R2-B.1: Orthogonal Sensors for Trace Detection

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II. PROJECT DESCRIPTION

A. Project Overview

The use of triacetone triperoxide (TATP) in improvised explosive devices (IEDs) has been recently highlighted in the Paris and Brussels bombings. Once again, the need to reliably detect TATP and its precursors has taken center stage in venues where public safety may be compromised. Currently, a small-footprint, portable explosives trace detection (ETD) system capable of continuously monitoring a wide variety of threats is not available. Therefore, providing such a capability to the Department of Homeland Security (DHS) and its stakeholders is a primary goal of this research. Our state-of-the-art ETD system is fundamentally different from others employing micro-thermal analysis. We are not aware of any other sensor that incorporates a catalyst into the platform to achieve the desired levels of sensitivity and selectivity (i.e. our approach relies on the catalytic-decomposition of explosive molecules).

In addition to continuing efforts to lower detection limits while maintaining adequate selectivity to potential threats, other challenges face this ALERT research project. Among these is the need for the ETD system to be adaptable. That is, as the nature of the “threat” changes and new processing routes and explosives become available, the sensor system must be able to detect these new threats. Our sensor does so simply by identifying a catalyst for a particular analyte and adding this characteristic response to the existing library of responses. Combinatorial chemistry techniques will be used for the rapid screening of new catalysts, and new catalyst-analyte pairings will be added to the existing library as part of the ALERT project. We have been building libraries of catalyst-analyte pairings for some time using combinatorial chemistry techniques. Thus, the libraries we generate are of value because they were developed for specific molecules of interest, as were the combinatorial chemistry techniques used for the rapid screening of new catalysts. In short, our ETD system is very adaptable, and as the nature of the “threat” changes and new explosive
threats emerge, new catalysts for our sensor system can be quickly synthesized. We plan to test our orthogonal sensor system in relatively confined air spaces using this approach. Specifically, we plan to screen vapors inside cargo containers at ports of entry for explosives (and possibly narcotics and toxic industrial chemicals (TICs)).

B. Biennial Review Results and Related Actions to Address

One of the strengths of our project is the built-in orthogonality of the sensing platform used to mitigate false positives and negatives. The metal oxide catalyst comprising our sensor is simultaneously interrogated using two orthogonal sensing protocols (i.e. a thermodynamic and a conductometric protocol). In addition to this redundancy, another strength of the project is the ability to detect both nitrogen-based and peroxide-based explosives, making it a valuable addition to existing detection techniques available to the Homeland Security Enterprise (HSE). This is especially true of those targeting explosives in the vapor phase. One of the identified weaknesses of our project was demonstrated selectivity; specifically, interference caused by streams of commerce vapors and other non-threatening background components, such as humidity and smoke. We have recognized the importance of this for some time and have recently completed a number of tests in the presence of acrylate adhesives, such as methyl acrylate, that may be present in high concentrations in the headspace of cargo containers, one of the first venues identified for field testing of our sensor. Figure 1 shows the signal response to a mixture of 1000ppm TATP and methyl acrylate (TATP/MA) (shown in blue) and the response corresponding to 1000 ppm MA (orange). The selectivity of the catalyst used for TATP is evident here, based on the lack of response for MA observed with our thermodynamic platform.

We have been developing catalysts for our sensor platform using combinatorial chemistry techniques for some time now, but we do not know if these newly developed metal oxide nanowire catalysts (based on zinc oxide (ZnO), copper (II) oxide (CuO), and iron (II) oxide (FeO)) also act on streams of commerce vapors. Some of our preliminary tests using nanowire catalysts have indicated excellent selectivity for different explosives. For example, when using iron oxide nanowires as the catalyst, we did not get a response for TATP as the analyte at any appreciable concentration in the vapor phase. However, when the analyte was switched to ammonium nitrate (AN), we were able to detect it at the ppb level. Thus, the selectivity of iron oxide nanowire catalysts for AN relative to TATP is considerable. Catalyst and sensor selectivity will continue to be a priority for the next year, and we will quantify sensor response in the presence of different concentrations of inter-

![Figure 1: Sensor response to TATP in the presence of 1000 ppm of MA.](image)
ferent or confuser molecules; that is, catalyst selectivity will be addressed more closely in the upcoming year by testing for explosive compounds in the presence of non-threatening background components, such as ammonia, humidity, and diesel smoke. We recognize that this is perhaps one of the most important aspects of our project yet to be completed, and we plan to evaluate the performance metrics of interferents as a priority in Year 4.

C. State of the Art and Technical Approach

Our orthogonal ETD system, comprised of a thermodynamic and conductometric sensor platform, is somewhat unique in that it can detect both nitrogen-based and peroxide-based explosives [1-3]. For example, TATP, 2,6-dinitrotoluene (DNT), and AN can be detected at the “single” ppb level in a single pass using our orthogonal ETD system. The thermodynamic sensor platform measures the heat effect associated with the interaction of a specific target molecule with a metal oxide catalyst. Specifically, a catalyst coated microheater is thermally scanned over a selected temperature range using a digital control system, and the electrical power difference due to catalytic activity is measured, similar to that in a microcalorimeter [1]. However, the catalyst plays a key role in that it amplifies the signal and sharpens the response, improving both sensor sensitivity and selectivity [1-3]. No other sensor that we are aware of incorporates a catalyst into the platform to achieve the desired levels of sensitivity/selectivity necessary for the detection of threat molecules at trace levels. The approach used by Chen and Bannister [4] for detecting explosives comes closest to our methodology. They were able to differentiate energetic (explosive) materials from non-energetic materials using micro-thermal analysis. They used a micro-calorimetry approach for detection, where changes in a material as it is heated generated a thermal “fingerprint” due to decomposition. They obtained different characteristics for explosives vs. non-explosives. Our approach relies on catalytic decomposition, which is much more specific and, when combined with metal oxide nanowires, much more sensitive to explosive molecules than non-explosive molecules. The effect of the TATP concentration on thermodynamic sensor response, with a SnO catalyst (blue) and without a catalyst (red), is shown in Figure 2. The sensor without a catalyst behaves very similar to that of a microcalorimeter [4], whereas the sensor with a metal oxide catalyst exhibits much greater response (amplification) without sacrificing specificity.

![Figure 2: Effect of the TATP concentration on thermodynamic sensor response, with a SnO catalyst (blue) and without a catalyst (red).](image-url)
Our approach relies on the catalytic decomposition of the analyte molecule, which is a fine-tuned version of Chen and Bannister’s method [4] and, thus, has a much more specific response. When this approach is combined with high surface-area catalysts (metal oxide nanowires), the sensitivity to explosive materials is in the ppb range and on the same order of magnitude as that of an electronic dog nose [5].

A complementary conductometric sensor platform was added to our thermodynamic sensor platform, which simultaneously monitors the electrical conductivity changes in the same metal oxide catalyst when it is exposed to the same target molecule [3]. The premise here is that analyte-specific thermodynamic and electrical conductivity changes induced during catalytic decomposition of the target molecule allow for ultra-high-resolution detection of explosives vapors using orthogonal modalities that minimize false positive signals. Thus, the sensor provides a “signature,” which allows the user to determine which explosive is present and uniquely differentiates each explosive.

The thermodynamic sensor consists of two microheaters that are dynamically controlled: one microheater is coated with a metal-oxide catalyst and a second microheater is left uncoated (see Fig. 3). As the heaters are thermally scanned, the catalyst-coated microheater detects any sensible heat effects plus the heat effect associated with catalyst-analyte interactions; whereas the uncoated microheater detects only the sensible heat effects. By subtracting the two signals, any extraneous heat effects are cancelled out, producing a response that is due only to catalytic activity.

![Figure 3: Schematic of the dynamically controlled thermodynamic sensor platform with pre-concentration. Upon thermal desorption, the explosive vapor is delivered from the pre-concentrator to the active sensor elements.](image)

**C.1. Surface area effects**

Given that the metal oxide catalyst plays a critical role in the performance of our thermodynamic sensor, the effect of catalyst surface area on sensor response is dramatic. Figure 4 on the next page shows the response of a SnO catalyst to various concentrations of TATP, with a porous and a non-porous catalyst. A SnO catalyst was sputtered onto an alumina support in both cases, but the sensor response and detection limit obtained using the higher surface-area alumina support was dramatically improved. A dynamically controlled, dual-sensor protocol was used in both cases, and suggests that catalyst surface area is the single most important variable for sensitivity and selectivity. With this in mind and an expectation to transition the thermodynamic sensor to a microelectromechanical systems (MEMS)-based platform in the near future, surface area of the active sensor elements could be dramatically increased using nanotechnology [6, 7, 8]. To meet this challenge, zinc nanowires were hydrothermally grown in an autoclave and subsequently deposited onto the active sensor elements to serve as catalyst and/or catalyst support. With the addition of zinc oxide nanowires, sensor responses to trace explosives were increased by nearly 300% and the detection limits were reduced into the “single” ppb range (see Fig. 5). Here, the zinc oxide nanowires added an additional catalytic activity not pre-
viously seen with the sputtered catalyst films. With further improvement, oxide nanowire catalysts have the potential to lower detection limits into the ppt range.

![Detection Limit for TATP using a Tin Oxide Thermodynamic Sensor](image)

**Figure 4:** Effect of SnO catalyst surface area on the response to various concentrations of TATP. A detection limit of 134ppb was achieved with the greater surface area catalyst; sensor response using porous catalyst support is shown in blue and sensor response with a non-porous support is in red.

![Response of two identical sensors to 2,6-DNT](image)

**Figure 5:** Response of two identical sensors to 2,6-DNT; response of sensor employing a tin oxide catalyst sputter-deposited onto ZnO nanowires (orange) and response of sensor employing a sputter-deposited tin oxide catalyst (blue).

### D. Major Contributions

The most recent contribution to the overall goals of this project was to improve the surface area of the catalyst and/or catalyst support, which was realized through nanotechnology. Specifically, zinc oxide, copper oxide, and iron oxide nanowires were grown in a controllable and reproducible manner such that they could be incorporated directly into the sensor platform. High-purity zinc foil was initially cleaned using acetone, methanol, and
water, and then submerged in a Teflon crucible containing a 3.5M solution of ethylene-diamine and autoclaved for 10 hours at 146°C [6, 7]. Figure 6 shows scanning electron microscopy (SEM) micrographs of a sputtered zinc oxide film and zinc oxide nanowires grown by hydrothermal means [6]. Here, the sputtered zinc oxide film is almost featureless compared to the hydrothermally grown zinc oxide, and the difference in surface area between the two different zinc oxide preparations can be readily seen from the SEM micrographs. Note that even though the orientation of the zinc oxide nanowires is somewhat random, the benefit in terms of surface area enhancement is still realized for the hydrothermally grown zinc oxide.

More recently, copper oxide and iron oxide nanowires were formed directly onto the active sensor elements [6]. Sputtered copper oxide and iron oxide catalysts have been successfully used for the detection of TATP and AN using our thermodynamic sensor and, thus, CuO and FeO were logical choices for integrating nanowires into our existing sensor platform. In addition to having the desired chemistry, CuO and FeO nanowires possess attributes similar to those of ZnO but can be readily fabricated onto the microheater's surface. To accomplish this, copper and iron thin films were sputtered onto the serpentine of the microheater and oxidized in ambient air at 410°C for 6 hours. Figure 7 and Figure 8 on the next page show SEM micrographs of CuO and FeO nanowires grown on the surface of nickel microheaters. It should be noted that the nickel microheaters were pre-coated with an aluminum oxide layer for electrical insulation, prior to the deposition of the copper.
Based on the SEM micrographs of the ZnO, CuO, and FeO nanowires shown in Figures 6, 7, and 8, extremely large aspect ratios were observed, and it was not surprising that their effect on sensor response was significant. Figure 9 shows the response of our thermodynamic sensor to various concentrations of TATP using a nanowire catalyst and a sputtered catalyst consisting of SnO.

In addition to increasing the surface area by 5-6 orders of magnitude over our existing sputtered catalyst, the ZnO nanowires used as a support also improved the conductometric sensor response. Other researchers [8] have determined that explosives molecules stick readily to and are adsorbed onto the surfaces of nanostructured oxides. This results in a change in surface chemistry and, thus, a change in electrical conductivity. Figure 10 on the next page shows the response of an orthogonal sensor to 0.5 ppm 2,6-DNT using a ZnO catalyst at 410 °C. The analyte vapor, 2,6-DNT, was introduced into the system for 60 sec. and both the thermodynamic and conductometric signals showed a large, rapid response (< 10 sec).
However, the two orthogonal sensor platforms appear to have different time constants (i.e. compared to the conductometric response, the thermodynamic response takes a longer time to reach equilibrium). Additional tests of the orthogonal sensor using SnO₂ as the catalyst and 2,6-DNT as the analyte were conducted. The purpose of these additional tests was to determine the effect of vapor concentration on recovery time (see Fig. 10). Here, the thermodynamic response was linear with respect to 2,6-DNT vapor concentration, whereas the conductometric response remained relatively constant as the 2,6-DNT vapor concentration was decreased below a certain concentration.

E. Milestones

A number of milestones have to be met before the orthogonal sensors developed by this project can be delivered to the HSE. First and foremost, field-testing of the orthogonal sensor system is a major milestone in Year 4, and the plan is to complete field testing over the next 6-12 months. Most of the sensor testing to date has been done using a bench-level or bench-scale apparatus under controlled laboratory conditions. Moving forward in Year 4, field-testing of our sensor will be a priority. Perhaps the single biggest obstacle to field-testing our orthogonal sensor is making it small enough to be easily transported from place to place while keeping many of the same attributes of the current bench-scale ETD system, including flow rates, selectivity, and detection limits. We have made considerable progress over the past few months during Year 3 in testing the individual components and packaging them in a small footprint platform (i.e. the components have to be packaged in such a way that the system is not only robust but portable as well). Towards this end, our portable ETD system is almost complete and will represent a major milestone in Year 4. New components, including mass flow controllers, electronics, software, etc., have been acquired in Year 3 and are being tested individually so that what was developed in the laboratory, will be duplicated in the portable ETD system, only in a much smaller package. Finally, we will compare the results generated from our portable ETD system with those generated from our bench scale ETD system for a number of different analytes. Once this preliminary testing is completed in the July 2016 timeframe, we will be ready for field-testing.

We will also continue our efforts to build a library of sensor responses (or signatures) for specific catalyst-analyte combinations in Year 4 and, at the same time, lower the detection limits for the threat molecules of interest. New oxide nanowire catalysts will be developed over the next 12 months and, finally, we will continue efforts to detect other explosives that have even lower vapor pressures than those energetic materials we have successfully detected to date. Part of this effort will focus on the conductometric properties of new oxide...
nanowire catalysts since it is well known that explosive molecules stick readily to and are adsorbed onto the surfaces of nanostructured oxides [8]. Another milestone in Year 4 that is not as critical but still important to the operation of our detection system is to decrease the response time. Morpho Detection has expressed an interest in funding an additional effort to reduce the response time of our current ETD system. Ultimately, this will be addressed by the MEMS version of our ETD system. However, in the interim, we plan to investigate much thinner substrates than are currently being used (e.g. mica). By reducing the thermal mass of the sensor/substrate, response times will be dramatically reduced.

We have demonstrated that our orthogonal sensor platform can detect TATP, 2,6-DNT and AN at the “single” ppb level, which was a major milestone in Year 3. These detection limits were achieved without pre-concentration and multi-pass protocols, and we anticipate that these detection limits will be reduced even further in Year 4. By implementing pre-concentration and multi-pass protocols, as well as integrating high surface-area, metal oxide nanowire catalysts into our ETD system, minimum detection limits in the ppt range will be a targeted metric and milestone in Year 4. Recently, ZnO, CuO, and FeO nanowires have been incorporated into our sensor platform and, in some cases, these have shown up to 2 orders of magnitude improvement in sensor response over sputtered catalysts. Performance metrics for sensor selectivity, including quantifying sensor responses in the presence of different concentrations of interferents, still need to be completed before the project reaches its final objective. However, we plan to focus on interference metrics as a milestone in Year 4. In addition to establishing performance metrics for sensor selectivity, field-testing will be done in a venue that has a relatively controlled environment which will be a major milestone in Year 4. Initially, field-testing will be done at The Naval Research Laboratory’s (NRL) Vapor Test Bed under the direction of Dr. Susan Rose-Pehrsson. This test bed is ideally suited for this purpose and will be the site of the first trials. It should provide us with preliminary data on how our sensor is performing in the field and help with future testing venues. A number of environmental variables such as humidity and temperature can be controlled there, which will be critical to the collection of reliable data. Some of these environmental factors can be mitigated using our dynamic control protocol, which employs two microheaters: one coated with a metal-oxide catalyst and one without a catalyst. By subtracting the two signals, most extraneous heat effects are cancelled out, producing a response that is due only to catalytic activity. If initial field-testing at NRL’s Vapor Testbed proves to be successful, we plan to do mock screening of containers at the Port of Savannah, Georgia, which is the second busiest port on the East Coast. Mr. Jamie McCurry, Director of Administration and Government Affairs for the Port Authority of Savannah has been contacted and has committed to our ETD system being field-tested at his facility.

F. Future Plans

Since September 11, 2001, the screening of cargo containers for chemical weapons at ports of entry has been a priority for DHS. However, a rapid, cost-effective screening method for explosives and explosives precursors does not currently exist [9, 10, 11]. Since the vapor space above the cargo in these containers can contain detectable concentrations of explosives vapors, our ETD sensing technology could be used to probe the space for potential threats. Thus, our future plans will focus on developing a portable sensing device (using an air pump to induce airflow) that will effectively draw vapor from the head-space over the sensor elements, to enable real-time detection. We will continue to pursue lower detection limits for both nitrogen- and peroxide-based explosives using our high surface-area catalyst and dynamic scanning protocols in the coming year. At the same time, we still plan to transition our thermodynamic sensor platform from a solid-state device to a MEMS-based device, now that we have addressed the issue of reduced surface area for the active sensor elements (catalyst-coated microheaters) in the MEMS, which would have a considerably smaller footprint. To address this reduction in sensor footprint, zinc oxide, copper oxide, and iron oxide nanowires will be employed as the catalyst and/or catalyst support in the MEMS platform. Since we are eventually planning to develop an integrated MEMS device (with electrical measurement unit) on a custom integrated circuit, this
will serve as a platform for multiple catalysts, thermal measuring devices, and reference microheaters. Using the MEMS platform, a handheld version of our ETD system is envisioned.

In the long term, we intend to use custom integrated circuit design techniques and MEMS sensors, whereby the acquisition of the signals derived from the detectors can be automatically screened for threat molecules. The Naval Undersea Warfare Center (NUWC) has considerable expertise in the development of MEMS devices, custom integrated circuit design, device packaging, and airflow issues. The premise here is that analyte-specific thermodynamic and electrical conductivity changes induced during adsorption by a metal oxide catalyst allow for the high-resolution detection of explosives vapors using orthogonal modalities that minimize false-positive signals. The long term goal for the Navy is to develop sensor arrays (i.e. arrays comprised of an integrated MEMS and electrical measurement unit on a custom integrated circuit), which can serve as a platform for multiple catalysts, thermal measuring devices, and reference microheaters.

III. RELEVANCE AND TRANSITION

A. Relevance of Research to the DHS Enterprise

The ultimate transition product for the HSE is a portable ETD system, the size of a large shoe-box, that is capable of continuously monitoring a wide variety of threats. The final product will be a passive, non-invasive ETD system that will provide an additional screening capability for DHS and its stakeholders. We will continue to collaborate with industry (Morpho Detection, FLIR-Nomadics, and DetectaChem), and government (NUWC in Middletown, RI and US Army Lab in Natick, MA) in establishing a path forward for commercializing this technology. We have a Cooperative Research and Development Agreement (CRADA) with NUWC, and are currently negotiating an extension of this document that will take us beyond Year 4 in the project. The intended end-users of our technology are the US Coast Guard, the Transportation Security Administration (TSA), Amtrak, first responders, and other DHS stakeholders. We have also reached out to potential commercialization partners, primarily the manufacturers of detection equipment including Morpho Detection, Smiths Detection, FLIR-Nomadics, DetectaChem, and Raytheon, to determine which aspects of our ETD system could be incorporated into existing systems and, in particular, how it could help detect peroxide-based explosives in their systems. Based on input from the US Coast Guard, it was strongly recommended that any ETD systems transitioning to the field have a capability to detect narcotics and TICs as well as explosives. Towards that end, a number of bench experiments using acetaminophen as the analyte have been performed this past year using our orthogonal sensor and, if time permits, we will re-visit narcotics and TIC’s in Years 4 and 5. With field-trials planned for the fall of 2016, and assuming that these field-trials go according to plan, devices based on our technology could reach end-users somewhere in the 2018-2019 timeframe. This, of course, assumes that we will have a commercial partner on-board by 2017.

This ALERT research project addresses one of the challenges for the HSE in that both nitrogen-based and non-nitrogen-based explosives can be detected at trace levels. A number of commercial ETD systems that can reliably detect nitrogen-based explosives are unable to detect peroxide-based explosives. Our sensor system is equally proficient in detecting TATP and 2,6-DNT at the ppb levels, but our goal is to lower the detection limits for both nitrogen- and peroxide-based explosives. Another major concern for the HSE is false alarms (i.e. false-positives and false-negatives). A potential confuser for TATP using our thermodynamic sensor platform is acetone, which is the decomposition product of TATP in the absence of any catalyst [12]. However, the catalytic decomposition of TATP using our sensor results in the formation of hydrogen peroxide and not acetone [1, 2]. Thus, those confusers that may be anticipated in the absence of a catalyst may not be an issue at all with our ETD system, since our sensor depends on catalytic decomposition. In our case, hydrogen peroxide would be more of a confuser than acetone. In addition, our project specifically addresses the issue of false-positives and negatives by employing orthogonal sensor modalities that are somewhat unique in that the metal oxide catalyst is simultaneously interrogated using two different sensing protocols. The result is
a built-in redundancy consisting of both a thermodynamic signature and a conductometric signature. The metric for the orthogonal modalities is to lower the detection limit for a given analyte-catalyst combination using each type of sensor platform. The metric for the MEMS-based sensor platform is to reduce the sensor footprint relative to the solid-state sensor without sacrificing capability (i.e. without sacrificing the current sensitivity and selectivity of the solid-state sensor).

B. Potential for Transition

We have been discussing our sensor technology with several equipment manufacturers including Morpho Detection, Detectachem, FLIR Nomadics, The Coghlin Companies, and AG Global Capital. Morpho Detection and Detectachem have expressed keen interest in licensing our technology and have signed NDAs. Specifically, Morpho Detection has expressed an interest to fund additional efforts to reduce the response time of our current ETD system.

NUWC and URI have entered into a CRADA (NUWC&DIVNPT-13-801) to assist in the design and implementation of a MEMS-based sensor platform. The US Army Lab in Natick, MA and URI have discussed potential partnerships to address chemical and biological threats, including a partnership to team with URI in response to select request for proposals (RFPs) from the Defense Threat Reduction Agency (DTRA) that impact Homeland Security.

C. Data and/or IP Acquisition Strategy


D. Transition Pathway

We have been working with potential commercialization partners and potential end-users to explore venues for field-testing our sensor technology. Field-testing will be a high priority over the next year, and collecting data in the field and processing the data in “real time” will go a long way toward satisfying the needs of potential end-users. SensorTech Inc. and the Port Authority of Savannah have offered their services to assist us in field-testing cargo containers immediately, but we are not yet prepared for a full field-trial. Before transitioning to a full-scale venue, we have to test our portable ETD system. Our latest effort along these lines includes the addition of an air pump to our portable ETD system to emulate how the sensor would be used in a “real testing environment”.

In addition to the above collaborators, we have continued to pursue potential commercialization efforts with other industrial partners, primarily the manufacturers of detection equipment including Morpho Detection, Smiths Detection, FLIR, and Raytheon. FLIR, for example, visits our laboratory several times a year to see the progress made and new technologies that have been incorporated into our sensor platform. They are interested in technologies that could possibly benefit their FIDO detection system. Morpho Detection and URI have entered into negotiations and signed NDAs, after they expressed an interest in funding efforts to reduce the response time of our ETD system.
E. User Partner or Customer Connections

- NUWC, CRADA- NUWCDIVNPT-13-801: Dr. Theresa Baus, Technology Transfer Chief, is our technical contact at NUWC.
- US Army Lab in Natick, MA: Dr. Kris Senecal is our contact at US Army RDECOM, NSRDEC.

IV. PROJECT ACCOMPLISHMENTS AND DOCUMENTATION

A. Peer Reviewed Journal Articles


Pending-


B. Peer Reviewed Conference Proceedings


C. Other Conference Proceedings


2. Z. Caron, V. Patel, D. Meekins, M. Platek and O.J. Gregory. “Orthogonal Sensors for Vapor Residue.” TESSA02 Workshop, Northeastern University, Boston, MA, 5 August 2015.

D. Other Presentations

1. Poster Sessions

2. Briefings
   a. On April 13, 2016, Commissioner R. Gil Kerlikowske of U.S. Customs and Border Protection
(DHS) made an impromptu visit to our labs at URI to discuss the threat from explosives such as TATP to cargo entering ports of entry and airports, and how to detect TATP.

3. Interviews and/or News Articles
      The Associated Press article appeared on the front page of 135 newspapers around the world, and related to the trace detection system for TATP developed at URI. As of Feb. 18, 2016, a Google roundup showed that more than 150 broadcast, print, and internet media outlets have carried the article, and it has trended on Facebook.

E. Student Theses or Dissertations Produced from This Project


V. REFERENCES


