"Science in Motion"

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Contractor's Progress, Status and Management Report – Final Project Report

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PROGRESS, STATUS, AND MANAGEMENT REPORT
Final Report

Summary

This report summarizes the results for contract N00014-05-M-0010. In summary, the objectives of this work were:

- Define sample collection scenarios that are suited for the screening of personnel who are likely to be involved in the production of improvised explosive devices (IEDs) or who may be suicide bombers, to include at least one swab approach and one vapor sampling of hands or clothing.
- Optimize the Fido technology to provide sample analysis in support of the defined scenarios.
- Demonstrate successful detection within the scenarios.
- Characterize samples of explosives with Fido and demonstrate the ability to determine probable matches to other samples.
- Demonstrate Fido as a detection tool for other forensics applications, such as the detection of explosives in hair samples.

Methods for collection of forensics evidence from humans and surfaces of objects that may have been exposed to explosives in the course of storage, construction, transport, and deployment of IEDs have been developed. These methods were been demonstrated with very encouraging results during laboratory and field trials. During field trials conducted at the Countermine Facility (CM) and the Joint Experimental Research Complex (JERC) site at Yuma Proving Grounds (YPG) from December 13-17, 2004, detection of explosives on explosive ordnance disposal (EOD) technicians who had recently assembled simulated IEDs was demonstrated with a high degree of probability. In addition, detection of explosives on vehicles used to transport the IEDs was demonstrated. Persons (mainly administrators at YPG) were also included in the study as persons who do not handle explosives (i.e., as ‘blank’ controls). With the exception of one individual, no sensor response to ‘blank’ individuals was noted. Contamination of facilities routinely utilized by EOD technicians at the CM site was also demonstrated.

Explosives samples were characterized to determine whether the samples in question were sufficiently different in chemical composition to enable differentiation using the Fido sensor. Laboratory analyses of two TNT samples from different sources were found to contain significant variations in the number and concentrations of important vapor-phase constituents. These results suggest that it may be possible to use the Fido sensor to determine whether samples of explosive are from a similar or different source or point of origin.

The utility of Fido for performing other forensics applications was demonstrated. An attempt to detect explosives traces in hair was undertaken, with little success. Modification of experimental protocols will be required to detect explosives in hair samples. In addition, a 'role playing' experiment was conducted in which a simulated TNT-based IED was constructed, transported and deployed by a team of five terrorists. All five subjects were easily detected via either direct or indirect contact with the device. The device and items used to transport the device were also

analyzed and found to be contaminated. A control group assembled an IED identical to that assembled by the first group, but the control group used an inert explosive simulant that did not contain TNT. As expected, no sensor alarms were registered on the control group. In addition, a test subject from the first group washed his hands a total of five times with soap and water after assembling the device. Even after washing his hands five times, explosive traces were detected on the subject. Detection of fingerprints contaminated with TNT was also demonstrated. Detection of fingerprints with Fido appears to be non-destructive, so connecting the presence of explosive traces to a fingerprint can be accomplished without destroying the print.

With the exception of demonstrating detection of explosives contamination in hair samples, all project objectives were achieved at the proof-of-concept level. The results of this work indicate that the Fido sensor has utility as a forensics tool for the apprehension of individuals involved in terrorist activities involving explosives. In Nomadics' opinion, the sensor system has demonstrated sufficient capability to warrant further development during a Phase II effort. The sensor is a relatively mature technology, and could be deployed for testing in-theatre very soon after initiation of a Phase II effort. The results of the project will now be presented.

Technical Background and Basis for Technology Development

Recent operations in Afghanistan, Iraq, and other areas have demonstrated the susceptibility of our deployed warfighters, allied assets, and peacekeeping forces to attacks involving IEDs. IEDs may be deployed in fixed locations or in vehicles, or as suicide bombs (SBs) transported on vehicles or hidden on persons. It is difficult for a bomber and accomplices to assemble, transport, and deploy an explosive device without becoming contaminated with explosives. In fact, unless a deliberate, well-executed plan to prevent contamination is followed, the device and bombers will likely be contaminated, as will any areas in which the explosive was stored, handled, or transported. This contamination is extremely difficult to remove, and with an adequately sensitive system can be detected several hours or even days after the initial transfer of contamination.

Place hand on glass tile

Use Fido to sample hand-print on tile

Figure 1. Glass tile transfer method.

Wipe residue off hand

Sample chemical-free tissue

Figure 2. Chemical wipe transfer method.

Consequently, detection of explosives contamination is a possible means of obtaining intelligence, locating covert threats, or identifying individuals involved in the construction of IEDs. Development of technology for detection of trace levels of explosives as an aid to force protection and for acquisition of forensic evidence is the goal of this work. This evidence could be used to apprehend bombers and to locate and confiscate bomb-making materials prior to deployment, preventing an incident.

In order to achieve these goals, sensors that are sensitive, portable, easy to use, inexpensive, adaptable, and reliable are required. Sampling methods capable of harvesting the chemical signature of explosives from persons and suspicious materials are equally important and typically do not receive the same level of effort during development efforts. Hence, sampling equipment is being developed to integrate with the Fido sensor to facilitate collection of the type of forensics evidence described above. The Fido sensor was originally developed for the detection of the vapor-phase chemical signature of explosives contained in landmines, which is a very different sampling paradigm than required for collection of forensics evidence. Hence, development of appropriate sampling equipment that is compatible with the sensor is a significant part of the work presented here. The sensor hardware has not required further modification for this application. A technical overview of the principles of operation of the sensor and previously demonstrated capabilities are presented in the proposal for this project (N042-901-0664), so will not be discussed further.

Development of Sample Collection Methods

As stated previously, a fundamental premise of this effort is that persons who have handled explosives will likely be contaminated with explosives. The most likely area to check for contamination would then be on the hands of individuals. Further, anything an individual who has explosive contamination on his hands touches will likely be contaminated as well. It was proposed to collect samples from persons via one of two methods. The first method was to have an individual touch a plate of glass with the palm of his hand. This would transfer contamination to the glass plate. The contamination, if present, would then be detected by analyzing the plate with the sensor (refer to Figure 1). It is not feasible to perform direct analysis of a person with the Fido sensor because the tip of the sensor is hot enough (120° C) to cause burns if bare skin is contacted. The second method involves asking the suspect to wad-up a piece of lint-free paper in his hands, which would contaminate the paper if the suspect had explosives contamination on his hands. Alternatively, the sensor operator could wipe or ‘swipe’ the hands of the suspect with the paper (refer to Figure 2. If explosives were transferred to the paper, it could then be detected by analysis of the paper with the sensor.

Both of these methods were shown to be effective during laboratory analysis. However, there were several issues with using these methods operationally. Transport of glass plates in a battlefield environment is problematic for several reasons. The most obvious is that the glass is fragile and can be easily broken, and presents a safety hazard. In addition, it would be difficult to sample other parts of a person’s body or surfaces of hard objects such as a vehicle. Also, the glass is somewhat expensive, and would either have to be cleaned meticulously prior to re-use or disposed of after a single use. Cleaning in the field would require use of a cleaning fluid, would be time consuming, and could lead to false responses if cleaning were not adequate. Treating the glass as a disposable item is not practical because of the expense involved. The glass windshield

in vehicles could be substituted for the glass plate, but this is also not practical because suspects will not always be screened in the vicinity of a vehicle with a glass windshield.

The paper sampling approach has some advantages over the use of glass plates. The paper is inexpensive and could be a disposable item. In addition, it will conform to hard, irregular surfaces, and could be used to sample areas on the body of a suspect other than the hands. The major drawback to using paper as a sampling medium is that it easily tears if a surface is sampled vigorously, making it difficult to analyze the paper with the sensor. In addition, once the paper is used it is no longer flat and is difficult to interrogate with the sensor unless the operator flattens the paper out prior to analysis. This is time-consuming and could easily lead to contamination of the sensor operator with explosives if the sample is positive. In order to handle the paper easily during sampling, it must also be large enough to hold without dropping. The larger the surface area of the paper, the longer it takes to analyze with the sensor. Hence, the paper sampling method was also regarded as problematic.

A search for a new sampling medium was conducted. There were several criteria for selection of a sampling medium. First, the sampling medium must effectively transfer explosive traces from surfaces to the sampling medium, yet easily liberate the vapor signature to the sensor during analysis. The medium must be inexpensive and easy to transport. Finally, it must be easy to analyze with the sensor. After evaluation of a number of materials, Teflon strips were found to yield the best performance of all materials tested. The strips are approximately 1 inch wide by 4 inches long, and are low in cost. The strips are relatively flexible, enabling sampling of irregular surfaces. In addition, they are not easily deformed during swiping (sample collection), making them easy to analyze with the sensor.

Samples are collected by grasping the strip between the thumb and middle finger, while the index finger pushes against the back side of the strip during sampling to apply pressure to the surface being sampled. The strip is then swiped across the surface to be sampled (Figure 3). Explosive traces, if present, are transferred to an area of approximately one square inch on one side of the strip, making analysis quick (three to five seconds) and straightforward. These strips were used successfully during the tests at YPG. Results are presented later in this report.

Because the tip of Fido is hot enough to burn exposed skin, it is not suitable for direct analysis of human subjects. However, Fido can be used to analyze many objects directly without the use of swipes. For example, direct analysis of surface contamination of vehicles was demonstrated during the tests at YPG, with excellent results. Development of sampling hardware under a second ONR SBIR effort (Explosive Chemical Signature-Based Detection of IEDs, contract N00014-04-M-0382) could enable direct analysis of human subjects with the sensor without any chance of burning exposed skin. This hardware, a high-volume preconcentrator, has been used to detect vapors of explosives emanating from contaminated surfaces. The inlet to the preconcentrator is not heated, so there is no chance of burns to exposed skin. Details of the design and performance of this hardware are documented in the final report for SBIR contract N00014-04-M-0382. If this approach is proven successful for human screening, it could eliminate the need for swipe sampling, eliminating a consumable item and would enable samples to be collected by a non-contact method.

Figure 3. Collection of swipe sample using Teflon strip

Optimization of Fido for Field Sample Analysis

No modifications to the existing Fido sensor hardware were necessary for analysis of samples in the field. However, an attachment for the sensor was developed to enhance analysis of swipe samples. This attachment is essentially a stainless steel block with a slot machined into it to accommodate the Teflon strips used for swipe samples. The block slides over the tip of the sensor and is held in place with a thumbscrew. The block can be attached to the sensor in seconds without use of any tools. This makes it possible to switch between swipe and direct sample introduction in seconds. When the block is installed on the sensor, heat is transferred from the inlet of the sensor to the block, heating the block to around 100° C. The heated block helps vaporize explosive from the strip, increasing the amount of explosive delivered to the sensor. When a strip is inserted into the block for analysis, it is automatically positioned near the inlet of the sensor in a position that is optimal for detection. Figure 4 illustrates use of the swipe desorber on the Fido sensor.

Figure 4. Analysis of a Teflon sample strip using the swipe desorber

The benefits of the swipe desorber became apparent when testing the system outdoors in cool and windy conditions. A comparison was made in which contaminated swipes were analyzed outdoors with and without the desorber. When analyzed without the desorber, swipes were simply held in close proximity to the inlet of the sensor. When temperatures fell below approximately 50 °F, or when conditions were windy, responses were more intense and

consistent using the desorber. However, a problem was sometimes encountered after analyzing certain samples with the desorber. If a heavily contaminated sample is analyzed with the desorber, the desorber can become contaminated with explosives. When this occurs, the desorber must be cleaned manually. This is easily accomplished by removing the desorber from the sensor and rinsing the part with alcohol. A quick rinsing is usually adequate to remove contamination from the desorber so that it can be returned to use. While rinsing is not an acceptable long-term fix, it did enable proof-of-concept testing to be performed. During a Phase II effort the desorber would be redesigned to reduce the possibility of cross-contamination. Additional heating of the desorber and reducing the area of contact between the swipe and desorber surfaces should solve the problem.

Field Demonstration of Collection of Forensics Evidence

A field trial of the Fido system for collection of forensics evidence was performed at YPG under the supervision of Jesús Estrada, Countermine Test Facility (CMTF) Manager. The system was tested against vehicle-borne IEDs (VBIEDs) and persons who may or may not have recently handled explosives. The IED targets were constructed from several types of munitions including 155mm TNT-filled artillery shells, 155mm Comp B-filled artillery shells, C4 demolition blocks, TNT Demolition blocks, and M19 anti-tank mines. Artillery shells had the shipping plugs removed, and the detonator well was packed with C4 to simulate an improvised detonator. The C4 was confined in the detonator well using duct tape.

Prior to placing explosives in the vehicles, the vehicles were screened for background contamination using Fido in direct-sniff mode. No evidence for background contamination was detected. The vehicles were then loaded with munitions as described in Table 1 and illustrated in Figure 5. When the vehicles were loaded, an assistant whose hands were not contaminated with TNT opened either the door or trunk lid to allow an EOD tech to place the IED in the vehicle. The EOD tech, whose hands were contaminated with explosives because of handling the IEDs, did not touch the vehicle while placing the IED.

After the IED was in place, the assistant closed the trunk or door of the vehicle. the EOD tech was then instructed to touch the vehicle in specific locations (trunk lid, door handles, steering wheel, gear shift, etc.). The contaminated locations on each vehicle are listed in Table 2. In this way there were areas of the vehicle that were contaminated and areas that were not contaminated by transfer of explosive from the EOD technician. Areas touched by an EOD technician were assumed to be contaminated, while all other areas of the vehicle were treated as clean. Care was taken to prevent spread of contamination to clean areas of the vehicle, but data will suggest that some accidental contamination occurred during the course of the tests.

TNT demolition blocks *AT mines*

C-4 ***155 howitzer shells***

Figure 5. Photos of IED targets

Results For VBIEDs

On the morning of December 14, the explosive targets were placed in the vehicles as noted in Table 1. After the IED was placed in the vehicle by the EOD tech (following the procedure outlined above), the EOD tech then contaminated each vehicle at the positions indicated in Table 2. Black squares in the table indicate locations that were contaminated. Contamination was achieved by the EOD tech touching the vehicle at the specified locations with his hands after handling the IED. For the purposes of scoring the results, areas touched by an EOD tech were considered positive or 'hot', while untouched areas of the vehicle were regarded as clean.

On the afternoon of December 14, the vehicles containing explosives were screened using direct sample introduction into the sensor. To verify proper sensor operation, the Fido sensor was presented with a calibration sample prior to the analysis of the first and after analysis of the last sample position on each vehicle.

Once sensor functionality was verified, the sensor was used to screen each of the sampling positions identified in the top row of Table 2. Screening was achieved by slowly sweeping the sensor across the surface of the vehicle at each location as shown in Figure 6. The sensor inlet was held within 1 cm of the surface of the vehicle during sampling. All data at each location was logged electronically for post-analysis.

Approximately 30 to 45 seconds of data was collected at each of the sampling positions. If a vehicle had to be touched (as when doors were opened to sample inside the vehicle), latex gloves were generally worn when the vehicle was touched and were immediately discarded after contact with the vehicle. The intention was to put on a new glove each time the vehicle was touched in order to reduce the chances of spread of contamination.

Vehicle ID	Vehicle Make	Explosive
1	Taurus	(3) Comp-B filled 155s
2	U-Haul	50 lbs of TNT Demo Blocks
3	Bonneville	(3) TNT filled 155s
4	Chrysler	(3) M-19 mines (Comp-B filled)
5	Impala	50 pounds of C4

Table 1: Summary of VBIED targets and explosives

Vehicle ID	Vehicle Make	Sampling Positions																
		Left Front Exterior Door Handle	Left Front Interior Door Handle	Left Rear Exterior Door Handle	Left Rear Interior Door Handle	Right Front Exterior Door Handle	Right Front Interior Door Handle	Right Rear Exterior Door Handle	Right Rear Interior Door Handle	Top of Trunk Lid	Trunk at Key	Steering Wheel	Gear Shift	U-Haul Door Handle	U-Haul Hitch	U-Haul Lock	U-Haul Side	U-Haul Back Door
1	Taurus	■					■			■		■						
2	U-Haul													■	■	■		
3	Bonneville																	
4	Chrysler			■	■	■	■											
5	Impala							■	■	■	■		■					

Contaminated ■ Uncontaminated □

Table 2: Summary of contaminated locations on vehicles

On December 15, swipe samples of the vehicles were taken from the same positions that direct vapor samples were collected the previous day. The procedure followed was the same as for direct vapor sampling except that a swipe sample was taken and analyzed. The contamination on the vehicles had been in place for two days prior to swipe sample collection. The vehicles had not been disturbed since placement of IEDs, except for opening of doors on the vehicles to collect vapor samples from the vehicle interiors the previous day.

Figure 6. Direct analysis of U-Haul for explosives contamination

Data analysts and sensor operators were not given information regarding which areas on the vehicles were contaminated. Hence, data was collected and analyzed in a blind manner. Operators scored each sample by a yes / no determination based on sensor response. For samples that were scored as positive, the response magnitude was also noted. The results of the analysis for direct and swipe sampling are listed in Table 3. Results are listed for all vehicles combined. Results are also listed for vehicles containing TNT and Comp-B (vehicles 1-4), and for vehicle 5 separately, which contained C4. Note that the results are based on the number of contaminated and blank areas sampled, not per vehicle. This method of scoring was selected because of the limited number of vehicles available for inclusion into the tests.

Table 3 lists the probabilities of detection (PD) and probability of false alarms (PFA) for both sampling methods. The probabilities of detection were excellent for vehicles containing TNT and Comp-B, reaching 91.7% and 93.3% for direct and swipe sampling respectively. P_D dropped slightly to 77.8% (direct) and 80% (swipes) when all vehicles were included in the analysis. P_D dropped to 50% (direct) and 40% (swipes) for the vehicle containing C4. The Fido sensor responds to RDX, the explosive contained in C4, but the sensitivity of the sensor to TNT is significantly greater than for RDX. This is reflected in the results.

Sampling Method	Vehicles	Explosives	Contaminated Areas			Blank Areas		
			Detected	Total	P_D	Responses	Total	P_{FA}
Direct	All	TNT, Comp-B, C4	14	18	77.8%	1	92	1.1%
Direct	1, 2, 3, 4	TNT, Comp-B	11	12	91.7%	0	70	0.0%
Direct	5	C4	3	6	50.0%	1	22	4.5%
Swipes	All	TNT, Comp-B, C4	16	20	80.0%	10	41	24.4%
Swipes	1, 2, 3, 4	TNT, Comp-B	14	15	93.3%	10	34	29.4%
Swipes	5	C4	2	5	40.0%	0	7	0.0%

Table 3. Results of vehicle screening analysis

False alarm performance was excellent during the background screening analysis on the first day of testing, and for the direct sampling analysis on the second day of testing. No false alarms were obtained during the background screening, and only one false alarm was registered using the direct screening method. However, the false alarm performance degraded significantly on day 3 of testing (swipe sampling). We hypothesize that the rise in false alarms was due to accidental spread of contamination from contaminated areas of the vehicles to clean areas during the previous day of testing. The doors of the vehicles were opened on day two to gain access to the inside of the vehicles for sampling. Since the sensor operators did not know which areas of the vehicles were contaminated, contaminated areas were touched by test participants. As previously mentioned, latex gloves were worn when opening and closing vehicle doors and were then immediately discarded to help prevent spread of contamination. However, it is possible that test participants failed to follow the contamination-prevention protocol in all instances. The false positive responses were on average approximately an order of magnitude less intense than true positive responses, which is consistent with secondary transfer of contamination.

To test the hypothesis that the false alarms on Day 3 could have been due to accidental spread of contamination, a clean area on a vehicle was sampled by direct and swipe methods. The area was determined to be blank. Next, a test participant opened a contaminated vehicle door. Finally, the test participant placed a handprint on the clean area using the hand that had been used to open the contaminated door. The previously clean area was again sampled after placing of the handprint, and was found to be contaminated. While this experiment does not prove that the false alarms were due to secondary contamination, it does show that it is very easy to spread contamination, even when measures are being taken to prevent it. In addition, false positive responses became more prevalent as the test progressed (none on day one, one on day two, and 10 on day three), we believe spread of contamination is the likely explanation. This is a potential item for further investigation.

Direct analysis of the air inside the vehicles was also performed on several occasions throughout the test period. When these samples were analyzed, a door was opened slightly (so as to not significantly disturb the air inside the vehicle) and the sensor head was inserted into the vehicle interior. These results are summarized in Table 4. The analyses were performed before and after explosives were placed in the vehicles. For all cases except the U-Haul, the explosives were in the trunk of the car, separated from the passenger compartment where samples were collected. For the U-Haul, the back door was raised slightly and the sample was collected by inserting the

sensor inside the trailer. Probabilities of detection were lower than for analysis of surfaces of the vehicles, but all vehicles were detected via this method except for Vehicle 5 containing C4. No false alarms were registered during direct analysis of air in the vehicles.

P_D, All	10 of 16 detected	62.5%
P_D, Vehicles 1-4	10 of 14 detected	71.4%
P_D, Vehicle 5	0 of 2 detected	0.0%
P_{FA}, All	0 of 11	0.0%
P_{FA}, Vehicles 1-4	0 of 8	0.0%
P_{FA}, Vehicle 5	0 of 3	0.0%

Table 4. Probabilities of detection and false alarm for direct sample analysis of air inside vehicles

Figure 7 compares the response of Fido via direct and swipe sampling. These samples were collected from a TNT-contaminated door lock on the U-Haul trailer. The response to the lock prior to contamination is also included as the 'blank' trace. The response to the swipe sample is larger due to the fact that a larger mass of explosive was transferred to the sensor than via direct sample introduction. This is likely why the probability of detection for swipe samples was higher than for direct sample introduction. Note that there are two responses in the direct sample trace, obtained when the sensor is swept back and forth across the contaminated area of the lock.

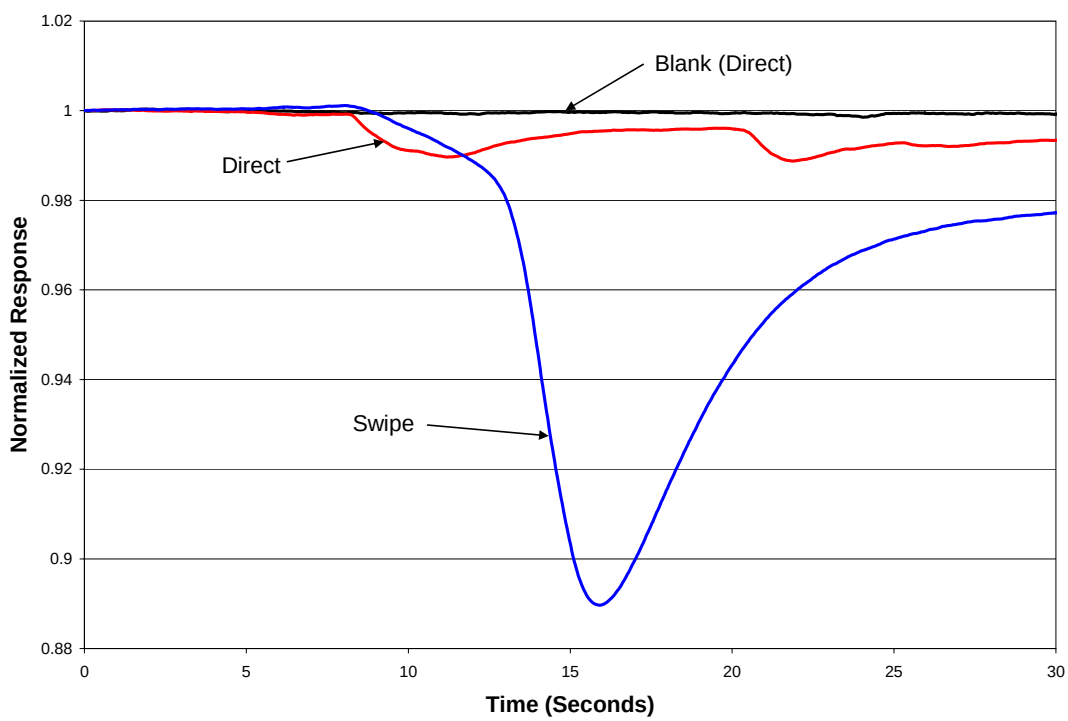

Figure 7. Detection of trace TNT contamination on a door lock.

Swipe Samples of Human Subjects

Swipe samples were collected from human subjects during the course of the testing at YPG. 17 test participants were sampled. Ten test subjects were employees at YPG who worked in an administrative role. These subjects do not encounter explosives in the normal course of their employment, but do come into contact with persons who do handle explosives. Because explosives are so widely used at YPG, there was concern that any person who frequented the facility would be contaminated with explosives. Nevertheless, these ten subjects were assumed to be free of explosives contamination. One subject was a program manager visiting the JERC site to monitor other testing that was being conducted at the site. The PM was assumed to be free of explosives contamination. Three subjects were Nomadics personnel present for the field trials. The Nomadics personnel were working around explosives for the duration of the test, but did not deliberately handle or come into contact with explosives. Finally, three test subjects were EOD technicians who handle explosives on a nearly daily basis. These subjects were assumed to be contaminated.

Swipe samples were collected from test subjects at various locations on their bodies. Samples from the hands were of particular interest. Objects such as eyeglasses, car keys, and cell phones were also sampled because they are routinely touched with the hands. Shoes were also sampled.

Tables 5 and 6 summarize the swipe sampling of human test subjects. Only one YPG administrator out of the ten sampled caused a sensor response. After some investigation, it was determined that the alarm was caused by the cologne the individual was wearing. Some colognes (musks, in particular) contain nitroaromatic compounds similar to TNT. Fido responds to these colognes. All test participants were asked if they wore cologne or perfume (all but one was). Hence, this problem does not appear to be widespread since most fragrances did not cause a sensor alarm.

One false alarm was registered on a Nomadics test subject. This person was sampled 8 times, and a response was observed only once. This led to an investigation as to how this person may have become contaminated. Swipe samples were taken of items at the CM facility. In particular, items that are routinely touched were sampled. The front door of the office at the facility, and handles in the men's bathroom tested positive. The individual that alarmed had recently entered the building through the contaminated door. It is not known if this false alarm was due to accidental contamination by explosives, or was a true false alarm.

Finally, the EOD technicians were analyzed. Almost all samples collected from EOD personnel tested positive. 23 of 28 samples collected from EOD techs were positive. The largest responses were found on cell phones and on the hands. Surprisingly, no explosive traces were detected on the shoes of EOD personnel.

Subject	Role	Correct	Total	False Positives	False Negatives	Positives	Negatives
A	EOD (JERC)	2	2	0	0	2	0
B	Nomadics	7	8	1	0	0	8
C	PM (JERC)	1	1	0	0	0	1
D	Nomadics	2	2	0	0	0	2
E	EOD (CM)	15	18	0	3	18	0
F	Nomadics	1	1	0	0	0	1
G	YPG Admin	3	3	0	0	0	3
H	YPG Admin	5	5	0	0	0	5
I	YPG Admin	8	8	0	0	0	8
J	YPG Admin	0	6	6	0	0	6
K	YPG Admin	4	4	0	0	0	4
L	YPG Admin	3	3	0	0	0	3
M	YPG Admin	3	3	0	0	0	3
N	YPG Admin	3	3	0	0	0	3
O	YPG Admin	3	3	0	0	0	3
P	YPG Admin	3	3	0	0	0	3
Q	EOD (CM)	6	8	0	2	8	0

Table 5. Summary of swipe sampling analysis of human test subjects

YPG Admin	1 of 10 persons alarmed	1 False Positive (cologne)
EOD	3 of 3 persons detected	All three handled explosives during test
Nomadics	1 of 3 persons alarmed	1 False Positive (May have been contaminated at site)
Other	1 person, No alarms	PM, had not been exposed to explosives

Table 6. Summary of swipe samples collected from human subjects

Characterization of Explosive Samples

Explosives are not pure materials, but are mixtures composed of multiple chemical constituents. For example, TNT contains other nitroaromatic compounds such as 2,4-dinitrotoluene (2,4-DNT) and 1,3-dinitrobenzene (1,3-DNB). Fido responds to these and other nitroaromatics, but the sensitivity of response and the sensor response kinetics for each compound is slightly different.

For example, the onset of response to TNT is typically slow compared to 2,4-DNT and 1,3-DNB, and the time required for the response of the sensor to return to baseline after a response to TNT takes longer than for 2,4-DNT or 1,3-DNB. When a sample of TNT is presented to Fido, the observed response is actually a composite of all the responses to the different nitroaromatic species in the sample. The resulting response profile therefore contains information indicative of the chemical composition of the explosive. Because samples of TNT from different points of origin may contain different chemical constituents, or the same constituents in different ratios,

the response profile to a given sample of explosive could be different than that of a second sample of explosive. As can be seen from Figure 8, the response of Fido to two TNT samples from different sources is significantly different. It was postulated that these differences were due to differences in chemical composition of the two samples.

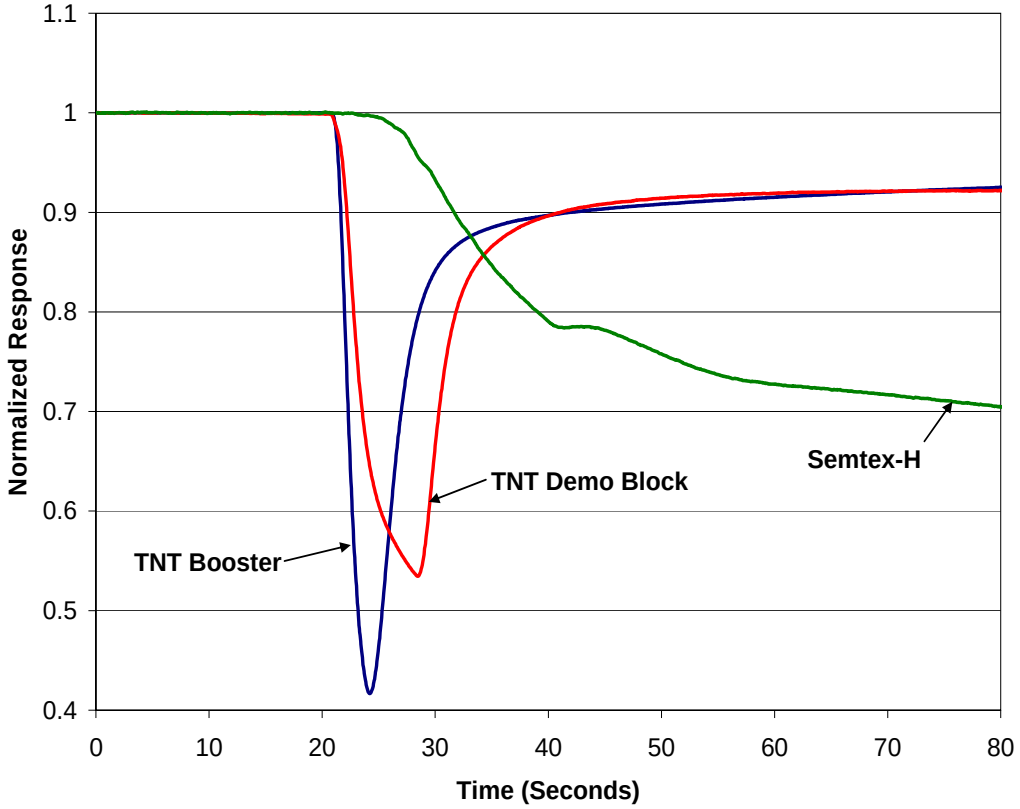

Figure 8. Comparison of Fido responses to two different samples of TNT and a sample of Semtex-H.

To test this hypothesis, the chemical composition of the two TNT samples was determined using standard laboratory methods of analysis. A sample of each explosive was placed in a separate 40 mL glass vial, and the vials were then sealed with a septum closure. The sealed vials were then placed in a temperature-controlled heating block held at 35° C. The samples were allowed to equilibrate in the heater block for approximately one hour. After the equilibration period, vapor samples were collected from each vial using solid-phase microextraction (SPME). This method of sampling is performed by exposing a sample of vapor to a glass fiber coated with a material to which molecules of explosive vapor strongly bind. The coated fiber is inserted through the septum and into the vapor inside the vial. The fiber is left exposed to the vapor sample inside the vial for a period of time. The uptake of constituents of the explosive vapor is proportional to the concentration of the constituents and the amount of time the fiber is left exposed to the sample. By exposing the fiber to the sample for long periods of time (hours), it is possible to accumulate detectable quantities of sample constituents that are present in a sample even when the concentrations of these constituents in the sample vapor are extremely small.

After the SPME samples were collected, they were analyzed using gas chromatography (GC) with electron-capture detection (ECD). The electron-capture detector can detect low picogram (1×10^{-12} gram) masses of most explosives, and when used as a detector in conjunction with the GC it is useful for identifying sample constituents. Fido is more than 1000 times more sensitive than the ECD and can also be used as a GC detector, but the ECD was used here because it is a recognized laboratory method for explosives analysis.

The GC method used to analyze samples was a modification of EPA Method 8095 (Analysis of Explosives by Gas Chromatography), a recognized method for analysis of explosives. Table 7 lists the compounds from Method 8095 that were searched for in each sample. The relative analyte concentrations in each sample (ranging from 0.00 for non-detects to 100.00 for the largest response obtained) are listed in the table. The relative concentrations are derived from the chromatographic peak areas and ECD response factors for each analyte. A sample of Semtex-H was also analyzed by this method.

Analyte	Relative Analyte Concentration		
	TNT Demo Block	TNT Booster	Semtex-H
Nitrobenzene	0.00	0.00	0.00
2-Nitrotoluene	0.00	0.00	0.00
3-Nitrotoluene	0.00	0.00	0.00
4-Nitrotoluene	0.00	0.00	0.00
2,6-Dinitrotoluene	0.09	0.00	0.00
1,3-Dinitrobenzene	2.43	0.00	0.06
2,4-Dinitrotoluene	64.58	0.24	0.03
2,4,6-Trinitrotoluene	100.00	6.53	0.03
1,3,5-Trinitrobenzene	0.00	0.00	0.00
4-Amino-2,6-Dinitrotoluene	8.97	0.62	0.06
2-Amino-4,6-Dinitrotoluene	15.94	1.19	0.00
RDX	0.00	0.00	0.87

Table 7. Results of SPME/GC/ECD analysis of explosive samples

The composition of the TNT demolition block and TNT booster were found to be significantly different. Interestingly, the number of constituents and their concentrations were higher for the TNT demo block. The largest response was to TNT vapor emanating from the demo block. In addition, the demo block contained 2,6-DNT and 1,3-DNB. These analytes are absent in the TNT booster sample. Of particular interest is the presence of higher concentrations of 4-amino and 2-amino dinitrotoluenes in the demo block. The onset of response of Fido to amino-DNTs is slow relative to other nitroaromatic compounds, which could account for the difference in response for the two samples.

These results suggest that it may be possible to use Fido to screen samples of explosive in the field for the purpose of determining if the chemical makeup of the samples is significantly different. The two samples included in this study were different in composition, and also generated Fido responses that were differentiable. Only a limited number of samples have been analyzed to date, so it is not known whether the origins of two samples of an explosive can be routinely linked to the same or different sources with any degree of certainty. While initial

results are promising, these results should be regarded as tentative until more samples have been analyzed.

Another interesting result was that the Semtex-H sample was found to contain traces of nitroaromatic compounds. Semtex-H is an RDX-based plastic explosive, and should not contain TNT. Fido does respond to RDX and PETN, but it is much more sensitive to nitroaromatic explosives such as TNT. The response to Semtex-H observed in Figure 8 is largely characteristic of RDX, which produces a sluggish response that is very slow to recover. The quenching response to RDX is typically slow to develop, and continues to increase in magnitude even after the sample is removed from the sensor. This sample of Semtex-H was presented to the sensor at 20 seconds into the data trace, and was removed from the sensor at 40 seconds. Interestingly, a small recovery in response was observed at 40 seconds when the sample was removed. This recovery is consistent with the presence of nitroaromatics in the sample (which recover after response), as opposed to RDX which recovers very slowly (or not at all) after a response. Hence, features consistent with the presence of RDX and nitroaromatics are both present in the Fido sample response. Note that the levels of nitroaromatics detected in the samples are very low, requiring a very sensitive sensor in order to enable detection with high levels of probability.

The presence of trace levels of nitroaromatics in non-nitroaromatic explosives could increase the probability of Fido detecting samples of plastic explosives such as Semtex, C-4, and PE-4. It is not known how frequently plastic explosives contain traces of nitroaromatics, but in a related study of explosives collected at a canine training facility, 19 of 19 samples were found to contain nitroaromatics. Only seven of the samples should have contained nitroaromatics, suggesting that cross-contamination of explosives could be common. Hence, the presence of trace levels of nitroaromatic contamination could enhance detection of low-vapor pressure plastic explosives via detection of the nitroaromatic contamination (with the nitroaromatics serving as an 'accidental' taggant). Figure 9 shows an arms cache that was seized during the liberation of

Figure 9. Arms cache seized in Fallujah, Iraq; cross-contamination of explosives will likely increase the probability of detection by Fido

Fallujah, Iraq. Note that many types of explosive devices containing a variety of types of explosive are stored in close proximity to each other. This could lead to cross-contamination of the explosives, which should increase the probability of detecting IEDs via detection of the higher vapor pressure nitroaromatic contamination. This finding also warrants further study.

Demonstration of Fido in Other Forensics Applications

Detection of Explosives Traces in Hair

A series of experiments were conducted in which hair samples collected from human test subjects were exposed to vapors of explosives. Hair samples were collected in accordance to the protocols approved by an Institutional Review Board. Hair samples were collected and placed in a glass container with a volume of 0.5 liters. Inside this container, a small container holding 1 gram of TNT was placed so that the TNT did not come into direct contact with the hair sample. The small container was not sealed so explosive vapor would fill the larger container, thereby exposing the hair sample to TNT vapor. Hair samples were left exposed to the TNT vapor overnight. The next morning, the hair was removed from the glass container and transferred to a second, clean glass container. Fido was then used to analyze the hair samples directly. No responses were obtained. Next, acetonitrile extracts of the hair samples were taken and analyzed by GC/ECD and GC/MS. Again, no responses consistent with the presence of explosives were observed. Hence, it was concluded that the hair samples were contaminated at levels below the detection limits of the laboratory instruments and Fido. The method used for contaminating the samples would limit the possibility of the hair containing trace particulate contamination, which should be easy to detect. Individuals preparing or handling IEDs would likely contaminate their hair with microscopic particles of TNT, either through exposure to the environment or by contact of their hair with contaminated hands. The hair samples collected for inclusion in this study were collected from persons who do not work around explosives, so the samples were only exposed to explosive vapor. This could account for the low levels of contamination observed. Perhaps a more realistic scenario would have been to collect samples of hair from individuals after they had participated in the role playing experiment that will be described later in this report. These individuals handled explosives as part of the role playing experiment, and could have contaminated their hair in the process.

Detection of explosives contamination in hair has been reported in the literature. Worked performed by Oxley et. al. demonstrated detection of explosives contamination using laboratory instruments that are approximately 1000 times less sensitive than Fido. Hence, this type of contamination should be possible to detect. During a Phase II effort, these experiments would be repeated in an attempt to determine why the contamination could not be detected with Fido.

Results of IED Bombmaking and Detection Experiment

The goal of this study was to determine whether detectable levels of trace contamination are spread by bomb makers during construction, transport, and deployment of IEDs. Ten test subjects were divided into two groups of five. Group 1 constructed a pipe bomb using a TNT simulant (plumber's putty containing NESTT TNT). Group 2 constructed a pipe bomb identical to the one constructed by Group 1, but Group 2 did not use the NESTT TNT simulant (the bomb

contained plumber's putty only). Each subject in each test group performed a specific task, as outlined below:

- Subject 1: Pack simulant (or decoy) into a pipe
- Subject 2: Screw caps on pipe and insert simulated detonator (wires)
- Subject 3: Placed assembled device in a backpack and delivered to subject 4.
- Subject 4: Removed device from backpack and placed the device in a toolbox. Delivered device to subject 5 using a simulated vehicle.
- Subject 5: Carried device to site of deployment

Prior to each group performing the assigned tasks, each subject was sampled using the swipe collection method described previously to verify that all test subjects were free of explosives contamination. Personal affects (cell phone, wallets, and eyeglasses) were also sampled. Figure 10 illustrates the sampling process, and also outlines the locations from which samples were collected from subjects. All subjects were found to be free of contamination prior to performing their individual tasks. Likewise, swipe samples were collected from the IED construction materials and simulated vehicle / transport materials prior to testing. All were free from explosives contamination.

After the inital screening was completed, the subjects in each test group performed their assigned tasks. Participants who 'drove' the simulate vehicle were instructed to touch items (a steering wheel, a gear shift, and a door handle), thereby emulating contact with items in a vehicle that would occur during driving. Figure 11 illustrates test participants executing their individual tasks. After all participants had completed their assigned tasks, they were individually placed in a room with a sensor operator who collected samples from the individual and analyzed them with Fido. For most participants, four samples were taken from each individual. All sampling locations outlined in Figure 10 were not sampled on each subject. However, the hands of each individual were sampled. The sensor operator did not know which test group or which task an individual had completed, so the analysis was conducted in a blind manner. Test subjects were not allowed discuss their task with the sensor operator.

Test results are summarized in Table 8. All subjects in Test Group 1 were found to be contaminated with explosives, as were the items making up the simulated vehicle. The subjects in the 'decoy' control group and their vehicle were free of explosives contamination. The hands of the subjects appear to be the most likely location to detect contamination. However, personal affects such as cell phones appear to be good sampling locations as well. Any object that would be touched through the activities of the contaminated individual is likely to become contaminated.

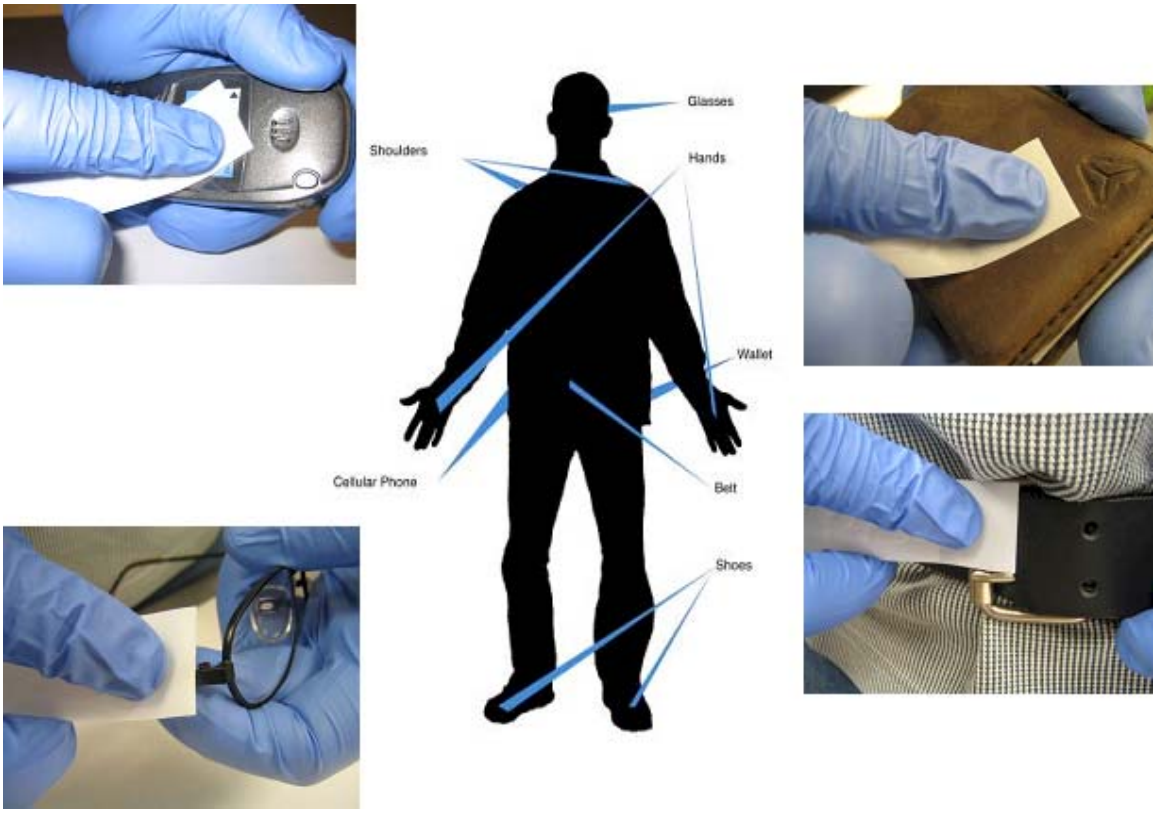

Figure 10. Locations from which swipe samples were collected

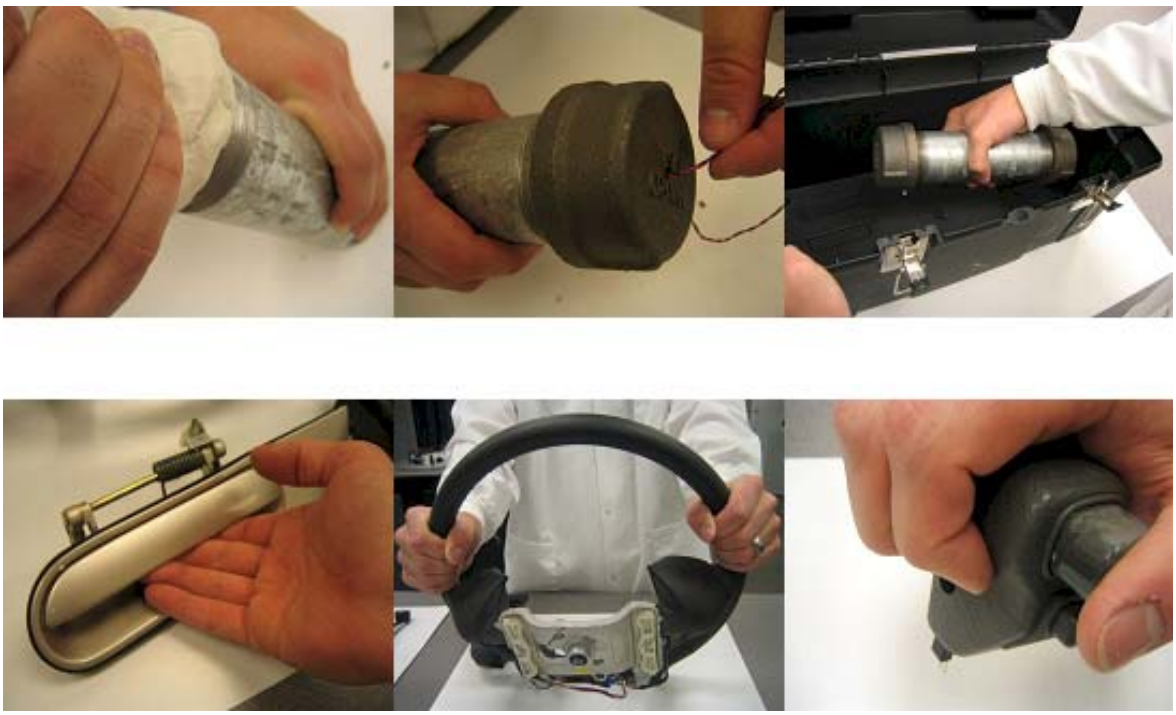

Figure 11. Test subjects completing assigned tasks

	Subject	Task	Sampling Locations						
			Hands	Belt	Cell Phone	Shoulders	Wallet	Glasses	Pocket
IED	1	Assembled	Positive	Negative	Positive	Unsampled	Positive	Unsampled	Unsampled
	2	Caps / Detonator	Positive	Positive	Positive	Unsampled	Unsampled	Negative	Unsampled
	3	Transported in Pack	Positive	Unsampled	Unsampled	Positive	Positive	Unsampled	Unsampled
	4	Transported in Car	Positive	Unsampled	Negative	Negative	Unsampled	Negative	Unsampled
	5	Deployed IED	Positive	Unsampled	Positive	Negative	Unsampled	Unsampled	Unsampled
Decoy	6	Assembled	Negative	Unsampled	Negative	Unsampled	Negative	Unsampled	Negative
	7	Caps / Detonator	Negative	Negative	Negative	Unsampled	Negative	Unsampled	Unsampled
	8	Transported in Pack	Negative	Unsampled	Unsampled	Negative	Negative	Unsampled	Unsampled
	9	Transported in Car	Negative	Unsampled	Negative	Negative	Unsampled	Negative	Unsampled
	10	Deployed IED	Negative	Unsampled	Negative	Unsampled	Negative	Unsampled	Negative

Positive Negative Unsampled

Table 8. IED fabrication / detection experiment results

Test Subject 1 in the IED group was asked to wash his hands after being detected after assembling the device. Subject 1 washed his hands with soap and water a total of five times. After the fifth washing, traces of explosive could still be detected on the individual. This illustrates how difficult it is to remove trace explosive contamination from surfaces, hence increasing the probability of detecting terrorists involved in the IED chain.

Detection of Explosive-Contaminated Fingerprints with Fido

During the course of the role-playing experiments described above, fingerprints of individuals whose hands were contaminated with explosives were transferred to surfaces contacted by these individuals. By using Fido in direct sample introduction mode (swipe sampling methods obviously smear the print), it was possible to sweep the sensor across a surface and detect localized areas of contamination associated with fingerprints of individuals who had handled explosives. No responses were obtained from surfaces contacted by individuals in the control group. The same contaminated fingerprint could be detected numerous times without any noticeable reduction in sensor response. Hence, the fingerprint was not being destroyed by the sensor, enabling collection of the print for identification purposes. This demonstrates the capability to associate explosives contamination to fingerprints of suspects. This information would link specific individuals to the handling of explosives, and hence possible terrorist activity.

Conclusions

All project objectives were successfully demonstrated at the proof-of-concept level except for detection of explosives contamination in hair. Sampling methods suitable for collection and analysis of forensics samples in the field have been identified and demonstrated. The Fido system has been modified to facilitate analysis of these samples on-site. Sample collection and analysis for swipe samples can be completed in under 30 seconds, while direct sampling of objects suspected of being contaminated can be conducted in near real-time. Field tests of the system were conducted at YPG in December 04. These tests successfully demonstrated the capabilities of the system at a proof-of-concept level. Vehicles contaminated with explosives and persons who had handled explosives were detected at high levels of probabilities with a low occurrence of false alarms.

An initial attempt at demonstrating the ability to differentiate between two samples of TNT was encouraging, suggesting that it may be possible to link samples of an explosive to the same or

different points of origin. In addition, traces of nitroaromatics were found in samples of non-nitroaromatic explosives, which could enhance the ability of Fido to detect low vapor pressure plastic explosives via nitroaromatic cross-contamination. These results are promising, but due to the limited scope of the study the results should be regarded as tentative.

The results of IED role playing experiments show that individuals who assemble, transport, and deploy IEDs will likely become contaminated with detectable levels of explosive, providing an avenue for interdiction of subjects involved in terrorist activities. The forensics evidence obtained by Fido could be used to detect terrorists and bomb-making materials and sites prior to deployment of an IED, preventing IED incidents resulting in death, injury, or damage to property. Non-destructive detection of fingerprints of bombers was also demonstrated using Fido in direct vapor sampling mode. It was also shown that it is very difficult to remove explosives contamination from surfaces, specifically the hands of contaminated individuals. After washing his hands 5 times with soap and water, explosives traces could still be detected on the bomber.

Proposed Work Plan for a Phase II Effort

The results of this Phase I effort were extremely encouraging, demonstrating that a small, portable vapor sensor could be used to collect forensics evidence that can be used to help apprehend those involved in the chain of events leading up to deployment of an IED. By detecting those involved prior to actual deployment of a device, and by detecting IED factories or arms caches, a greater impact can be realized relative to detection of deployed devices. Detection of an IED factory or arms cache could result in the seizure of IED construction materials that could be used to make many IEDs, and the chances of apprehending those involved in the construction of the devices is excellent.

At the end of the Phase I effort, the technology is mature enough to undergo further testing and possible deployment in-theatre early in a Phase II effort. As part of the Phase II effort, the hardware would be further ruggedized for use in battlefield environments. In addition, feedback from soldiers who have been in-theatre would be evaluated and recommendations for system improvements would be incorporated. In addition, new forensics applications would be pursued based on end-user needs and feedback. The system is small, portable, and adaptable so that CONOPS involving its use can be easily modified to meet the needs of the soldier. For example, the same sensor that was used in a handheld mode for this work has been mounted on a variety of robotic platforms to facilitate remote detection of targets. We envision that the system could be used at checkpoints or on patrols to screen suspects, vehicles, buildings, and other items that are potentially being used in terrorist activities. We welcome the opportunity to submit a Phase II proposal if interest in this technology warrants it.