R1-B.1: Metrics for Explosivity, Inverting & Compatibility

I. PARTICIPANTS

<table>
<thead>
<tr>
<th>Faculty/Staff</th>
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<tbody>
<tr>
<td>Name</td>
<td>Title</td>
<td>Institution</td>
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<tr>
<td>Jimmie Oxley</td>
<td>Co-PI</td>
<td>URI</td>
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<tr>
<td>Jim Smith</td>
<td>Co-PI</td>
<td>URI</td>
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<tr>
<th>Graduate, Undergraduate and REU Students</th>
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<tr>
<td>Name</td>
<td>Degree Pursued</td>
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<td>Month/Year of Graduation</td>
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<tr>
<td>Ryan Rettinger</td>
<td>PhD</td>
<td>URI</td>
<td>5/2016</td>
</tr>
<tr>
<td>Matt Porter</td>
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<td>URI</td>
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<td>Tailor Busbee</td>
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<td>Devon Swanson</td>
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<tr>
<td>Jon Canino</td>
<td>PhD</td>
<td>URI</td>
<td>12/2014</td>
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II. PROJECT DESCRIPTION

A. Overview and Significance

Determining if a material or formulation is detonable and determining if an adulterant has inerted a detonable material are extremely difficult problems that cannot be properly addressed unless better metrics are developed. That development is the goal of this project. Because the potential matrix of threatening combinations of fuels and oxidizers is large, we seek to determine the characteristics required for detonability; bounding the problem in terms of oxidizer and its ratio with each fuel. In the laboratory, we probe characteristics such as heat and gas release, and a full suite of chemical, thermal and sensitivity analyses to correlate to larger scale detonation performance tests. A method which can successfully determine what formulations are potentially detonable would also reveal if “inerting” of an explosive had successfully made it non-detonable or just “safer”. Either question, what is potentially detonable and if adulteration has achieved non-detonability, currently requires very large-scale testing or a reliable small-scale test. The goal of the R1-B projects is development of the latter—a reliable small-scale test which screens large scale threat combinations quickly and inexpensively. We have taken here a number of approaches to this problem. They are discussed below.

Approach 1: How well an explosive functions is highly dependent on bulk properties, e.g. density, lattice structure, but whether a chemical can detonate at all, requires that the molecule have certain molecular features. To be an explosive, the molecule must be able to react with chemistry that produces heat and gas; and this must happen rapidly enough that the detonation front is supported by the energy release. Examination of the atoms making up the molecule allows prediction of whether heat and gas can be produced. This aspect of the molecule is being investigated under Approach 1 with full details as referenced in paper [1] and in R1-A.1. The thermal and burn behaviors of 11 solid oxidizers and combinations of 13 fuels were determined; burn rate was found to roughly correlate with standard reduction potentials. The thermal studies highlighted the
importance of a melt or phase change of one component of the formulation in triggering the reaction. These studies also indicated that the choice in oxidizer, outweighed the choice in fuel, in determining the total energy released. These exciting observations are the first steps in finding behaviors observed on the milligram scale that may correlate with detonability measured on the kilogram scale. Figure 1 is a plot of temperature of decomposition vs heat of decomposition [2, 3]. The fact that explosives clearly group in a different region than non-explosives suggests we can use thermal analysis of small samples as one metric to rate detonability.

Figure 1: Plotting DSC (differential scanning calorimetric) response for peroxides (green diamonds), high explosives (blue square), dinitroarenes (red circles) and various energetic salts (pink triangles).

The critical question of whether the reaction can happen fast enough to support detonation is usually found experimentally. Other approaches in this project are examining the reaction that may or may not support steady detonation.

Approach 2 is looking at one of the fundamental molecular properties--dissociation energies during gas phase ion impact with an inert gas. By examining a variety of explosive and non-explosive compounds in an ion-trap or a triple-quadrupole mass spectrometer, a correlation may be observed between ease of fragmentation from the energy input required and the rank order of detonability.

In the past researchers developed a method for mass spectrometeric (MS) applications which was termed survival yield. The basic idea behind it was to supply enough energy to the molecule to see when only 50% of it was left over and the rest was gone due to fragmentation [4]. Recently, with the advent of new technologies and the progress in MS field resulted in reviving of this application as a proof of a concept for established ionization methods such as desorption electrospray ionization (DESI)[5, 6], electrospray ionization (ESI)[7, 8], and the newly developed accessories (mainly ionization probes) such as laser electrospray MS (LEMS) [9]. However, most of these applications are being performed on very simple molecules termed thermometer ions [10], which in the process produce only one or two fragments that can be easily identified and analyzed. Unfortunately, for most compounds (including virtually all energetic materials), this is not the case. Usually an array of fragments is formed; some cannot even be accounted for because of the constraints of the instrument, itself. Therefore, a new method must be developed which still has similar basis of the survival yield approach, but accounts for its limitations.

The concept is to produce and isolate ions of individual molecules within either an ion trap or a collision cell of a triple quadrupole mass spectrometer (MS). Once the ion has been isolated from the matrix (liquid phase, impurities, fragments or other unwanted ions), the collision energy provided by the MS can be gradually increased to observe several unique molecular properties: 1) the minimum energy eliciting initial fragmentation; 2) 50 % dissociation; 3) 100 % dissociation; 4) the window of energy associated with fragmentation;
and 5) a product ion spectrum. Each analysis requires less than 500 micrograms and presently takes 5 to 40 minutes to produce up to 6 full scans from 0 to 50 normalized collision energy units (eV). Initially, the ion trap MS is being used for method development and proof of principle. A quick-look experiment shows that innocuous compounds (see Table 1) can be differentiated from energetic ones (see Table 2), the latter being fragmented with much less energy. Once this method is optimized, we will attempt to establish consistent parameter sets across all compounds, e.g., solvent selection, tune conditions, percent of ion trap fill, etc. At what concentration a compound fills the ion trap may provide additional information about the ionization efficiencies. Because the ion-trap is attached to an exact mass detector (Orbitrap), molecular fragments can be assigned molecular formulas within 10 ppm accuracy.

<table>
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<tr>
<th>Stable compounds</th>
<th>Mode</th>
<th>Ion</th>
<th>m/z</th>
<th>Time (sec)</th>
<th>E(eV) onset</th>
</tr>
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<tbody>
<tr>
<td>2,4-Dichlorophenoxyacetic acid</td>
<td>ESI-</td>
<td>[M-H]-</td>
<td>218.9618</td>
<td>89.8</td>
<td>9.2</td>
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<td>Hexamine</td>
<td>ESI+</td>
<td>[M+H]+</td>
<td>141.1128</td>
<td>118.8</td>
<td>11.0</td>
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<td>DiNBenzA</td>
<td>ESI-</td>
<td>[M-H]-</td>
<td>210.9983</td>
<td>102.7</td>
<td>11</td>
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<td>Sucrose</td>
<td>ESI+</td>
<td>[M+Na]+</td>
<td>365.1050</td>
<td>43.4</td>
<td>11.2</td>
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<td>Dimedone</td>
<td>ESI+</td>
<td>[M+H]+</td>
<td>141.0904</td>
<td>104.2</td>
<td>14.8</td>
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<td>Caffeine</td>
<td>APCI-</td>
<td>[M-H]-</td>
<td>195.0874</td>
<td>91.2</td>
<td>15.4</td>
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<td>Gallic Acid</td>
<td>ESI-</td>
<td>[M-H]-</td>
<td>169.0132</td>
<td>58.5</td>
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<td>Chrysidione</td>
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<td>[M+H]+</td>
<td>213.1135</td>
<td>49.6</td>
<td>17.8</td>
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<td>Oleritic acid</td>
<td>ESI-</td>
<td>[M-H]-</td>
<td>303.2181</td>
<td>76.3</td>
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<td>Tolidine</td>
<td>ESI+</td>
<td>[M+H]+</td>
<td>213.137</td>
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<tr>
<td>AVERAGE</td>
<td></td>
<td></td>
<td></td>
<td>78.80</td>
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Table 1: Ionization energies required for non-explosive compounds.

<table>
<thead>
<tr>
<th>Energetic compounds</th>
<th>Mode</th>
<th>Ion</th>
<th>m/z</th>
<th>Time (sec)</th>
<th>E(eV) onset</th>
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<tr>
<td>PETN</td>
<td>ESI-</td>
<td>[M+formate]-</td>
<td>295.0097</td>
<td>29.5</td>
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<td>Tetryl</td>
<td>ESI-</td>
<td>[M-H]-</td>
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<td>HMX</td>
<td>ESI-</td>
<td>[M+formate]-</td>
<td>341.0430</td>
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<td>RDX</td>
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<td>[M+formate]-</td>
<td>267.0310</td>
<td>25.5</td>
<td>7.0</td>
</tr>
<tr>
<td>R-salt</td>
<td>ESI-</td>
<td>[M+formate]-</td>
<td>219.0491</td>
<td>59.8</td>
<td>7.4</td>
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<tr>
<td>TNT</td>
<td>APPI/ACPI-</td>
<td>[M-H]-</td>
<td>226.0097</td>
<td>44.5</td>
<td>14.0</td>
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<td>TATB</td>
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<td>[M-H]-</td>
<td>257.0260</td>
<td>49.6</td>
<td>15.6</td>
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<td>DNAN</td>
<td>ESI-</td>
<td>[M-CH3]-</td>
<td>183.0042</td>
<td>50.9</td>
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<tr>
<td>AVERAGE</td>
<td></td>
<td></td>
<td></td>
<td>44.59</td>
<td>9.73</td>
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</table>

Table 2: Ionization energies required for explosive compounds.

Approach 3: Materials characterized as “explosives” release sufficient energy to “support” or “propagate” a detonation. Military explosives have been classified as such using detonation tests of prescribed size and initiating charge [11]. Homemade explosives (HMEs) often fail these tests because they release too little energy to support detonation in the prescribed tests; therefore, they are not recognized as real explosive threats. However, these HMEs will perform as explosive materials if the charge size is increased beyond a material-specific size, the critical diameter (Dc). At sizes less than Dc, an explosive will not propagate detonation; any conventional explosivity or detonability test performed under the critical diameter of the material will indicate that the material is not an explosive. The critical charge size of many potential threat materials is so
large that they are frequently not perceived as threats, when in reality they were simply tested below $D_{cr}$. For example, as dictated by shipping regulations, ammonium nitrate (AN) is not classed as an explosive, rather as DOT 5.1, because it does not propagate detonation at a diameter of 3.65 cm [11]. However, with sufficient AN (e.g. when the diameter exceeds 100 cm) it becomes detonable [12], as was accidentally demonstrated by the explosion in West Texas in April, 2013 [13]. Field testing at large scales is hazardous, expensive and slow. Thus, the goal of the R1-B projects is to determine whether a material is detonable at any scale by performing experiments with less than a few pounds of the material in question. A further complication exists in screening a material for explosivity. To confirm that a material is an explosive, traditional testing must be done well above critical diameter and with a sufficient initiating charge [14]. Thus, detonation failure can occur for several reasons including: (1) The material is too small in size; (2) It is insufficiently initiated; or (3) It is not an explosive. Traditional detonability tests do not differentiate.

For non-ideal explosives, a term which describes most HMEs, small-scale testing necessarily means studying these materials well below their critical diameters ($D_{cr}$). When steady detonation is not possible, conventional metrics, such as detonation velocity, yield little information. New diagnostics must be devised. Several approaches to this problem have been considered. Our initial approach was over-compensating for edge losses [15].

Approach 4 was actively soliciting other groups to join us in this effort. As a result, a group at Los Alamos National Lab (LANL) successfully probed evidence of detonable characteristics using 25 mL samples of hydrogen peroxide aqueous solutions of varying concentrations. While they were successful at that scale, they used instrumentation unique to that lab [16]. It has also been demonstrated by LANL researchers that the reaction zone of detonating nitromethane (NM) can be observed using photon Doppler velocimetry (PDV) [17]. We believe that a similar approach used to characterize a failing detonation can yield useful information about the material’s capacity to detonate, i.e. confirming or denying the existence of a critical diameter [18].

### B. State-of-the-Art and Technical Approach

Non-ideal detonation is difficult to study because, to date, no elegant, inexpensive approach exists. To determine if the rate at which a material releases energy is sufficient to support detonation, detonation testing is required at the sub-microsecond temporal- and millimeter spacial-scales. At this scale, resolved temporal resolution of run-up to detonation and failure can be observed. At present, state-of-the-art velocity measurements include microwave interferometry (MI) [19], Velocity Interferometer System for Any Reflector (VISAR) [20-22], Fabery-Perot interferometry (FPV) [23, 24] and PDV [25-28]. Microwave interferometry follows the reflection of a moving impedance discontinuity as a shock (or detonation) wave sweeps through an energetic material. However, the spatial resolution is poor (~cm) and the technique relies on the ability of the explosive to act as a waveguide (i.e. the explosive must be transparent to microwaves); likewise, the microwaves themselves require a large diameter waveguide (~1/4”) which is invasive to small shots and will only average radial instabilities. Some explosives (e.g. H$_2$O$_2$, mixtures or aluminized mixtures) absorb or reflect microwave radiation and, therefore, cannot be examined by MI. VISAR uses a Michelson interferometer to measure the phase-interfered Doppler shift in the light frequency of a laser beam as it is reflected from a moving reflector. Unfortunately, amplitudes of returned light can vary greatly during a single experiment, and this technique has been largely replaced by PDV. FPV can be considered as a modified version of VISAR that requires the use of a streak camera to record fringe patterns; however, these are subject to various distortions caused by the camera, itself. PDV is a relatively new technological breakthrough that directly measures the beat frequency between the incident laser and the reflected light. The beat frequency is linearly proportional to the velocity of a moving reflector, which in our experiments, is either the shock or detonation front or a reflective interface between the explosive charge and a polymer window. PDV is useful for measuring velocities ranging from a few meters per second to roughly 50 km/s, with high accuracy and nanosecond resolution, and will work well for any index of refraction discontinuity in free space or within the fiber itself.
Characterizing detonation behavior for sub-critical quantities of non-ideal explosives is extremely challenging. Unless supported by special device design, detonation fronts fail for lack of sufficient and timely energy release from the reaction, which prevents traditional metrics from predicting the potential of a threat which failed at a small diameter to detonate above the tested configuration size. Steady detonations are achieved with very small diameters using military explosives, but many HMEs, especially fuel/oxidizer explosives (FOX) mixtures, may only perform as explosives on very large scales. If the material fails to support a steady detonation, meaning a ‘no-go’ result, the only meaningful conclusion is that the material is not explosive at that scale. Using conventional metrics, a failure to detonate may only mean that the size of the test was insufficient.

Detonation velocity is used as a measure of explosive performance; high detonation velocities reflect the high rate of energy release of conventional explosives. However, if the energy release lags in time (i.e., the reaction cannot keep up with the shock), the shock wave will decouple from the chemical conversion process, and the detonation will “fail”. Thus, an accurate detonation velocity profile gives critical insight into the chemical reaction zone structure of high explosives. A versatile array of techniques will enable in-situ monitoring of both ignition and this delicate failure transition both temporally and spatially, beginning with a sample’s overdriven detonation through failure and decoupling of the shock wave from chemistry. Using high speed photography and PDV, we may also be able to visually discern the decoupling frame-by-frame. We intend to use a collection of traditional, readily-accessible technologies with modified techniques and strategies to examine detonation structure and probe explosive behavior far below the critical diameter of the potential threat materials.

Since hydrogen peroxide was our chosen characterization challenge, PDV was the metric of choice. The first hurdle was that a data acquisition system that could sample at a rate of 18 GHz was required. Outside funding eventually supplied that requirement, but in the meantime, we investigated a novel approach to using PDV with a lower bandwidth acquisition system and modern telecommunications components. These successful investigations are making this technique available to a wide number of users; they are described in detail in reference [15]. Figure 2 on the next page and the discussion of the content below gives further details of the concept.
Typical detonation velocities are between 5-9 km/s for most military high explosives and typical particle velocities at the detonation condition range from 1-5 km/s. Configuring an interferometric experiment to measure these relatively high speeds requires the capacity to measure the beat frequency of the incident light (usually vis-NIR: 200-600 THz) with the Doppler-shifted reflected signal governed by:

\[
f_{\text{Doppler beat}} = 2 \frac{v_{\text{reflector}}}{c} f_0
\]

where \( f_{\text{Doppler beat}} \) is the Doppler-shifted beat frequency, \( f_0 \) is the incident laser frequency, \( c \) is the speed of light, and \( v_{\text{reflector}} \) is the speed of the reflecting surface. This sets the native Doppler beat frequency at 10s of gigahertz for visible-NIR wavelengths at typical explosive velocities. The limitation of PDV is mostly determined by the bandwidth of instruments, e.g. the high speed oscilloscope and photo receiver, which implies high instrument costs. However, by introducing a modulation frequency carried by the input laser beam, the beat frequency generated by the original PDV mixes with the modulation frequency, which allows a second beat to bring down the measurement frequency. This modified PDV extends the current system capability with little change, and far less expensive digitizers and receivers can be used. Short-time fast Fourier transform is performed to map the velocity change among the times.

The second hurdle was created by our desire to use embedded PVD probes, a technique which has only been attempted occasionally and with little success. [29, 30] As PVD is normally used, it observes the optical response at the surface of the charge. For this, the optical fiber used is normally glass (for expense) and single-mode fiber (SMF) for distance. However, because glass is not a good acoustic impedance match with explosives, pressure fluctuations can propagate ahead of the shock front (see Fig. 3 on the next page). A better match would be plastic fibers, but these are generally only manufactured as multi-mode. We would like to run glass fiber to the explosive test article and then change to plastic fiber for the embedded section. Unfortunately, there is not a good way to connect the glass fiber (9 micron diameter) to the plastic fiber (62.5 micron). This is a diameter as well as optical impedance mismatch. Our approach to this (in collaborating with the T. Wei in electrical engineering at URI) is lensing to handle the diameter problem and a refractive index fluid to ameliorate the optical impedance problem (see Fig. 4 on the next page).

The third hurdle is interpretation of shock velocity data below actual detonation. Our approach is to begin testing with a well-characterized material, such as nitromethane (NM), and to use an end-on interfacial surface velocity PDV probe with the amount of NM large enough to achieve detonation. This test will then be repeated with the embedded PDV probe. Further tests in that configuration will be performed with smaller diameters or concentrations of NM. Streak photography will be used to record detonation curvature and assess the structure of the failed detonation. In addition, ultra-high speed photography (>300 million frames per second or <3 ns interframe time) will allow observation of the reaction wave directly as it forms (run-up)
and dies (failure). This total characterization will provide a failure fingerprint which will characterize exactly how non-ideal materials perform at known fractions of critical diameter. At this point, this technique will be used to examine hydrogen peroxide.

Visualizing the reaction wave should be straightforward with clear liquid explosives, such as NM or hydrogen peroxide because they should be radiating brilliantly but that has yet to be proved with ultra-high speed photography. The premise is that the initial shock wave will be unreactive for some time, and the superdetonation wave will be visible as it runs through the shocked nitromethane or hydrogen peroxide and catches the shock front. It is unclear whether the PDV probe will survive (and be optically functional) after the initial shock-up, but if it does, the superdetonation velocity may also be visible.

C. Major Contributions

Laboratory studies have shown the importance of low-melting fuels, such as sugars or sulfur, in creating reactive FOX mixtures. Field tests have yet to correlate these results with detonability.

Important differences in results arising from instrumental methodology, i.e. differential scanning calorimetry (DSC) vs. simultaneous differential thermolysis (SDT), have been revealed. Results point out the value of sealed DSC runs for evaluating heat release and open SDT runs for evaluating heat absorbed.

Determining the appropriate approach to detonability and equipping and familiarizing ourselves with the tools for the necessary metrics has been a significant part of this effort.

Work to date has resulted in one student obtaining staff status at LANL (Los Alamos National Lab), a poster at JANNAF, an award from the National Science Foundation (NSF, Low-cost velocimetry for ultra-fast shock wave measurements) and a Center report and a paper in review.

D. Milestones

We intend to use a compilation of previous ideas to approach a small scale test suite that can qualify the failure of explosives below their critical diameter. The first technique is similar to LANL’s use of end-on interfacial surface velocity to measure reaction zone structure. Our preliminary surface velocity tests have proven successful. Because of the acoustic impedance challenge, few experimenters have successfully implemented
embedded PDV silica fibers. We are experimenting with ways to optically couple polymer fiber embedded probes (impedance more closely matching the explosive and its detonation products) with single-mode silica fibers that compose the rest of the optical system.

Recording detonation curvature with streak photography is well established. Visualizing the reaction wave with ultra-high speed photography should be straightforward with clear liquid explosives but that has yet to be proved. As mentioned above, the premise is that the initial shock wave will be unreactive for some time and the superdetonation wave will be visible as it runs through the shocked NM and catches the shock front. It is unclear whether the PDV probe will survive (and be optically functional) after the initial shock-up but, if it does, the superdetonation reaction wave may also be visible.

Theoretically, PDV can be adapted as an embedded probe inside the explosive material; thus, it would act as a time-resolved velocimeter similar to MI but without the size constraints of microwave waveguides and with very high spacial and temporal resolution. Fiber optic probes are non-intrusive and, potentially, they can be assembled using commercially available telecom components, making them extremely inexpensive. In contrast to VISAR/FPV, the derived velocity measurement is directly related to the observed beat frequency, reducing the need for extra components and complex data analysis. The main disadvantage of the PDV system is its critical demand on the sampling speed of the digitizer. Most PDV experiments are currently conducted with a sampling rate above 80 GSa/s. The cost for such large bandwidth has limited the wide adoption of PDV. Some approaches to making PDV more affordable are being investigated in collaboration with URI electrical engineering Professor Tao Wei under a program funded by NSF.

E. Future Work

NM will be used for the proof-of-concept of the PDV experiment. Once the literature values for NM have been successfully replicated, NM will be successively diluted with chemicals known to increase the sensitivity of NM without providing more energy to the detonation front. The adulterated samples are expected to exhibit shorter reaction zones due to their increased sensitivity. As the adulterant concentration is increased, the reaction zone will eventually begin to spread apart because the active explosive ingredient is diminishing. At some critical amount, detonation will fail to propagate. The study will examine the failure point as well as points of dilution beyond detonation failure in conjunction with larger scale tests, at our outdoor test facility, to measure the actual $D_{cr}$ for the samples below their critical diameter in the small-scale tests.

Once proof-of-concept tests are successfully completed, tests are planned with both hydrogen peroxide-fuel mixtures and solid oxidizer-fuel mixtures. Project R1-A.1 has already begun performing the laboratory characterization of FOX combinations. Characterizing the detonability of these mixtures will then be combined in correlation with other small-scale tests and may allow certain materials to be deleted from the threat list. This test will also allow us to assess the effectiveness of a given diluent or adulterant in an explosive mixture. True safe limits for materials can be established.

III. EDUCATION AND WORKFORCE DEVELOPMENT ACTIVITY

A. Course, Seminar or Workshop Development

"Advanced Studied in Explosives" course was offered for the first time in spring of 2015 with 15 graduate students in attendance.

In May 2015, a hands-on course entitled “Explosives Analysis” was offered for the first time; six members of the HSE came to URI to attend.

Graduate student Devon Swanson was selected to give an award talk at the Trace Explosive Detection conference for his work on AFM of explosives (April 2015, Pittsburgh).
Dr. Smith presented “An Introduction to the Properties of Explosive and Trace Detection” at the IEEE HST ’15 ALERT Tutorial Session: Introduction to Explosives/Threat Screening Tools and Technologies in April 2015. Courses were presented for the Army, Navy, Air Force, and the Transportation Security Administration (TSA-TSIF, 10 classes and 200 people) and TSA explosive specialists (TSA-TSS-E, 5 classes and 110 people).

A.1. Invited lectures

- JANNAF, December 10, 2014, Academic Research to Real Life Application, ABQ.
- 7th Annual CBRNe Convergence, October 28-30 2014, New York, NY, tutorial to first responders
- Recognizing Improvise Drug vs Explosive Labs, 23rd Annual Haz-Mat Training Conf. September 18, 2014, Plymouth, MA, tutorial to first responders

B. Student Internship, Job or Research Opportunities

Each URI project supports one or more graduate students. This is their best learning experience. Undergraduates are also supported on the projects as their class schedules permit. A newly minted PhD from our group, Jon Canino, accepted a position at Signature Science and is working at the Transportation Security Laboratory in New Jersey.

C. Interactions and Outreach to K-12, Community College, Minority Serving Institution Students or Faculty

We have continued our K-12 outreach by hosting high school teachers in the summer and providing chemical magic shows at schools K-12. High school teachers conduct research in URI labs for 8 to 10 weeks under the mentorship of a graduate student. As a result, two have gone back to seek advanced degrees.

In addition, in the summer of 2014, we hosted 2 forensic scientists from Qatar and a West Point cadet for several weeks. For the summer of 2014, we hosted a professor from Tuskegee University and one of her students. In summer of 2015, we will host two Navy midshipmen and a Penn State engineer, and air force employee will be placed at URI to begin work on a master’s degree.

D. Training to Professionals or Others

We trained 110 TSS-E (TSA explosive specialists) in five classes and approximately 230 other people involved in the HSE in twelve classes, one of which was created to meet the needs of the U.S. Army forensic laboratory.

IV. RELEVANCE AND TRANSITION

A. Relevance of Research to the DHS enterprise

There are, potentially, hundreds of explosive threat materials. Distinguishing between actual threats and benign chemicals is of high interest. This effort also extends to the question of concentration, e.g. absolute safe concentrations of hydrogen peroxide- the type of questions incoming from TSA and explosive trace detection (ETD) vendors. When the proposed tests are developed and executed, they will be available as screening tools to forge the answers to these problems.

This understanding of non-ideal detonation is an ongoing security research effort; URI’s Energetics Laboratory was the only academic institution invited to the DHS Chemical Security Analysis Center & Explosives Division 1st inter-agency Explosives Terrorism Risk Assessment working group meetings established in May
The characterization of non-ideal detonation is also of valuable interest to insensitive munitions (IM) research efforts, which also require better metrics and diagnostics to track detonation kinetics.

B. Potential for Transition

• R1-B.1 addresses the characterization of HMEs. We have received requests to license the database.
• R1-B.1 addresses safe samples of explosive. We have received requests to license our safe source of explosive vapor.
• Traditional transition methods such as publication and presentation will also be used to transmit our new methodologies.

C. Data and/or IP Acquisition Strategy

As the data from the program becomes available it will be provided to the community through DHS, publications, and presentations.

D. Transition Pathway

R1-B will primarily be transferred to the user community by publications and presentations.

V. PROJECT DOCUMENTATION

A. Peer Reviewed Journal Articles


Pending –


B. Other Conference Proceedings

1. Donnelly (presenter) with J Oxley; J Smith; M. Porter Fuel-Oxidizers Mixtures: Their Stabilities and Burn Characteristics North American Thermal Analysis Society (see paper), 2014

3. Phase 2, Year 2, DHS Annual Program Review, Northeastern University, March 2015.

C. Other Presentations

1. Seminars
   a. Devon Swanson (presenter) with J. Oxley; J. Smith; G. Kagan “Adhesion Forces of Energetic Materials on Polymer Surfaces” Trace Explosive Detection April 2015; Pittsburgh

2. Poster Sessions

3. Short Courses - listed under education

D. Student Theses or Dissertations


E. New and Existing Courses Developed and Student Enrollment

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<th>Title</th>
<th>Description</th>
<th>Student Enrollment</th>
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</table>

* Included DHS personnel

F. Requests for Assistance/Advice

1. From DHS
   a. On call for a variety of TSA TSS-ES personnel
   b. Oxley is part of the DHS-formed Inter-Agency Explosive Terrorism Risk Assessment Working Group (IExTRAWG)

2. From Federal/State/Local Government
   a. Singapore, India, Turkey Defense groups ask questions, request classes; class request from India
b. We have been asked to support Brookhaven National Lab in some of their international outreach.

VI. REFERENCES


[12] CTTTSO BAA 14-Q-3272 R3826; March 19, 2014


[14] Most energetic materials capable of detonation can be initiated with the help of a high explosive booster charge, but if the sample energetic is below its critical diameter, the chemical reaction will quickly (less than an inch) decouple from the shock front and the shock will propagate as an inert pressure wave through the rest of the non-reacting material, giving the appearance that the material is non-explosive. This detonation failure phenomenon can be very delicate; many detonations near the critical diameter are very unstable, which means conventional explosive testing must be done well above the critical diameter.


[17] Bouyer, V; Sheffield, S.A. Dattelbaum, D.M; Gustavsen, R.L.; Stahl, D.B; Doucet, M.; Decaris, L.
“Experimental Measurements of the Chemical Reaction Zone of Detonating Liquid Explosives”


[29] Mercier, P.; Benier, J.; Frugier, P.A.; Debruyne, M.; Crouzet, B. “Nitromethane ignition observed with embedded PDV optical fibers” EPJ web of conferences 10, 00016 (2010); DOI: 10.1051/epjconf/20101000016

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