Basic research interests in nanoscale radiation sensing

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ABSTRACT

Identification of the presence of radioactive materials is important for both defense and environmental concerns. Nanoscience may enable improved understanding of energy storage or transfer processes that can be exploited for indicators. For example, nanoscale materials that emit spectral signatures in the presence of ionizing radiation or nuclear particles, when incorporated in other widely used materials or objects, would assist in locating and securing radiological or nuclear materials.

Keywords: nanoscience, radiation, sensor, research

1. DTRA BASIC RESEARCH

The Defense Threat Reduction Agency is the U.S. Department of Defense's (DoD) official Combat Support Agency for countering weapons of mass destruction (WMD).

- Established in 1998 by consolidating other DoD agencies
- Headquartered at Fort Belvoir, Virginia (with test site in Albuquerque, and 12 other offices world-wide)
- Employing 2,000 military and civilian personnel

DTRA safeguards the United States and its Allies from Weapons of Mass Destruction (WMD) by providing capabilities to reduce, eliminate and counter the threat and mitigate its effects. Providing solutions across the full spectrum of combating WMD includes addressing threats from:

- Chemical weapons
  - cheap and easy to make
  - casualties not widespread
- Biological weapons
  - use available technology
  - attacks not quickly recognized, propagate w/ time
- Radiological devices
  - dangerous to assemble with high contamination impact
  - low lethality
- Nuclear weapons
  - difficult to acquire, devastating in use
- High-yield explosives
  - easily available materials with many ways to deliver
  - point targets

DTRA efforts cover the entire spectrum of technology readiness: knowledge and invention, proof of concept, technology development and risk management, and military utility. DoD 6.1 funds basic research.

1.1 DTRA/RD-BA Directorate and focus

The basic research program facilitates leveraging fundamental knowledge for future wide-spread applications and long-term needs. The Directorate fosters farsighted, high payoff research focused on the unique challenges to prevent, reduce, eliminate, defeat and mitigate threats from weapons of mass destruction.

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- Spark and encourage student interest in science and technology challenges.
- Advance the fundamental knowledge and understanding in the sciences.
    - Catalyze new thinking and capabilities to protect the US, allies, and partners.
- Promote international university research.

1.2 Thrust areas in DTRA/RD-BA basic research

1. Science of WMD Sensing and Recognition - generation of information that provides knowledge of the presence, identity, and/or quantity of material or energy in the environment that may be significant
2. Cognitive and Information Science - convergence of computer, information, mathematical, natural, and social science, including social networks and prediction of adversarial intent to employ WMD
3. Science for Protection - knowledge to protect life and life-sustaining resources including threat containment, decontamination, threat filtering, and shielding of systems
4. Science to Defeat WMD - phenomena that improve success of defeat actions (use of weapons) including explosives, accessing target WMDs such as bio agents and weapon modeling
5. Science to Secure WMD - environmentally responsible processes to secure, neutralize and control WMD and disrupt proliferation pathways

2. RESEARCH NEEDS AND TECHNICAL CHALLENGES

Representative basic research interests in nanoscale radiation indicators/unattended sensors address multiple goals, pay-offs and technical needs.

2.1 Objectives, opportunities, and challenges

Objectives:

- Improved detection and tracking of movement of:
    - radiological materials
    - nuclear weapons
- Environmentally benign indicators could be spread over open areas to find nuclear materials in areas of interest.
    - Indicators might be functionalized into many common structures or objects.
    - Stable environments for detection

Opportunities:

- Nano- or micro-scale phenomena & materials may be designed to reveal object histories.
- Radiation may be transduced into a form that has significantly greater range in the atmosphere.
    - e.g., visible light allowing stand-off
- Radiation detection material may be emplaced remotely from readout and power electronics.
- Nanomaterials provide a frontier for chem/bio sensing.

Technical challenges

- Radiation stopping power of materials places constraints on use of nanoscale materials.
- Must demonstrate viable detection efficiency for nanoscale materials that transduce radiation to observables.
- Materials must be emplaced in a form that can be dispersed.
    - durability
    - responsiveness to multiple signatures
    - communications

2.2 Broad Agency Announcement (BAA), 2011 topic[1]

Figure 1 shows locations of DTRA/RD-BA basic science awards, which includes University Strategic Partnership (USP). "Novel materials and methods for sensing" is an example of a recent basic research topic. This topic includes the following impacts and objectives.

Impacts:

- Basic research will support future opportunities to build or extend partnerships in WMD threat reduction.
    - For example, significant improvements in the ability to eliminate, secure, or consolidate WMD, related materials, and associated delivery systems and their infrastructure will build assurance in our ability to partner with willing countries to reduce the threat from WMD in the spirit of Cooperative Threat Reduction.
    - Sensing material may, for example, be applied to weapons, systems, sites, or locks/seals as indicators of activity or integrity between inspections. Novel sensing materials can help provide unique assurance against tampering, thereby assisting verification of compliance.
    - This may enable confidence: in greater reductions in arms; for agreements with new signatory nation states regarding their nuclear forces (or non-nuclear weapons); and, in existing or future treaties/agreements.

Objectives:

- to explore phenomena in materials that can provide passive or active indicators of interference with unattended monitoring (i.e., 24/7 sensing);
- to understand interactions that reveal the nearby but greatly displaced presence of novel tag materials (i.e., not incremental improvements in RFIDs) structured for cooperative efforts; e.g., locate transported objects by sensors within ranges of 10s of meters; and,
- to explore scientific methods that provide transparency into activities in a partner nation's facilities while being flexible in measurement and reporting (i.e., adjustable to not intrude in areas of knowledge protected by agreement).

Examples of basic research areas:

- Study properties of unique micro/nanostructures that sense and store memories of the type, magnitude and time history of actions that change the structure.
    - For example, investigation of changes in the state of materials on the molecular level that provides passive indication of external manipulation, such as unique changes in molecular structure; electrical, magnetic, or thermal properties; etc.
- Investigate active phenomena (e.g., processes that store and transduce energy) that help passive structures such as those identified above.
    - For example, signal enhancement via methods to control molecular storage in caged molecules or nanotubes and subsequent energy generating interactions such as charge release.
- Explore quantum states that provide unique information that support knowledge of tampering or the state of objects.
    - For example, atom interferometry etc. for mass distribution, entanglement/decoherence of states to identify tampering, weak measurements of observables; etc.
- Explore properties—such as electrical, magnetic, radiative, chemical volatility etc. — of novel material structure and function, and how these interact with photons, acoustic energy, chemical sensors etc. to provide measureable observables such as location.

Table 1 lists several additional examples of topics published under the basic research BAA. These fall under the five thrust areas previously described.

3. GENERAL OPPORTUNITIES FOR FUTURE TRANSITIONS FROM BASIC RESEARCH

Identification of the presence of radioactive materials is important for both defense and environmental concerns. Multiple areas support potential examples of systems perspectives.

3.1 Nanoscale radiation indicators

Sensing the presence of radioactive material is important to reduce the threat from nuclear/radiological WMD and to verify international nuclear treaties and pacts that promise the reduction and control of nuclear stockpiles. Nano-sized materials that emit spectral signatures in the presence of ionizing radiation or nuclear particles when incorporated in other widely used materials or objects (paint, metals, cloth etc.), would assist in locating and securing radiological or nuclear materials. The nanomaterials should be robust and nonreactive in field environments such as continuous exposure to sunlight and wide temperature range.

The incorporation of nano-sized radiation indicators into other widely used materials would ensure radiation detection without needing electronic detectors. Further, they could be spread over wide areas where nuclear material is suspected, to identify specific locations.

3.2 Post-detonation radiological and nuclear forensics

Another area for basic research support is to develop/implement accurate, rapid & reliable DOD global capabilities to collect/analyze post-detonation prompt data and ground debris.

- Prompt data collection
  - Ground-based gamma collection and alternative signatures for yield determination
- Sample debris collection
  - Ground sample
  - UAV-based airborne particle collection
- Sample debris analysis
  - Deployable analytical and screening capabilities
  - Rapid analytical technologies
- Data evaluation and knowledge management
  - Database development
  - Forensics tools development

3.3 Secure WMD, arms control, nonproliferation

The objective of this topic is to identify and explore novel approaches to monitor or secure WMD, by conducting the basic science that will enable very significant advances in current techniques that may allow improved future capabilities for treaties/agreements. The impact of this is advancement in fundamental science may foster future technologies that help maintain confidence in arms control and prevent proliferation of nuclear weapons.

3.4 Novel radiation-hardened electronic materials

The goal of this basic science area is to conduct theoretical and experimental research to further the fundamental understanding of the radiation mechanisms of new materials. The emphasis will be on the basic mechanisms of radiation interaction with small geometries and new materials. The objective is development of novel radiation hardened materials and components to facilitate improvements in electronic component or device number/density, performance, and reduced power.

4. SUMMARY

DTRA's Basic Research Program seeks to support the DTRA mission to counter-WMD by fostering innovative basic research and growing a future technical work force. One area is nanostructured radiation sensing materials that may present opportunities to improve detection- this includes basic research into materials properties, radiation interaction mechanisms, and emission signatures. We invite ideas, peer reviewers, research partnerships and collaboration.

REFERENCE

[1] "DTRA FY2011 – 2016 Basic Research for Combating Weapons of Mass Destruction (C-WMD) Broad Agency Announcement (BAA)", DTRA, HDTRA1-11-16-BRCWMD-BAA (01 March 2011). http://www.grants.gov/search/search.do;jsessionid=WkPNTXKdH1bLVYNDGYs2sh5pJ8w9R9mCkr1xkhrvs2FLDFdndlhR!-1890905838?oppId=75633&mode=VIEW

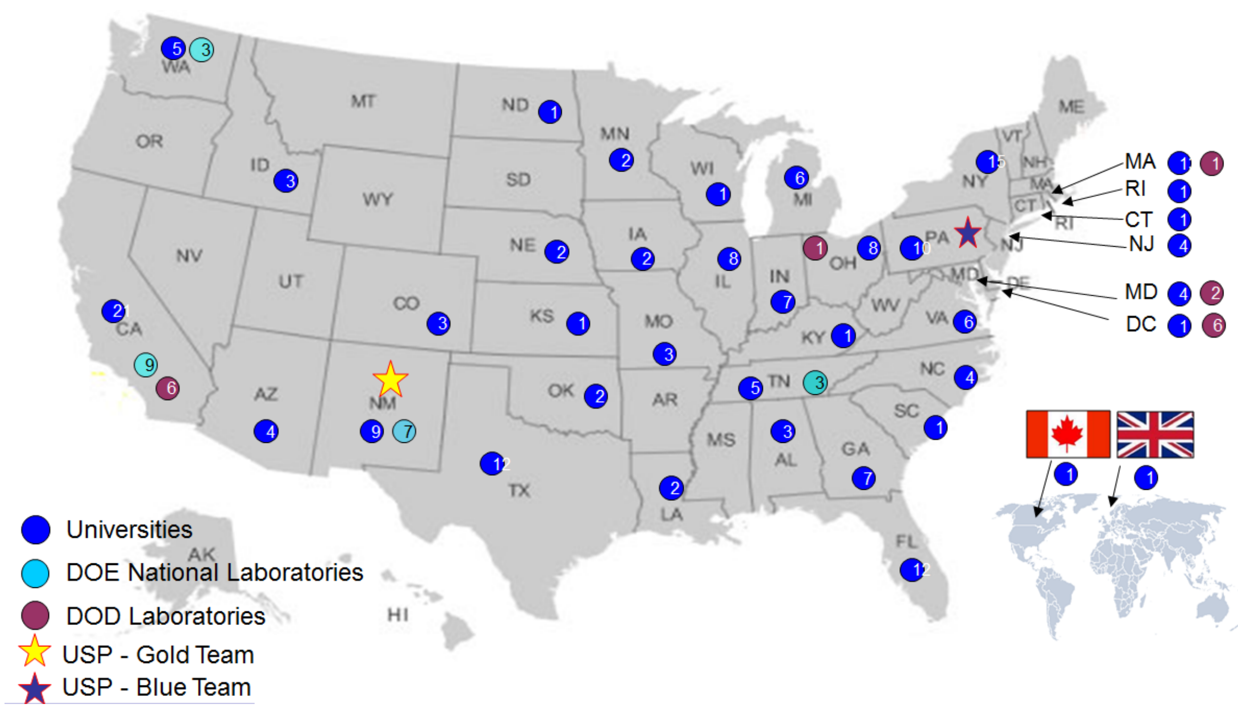

Figure 1. DTRA basic research BAA awards FY07-FY11

Table 1. Examples of DTRA basic research Broad Agency Announcement (BAA) topics

Thrust	Title
1	Terahertz Propagation Phenomena and Signatures
1 + 5	Ultra-Low Level Detection of Nuclear Materials
2	Network Survivability from WMD Disruption and Cascading Failures
2	Challenges in Integrating Motivation and Intent Knowledge
3	Novel Radiation-Hardened Electronic Materials
3	Laser-Driven X-Ray Sources
3	Transparent Impact-Resistant Materials
4	Nano-Sized Thermo-sensor Materials
4	New Materials with Fast Energy Release Using Novel Methods
5	Radio-noble Gases and Chemical Fractionation
5	Flora, Fauna, and Microorganisms as Screening Indicators for Underground Nuclear Tests
5	Unattended Sensors and Nanoscale Radiation Indicators