Performance of a Handheld Raman Spectrometer for Explosives Identification

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ABSTRACT

Rapid, precise explosives identification is one of the central tasks of homeland security and public safety personnel, particularly with the recent proliferation of improvised explosive devices (IEDs) worldwide. Instruments that can be used in the field to rapidly and accurately identify various explosives and their precursors are integral tools for first responders. One such commercially available handheld Raman spectrometer designed for chemical identification, FirstDefender, was evaluated as a screening tool for the field identification of hundreds of commercial, military, homemade explosives, and explosive precursors in situ. FirstDefender correctly, accurately, and rapidly identified 206 substances (including mixtures) for an 89 percent positive identification rate for the 231 samples presented with no false positive results. This paper provides an overview of Raman spectroscopy and explosive materials, and details the methods used and results evaluated during the course of this explosives testing exercise. Additionally, practical considerations of sampling-safety and interpretation of results (both pure samples and samples of mixed compounds) are also discussed.

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Introduction

As a result of the decline in the availability of commercial and military explosives, homemade explosives (HMEs) are an increasing threat. Readily available ingredients and information on the simple methods of production for these materials have turned HMEs into a primary weapon of choice for terrorist activities worldwide. From a safety standpoint, the instability of these materials makes gathering analytical forensic evidence from improvised explosive devices (IEDs) and laboratories a dangerous activity. Furthermore, the line between explosives hazards and toxic chemical hazards has been blurred by the use of toxic industrial chemicals (TIC) as weapons by terrorist groups, as well as the use of explosive booby-traps in methamphetamine labs[1]. First responders typically have two options available when encountering explosive materials in the field:

- Remove the unknown materials from the scene,
- Destroy them in place.

Each option is complicated with their own safety issues when dealing with unknown chemicals/materials. Specifically, removing a chemical for analysis from a hazardous material (hazmat) or terrorist scenario may exacerbate the problem owing to the time required to carry out the removal, or movement of the chemicals could possibly unintentionally spread the hazard. In on site detonation instances, while detonating a device in place may be the only safe method of disposing of a potential explosive hazard, the explosion destroys any forensic evidence and other chemical hazards could be released into the environment during the process.

What is urgently needed and—in my opinion—is currently available, are small, rugged analytical tools that may be brought to the incident scene and decontaminated after use. These instruments provide a logical approach to identify and assess the hazard and collect forensic evidence quickly without spreading contamination. Essentially these tools should provide through a rapid identification of the unknown material, a clear and accurate assessment of the hazard so appropriate decisions can be made by the first responder.

Handheld instruments employing Raman and Fourier Transform Infrared (FTIR) spectroscopy are powerful and proven analytical methods that provide not only laboratory quality, but on-scene analyses of unknown materials. Recent advances in optical packaging and other technologies have transformed these spectroscopic systems from large laboratory instruments requiring dedicated expert users to handheld, lightweight [<4 lbs (<2 kg)], rugged devices that are operable by users with a wide range of backgrounds. Raman spectroscopy is particularly well suited for the field analysis of threat materials not only because it produces real-time analysis, but because it may be used without sample preparation or contact. In fact, this laser-based method can be performed through translucent containers such as glass or plastic, significantly reducing the potential of both chemical hazards to the investigator, as well as contamination of forensic evidence. In the past, the most commonly deployed bulk identification techniques were only man-portable and required the actual sampling or handling of the material of interest. Many of these previous these tools are also far from the ruggedness and robustness needed in the field.

The objective of this exercise was to provide an independent, third-party evaluation of the commercially available Raman spectroscopy instrument FirstDefender from Ahura Scientific in a series of identification challenges using a wide variety of common commercial and military explosives, as well as HME and explosive chemical precursors. Specifically, FirstDefender was evaluated as a screening tool for its ability to serve as an accurate, easy to operate system to provide reliable real-time information to on-scene first responders and explosive ordnance disposal (EOD) technicians, to enhance their safety and direct evidence collection for laboratory confirmation.

1 Krebs, Dennis R. When Violence Erupts: A Survival Guide for Emergency Responders. EMS continuing education series. Boston: Jones and Bartlett Publishers, 2003, p.81.

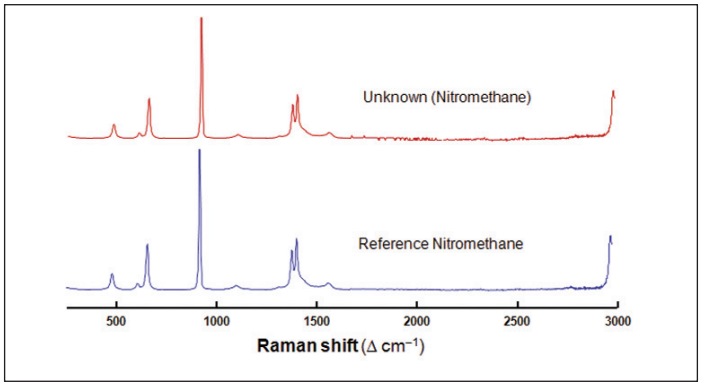
Raman Spectroscopy Overview

Raman spectroscopy uses a single wavelength laser light source to interact with the bonds of the molecules in a sample. Depending on the types of chemical bonds which are present, the light interacts differently with each bond and produces wavelengths of scattered light. This scattered light creates a Raman spectrum with features (peaks) unique to a particular material. The peaks in a Raman spectrum are viewed as a function of wavenumber, which provides information about the specific energies required to interact with each bond present in the sample.

The three major components required to obtain a Raman spectrum are the laser, a probe to direct light at the sample and collect the Raman light scattered off of the sample, and a spectrometer that separates and detects the resultant light. Improvements in each of these components as well as supporting electronics, computing power, software and algorithms used to interpret the spectrum have enabled better sensitivity, as well as tolerance to fluorescence (typically a nuisance source of "noise" in Raman measurements) in modern Raman systems. Modern algorithm development has also enabled more robust automated mixture analysis.

An example of Raman spectrum of nitromethane is shown in **Figure 1**. Each peak in the spectrum represents a molecular bond present in the sample. In situations where the sample is a mixture of two or more unknown compounds, the Raman spectrum may be very complex and difficult to interpret.

FIGURE 1. FirstDefender Raman spectrum of a nitromethane sample (unknown) and library reference: intensity (Y) versus Raman shift (wavenumbers, cm^{-1}).



A limiting factor of Raman spectroscopy is the analysis of fluorescent materials. With fluorescence, a molecule absorbs a photon then emits another longer wavelength photon. Because the fluorescence process is more efficient than the Raman process, fluorescence may essentially "blind" a system that is monitoring for Raman signal. Fluorescent sample results will be discussed further in the Results and Discussion section.

Explosives Overview

To initiate combustion, a fuel source (e.g., wood, gasoline), oxygen, and heat are required. Using a candle as an example, wax is the fuel, a match is the heat source, and oxygen is simply drawn from the surrounding atmosphere. In an explosive, the oxygen (oxidizer) is normally densely packaged into a molecule (for example nitrate molecules) so that it reacts very quickly with the fuel source, rather than slowly drawing oxygen from the air. In fact, many explosives combine oxygen and fuel (carbon) in the same molecule for more rapid reactions. Furthermore, some explosive molecules are extremely volatile, which is to say the material will react to shock, heat, or friction to start the reaction. Peroxide-based explosives, such as triacetone triperoxide (TATP)

and hexamethylene triperoxide diamine (HMTD), are examples of extremely sensitive HMEs as the explosive molecules incorporate weak bonds between two oxygen atoms which are unstable, and very reactive. This category of HMEs is incredibly dangerous to produce and handle.

Explosives can be characterized as either high or low explosives:

- **High explosive** materials, such as TNT, RDX, dynamite and ammonium nitrate-fuel oil (ANFO), decompose rapidly in a process called detonation. Once initiated, the instantaneous combustion is propagated by a detonation wave through the material.
- **Low explosive** materials require specific conditions, such as confinement, to produce an explosion (deflagration). Low explosives, such as black powder, smokeless powder, and pyrotechnics, decompose via deflagration as the material undergoes a rapid combustion without the support of a detonation wave.

Additionally, high explosives can be further classified into more specific families:

- A **primary explosive**, such as lead azide or lead styphnate, is a type of high explosive that detonates easily when exposed to heat, spark, flame, mechanical impact, and so forth. These materials are packaged into detonators or blasting caps and initiation systems which are used to initiate less sensitive, secondary explosives. A **secondary explosive** is a second type of high explosive that is less sensitive to initiation than a primary explosive, but a material that must be initiated with a primary explosive. Because it is less sensitive, the secondary explosive is safer to manipulate and therefore normally comprises the bulk of the explosive charge in commercial and military applications.

Additional components and or types of explosive devices could be any of the following:

- A **booster charge**, normally consisting of TNT or a combination of TNT and PETN, is a high explosive that is used to increase the power of the initiating primary explosive in order to ensure reliable initiation of a secondary charge. The type of high explosives which require a booster are referred to as "blasting agents", for example ANFO, as blasting agents are incapable of detonating without the increased power of a booster charge. Most booster charges are in cast form, which is when an explosive material has been heated to a liquid, poured into a mold, and left to re-solidify. Cast booster charges are not to be confused with malleable explosive materials; cast boosters have an extremely hard consistency.
- A **main charge** is the explosive that is detonated by the primary explosive contained within a detonator and/or booster charge. Normal commercial main charge explosives, either detonator or non-detonator sensitive, are produced in containers, or packages of varying sizes and/or weights, and can be delivered in "bulk" form (such as a truck load). Although dynamite is probably the most recognized name in commercial main charge explosives, it is actually the least manufactured due to its cost and use of nitroglycerin. The most common types of main charge explosives are ANFO, water gels, and emulsions. However, the illicit use of these explosives in the United States accounts for extremely few bombing incidents. The most common bombing incidents incorporate commercial or homemade low explosives. The opposite is true in foreign locations; with high explosives (commercial, military and HME) being the type of explosive of choice.
- **Plastic explosives**, such as C4 and Semtex, are soft, moldable, malleable solid explosives often used for demolition. These materials are composed of plasticizers, as a binder, and the explosive RDX or a combination of RDX and PETN. Depending on the country of manufacture, RDX may contain minute quantities of HMX. Detonating cord, also known as detcord, is a flexible cord-like material that is filled with high explosive (normally PETN). Detcord is normally used to initiate high explosive charges in a chain, or may even be used as the main charge for very small-scale demolition tasks, such as breaching operations.

- **Liquid explosives** may be one compound that is detonated, such as nitroglycerine, or they may be "**binary explosives.**" A binary explosive, such as liquid nitromethane and diethylamine mixture, is composed of two relatively benign materials that only become explosive when mixed, which improves handling safety for commercial applications. Liquid explosives are a particular security concern as they are easily concealed in a variety of containers, and assembled as binary explosives after a screening checkpoint.

Evaluation Details

This section details the specifics of the instrument used throughout this exercise, the instrument methodology, and a summary of the samples and their manufacturers.

Instrument

The instrument used in this investigation was a FirstDefender (**Figure 2**) Raman spectrometer manufactured by Ahura Scientific, Inc. located in Wilmington, MA.

FIGURE 2. Ahura Scientific, Inc. FirstDefender Raman spectrometer.

FirstDefender uses a 785 nm laser for Raman measurement. Although the laser power may be adjusted to 300 mW, 150 mW, or 50 mW to reduce potential hazards associated with sample heating, in practice it was found that most samples would tolerate the use of the 300 mW laser power. Caution was exercised in testing darker substances, as it is known that these would absorb laser energy and could ignite. In these cases, small samples were tested and the laser power was stopped if sample smoking was observed, which occurred on a few samples.

FirstDefender incorporates advanced algorithms that interpret Raman spectra, including mixtures. The graphical user interface (GUI) allows the user to save and access spectra, as well as Material Safety Data Sheet (MSDS), National Institute for Occupational Safety and Health (NIOSH), Computer Aided Management of Emergency Operations (CAMEO) and other hazard related information for the thousands of unique chemical materials in the library.

The system was tested in three sampling modes: placing a sample in a vial into the internal vial compartment of the system, free-space analysis using the integrated "Point-and-Shoot™", and free-space "Point-and-Shoot" using the detachable one meter FlexProbe (**Figure 3**). Free-space samples were tested directly through glass vials, through translucent plastic bags, plastic bottles, and through waxed paper packaging material.

FIGURE 3. Left to right: Free space Point-and-Shoot analysis through glass container; internal vial compartment analysis; Point-and-Shoot analysis using the one meter semi-rigid FlexProbe.

Manufacturer's literature advises that the system is waterproof to one meter submersion, operates in ambient conditions of -20 °C to +40 °C and is rugged as per MIL-STD-810F compliance for drop, shock, and vibration. However, these specifications were not the object of the testing.

Samples Tested

The samples tested included a wide variety of commercial explosives, HME, and explosive precursor chemicals. In some cases, multiple samples of individual explosives were tested from separate manufacturers in order to assess the robustness of the system to small variations in formulation. A total of 231 samples were analyzed across five separate sites in June and July of 2008. The sites that provided samples included:

- University of Rhode Island
- Eastern Kentucky University
- Federal Bureau of Investigation
- Loudoun County, VA Fire Marshall
- Skylighter; Firework & Pyrotechnic Manufacturer
- Department of Homeland Security (DHS), Transportation Security Administration (TSA), Atlantic City, NJ

Results and Discussion

FirstDefender positively identified 206 of the total 231 samples presented (89%). A small number of the 25 "missed" identifications (11%) were attributable to sampling methodology; for example sampling through paper packaging, or not properly focusing the laser spot on a free-space during Point-and-Shoot analysis. Additionally, eight of the 25 "no match found" samples can be attributed to a sample not being included in the library for comparison purposes. After building standards for these detection misses, and adding them to the library, the no match found percentage rate can be further reduced from 11 to seven percent. A summary table of the categories for the 231 samples, and their identification rates by FirstDefender can be seen in **Table 1**. The full set of sample data and results can be found in Appendix A.

TABLE 1. Summary table of FirstDefender identification results sorted by category.

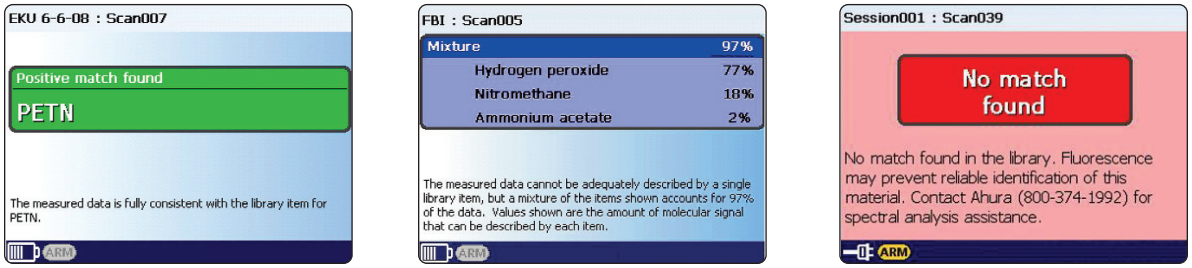
Explosive Category	Green Screen Positive Match	Blue Screen Mixture Present	Red Screen No Match Found	Total
Commercial Explosive	17	3	4	24
Explosive component	101	6	9	116
HME	16	5	2	23
Military Explosive	53	5	10	68
GRAND TOTAL	**187 (81%)**	**19 (8%)**	**25 (11%)**	**231**

The "red light/green light" presentation of results was easy to understand and well suited for field use. "Green screens" indicate that a positive match has been found between the sample provided and the onboard chemical identification library. A "red screen" indicates that no match was found between the sample and the onboard chemical identification library. However, in cases where the identity of the sample cannot be determined, FirstDefender provides a reason (i.e., sample fluorescence, spectrum does not match library items, or poor spectral data) which provides valuable information to aid users in further analysis.

In cases where FirstDefender delivered "blue screen" results, it should be noted that the instrument identified that the sample was a mixture of multiple substances. Automatic mixture analysis is extremely valuable in a field explosives screening scenario. Many spectroscopy systems rely on spectral libraries and simply report a list of hit-quality-indices (HQI) or similarity scores to items in the library, which is similar to multiple choice identification of what the substance could be. FirstDefender software is unique and is not susceptible to the errors of using HQI-based decision making since it searches (transparent to the user) mixtures of up to five library items. If a match is found, FirstDefender delivers a mixture result which includes not only the substances identified, but the percentage each substance contributed to the result identification as a reflection of Raman signal. If the FirstDefender does not identify a plausible match for the measured spectra, the unit will display a red "no match found" result.

Examples of the positive match, mixture, and no match found result screens provided by FirstDefender are shown in **Figure 4**.

FIGURE 4. Example results screens for FirstDefender, left to right: One positive match; Mixture; No match found. Note that the no match found screen provides information on the probable reason for a lack of match.



Identification results were obtained in scan times ranges from as minimal as 30 seconds up to a series of minutes. Shorter identification scans can be associated with samples with strong Raman signatures while longer scans are typically associated with samples that are dark in color and exhibited fluorescence, samples with complex chemical structures, or mixtures of multiple substances. It is also important to note that when using the detachable one meter FlexProbe analytical identification response times increased slightly because of the extension of the optical lens; however, this increase in sampling time was offset by the benefits of using the tool for being able to better direct the laser for sampling purposes, and ease of movement.

Notable Commercial Explosive Testing Results

FirstDefender correctly identified commercial explosives in 83 percent of the samples, or in 20 out of 24 unknowns (including mixtures). It is important to note that when samples of dynamite (normally a mixture of ammonium nitrate, nitroglycerin, ethylene glycol dinitrate, and fuels) were analyzed, only the ammonium nitrate was identified in the mixture returning a red screen result. I do not believe this "miss" to be problematic inasmuch as the ammonium nitrate was correctly identified, which would indicate a "probable" explosive being present. Similar results were obtained when an emulsion (a high explosive) was tested, specifically ammonium nitrate was identified, but no other ingredients. Essentially, FirstDefender did its job in both cases for either the first responder or bomb technician by alerting the user of a possible hazard (further information regarding the dynamite and the emulsion samples can be seen in the section Notable Mixture Analysis Testing Results). **Table 2** provides the samples that were considered commercial explosives throughout this evaluation, and the results obtained by FirstDefender.

TABLE 2. Commercial Explosive Sample Testing Results Summary

Commercial Explosive Sample Type	Green Screen Positive Match	Blue Screen Mixture Present	Red Screen No Match Found	Total
ANFO	1			1
Dynamite	2	1	3	6
Emulsion	4		1	5
Lead Azide	3			3
Nitroglycerine (NG)	2	2		4
Urea Nitrate	5			5
GRAND TOTAL	**17 (71%)**	**3 (12%)**	**4 (17%)**	**24**

Notable Military Explosive Testing Results

FirstDefender was able to identify 85 percent of the military substances tested, or 58 out of 68 samples (mixtures included), as shown in **Table 3**. Interesting tests of note were tests of Semtex H, which is composed of RDX, PETN, and plasticizers, in two out of two samples the results showed as a mixture of PETN, RDX, and RDX/HMX mixture. The RDX/HMX mixture was in the system library as one entry, which was commonly indicated when pure RDX or plastic explosives containing RDX were tested. Although HMX is a side product in the production of RDX, and may exist at low concentrations in RDX-based explosives, it should not normally be detected by a bulk detection method such as Raman that relies on larger percentages of a mixture to provide enough signal to be visible. The system was not able to give a result for Pentolite, which also contain TNT and PETN, because of fluorescence due, in my opinion, to the product being a cast booster explosive. Composition B was also not able to be identified owing to its high fluorescence properties.

TABLE 3. Military Explosive Sample Testing Results Summary

Military Explosive Sample Type	Green Screen Positive Match	Blue Screen Mixture Present	Red Screen No Match Found	Total
C4	8			8
C4 (foreign)	9			9
Composition B		1	3	4
Demex	2			2
DetaSheet (PETN rubber binder)	3			3
Hexalite		1		1
Hexamine	6			6
HMX	3		3	6
Pentolite	1		2	3
PETN	3			3
RDX	2			2
RDX (foreign)	2			2
RDX/HMX (US)	3			3
Semtex 1A	1		2	3
Semtex H		2		2
Sodium Nitrate	1			1
Sulfur & Hexamine	1			1
Tetryl	3			3
TNT	4	1		5
Xylene	1			1
GRAND TOTAL	**53 (78%)**	**5 (7%)**	**10 (15%)**	**68**

Notable Explosive Components Testing Results

Several oxidizing compounds used in binary explosives and as precursors were tested. Several common precursors and components were tested, including a variety of strong acids, organic compounds used as fuel sources, and sulfur. The strong acids were correctly identified, as well as the acetone, the sulfur samples and the sulfur mixture samples. No black powder samples containing sulfur were tested, because of the possibility of sample ignition. The system correctly identified urea, nitromethane, glycerine, and other compounds in this category. Xylene was incorrectly identified as a multiple positive match; 3-ethylphenol (a compound similar in structure to xylene) and m-xylene.

Table 4 displays the results of the explosive component portion of this exercise, with a 92 percent correct identification rate (including mixtures) in 107 out of 116 explosive precursor samples.

TABLE 4. Explosive Component/Precursor Sample Testing Results Summary

Explosive Component Sample Type	Green Screen Positive Match	Blue Screen Mixture Present	Red Screen No Match Found	Total
2-Butanone Peroxide			1	1
Acetone	4			4
Ammonium Nitrate	4		2	6
Ammonium Perchlorate	8			8
Barium Peroxide	4			4
Calcium Hypochlorite	3		1	4
Calcium Nitrate	2		2	4
Dimethylhydrazine	1			1
DMNB	1			1
EGDN	3			3
Glycerin	1			1
Hexane	1			1
Hydrazine Anhydrous			1	1
Hydrogen Peroxide	2			2
Isopropanol	2			2
Magnesium Perchlorate	1			1
Magnesium Sulfate	1	1		2
Mercury Chlorate	1			1
Mercury Chloride	2			2
Methyl Nitrate	2		1	3
N,N Dimethylhydrazine	1			1
N-Hexane	2			2
Nitric Acid	2			2
Nitromethane	9			9
Perchlorate Acid	1			1
Perchloric Acid	1			1
Potassium Chlorate	2	1		3
Potassium Dichromate	1			1
Potassium Nitrate	3			3
Potassium Perchlorate	3			3
Potassium Permanganate	3			3
Sodium Azide	3			3
Sodium Chlorate	3			3
Sodium Nitrate	6			6
Sodium Nitrate & Ammonium Perchlorate		3		3
Sodium Nitrate & Potassium Nitrate	1	1		2
Sodium Perchlorate	3			3
Sodium Peroxide	2		1	3
Sulfur	6			6
Sulfuric Acid	3			3
Urea	3			3
GRAND TOTAL	**101 (87%)**	**6 (5%)**	**9 (8%)**	**116**

For the two samples of ammonium nitrate that returned red screen results, the ammonium nitrate was yellowish in color which led to a fluorescent reading, and were samples that were quite degraded with age. The sample of methyl nitrate that was not identified was owing to the compound not being in the library, after being added to the onboard library, the two subsequent samples returned positive identification results.

Notable Homemade and Sensitive Explosives Results

A variety of primary sensitive explosives and homemade peroxide explosives were tested. While there was some concern about laser ignition of these materials, there was no ignition of materials during the experiments. Caution was exercised by only testing light colored samples, and in using small quantities. The primary explosives lead azide, picric acid, and the peroxide explosives TATP and HMTD were readily identified in all samples. The peroxide explosive MEKP was not identified in initial samples for the obvious reason that it was not in the library. After being added, it was then detected in solid samples. While most sensitive explosives tested were detected with FirstDefender, misses on some materials may be attributable to the difficulty in accessing and working with these materials for Raman library building. There is a wide variety of product quality and purity in the homemade materials because of the nature of the "kitchen chemistry" and the variety of recipes available. **Table 5** summarizes the samples substances and FirstDefender results in the HME category.

TABLE 5. HME Sample Testing Results Summary

HME Sample Type	Green Screen Positive Match	Blue Screen Mixture Present	Red Screen No Match Found	Total
DADP (Diacetonediperoxide)		1		1
HMTD	4			4
Hydrogen Peroxide & Nitromethane	1	4		5
Hydrogen Peroxide & Tang 80/20	2			2
MEKP	2		2	4
Picric Acid	3			3
TATP	4			4
GRAND TOTAL	**16 (70%)**	**5 (22%)**	**2 (8%)**	**23**

Several mixtures analyzed in this study included hydrogen peroxide, a common ingredient in many HMEs, which was detected by the system in a pure sample. Both components of nitromethane and hydrogen peroxide mixtures were indicated in three out of five of these mixtures. Although only nitromethane was indicated in the remaining two of the five nitromethane/hydrogen peroxide mixtures, nitromethane is a well known explosive component and the indication of any explosive component in a mixture, although not a complete analysis of all substances contained therein, can be considered a true positive result for a test for an explosive substance. In mixtures of hydrogen peroxide and Tang® breakfast drink, a two component HME, hydrogen peroxide was detected. A mixture of sulfur and hexamine was identified as sulfur; while sulfur is a component of explosives, hexamine is an important explosive which was identified in a separate pure sample. It is impressive to note that FirstDefender identified homemade explosive ingredients in 91 percent (including mixture results) of the samples, or 21 out of 23 samples, in this category.

Notable Fluorescence Considerations

Fluorescence was found to thwart Raman identification in some samples by either saturating the detector so that data could not be processed (Semtex 1A, Pentolite, Comp B), or because the system estimated a prohibitively long scan time of several minutes up to an hour that was deemed not acceptable for field use. Fluorescence during Raman analysis was found to be somewhat predictable based on sample color; white or colorless samples generally did not exhibit fluorescence, and "natural" tan or brightly colored samples did generally exhibit fluorescence.

Notable Dark Colored Sample Considerations

Sample color also affects Raman analysis because of potential sample heating due to laser absorption. In the case of green DetaSheet, a PETN-based plastic explosive, the samples occasionally smoked due to sample heating; pink samples containing PETN were readily identified. One should consider sample color carefully in such an analysis, as a dark colored and more sensitive explosive, e.g., black powder, could be initiated. Ahura Scientific recommends segregating small samples for analysis to limit any safety issues associated with colored samples. Furthermore, FirstDefender is available with a scan delay feature that will not engage the laser for a set delay period to allow an investigator to leave the scene during analysis. The one meter FlexProbe can also be used to increase the distance between the analyst/instrument and the sample for safety purposes.

Notable Oxidizer Sample Considerations

FirstDefender performed exceptionally well in identifying single oxidizer samples of ammonium perchlorate, sodium nitrate, ammonium nitrate, potassium chlorate and some mixtures of these common oxidizers used in the manufacture of low and high explosives. However, in one case a mixture of sodium nitrate and potassium nitrate was misidentified as only being sodium nitrate. This was calculated as a "no match found," but was later reanalyzed after a more through mixing, which correctly identified both constituents.

Notable Mixture Analysis Results Discussion

It was found in screening solid or semisolid mixtures (dynamite and emulsion) that the small laser spot size of FirstDefender may sample one component of the mixture and not another if the grain size of the materials is not large enough to be registered, or if the substance was not mixed properly . Other hastily, onsite samples were mixed and provided similar results; a "miss" followed by correct analysis following a thorough mixing. As stated previously, this is an issue with the very narrow laser beam of the instrument and turning the vial so that multiple spots are sampled during measurements through the vial may also be used to randomize the Raman sampling.

Conclusions

To me, as a former bomb technician, post blast investigator and first responder, the evaluation has shown FirstDefender to be an extremely valuable tool in the investigators and first responders' arsenal to identify hazards, collect evidence and provide a greater margin of safety for those professionals charged with that responsibility.

A large range of commercial, military, and homemade explosives and precursors were tested. More than 89 percent of the samples presented were properly identified using FirstDefender, which indicates that the system would be a valuable tool for screening field samples. The system's simple "red light/green light" results presentation is very practical, easy to understand, and useful for field use. The simplistic method of operation allowed for a very short training session. In a matter of a few hours, I was able to effectively and confidently use FirstDefender to examine the first of more than 200 samples during the evaluation.

What is important and impressive to note is, the evaluation resulted in no false positives. Some "misses" or no identifications were documented, but no instances where the analysis indicated that an explosive or precursor was present when it was not.

There were samples that were too fluorescent to be analyzed by FirstDefender. The system, however, dealt well with fluorescence overall, which has classically been a major difficulty for Raman spectroscopy.

Although the unit's automatic mixture analysis was not flawless, it did enhance the ability to screen for materials of interest with no burden on the operator. Similarly, the system was able in almost all cases to correctly identify the functional portion of oxidizers of interest even when the exact identity was not determined. While sensitive explosives, including primary explosives and peroxide explosives, were identified without accidental ignition by the system's laser, care should be taken whenever possible to segregate small samples and to not test materials with any dark matter in them that might absorb laser energy and cause ignition.

The major issues encountered with the system involved dark samples, fluorescence, and substances that were not in the library. The manufacturer, Ahura Scientific, Inc., recommends against testing any dark materials for safety reasons. The difficulties in accessing and handling many of these materials may account for some of the items missing from the onboard substance library. However, this was corrected by adding several materials during this evaluation. Because there is a wide variability in HME composition, multiple samples are required to train the detection algorithms. Ahura Scientific offers library updates on a regular basis and it is expected that this issue will be mitigated throughout the library development process.

FirstDefender, overall, is a small, rugged analytical tool thats value lies in the fact that it can be brought to the incident scene to provide a rapid, reliable, accurate, and logical approach to identify and assess the hazard so that appropriate decisions can be made by first responders.

About James T. (Tom) Thurman

James T. Thurman, Tom, has worked in the explosives field for over thirty years, first as an Army Bomb Disposal Technician and then as a Special Agent with the FBI. As a Supervisory Special Agent in the FBI Laboratory, he forensically examined the exploded remains of hundreds of improvised explosive devices and traveled extensively throughout the United States and the world to collect evidence and conduct bombing scene investigations. These investigations have included the bombing of the U.S. Embassy in Lebanon in 1983 and 1984, the bombing of the Marine Barracks, also in Lebanon in 1983, the bombing of Pan American Flight 103 over Lockerbie, Scotland, the bombing deaths of a Federal Judge in Alabama and an attorney in Georgia in 1989 and the 1993 Bombing of the World Trade Center in New York. Prior to his retirement from the FBI in 1998, Thurman was the Chief of the FBI Bomb Data Center, whose responsibilities included the training of all public safety bomb disposal technicians in the United States.

Thurman has and continues to lecture and provide training into the methods of bomb scene investigation, terrorism crime scene investigation and explosives avoidance to domestic and international training schools and audiences. He is member of a number of professional organizations, which include the International Association of Bomb Technicians and Investigators (IABTI), as an advisor, National Association of Fire Investigators (NAFI) and the International Society of Explosives Engineers (ISEE). Thurman is a Certified Fire and Explosion Investigator (CFEI) and Certified Vehicle Fire Investigator (CVFI) under the National Association of Fire Investigators (NAFI). As a member of various national planning panels, he participated in the preparation of two best practice guides published by the U.S. Department of Justice; Crime Scene Investigation: A Guide for Law Enforcement and A Guide for Explosion and Bombing Scene Investigation. Additionally, he is a member of the Training and Education sub-committee for the Technical Working Group for Fire and Explosions (TWGFEX) under the National Center for Forensic Science, University of Central Florida. Thurman is the author of *Practical Bomb Scene Investigation* published by CRC Press in 2006. This book is the first comprehensive work on the subject and includes over 500 pages and 200 photographs and diagrams, in addition to an extensive chapter on the investigative methods employed at the post blast scene, chapters on explosion dynamics, identification of commercial and military explosives, pre and post blast identification of bomb construction components, weapons of mass destruction, military ordnance identification features and the capabilities of the forensic laboratory in the examination of bomb debris and reading the bombers' signature.

Thurman currently is an Associate Professor at Eastern Kentucky University teaching in a unique academic program, Fire, Arson and Explosion Investigation. He holds a B.A from Eastern Kentucky University and a M.S. degree in Forensic Science from George Washington University.

Appendix A. Complete List of Samples and Results

#	Sample	Category	Mode	Screen Color	Result
1	2-Butanone Peroxide	Explosive Component	Vial	Red	Red screen
2	Acetone	Explosive Component	Point-and-Shoot through brown glass container	Green	Green screen single result for Acetone
3	Acetone	Explosive Component	Vial	Green	Green screen single result for Acetone
4	Acetone	Explosive Component	Vial	Green	Green screen single result for Acetone
5	Acetone	Explosive Component	FlexProbe	Green	Green screen single match for Acetone
6	Ammonium Nitrate	Explosive Component	Vial	Green	66% green screen multiple positive match for ammonium nitrate, silver nitrate and ammonium carbonate
7	Ammonium Nitrate	Explosive Component	FlexProbe	Green	Green screen, single result for Ammonium Nitrate
8	Ammonium Nitrate	Explosive Component	FlexProbe	Green	Green screen, single result for Ammonium Nitrate
9	Ammonium Nitrate	Explosive Component	Point-and-Shoot through plastic container	Green	Green screen multiple match for Ammonium Nitrate 72.3%, Silver Nitrate 11.3% & Ammonium Carbonate 10.6%
10	Ammonium Nitrate	Explosive Component	Point-and-Shoot	Red	Red screen with 3 similar materials ammonium nitrate, silver nitrate and ammonium carbonate
11	Ammonium Nitrate	Explosive Component	FlexProbe	Red	Red Screen, no match found
12	Ammonium Perchlorate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Ammonium Perchlorate
13	Ammonium Perchlorate	Explosive Component	Vial	Green	Green screen single match for Ammonium Perchlorate
14	Ammonium Perchlorate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Ammonium Perchlorate
15	Ammonium Perchlorate	Explosive Component	Vial	Green	Green screen single match for Ammonium Perchlorate
16	Ammonium Perchlorate	Explosive Component	FlexProbe	Green	Green screen single match for Ammonium Perchlorate
17	Ammonium Perchlorate	Explosive Component	FlexProbe	Green	Green screen single match for Ammonium Perchlorate
18	Ammonium Perchlorate	Explosive Component	Point-and-Shoot through plastic bag	Green	Green screen single match for Ammonium Perchlorate
19	Ammonium Perchlorate	Explosive Component	Point-and-Shoot through bag	Green	Green screen single match for Ammonium Perchlorate
20	ANFO	Commercial Explosive	Point-and-Shoot through bag	Green	Green screen multiple match for ammonium nitrate 77.8%, Silver Nitrate 8.1% & Ammonium Carbonate 7.3%
21	Barium Peroxide	Explosive Component	Point-and-Shoot through brown bottle	Green	Green screen single result for Barium Peroxide
22	Barium Peroxide	Explosive Component	Point-and-Shoot	Green	Green screen single result for Barium Peroxide
23	Barium Peroxide	Explosive Component	Vial	Green	Green screen single result for Barium Peroxide
24	Barium Peroxide	Explosive Component	FlexProbe	Green	Green screen single match for Barium Peroxide
25	C4	Military Explosive	Point-and-Shoot	Green	Green screen, multiple positive match, for RDX/HMX and RDX
26	C4	Military Explosive	Vial	Green	Green screen, multiple positive match, for RDX/HMX and RDX
27	C4	Military Explosive	FlexProbe	Green	Green screen, multiple positive match, for RDX/HMX and RDX
28	C4	Military Explosive	Point-and-Shoot through clear plastic	Green	Green screen multiple match for RDX/HMX 61.9% and RDX 38.1 %.
29	C4	Military Explosive	Point-and-Shoot	Green	Green screen multiple match for RDX/HMX 61.9 % and RDX 38.1%
30	C4	Military Explosive	Vial	Green	Green screen multiple match for RDX/HMX 70.4% & RDX 29.6%
31	C4	Military Explosive	Point-and-Shoot through clear plastic	Green	Green screen multiple match for RDX/HMX 62.6 % & RDX 37.4%
32	C4	Military Explosive	FlexProbe Point-and-Shoot	Green	Green screen multiple match of RDX/HMX 60.4% and RDX 39.6%
33	C4 (foreign)	Military Explosive	Vial	Green	Green screen multiple match for RDX 56% and RDX/HMX 44%.
34	C4 (foreign)	Military Explosive	Point-and-Shoot	Green	Green screen multiple match for RDX 53.4% & RDX/HMX 46.6 %
35	C4 (foreign)	Military Explosive	Point-and-Shoot through poly bag	Green	Green screen multiple match for RDX 54% & RDX/HMX 46%
36	C4 (foreign)	Military Explosive	Point-and-Shoot through poly & Nylon bag	Green	Green screen multiple match for RDX 54.8% & RDX/HMX 45.2%
37	C4 (foreign)	Military Explosive	Point-and-Shoot through poly and nylon bags	Green	Green screen multiple match of RDX 53.2% and RDX/HMX 46.8%
38	C4 (foreign)	Military Explosive	Vial	Green	Green screen multiple match of RDX 51.3% and RDX/HMX 48.7%
39	C4 (foreign)	Military Explosive	Point-and-Shoot	Green	Green screen multiple match of RDX 52.7% and RDX/HMX 47.3%
40	C4 (foreign)	Military Explosive	FlexProbe through poly and nylon bags	Green	Green screen multiple match of RDX 55.4% and RDX/HMX 44.6%
41	C4 (foreign)	Military Explosive	FlexProbe through poly & nylon bags	Green	Green screen multiple result of RDX 51.2% and RDX/HMX 48.6%
42	Calcium Hypochlorite	Explosive Component	Point-and-Shoot	Green	Green screen single match for Calcium Hypochlorite
43	Calcium Hypochlorite	Explosive Component	Vial	Green	Green screen single match for Calcium Hypochlorite
44	Calcium Hypochlorite	Explosive Component	FlexProbe	Green	Green screen single match for Calcium Hypochlorite
45	Calcium Hypochlorite	Explosive Component	Point-and-Shoot	Red	Red screen, no match found
46	Calcium Nitrate	Explosive Component	Vial	Green	Green screen single match for Calcium Nitrate
47	Calcium Nitrate	Explosive Component	FlexProbe	Green	Green screen single match for Calcium Nitrate
48	Calcium Nitrate	Explosive Component	Point-and-Shoot	Red	Red screen, no match found
49	Calcium Nitrate	Explosive Component	Vial	Red	Red screen, no match found
50	Composition B	Military Explosive	Point-and-Shoot	Blue	Blue screen mixture 93% of TNT 54% and a cluster of RDX & RDX/HMX 39%
51	Composition B	Military Explosive	Point-and-Shoot	Red	Red screen, no match found
52	Composition B	Military Explosive	Point-and-Shoot	Red	Red screen, no match found
53	Composition B	Military Explosive	Vial	Red	Red screen, no match found
54	DADP (Diacetonediperoxide)	HME	FlexProbe	Blue	Blue screen mixture 71% of Bromo-difluoroaniline 29%, Bis-hydroxy-methylphenyl propane 17%, Methlcycloexylamine, mixture 14% & Dimethylfor-mamide dineopentyl acetal 11%
55	Demex	Military Explosive	Point-and-Shoot	Green	Green screen multiple result of RDX/HMX 72.2% & RDX 27.8%
56	Demex	Military Explosive	Point-and-Shoot through plastic container	Green	Green screen multiple result of RDX/HMX 72.2% & RDX 27.8%

#	Sample	Category	Mode	Screen Color	Result
57	DetaSheet (PETN rubber binder)	Military Explosive	Point-and-Shoot	Green	Green screen, positive match for PETN
58	DetaSheet (PETN rubber binder)	Military Explosive	Vial	Green	Green screen, positive match for PETN
59	DetaSheet (PETN rubber binder)	Military Explosive	FlexProbe	Green	Green screen, multiple positive match ammonium nitrate saturated solution, ammonium nitrate, potassium nitrate, beryllium nitrate
60	Dimethylhydrazine	Explosive Component	FlexProbe	Green	Green screen single match for Dimethylhydrazine
61	DMNB	Explosive Component	Vial	Green	Green screen single match for DMNB
62	Dynamite	Commercial Explosive	Point-and-Shoot	Blue	Blue screen mixture 74% for AN @ 72% and a cluster 1%
63	Dynamite	Commercial Explosive	Point-and-Shoot	Green	Green screen multiple match of Ammonium Nitrate Saturated Solution 21.2%, Ammonium Nitrate 50% solution 18.7%, Ammonium Nitrate 10.6% & Silver Nitrate 8.3%
64	Dynamite	Commercial Explosive	Point-and-Shoot on liquid	Green	Green screen multiple match for Beryllium nitrate solution, Gallium (III) Nitrate, Manganese (II) Nitrate solution & Ammonium Nitrate
65	Dynamite	Commercial Explosive	Point-and-Shoot	Red	Red screen but indicated AN
66	Dynamite	Commercial Explosive	Point-and-Shoot	Red	Red screen but indicated AN
67	Dynamite	Commercial Explosive	Point-and-Shoot	Red	Red screen, no match found
68	EGDN	Explosive Component	Point-and-Shoot through dark brown bottle	Green	Green screen single match for EGDN
69	EGDN	Explosive Component	Vial	Green	Green screen single match for EGDN
70	EGDN	Explosive Component	FlexProbe	Green	Green screen single match for EGDN
71	Emulsion	Commercial Explosive	Point-and-Shoot	Green	Green screen, multiple positive match Ammonium Nitrate saturated solution, Ammonium Nitrate, Potassium Nitrate, Beryllium Nitrate
72	Emulsion	Commercial Explosive	Vial	Green	Green screen, multiple positive match Ammonium Nitrate saturated solution, Ammonium Nitrate, Potassium Nitrate, Beryllium Nitrate
73	Emulsion	Commercial Explosive	Point-and-Shoot	Green	Green screen multiple matches for saturated Ammonium Nitrate solution 15%, Ammonium Nitrate 50% solution 14.8 %, Beryllium Nitrate solution 14.1% and Gallium (III) Nitrate 13.2%.
74	Emulsion	Commercial Explosive	Vial	Green	Green screen multiple match of Ammonium Nitrate saturated solution 20.4%, Ammonium Nitrate 50% solution 18.6%, Ammonium Nitrate saturated solution 20.4%, Ammonium Nitrate 50% solution 18.6%, Beryllium Nitrate Solution 13.6% & Gallium (III) Nitrate 12.4%
75	Emulsion	Commercial Explosive	Point-and-Shoot	Red	Red screen, no match found
76	Glycerin	Explosive Component	Point-and-Shoot through plastic bottle	Green	Green screen multiple match for Glycerin 51.6% & Glycerol 48.4%
77	Hexalite	Military Explosive	Point-and-Shoot	Blue	Blue screen mixture 95% of TNT 51% and a cluster of RDX & RDX/HMX 44%
78	Hexamine	Military Explosive	Point-and-Shoot	Green	Green screen single match for Hexamine
79	Hexamine	Military Explosive	Vial	Green	Green screen single match for Hexamine
80	Hexamine	Military Explosive	FlexProbe	Green	Green screen single match for Hexamine
81	Hexamine	Military Explosive	Point-and-Shoot through clear bottle	Green	Green screen single match for Hexamine
82	Hexamine	Military Explosive	Vial	Green	Green screen single match for Hexamine
83	Hexamine	Military Explosive	FlexProbe	Green	Green screen single match for Hexamine
84	Hexane	Explosive Component	Vial	Green	Green screen multiple matches for Ligroin 53% and Petroleum Ether 47%
85	HMTD	HME	Vial	Green	Green screen single match for HMTD
86	HMTD	HME	Point-and-Shoot	Green	Green screen single match for HMTD
87	HMTD	HME	Vial	Green	Green screen single match for HMTD
88	HMTD	HME	FlexProbe	Green	Green screen single match for HMTD
89	HMX	Military Explosive	Vial	Green	Green screen single match for HMX- Holston
90	HMX	Military Explosive	FlexProbe	Green	Green screen single match for HMX-Holston
91	HMX	Military Explosive	FlexProbe	Green	Green screen single match for HMX-Holston
92	HMX	Military Explosive	Point-and-Shoot	Red	Red screen, no match found
93	HMX	Military Explosive	Vial	Red	Red screen, no match found
94	HMX	Military Explosive	Vial	Red	Red screen, no match found
95	Hydrazine Anhydrous	Explosive Component	Vial	Red	Red screen, but indicates Hydrazine
96	Hydrogen Peroxide	Explosive Component	Vial	Green	Green screen single match for Hydrogen Peroxide
97	Hydrogen Peroxide	Explosive Component	FlexProbe	Green	Green screen single match for Hydrogen Peroxide
98	Hydrogen Peroxide & Nitromethane	HME	Vial	Blue	Blue screen mixture of Nitromethane 99%
99	Hydrogen Peroxide & Nitromethane	HME	Point-and-Shoot through glass container	Blue	Blue screen mixture 97% of Hydrogen Peroxide 77%, Nitromethane 18% & Ammonium Acetate 2%
100	Hydrogen Peroxide & Nitromethane	HME	Vial	Blue	Blue screen mixture 97% of Hydrogen Peroxide 77%, Nitromethane 18% & Ammonium Acetate 2%
101	Hydrogen Peroxide & Nitromethane	HME	Vial	Blue	Blue screen mixture 97% of Hydrogen Peroxide 76%, Nitromethane 18% & Ammonium Acetate 3%
102	Hydrogen Peroxide &	HME	Point-and-Shoot through glass container	Green	Green screen single match for Nitromethane
103	Hydrogen Peroxide & Tang 80/20	HME	Point-and-Shoot through glass container	Green	Green screen single match for Hydrogen Peroxide
104	Hydrogen Peroxide & Tang 80/20	HME	Vial	Green	Green screen single match for Hydrogen Peroxide
105	Isoprophanol	Explosive Component	Point-and-Shoot through plastic bottle	Green	Green screen single match for Isoprophanol
106	Isoprophanol	Explosive Component	Vial	Green	Green screen single match for Isoprophanol
107	Lead Azide	Commercial Explosive	Vial	Green	Green screen single match for Lead Azide
108	Lead Azide	Commercial Explosive	Point-and-Shoot	Green	Green screen single match for Lead Azide
109	Lead Azide	Commercial Explosive	FlexProbe	Green	Green screen single match for Lead Azide
110	Magnesium Perchlorate	Explosive Component	Point-and-Shoot	Green	Green screen multiple match for Ammonium Perchlorate 61.8% and Perchlorate Acid 28.7%

#	Sample	Category	Mode	Screen Color	Result
111	Magnesium Sulfate	Explosive Component	Vial	Blue	Blue screen mixture (84%) of Magnesium Sulfate & Bromacil 2%
112	Magnesium Sulfate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Magnesium Sulfate
113	MEKP	HME	FlexProbe	Green	Green screen single match for MEKP
114	MEKP	HME	Vial	Green	Green screen single match for MEKP-URI
115	MEKP	HME	Point-and-Shoot	Red	Red screen, no match found
116	MEKP	HME	Vial	Red	Red screen, no match found
117	Mercury Chlorate	Explosive Component	FlexProbe	Green	Green screen single match for Mercury Chlorate
118	Mercury Chloride	Explosive Component	Point-and-Shoot	Green	Green screen single match for Mercury Chloride
119	Mercury Chloride	Explosive Component	Vial	Green	Green screen single match for Mercury Chloride
120	Methyl Nitrate	Explosive Component	Vial	Green	Green screen single match for Methyl Nitrate
121	Methyl Nitrate	Explosive Component	FlexProbe	Green	Green screen single match for Methyl Nitrate
122	Methyl Nitrate	Explosive Component	Vial	Red	Red screen, no match found
123	N,N Dimethylhydrazine	Explosive Component	Vial	Green	Green screen single match for N,N Dimethylhydrazine
124	N-Hexane	Explosive Component	Vial	Green	Green screen multiple matches for N-Hexane 36.2%, Petroleum Ether 33% & Ligroin 30.7%
125	N-Hexane	Explosive Component	FlexProbe	Green	Green screen multiple match for Petroleum ether 33.7%, N-Hexane 32.7% & Ligroin 27.9%
126	Nitric Acid	Explosive Component	Vial	Green	Green screen single match for Nitric Acid
127	Nitric Acid	Explosive Component	FlexProbe	Green	Green screen single match for Nitric Acid
128	Nitroglycerine (NG)	Commercial Explosive	Vial	Blue	Blue screen mixture (81%) for Acetone 60%, Acetone in water 12% & Strontium Peroxide 8%
129	Nitroglycerine (NG)	Commercial Explosive	Vial	Blue	Blue screen mixture (82%) of NG 42%, Acetone in water 38% & Strontium Peroxide 2%
130	Nitroglycerine (NG)	Commercial Explosive	FlexProbe	Green	Green screen single match for NG
131	Nitroglycerine (NG)	Commercial Explosive	Vial	Green	Green screen single match for Acetone
132	Nitromethane	Explosive Component	Point-and-Shoot	Green	Green screen single match for Nitromethane
133	Nitromethane	Explosive Component	Point-and-Shoot	Green	Green screen single match for Nitromethane
134	Nitromethane	Explosive Component	FlexProbe	Green	Green screen single match for Nitromethane
135	Nitromethane	Explosive Component	FlexProbe	Green	Green screen single match for Nitromethane
136	Nitromethane	Explosive Component	FlexProbe	Green	Green screen, single match for Nitromethane
137	Nitromethane	Explosive Component	Point-and-Shoot through plastic bottle	Green	Green screen single match for Nitromethane
138	Nitromethane	Explosive Component	Point-and-Shoot through plastic bottle	Green	Green screen single match for Nitromethane
139	Nitromethane	Explosive Component	Vial	Green	Green screen single match for Nitromethane
140	Nitromethane	Explosive Component	FlexProbe	Green	Green screen single match for Nitromethane
141	Pentolite	Military Explosive	Point-and-Shoot	Green	Green screen single match for PETN
142	Pentolite	Military Explosive	Point-and-Shoot	Red	Red screen, no match found; florescence peak—very, slight peaks
143	Pentolite	Military Explosive	Point-and-Shoot	Red	Red screen, no match found
144	Perchlorate Acid	Explosive Component	Vial	Green	Green screen multiple matches for Perchlorate Acid 86.8% & Lead (III) Perchlorate Trihydrate 13%
145	Perchloric Acid	Explosive Component	FlexProbe	Green	Green screen multiple match for Perchloric Acid 61.7% & Lead (III) Perchloric Trihydrate 35.1%
146	PETN	Military Explosive	Point-and-Shoot	Green	Green screen, single positive result for PETN
147	PETN	Military Explosive	Vial	Green	Green screen, single positive result for PETN
148	PETN	Military Explosive	FlexProbe	Green	Green screen, single positive result for PETN
149	Picric Acid	HME	Vial	Green	Green screen single match for TNP (also known as Picric Acid)
150	Picric Acid	HME	FlexProbe	Green	Green screen single match for Picric Acid
151	Picric Acid	HME	Point-and-Shoot through clear bottle	Green	Green screen single match for TNP (also known as Picric Acid)
152	Potassium Chlorate	Explosive Component	Point-and-Shoot	Blue	Blue screen mixture 96% for Potassium Chlorate 92%, Platinum (II) Acetylacetonate 2%, Sodium Chlorate 2%
153	Potassium Chlorate	Explosive Component	Vial	Green	Green screen single match for Potassium Chlorate
154	Potassium Chlorate	Explosive Component	FlexProbe	Green	Green screen single match for Potassium Chlorate
155	Potassium Dichromate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Potassium Dichromate
156	Potassium Nitrate	Explosive Component	Point-and-Shoot	Green	Green screen multiple match for Potassium Nitrate 81% & Cesium Nitrate 16.8%
157	Potassium Nitrate	Explosive Component	Vial	Green	Green screen multiple match for Potassium Nitrate 81% & Cesium Nitrate 16.8%
158	Potassium Nitrate	Explosive Component	FlexProbe	Green	Green screen multiple match for Potassium Nitrate 60.8%, Cesium Nitrate 21.7%, Ammonium Nitrate solution 4.4% & Ammonium Nitrate 50 % saturated solution 3.9%
159	Potassium Perchlorate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Potassium Perchlorate
160	Potassium Perchlorate	Explosive Component	Vial	Green	Green screen single match for Potassium Perchlorate
161	Potassium Perchlorate	Explosive Component	FlexProbe	Green	Green screen single match for Potassium Perchlorate
162	Potassium Permanganate	Explosive Component	Point-and-Shoot	Green	Green screen multiple matches for Potassium Permanganate 86.6% & Barium Peroxide 11.5%
163	Potassium Permanganate	Explosive Component	Vial	Green	Green screen single match for Potassium Permanganate
164	Potassium Permanganate	Explosive Component	FlexProbe	Green	Green screen single match for Potassium Permanganate
165	RDX	Military Explosive	FlexProbe	Green	Green screen multiple match for RDX 55% & RDX/HMX 45%
166	RDX	Military Explosive	Vial	Green	Green Screen multiple match of RDX/HMX 84.4% & RDX 15.7%
167	RDX (foreign)	Military Explosive	Point-and-Shoot	Green	Green screen multiple match for RDX/HMX 52.6% & RDX 47.4%
168	RDX (foreign)	Military Explosive	Vial	Green	Green screen multiple match for RDX 53.6% & RDX/HMX 46.4%
169	RDX/HMX (US)	Military Explosive	Point-and-Shoot	Green	Green screen multiple match for RDX/HMX 51.2% & RDX 48.8%
170	RDX/HMX (US)	Military Explosive	Point-and-Shoot	Green	Green screen multiple match for RDX/HMX 78.7% & RDX 21.2%
171	RDX/HMX (US)	Military Explosive	Vial	Green	Green screen multiple match for RDX/HMX 66.2% & RDX 33.8 %
172	Semtex 1A	Military Explosive	Point-and-Shoot	Green	Green screen single match for PETN

#	Sample	Category	Mode	Screen Color	Result
173	Semtex 1A	Military Explosive	Point-and-Shoot through wax paper	Red	Red screen, no match found
174	Semtex 1A	Military Explosive	Point-and-Shoot through wax paper	Red	Red screen, no match found
175	Semtex H	Military Explosive	Point-and-Shoot through poly bag & wax paper	Blue	Blue screen mixture 68% for RDX & RDX/HMX 37% with PETN 31%.
176	Semtex H	Military Explosive	Point-and-Shoot	Blue	Blue screen mixture for 88% mixture. PETN 56% & RDX & RDX/HMX 32%.
177	Sodium Azide	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sodium Azide
178	Sodium Azide	Explosive Component	Vial	Green	Green screen single match for Sodium Azide
179	Sodium Azide	Explosive Component	FlexProbe	Green	Green screen single match for Sodium Azide
180	Sodium Chlorate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sodium Chlorate
181	Sodium Chlorate	Explosive Component	Vial	Green	Green screen single match for Sodium Chlorate
182	Sodium Chlorate	Explosive Component	FlexProbe	Green	Green screen single match for Sodium Chlorate
183	Sodium Nitrate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sodium Nitrate
184	Sodium Nitrate	Explosive Component	Vial	Green	Green screen single match for Sodium Nitrate
185	Sodium Nitrate	Explosive Component	FlexProbe	Green	Green screen single match for Sodium Nitrate
186	Sodium Nitrate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sodium Nitrate
187	Sodium Nitrate	Explosive Component	FlexProbe	Green	Green screen single match for Sodium Nitrate
188	Sodium Nitrate	Explosive Component	Vial	Green	Green screen single match for Sodium Nitrate
189	Sodium Nitrate	Military Explosive		Green	Green screen single match for Sodium Nitrate
190	Sodium Nitrate & Ammonium Perchlorate	Explosive Component	Point-and-Shoot	Blue	Blue screen mixture 95% of Sodium Nitrate 89% & Lithium Nitrate
191	Sodium Nitrate & Ammonium Perchlorate	Explosive Component	Vial	Blue	Blue screen mixture 95% of Sodium Nitrate 76% & Ammonium Perchlorate 19%
192	Sodium Nitrate & Ammonium Perchlorate	Explosive Component	Vial	Blue	Blue screen mixture 95% of Sodium Nitrate 76% & Ammonium Perchlorate 19%
193	Sodium Nitrate & Potassium Nitrate	Explosive Component	Vial	Blue	Blue screen mixture 96% of Sodium Nitrate & Lithium Nitrate70 % & 22% Potassium Nitrate & Cesium Nitrate
194	Sodium Nitrate & Potassium Nitrate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sodium Nitrate
195	Sodium Perchlorate	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sodium Perchlorate
196	Sodium Perchlorate	Explosive Component	Vial	Green	Green screen single match for Sodium Perchlorate
197	Sodium Perchlorate	Explosive Component	FlexProbe	Green	Green screen single match for Sodium Perchlorate
198	Sodium Peroxide	Explosive Component	Vial	Green	Green screen single match for Sodium Peroxide
199	Sodium Peroxide	Explosive Component	FlexProbe	Green	Green screen single match for Sodium Peroxide
200	Sodium Peroxide	Explosive Component	Point-and-Shoot	Red	Red screen, no match found
201	Sulfur	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sulfur
202	Sulfur	Explosive Component	Vial	Green	Green screen single match for Sulfur
203	Sulfur	Explosive Component	FlexProbe	Green	Green screen single match for Sulfur
204	Sulfur	Explosive Component	Point-and-Shoot	Green	Green screen single match for Sulfur
205	Sulfur	Explosive Component	Vial	Green	Green screen single match for Sulfur
206	Sulfur	Explosive Component	FlexProbe	Green	Green screen single match for Sulfur
207	Sulfur & Hexamine	Military Explosive	Vial	Green	Green screen single match for Sulfur
208	Sulfuric Acid	Explosive Component	Point-and-Shoot through clear bottle	Green	Green screen single match for Sulfuric Acid
209	Sulfuric Acid	Explosive Component	Vial	Green	Green screen single match for Sulfuric Acid
210	Sulfuric Acid	Explosive Component	FlexProbe	Green	Green screen single match for Sulfuric Acid
211	TATP	HME	Vial	Green	Green screen single match for TATP
212	TATP	HME	Point-and-Shoot	Green	Green screen single match for TATP
213	TATP	HME	Vial	Green	Green screen single match for TATP
214	TATP	HME	FlexProbe	Green	Green screen single match for TATP
215	Tetryl	Military Explosive	Point-and-Shoot	Green	Green screen single match for Tetryl
216	Tetryl	Military Explosive	Vial	Green	Green screen single match for Tetryl
217	Tetryl	Military Explosive	FlexProbe	Green	Green screen single match for Tetryl
218	TNT	Military Explosive	Point-and-Shoot	Blue	Blue Screen Mixture (80%) of TNT (57%) and other materials.
219	TNT	Military Explosive	Vial	Green	Green screen single match for TNT
220	TNT	Military Explosive	Point-and-Shoot	Green	Green screen single match for TNT
221	TNT	Military Explosive	Vial	Green	Green screen single match for TNT
222	TNT	Military Explosive	FlexProbe	Green	Green screen single match for TNT
223	Urea	Explosive Component	Point-and-Shoot	Green	Green screen single match for Urea
224	Urea	Explosive Component	FlexProbe	Green	Green screen single match for Urea
225	Urea	Explosive Component	Vial	Green	Green screen single match for Urea
226	Urea Nitrate	Commercial Explosive	Point-and-Shoot through bag	Green	Green screen single match for Urea Nitrate
227	Urea Nitrate	Commercial Explosive	Vial	Green	Green screen single match for Urea Nitrate
228	Urea Nitrate	Commercial Explosive	Point-and-Shoot	Green	Green screen single match for Urea Nitrate
229	Urea Nitrate	Commercial Explosive	Vial	Green	Green screen single match for Urea Nitrate
230	Urea Nitrate	Commercial Explosive	FlexProbe	Green	Green screen single match for Urea Nitrate
231	Xylene	Military Explosive	Point-and-Shoot through brown bottle	Green	Green screen multiple match for 3-Ethylphenol 56.3% & m-Xylene 43.6%