect

Z=0  Z_T

$$E(x,z) = C\int e^{i\frac{k}{2z}(x-x')^2} E(x',0)dx'$$

$$E(x,0) = T(x) = \sum_n a_n e^{i\frac{2\pi}{p_0}nx}$$

$$E(x,z) = C\sum_n a_n \int e^{i\frac{k}{2z}(x'-x)^2} e^{i\frac{2\pi}{p_0}nx'} dx'$$

$$E(x,z) = C'\sum_n a_n e^{i\frac{2\pi}{p_0}nx} e^{-i\frac{\pi\lambda z}{p_0^2}n^2}$$

$$2\pi m = \frac{\pi\lambda z}{p_0^2}$$

$$z = mz_T$$

$$\boxed{z_T = \frac{2p_0^2}{\lambda}}$$

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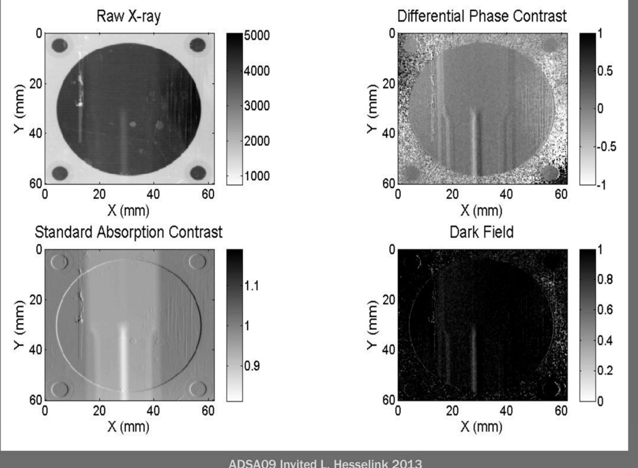
X-ray Absorption, DPC, and Dark Field Contrast Images of Empty Cuvette



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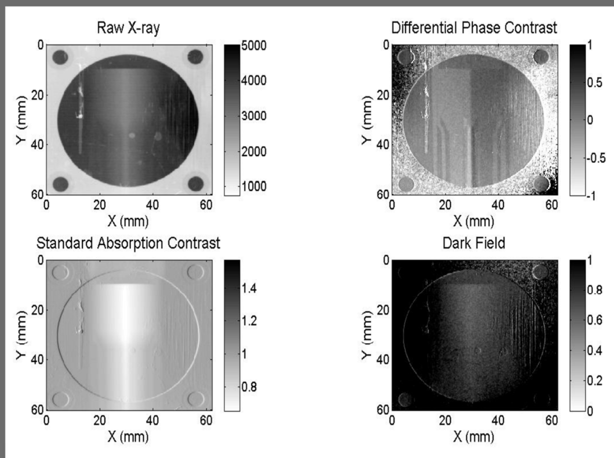
X-ray Absorption, DPC, and Dark Field Contrast Images of Water + Cuvette



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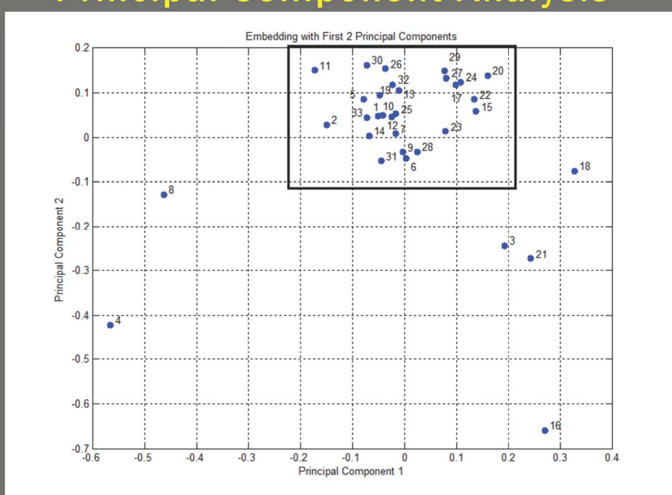
Principal Component Analysis



Squared area shows in next figure

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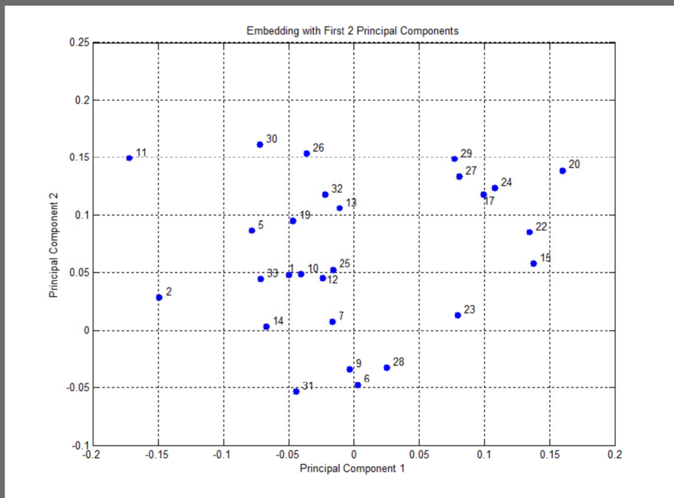
Principal Component Analysis



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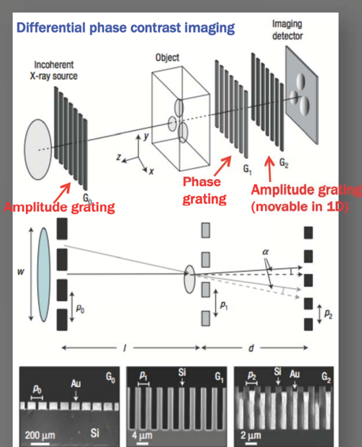
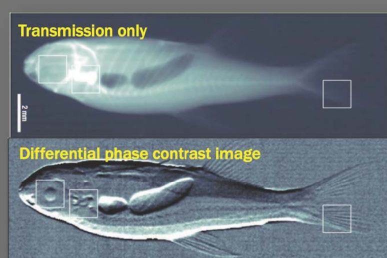
X-ray Differential Phase-Contrast Imaging





Pfeiffer et al., Nature Phys.. (2006)

Problems:

- Amplitude grating G_0 blocks > 75% of incident X-rays (for spatial coherence).
- Need high aspect-ratio (> 100X) amplitude grating for high energy (> 100 keV) X-ray design.

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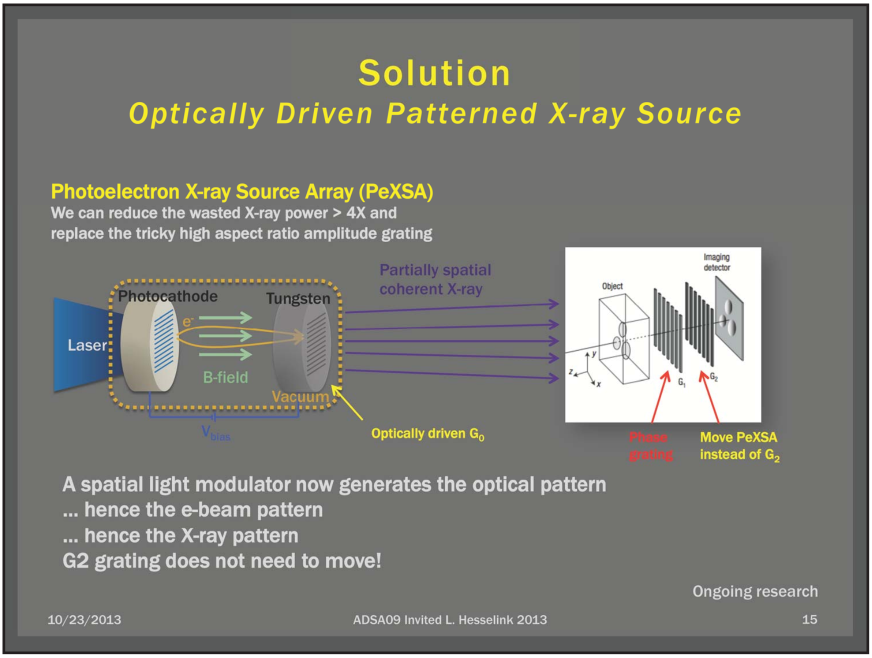
Solution
Optically Driven Patterned X-ray Source
Photoelectron X-ray Source Array (PeXSA)
We can reduce the wasted X-ray power > 4X and
replace the tricky high aspect ratio amplitude grating
Partially spatial
coherent X-ray
Photocathode
Tungsten
Laser
e-
B-field
Vacuum
Vbias
Optically driven G0
Imaging
detector
Object
Phase
grating
Move PeXSA
instead of G2
A spatial light modulator now generates the optical pattern
... hence the e-beam pattern
... hence the X-ray pattern
G2 grating does not need to move!
Ongoing research
10/23/2013
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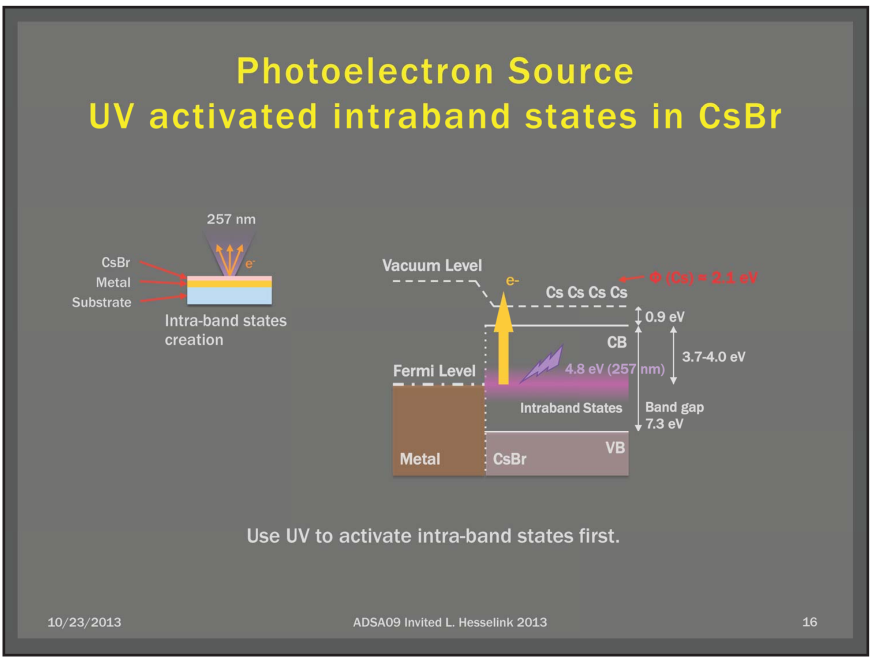
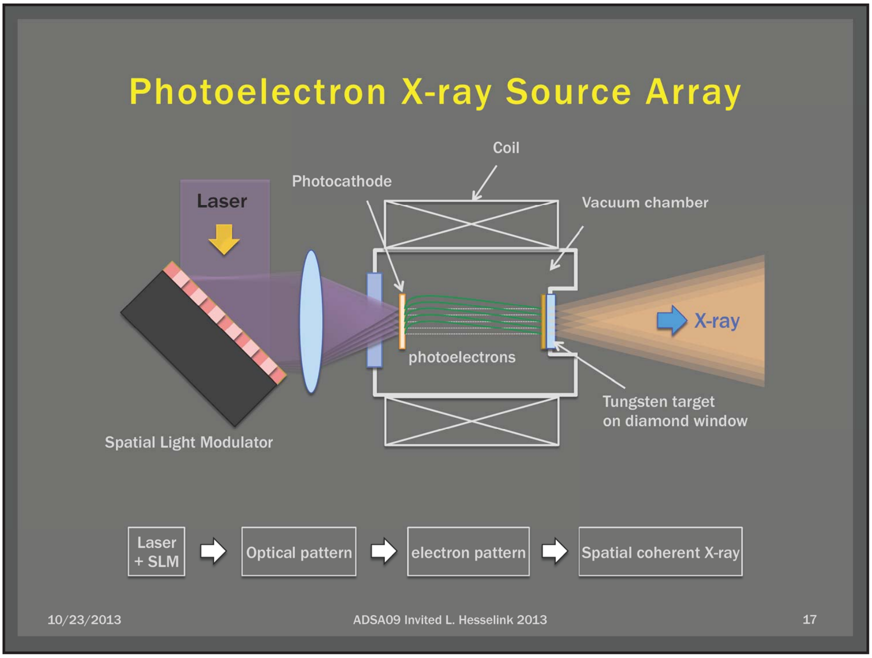
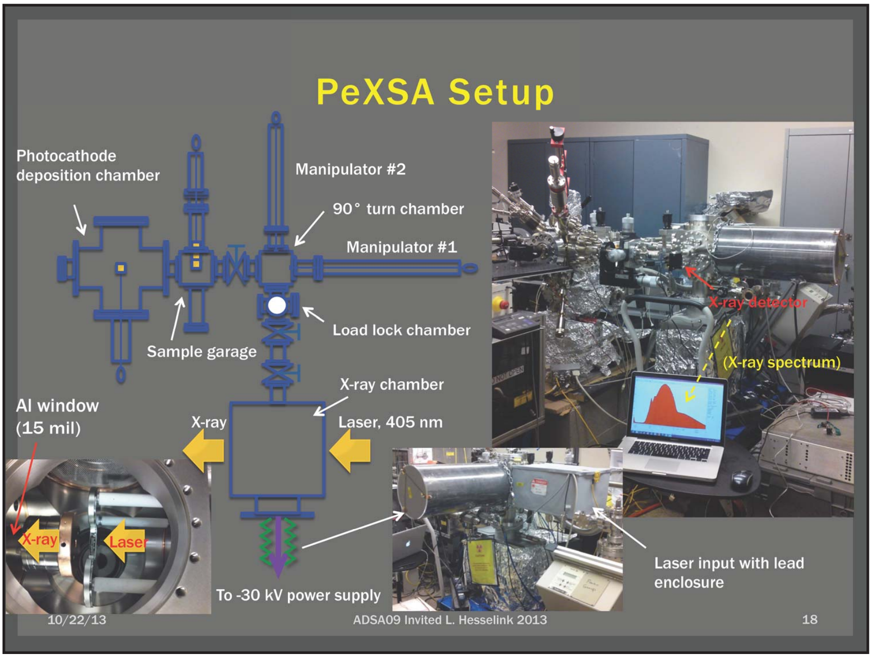

Photoelectron Source
UV activated intraband states in CsBr
257 nm
CsBr
Metal
Substrate
e-
Intra-band states
creation
Vacuum Level
e-
Cs Cs Cs Cs
Φ (Cs) = 2.1 eV
0.9 eV
CB
3.7-4.0 eV
Fermi Level
4.8 eV (257 nm)
Intraband States
Band gap
7.3 eV
VB
Metal
CsBr
Use UV to activate intra-band states first.
10/23/2013
ADSA09 Invited L. Hesselink 2013
16


Photoelectron X-ray Source Array
Coil
Photocathode
Vacuum chamber
Laser
X-ray
photoelectrons
Tungsten target
on diamond window
Spatial Light Modulator
Laser
+ SLM
Optical pattern
electron pattern
Spatial coherent X-ray
10/23/2013
ADSA09 Invited L. Hesselink 2013
17


PeXSA Setup
Photocathode
deposition chamber
Manipulator #2
90° turn chamber
Manipulator #1
Load lock chamber
Sample garage
X-ray chamber
Al window
(15 mil)
X-ray
Laser, 405 nm
X-ray
Laser
X-ray detector
(X-ray spectrum)
To -30 kV power supply
Laser input with lead
enclosure
10/22/13
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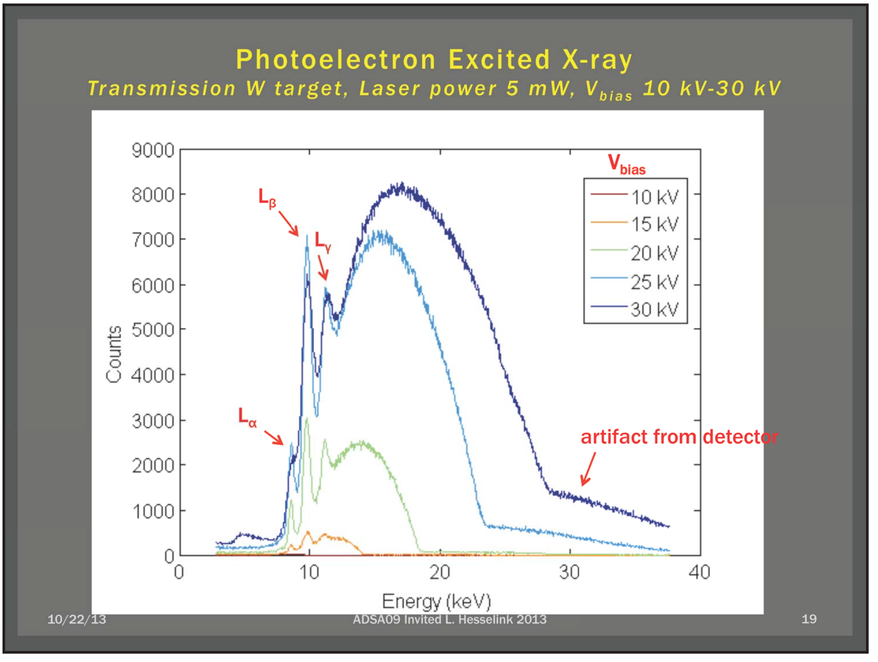


Summary

- DPC measurements provide richer detection signatures
  - *More work to be done to determine effectiveness within cluttered bag*
- *Photo Electron X-ray Source Array (PeXSA) enables simpler and more sensitive DPC system with large FoV*
  - *Gratings severely limit FoV for high energy system*

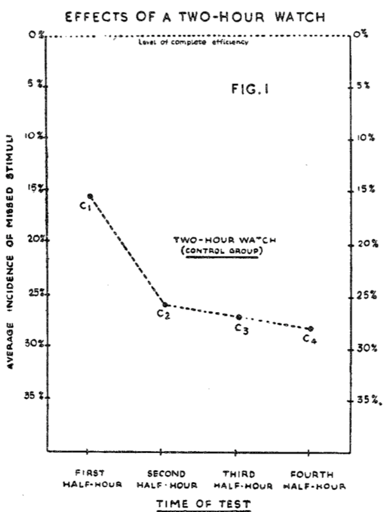
10/23/2013 ADSA09 Invited L. Hesselink 2013 20

17.32 Matthew Cain: Vigilance Decrement: When Does It Happen and What Might Be Done

Vigilance decrement: When does it happen and what might be done?

Matthew S. Cain, Ph.D.
Brigham & Women's Hospital
Harvard Medical School

Early Vigilance Research



Mackworth, 1948, QJEP

Conclusions

- Vigilance Decrement is a long-studied problem endemic to boring tasks
  - Leads to an increase in ‘default’ responses
  - Affected by prevalence
- What’s to be done?
  - Give frequent breaks
  - Give adequate, individualized handling time
  - Encourage consistent handling

Does Prevalence Matter?

Let’s take 20 bags with guns and knives

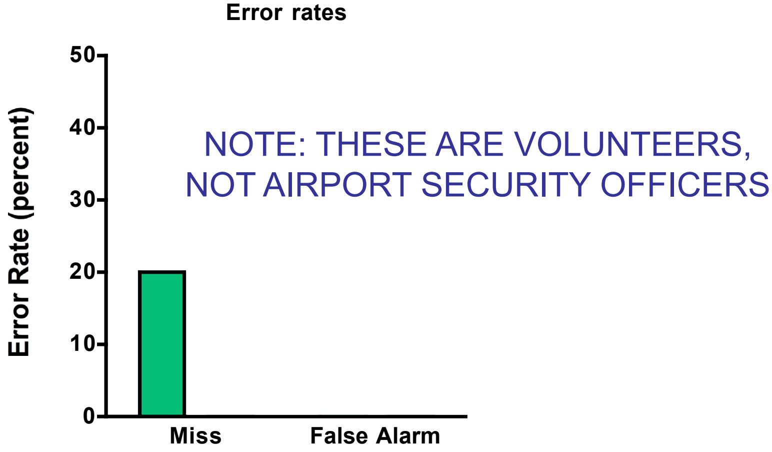
And put them in a stack of 40 bags
50% Prevalence

http://www.selectism.com/news/tag/luggage/page/4/

Or 1000 bags
2%
Prevalence

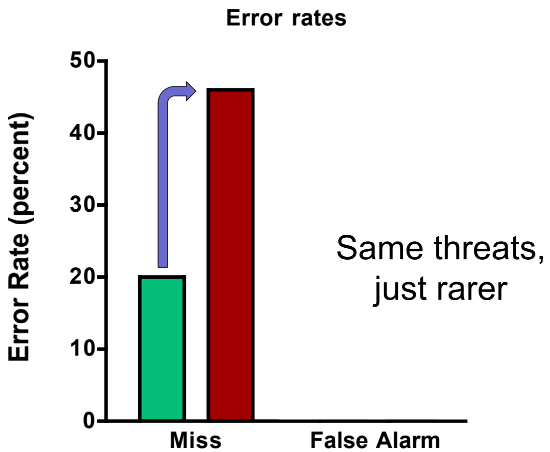
http://jamesthecomic.com/blog1/2010/05/03/top-10-reasons-why-your-luggage-gets-lost-or-damaged/

When targets are present in half of the bags people miss about 20% of them



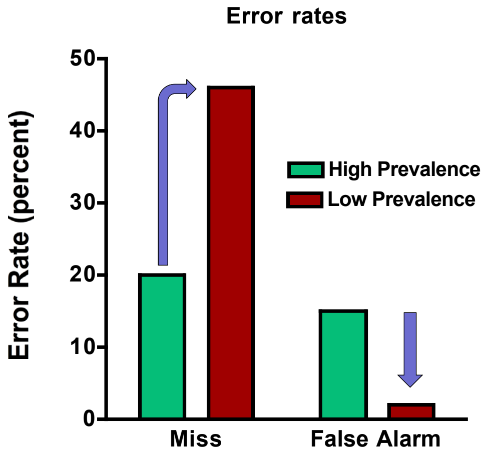
Wolfe et al., 2007, JEP: General

When targets are present in 2% of the bags people miss over 40% of them!



Wolfe et al., 2007, JEP: General

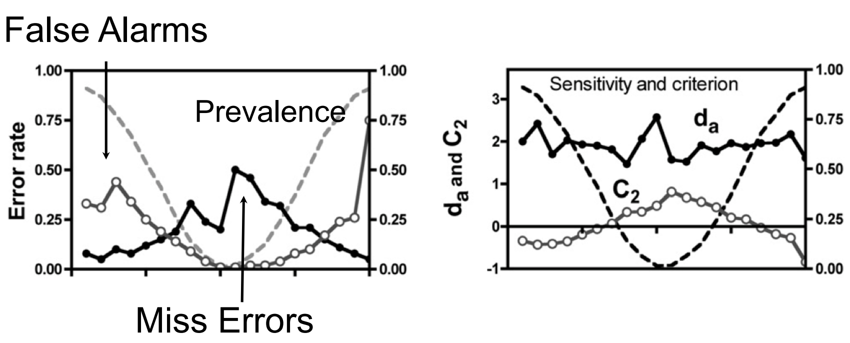
False alarm errors go the other way



Which kind of error do you want to minimize?

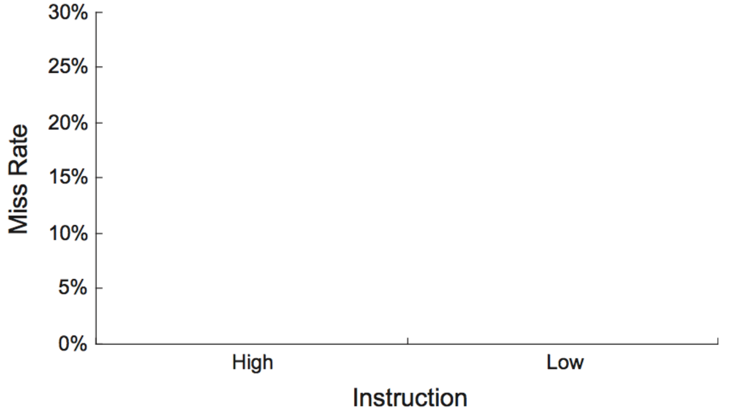
Wolfe et al., 2007, JEP: General

Sensitivity to Prevalence



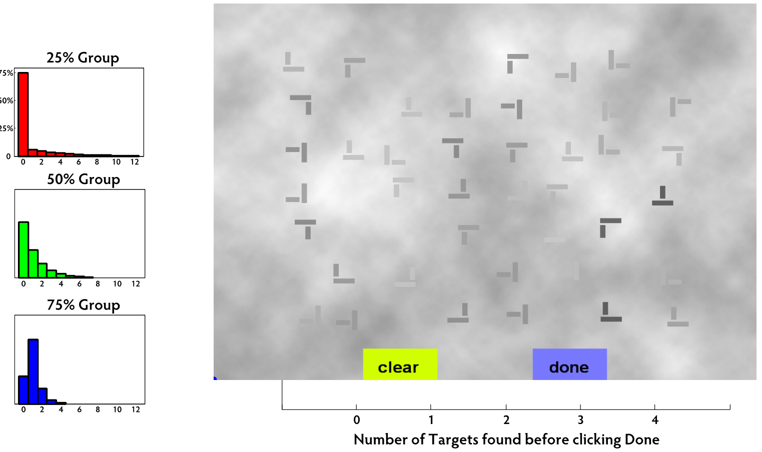
Wolfe & Van Wert, 2010, Current Biology

Implicitly Driven



Lau & Huang, 2010, Vision Research

Sensitivity to Complex Target Distribution Statistics



Cain, Vul, Clark, & Mitroff, 2011, Psychological Science

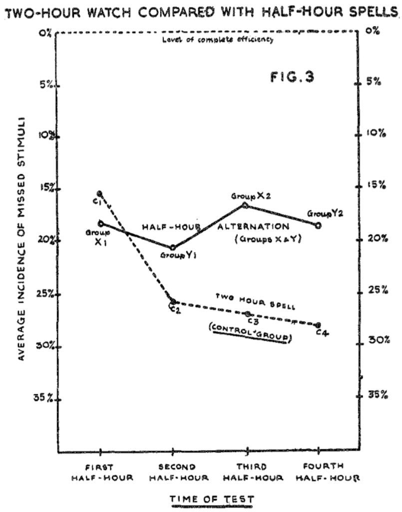
Sensitivity to Task

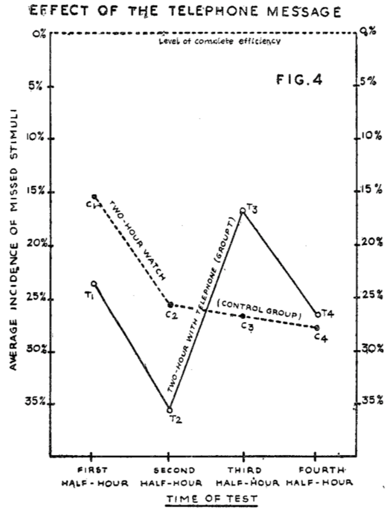
Drew, Võ, & Wolfe, 2013, Psychological Science

How Do We Address This?

- Step 1: Give breaks
- Step 2: Allow adequate handling time
  - Preferably Individualized

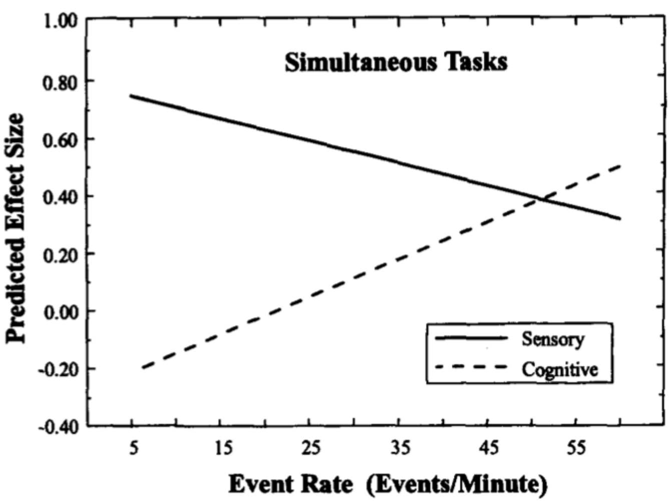
Breaks





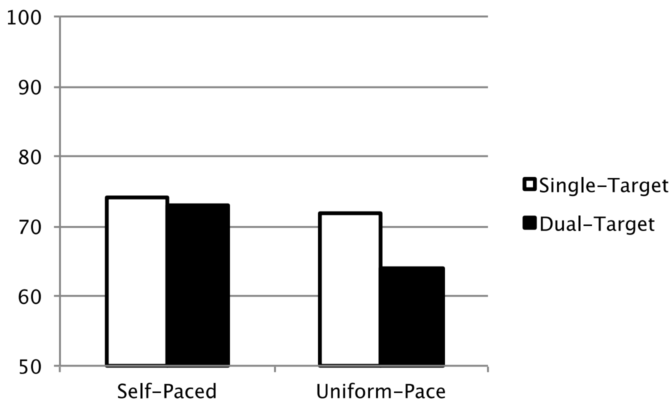
Mackworth, 1948, QJEP

Adequate Handling Time



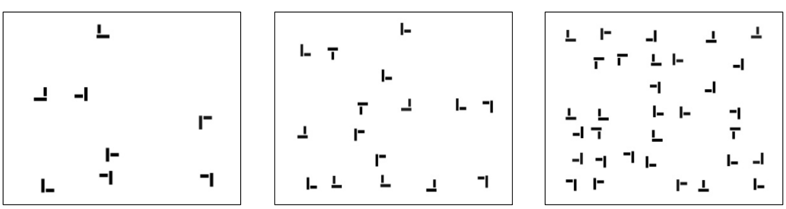
See, Howe, Warm, & Dember, 1995, Psychological Bulletin

Control Over Pace

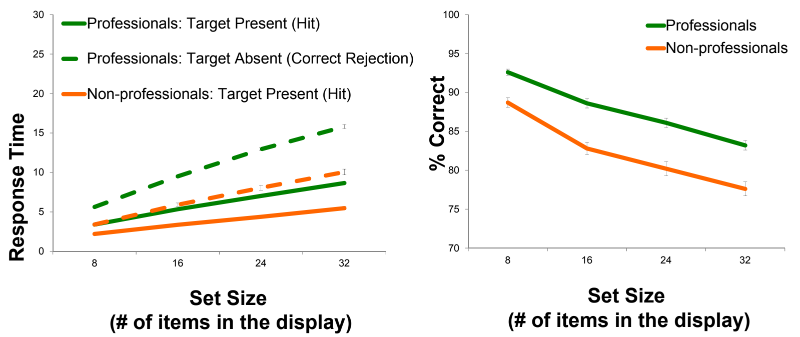


Fleck, Samei, & Mitroff, 2010, Psychological Science

Work with TSA Officers

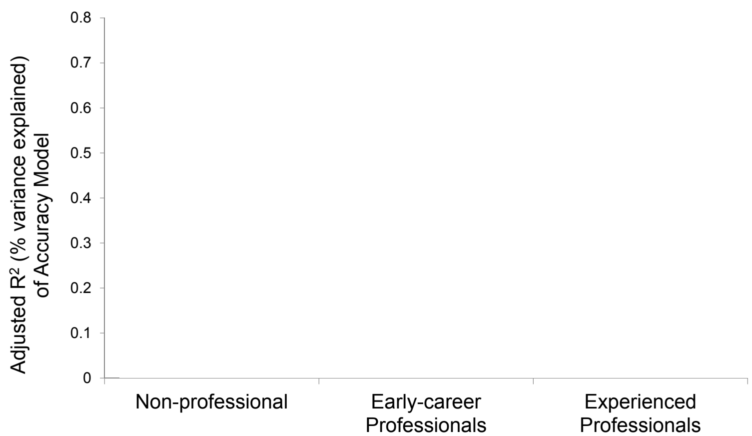


Speed/Accuracy Trade-off



Biggs, Cain, Clark, Darling, & Mitroff, 2013, Visual Cognition

Search Consistency



Biggs, Cain, Clark, Darling, & Mitroff, 2013, Visual Cognition

Conclusions Redux

- Vigilance Decrement is a long-studied problem endemic to boring tasks
  - Leads to an increase in 'default' responses
  - Affected by prevalence
- What's to be done?
  - Give frequent breaks
  - Give adequate, individualized handling time
  - Encourage consistent handling

Thanks!

Duke Visual Cognition Lab

BWH Visual Attention Lab

17.33 Tim White: Missed Technologies

Missed Technologies

- Acoustic
  - Battelle / Sellex – TOF and mm-wave (dielectric properties)
  - {velocity, attenuation, density} form signature
  - Or look for anomalies
- Flavors of IR spectroscopy
  - FTIR, Raman, SORS, CARS, CRDS, … molecular vibrations
- Thermal Imaging
- Metal detectors

- Note on Fusion: likely that no single technology will solve the problem
  - An approach to fusion is to look at available signatures and look for complementary ones (more on that later)

Some Technologies Have Not Made It

- Trace portal (IMS, MS) – maintenance
- Neutrons (PFNA, others) – engineering? (& neutrons are scary)
- X-ray backscatter – ATR?
- Electronic noses – sensitivity and mixtures

- Still in the lab (maybe for a long time)
  - CARS
  - THz

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Our Definition of Signature

- Signature (strict) – unequivocal evidence identifying a phenomenon

There are precious few strict signatures of an IED available non-intrusively

- Signature (less strict) – evidence that implies the presence of a phenomenon
  - Any observable that indicates the presence of an IED or a component of an IED will be considered a signature
  - Signatures can be ranked according to accessibility, availability, and diagnostic utility
- Availability is *how much* of the signature is present
  - Independent of detection modality, Dependent on scenario
- Accessibility is *how easy* it is to get at an signature
  - Dependent upon detection modality, Relatively independent of scenario
- Diagnostic Utility is *how well* the signature points to a chemical explosive, component, or device
  - There is a diagnostic utility of the indicator alone
  - And a diagnostic utility of the detection modality

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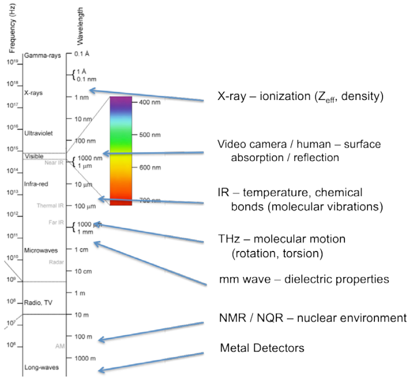
Signatures and Interrogation Techniques

- Neutrons – elemental ID (& ratios)
- X-rays – Z_{eff}, density, texture, molecular structure (diffraction)
- Imaging – shape, context, contrast (density, reflectance, dielectric constant)
  - Include ionizing radiation and EM
- IR – molecular vibrations (functional- group specific)
  - Raman (more specific. Less sensitive)
- IMS – molecular size and shape
- MS – molecular mass
- Chemical structure – MEMS, colorimetric, AFP
- Acoustic – density, viscosity



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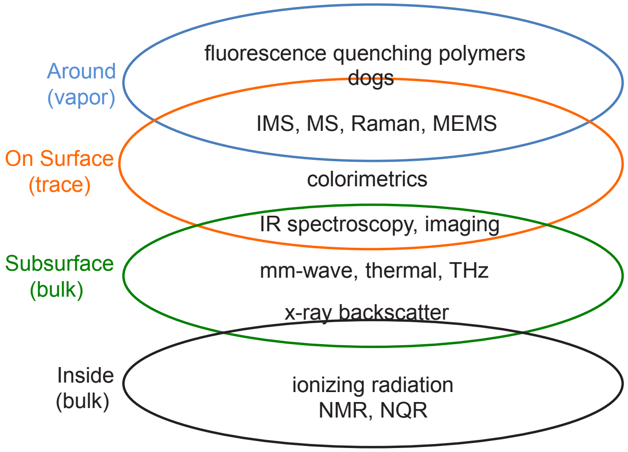
Where, What, and How



General Detection Modalities

Signatures for explosives detection grouped depending on point of view

Generic Interrogation Technique	Category of Signature			
Physically Sample and Analyze	Vapor	Trace		
EM Spectroscopy	Vapor	Trace	Bulk	Ancillary
EM Imaging	Vapor	Trace	Bulk	Ancillary
Ionizing Radiation Imaging			Bulk	Ancillary
Magnetics		Trace	Bulk	Ancillary
Acoustics			Bulk	

Physically Sample and Analyze
- Amplifying Fluorescent Polymers
- *Bio-Inspired Detection*
- Canines
- *Cavity Ring-Down Spectroscopy*
- Colorimetric Methods
- Ion Mobility Spectroscopy
- *Mass Spectroscopy*
- Micro-Mechanical Systems (MEMS)
- *Other Species*

EM Spectroscopy
- *Coherent Anti-Stokes Raman Scattering*
- IR Spectroscopy
- *Laser-Induced Breakdown Spectroscopy (LIBS)*
- Nuclear Quadrupole Resonance
- *Photoacoustic Spectroscopy*
- Raman Spectroscopy
- *THz Spectroscopy*

EM Imaging
- *Hyperspectral IR Imaging*
- Infrared/Thermal Imaging
- Mm-wave imaging
- *THz Imaging*
- Visible Imaging
- NMR

Ionizing Radiation Imaging
- Backscatter X-ray Imaging
- *Neutron Inelastic Scattering*
- *Nuclear Resonance Fluorescence*
- *Photonuclear Methods*
- *Thermal-Neutron Activation*
- X-ray Transmission Radiography
- X-ray CT

Detection Technology Categories

- Laser-Based Standoff Spectroscopy – molecular ID
  - IR (Raman (inc. coherent anti-Stokes Raman), LIBS, cavity ring-down spectroscopy, photoacoustic)
  - THz
- Electronic- and Chemical-Based Trace – molecular ID
  - Ion mobility spectrometry, mass spectrometry, MEMS
  - colorimetric, amplifying fluorescent polymers,
  - IR-imaging spectroscopy
- Biosensors – ?
  - Canines, bees, mice, pigs
  - Bio-inspired detection methods
- Electromagnetic – molecular ID, anomaly
  - NQR, mm-wave imaging, THz imaging
- Neutrons – elemental ratios (shape)
  - Thermal neutron activation, neutron inelastic scattering
- High-energy photons – elemental ratios, (shape)
  - Photonuclear, NRF
- X-ray imaging – density, Z_{eff}, shape
  - Radiography, CT, backscatter

Sampling and preconcentration may improve many of these technologies

"Bulk" techniques, often called anomaly detectors

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		Wavelength / energy	Signature	Type of detection	Type of data	Status	Threat Recognition
PEOPLE	NQR	0.5-5MHz	RF resonance (molecular environment or N content)	Material ID (N lines)	Spectrum	COTS, lab	Automated
PEOPLE	Active mm-wave	20-40GHz (15-7.5mm)	Anomalous scattering from dielectrics	Anomaly	2D+ images (motion, 3D surface)	COTS	Human / ATR assist
PEOPLE	Passive mm-wave	30-300GHz (10-1mm)	Anomalous attenuation/scattering of natural radiation	Anomaly	2D image sequence	COTS	Human / limited ATR
PEOPLE	THz imaging	0.1-3THz (3-0.01mm)	Anomalous attenuation /scattering from dielectrics	Anomaly	2D image sequence (~4Hz)	COTS, lab	Human
PEOPLE	THz spectroscopy	0.1-3THz (3-0.01mm)	RF absorption bands due to molecular vibrations	Material ID	spectrum	lab	Automated(?)
PEOPLE	Thermography	8-10µm (37.5-30THz)	Differential transmission of thermal emission from body	Anomaly	2D image sequence	COTS	Human
PEOPLE	IR spectroscopy	8-13µm (37.5-23THz)	RF absorption bands due to molecular vibrations	Material ID	Spectrum Spectral image	COTS, lab	automated
PEOPLE	X-ray backscatter	50-125kVp	Differential scattering (Z_{eff}, ρ)	Anomaly	2D image	COTS	Human
PEOPLE	Trace Portals (puffers)		IMS (or MS) spectral match	Material ID	spectrum	COTS	Automated
PEOPLE	Metal Detectors		Eddy current induced in metals	Anomaly (metal)	Alarm (1-2D field pert.)	COTS	Automated
BAGGAGE & CARGO	X-ray transmission imaging	80-160kVp < 450kVp > 1MeV	Differential attenuation (Z_{eff}, ρ)	Anomaly (material discrim. (CT))	2D or 3D image	COTS, lab	Human / Automated
BAGGAGE & CARGO	NMR	kHz	Characteristic decay of RF signal from ^{1}H	Material ID	3D material map	COTS, lab	Automated
BAGGAGE & CARGO	Acoustics	20Hz – 200MHz	Resonant spectra, density, acoustic impedance, velocity	Anomaly (material ID)	2-3D image, spectral data	COTS, lab	Human or automated
BAGGAGE & CARGO	Neutrons Interrogation	eV to 14MeV	Differential attenuation Characteristic gamma emission	Material ID	Elemental ratios (spectral)	Lab	Automated

Strategies

- Consider approaching explosives detection as a signature "pull" rather than a technology / widget "push"
  - This is tricky 'cause we are widgeteers
- Possible approaches – consider broad categories of…
  - … types of signatures
    - vapor, trace, bulk
  - … technologies and the types of signatures accessible
    - PSA, EMS, EMI, ionizing, metal, acoustic
  - … places to look
    - around object, on surface, subsurface, inside
    - "object" could be person or bag
- Or consider methods to improve existing widgets

ECAC LEDS Testing

European Civil Aviation Conference Liquid-Explosives Detection System

- Testing and performance standards for liquids
- Common Evaluation Process does not constitute certification or approval
- Increasing orders of intrusiveness
- Indication of which technologies fit where

Type	Description	Technologies
A	Open Container	Fluorescence quenching, chemiluminescence, colorimetric, Raman
B	Closed Container	X-ray scatter, {RF, IR, magnetic inductance, gravimetric}, Raman, microwave, {RF & ultrasound}
C	Multiple Containers	Radiography (multiview, multienergy)
D	Containers in baggage	CT
D+	with electronics present	CT

17.34 Harry Martz: Next Steps

Next Steps

Harry Martz and Carl Crawford

ADSA09

October 23, 2013

Version 1a

We heard about a lot of new technologies, but

- We mainly only heard about the advantages little on disadvantages of proposed technologies
- Little on pitfalls was presented
- As Matthew pointed out seriously consider
  - Does it work (are there any holes)?
  - Is it better than what is there today?
  - Can it be improved in the future?
  - Is it small, light and cheap?
  - Does it meets a regulatory requirement?
- Fusion of multiple technologies being investigated

As DOE EM used to ask is it Faster, Better, Cheaper and Safer?

What do you want to hear at ADSA?

- Industry
- Academia
- National labs

Still the preferred technology seems to be X-rays

- Why?

Topics for ADSA10

- Cargo
- Check point of the future
- Stand-off
- On the go scanning
- Metrics to measure impact on operational impact of FARs
- Need critical review of the technologies how do we do this?
- Testing to prepare for cert or qualification process
- Simulants and their validation
- Help gov't determine regulations
- University-Industry-National Lab collaborations
- Sensitive National Security and Classification Issues

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ALERT

AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

Awareness and Localization of Explosives-Related Threats

Northeastern University — 360 Huntington Avenue — Boston MA 02115
phone: 617.373.4673 — fax: 617.373.8627 — web: www.neu.edu/alert

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