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T&E FOR NATIONAL SECURITY

FEATURED CAPABILITY

Battelle—Innovative Contributions to the Nation's Chemical and Biological Defense

TECHNICAL ARTICLE ABSTRACTS:

Benefits of T&E Atmospheric Modeling Technologies to Homeland Security and Defense

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This article describes how atmospheric modeling technologies developed at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, to support test and evaluation activities have been applied for homeland security and homeland defense. The models to be discussed define atmospheric processes ranging from the large weather-map scale to the scales of turbulence in urban street canyons. These models have been used to satisfy both domestic and worldwide needs, and they have the ability to be used for forensic analysis or operational prediction. They also can be linked with many other models to produce specialized products such as predictions of the transport and diffusion of hazardous chemical, biological or radiological material released into the atmosphere.

Pushing T&E Out of the Box: Engaging ITEA M&S with Homeland Security Issues

Dr. Julie A. Seton
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In 2002, the ITEA Modeling and Simulation Workshop committee ventured to include a session regarding the new arena of Homeland Security (HLS)/Homeland Defense (HLD). This bold move was intended to provide an opportunity to gain a fuller understanding of issues and concerns that flooded the U.S. consciousness after the September 11, 2001, terrorist attacks. The conference committee chair invited me to serve as the HLS/HLD session chair, stating that, "You are the only one I know who is actively involved in homeland security." My background as an emergency response exercise coordinator, civilian volunteer fire fighter and fire officer, and liaison between government and industry, seemed a good fit for the challenge, so I accepted.

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Use of Commercial Gaming Software for Object Model Visualization in a Live, Virtual and Constructive Testing Environment

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New transformation initiatives across the Department of Defense are driving more modular and adaptive technologies in evolving military systems. To properly test these upcoming systems, similar transformation must also occur in the test and evaluation environment. Changes will require the seamless interaction of static and dynamic components. The Aberdeen Test Center is using static object model design to provide the interface between live, virtual and constructive entities within a dynamic environment provided by a commercial gaming engine.

Spectrum Monitoring for Training Centers Adapted to Support Testing

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This article outlines the spectrum surveys conducted at two major continental U.S. training centers, describes the challenges that led to the development of the Mini-Spectrum Monitoring and Engineering Control System devices, and outlines their application to test and evaluation ranges.

The Four-Element Framework: A Mission-Focused Test and Evaluation Strategy

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The test and evaluation (T&E) community has recognized that the results of system evaluations can be improved by finding a way to link the system's performance to the desired mission capability. This article presents a method of achieving this goal by developing a "four-element framework" that extends the traditional function-based evaluation methodologies to a mission-based methodology. The four elements at the heart of the method are: mission, system, evaluation and test. The construction of each element and the interfaces between them is presented. The four-element framework provides a systematic approach to developing a T&E plan that evaluates mission capabilities, system effectiveness and system suitability, as well as enhances the T&E effort by focusing on the accomplishment of mission tasks and promoting synergistic use of all data into a fully integrated T&E effort. This article presents the conclusions of the evaluation characterizing a system's military utility in terms of the warfighter's ability to perform the tasks essential to a successful mission while maintaining an evaluation of system effectiveness and suitability.

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Sequential-Designed Experiment Yields Concrete Debris Models for Penetrating Fragments

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Northrop Grumman provides advisory and assistance services to the Defense Threat Reduction Agency (DTRA). DTRA is interested in quantifying the attributes of secondary debris in rooms adjacent to munition bursts resulting from weapons detonated in urban environments. If the detonation leaves the wall intact, the debris in the room can be generated by bomb fragments that penetrate the wall. Little data exist on this phenomenon, so tests were run to collect information. A sequential D-optimal designed experiment (described in the June/July 2007 issue of The ITEA Journal*) was used to obtain data for fragments that penetrate all the way through concrete walls. The sequential experiment overcame inexact test input settings, a test failure, budget cuts and missing data to yield models that describe slab damage, concrete debris and the statistical distributions for debris mass and diameter.*

Ultraviolet (UV) Stimulators Based on LED Technology for Testing of UV Missile Warning Systems

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This article describes the results of a technology evaluation focused on ultraviolet (UV) light-emitting diodes (LEDs) as possible sources for use in optical test stimulators. This article also describes concepts for stimulators that might be used for testing UV missile warning sensors and systems in laboratory, flight-line and open-range test environments. This work was funded by the Test Resource Management Center's Test and Evaluation/Science and Technology Multi-Spectral Test Focus Area.

Overcoming Integration Complexity: USAOTC's Two-Pronged Approach

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In an effort to improve integration of modeling and simulation, there are many improvements being made that, in and of themselves, are very positive steps. The move toward "open" standards and protocols, increased understanding through metadata and ontological technologies, increased ease of use through standardizing architectures, and the improvements being made in middleware technologies each address a piece of the integration puzzle. But when taken in the aggregate, these standards, protocols, frameworks and architectures contribute to an ever-increasing integration complexity that tends toward unmanageability. This article discusses the integration complexity problem and how crucial it is to adopt a new way of thinking in order to achieve efficient and flexible integration. This article then discusses the advances being made within U.S. Army Operational Test Command toward application of complex adaptive systems and capabilities-based testing methodologies.

PRESIDENT'S CORNER

I trust each of you is enjoying the fall season. Autumn is particularly beautiful here in the New England area. Once again, thank you for your support of ITEA.

For this edition of the *ITEA Journal*, I would like to address a serious problem that is impacting the ability of the test community to do its job: the loss of key test resources. Three specific areas are of concern. First, our future test and evaluation (T&E) workforce may not have the skill set necessary to test complex weapon systems. Second, our land ranges already lack sufficient space to test advanced weapon systems, and what space we *do* have is being encroached upon. And third, the radio frequency (RF) spectrum critical to range operations is being auctioned off.

As some of you may be aware, the Test Resource Management Center is conducting a Major Range and Test Facility Base (MRTFB) workforce study for the Under Secretary of Defense (Acquisition, Technology and Logistics). One issue the study will be addressing is that of an aging T&E workforce, whose members are retiring and not being replaced. From 1990 to 2000, the average age within the Department of Defense-wide government civilian sector increased by four years. Is the same trend true for T&E? In addition to losing our legacy system T&E capabilities, we are finding that our workforce lacks the advanced training and skill set necessary to test advanced weapon technologies, such as directed energy, hypersonics and ChemBio. How do we attract the talent to address this problem? Do we continue with the trend of replacing organic capability with contractors? How much organic capability is needed? Once these and other workforce issues have been quantified, we must develop, execute and track the progress of a plan to provide our workforce with the expertise, along with the proper blend of organic and contractor talent, in order to meet the T&E needs of tomorrow's weapons.

Directed energy, ChemBio and hypersonics testing also pose unique challenges to range resources. The requirements of new, stringent environmental legislation, increased population in the vicinity of ranges, and land encroachment are limiting the types of testing that we can conduct. The testing of hypersonic vehicles poses a different problem in that sufficient unencumbered and contiguous real estate does not exist to support testing over the full flight envelope of the system under test. We are working this problem. We have agreements with the Australians to share their vast land resource. However, for reasons of cost avoidance, a U.S.-based solution is also required. One solution is the increased use of large-area water ranges, such as those that already exist in the Gulf of Mexico and Barking Sands, Hawaii. Satellite-based systems, such as GPS and Iridium, will play a major role in instrumenting these non-land-based ranges. Also, we can no longer afford to maintain separate ranges for the test and training communities—we must share our limited range resources and their attendant instrumentation. This is slowly happening. Eglin Air Force Base in Florida, primarily a munitions test range, will soon be the training range for the Joint Strike Fighter (JSF). To facilitate changes such as these, interoperable instrumentation must be developed (see "President's Corner," *ITEA Journal*, March/April 2007). This brings us to the third item…RF spectrum.

Thomas J. Macdonald

Beginning in 1900 when Marconi commercialized the spark generator for worldwide wireless communication, there has been exponential growth in the demand for RF spectrum. This has been particularly true in the last 10 years with the explosion in the use of RF-hungry commercial products such as high-definition (HD) satellite-based television, cell phones, personal digital assistants (PDAs) and more. The U.S. government has met this demand by selling off 21 percent of the L- and S-bands used by our test community as the workhorses of telemetry systems. At the same time, the test community's demands in data rate capacity have soared from data rates measured in kbits for F-16 testing to Mbits for F-22 and JSF testing. The Office of the Secretary of Defense predicts that we need an additional 650 MHz of telemetry bandwidth, and we are working with the World Radio Conference to gain access to the super high frequency (SHF) band to meet this need.

However, more spectrum allocation is not the only answer. We must develop new telemetry technologies to replace our present ones, which were developed in the 1950s. This includes improving and adopting spectrally efficient waveforms and moving toward wideband, wireless networking. We must promote more efficient use of the spectrum by employing a single system that supports all range functions (for example, time-space-position information [TSPI], telemetry, platform termination and end-game scoring) that are currently supported with individual dedicated datalinks. Additionally, we must work to make viable such "out-of-the-box" technologies as free-space optical communications. Lastly, as with ranges, testers and trainers must share the same spectrum. This sharing will enhance spectrum utilization, while providing a larger advocacy base to defend this most valuable resource.

It is axiomatic that testing of tomorrow's advanced weapon systems will require investing in the development of advanced test range instrumentation and capabilities. But this is not enough. We must invest in our three key range resource areas: personnel, ranges and spectrum. The test community must be committed to this undertaking. Your comments are always welcomed and encouraged. Please e-mail me at: **comments@itea.org**.

Test and Evaluation in a Time of War: Making Defense Systems Reliable

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With our nation engaged in the historic Global War on Terrorism, every element of our national security apparatus must maintain a sharp focus on how to best aid this effort. Test and evaluation (T&E) is no different in this regard and is doing many things with the single aim of getting effective and suitable weapon systems to our warfighters in the field as quickly and efficiently as possible. To accomplish these goals, the T&E community is engaged on two fronts: first, we are responding to today's call for urgency in all we do to support the warfighter's operational needs; and second, we are working to effect lasting policy changes that will result in more reliable future defense systems.


Dr. Charles E. McQueary

To ensure that systems designed to meet urgent operational requirements are deployed as quickly as possible and with as much confidence as possible, the T&E community has developed and is utilizing organizational commitment—and individual creativity—and flexibility. These characteristics are necessary ingredients because requirements and concepts-of-operations terms for urgently needed systems are often vaguely stated. Many times, the requirement is simply boiled down to "something better than what we have." Another characteristic of urgent operational requirements is shortened timelines, which often means fielding without the usual breadth of testing, because when threat operational modes change, our engaged warriors must have responsive systems immediately. When all of these factors are considered, it is obvious to see why the T&E community is working so hard to react to and accommodate shortened timelines that are consistent with meeting urgent requirements.

Why is it so important for us to ensure that our warfighters can employ new capabilities as quickly as possible and with as much confidence as possible? Because if a system cannot be counted on to perform when needed, not only is mission success jeopardized, but our warriors will develop doubts about the weapon system's performance, which can impact both individual and organizational mission performance.

The T&E community has responded to these challenges by sometimes working around the clock at ranges such as Yuma (Arizona) and Aberdeen (Maryland) to provide 24- or 48-hour turnarounds for information on critical equipment and systems, such as body and vehicle armor.

Testers are also working to help meet the urgent needs of our warfighters in the critical mission of defeating Improvised Explosive Devices (IEDs). For this urgent need, the Army Test and Evaluation Command (ATEC) has taken on the mission to plan, conduct and report the results of tests, simulations, experiments and evaluations to ensure that our warfighters have the right capabilities for success across the entire spectrum of operations. As part of these efforts, testers at ATEC are conducting rapid testing in direct support of the warfighter to provide information on the capabilities and limitations of untested weapon systems issued directly to our soldiers conducting combat operations. The Joint IED Defeat Organization (JIEDDO) expects testers to use flexible, streamlined and tailored test procedures that are based on standard test protocols. Examples include: reusing knowledge and data from other projects; sharing data among services and agencies; and providing concise and timely reports to enable decisions on fielding, improvement or termination.

Like the Army, the Air Force T&E community is working hard to be responsive to the urgent operational needs of our warfighters, and is providing rapid evaluations of components for urgently needed capabilities such as Integrated Base Defense Security, and Global Hawk and Small Diameter Bomb employment.

The Navy T&E community also is responding across the entire spectrum of urgently needed warfighter capabilities, including efforts to evaluate and provide information on the Counter-Bomb/Counter-Bomber Advanced Concept Technology Demonstration, which will help meet evolving, asymmetrical and sophisticated terrorist threats. These detection and mitigation systems will provide force protection personnel with the latest concept of operations, tactics, techniques and procedures, as well as rules of engagement generation, update and dissemination.

Another way that testers are meeting the challenges of urgent operational requirements is through deployed Forward Operational Assessment (FOA) teams. FOA teams ensure that information needs are identified to state-side ranges and that the information supplied from the ranges is relevant and properly reported to our forces. This response by the T&E community is especially noteworthy because it often involves a level of commitment and sacrifice that is outside the typical T&E operating envelope, and it exemplifies the ends to which the T&E community is prepared to go to support our warfighters.

The second front on which the T&E community is engaged is the policy arena: to effect lasting policy changes that will result in more reliable future defense systems. This front involves efforts in the Pentagon, by the offices of the Director, Operational Test & Evaluation (DOT&E) and the Under Secretary of Defense for Acquisition, Technology and Logistics (USD[AT&L]), to develop and implement policies that will improve the reliability of systems that reach our warfighters through the traditional or formal acquisition process.

This effort is important because a large number of programs are not satisfactorily demonstrating that they meet reliability requirements, and poor reliability drives down mission accomplishment and affordability, as well as drives up force structure, total cost of ownership and the logistics footprint. This means that if a weapon system is dependent upon a component that is prone to failure, the affected military service must plan, organize, equip and operate in a manner to offset or accommodate the expected component failure. The resulting logistical footprint of components needed to replace a failed system include: the creation of redundant systems and the provision of spares that must be purchased, transported, stored and used to repair the system. These steps may require added personnel, tools, test equipment and training (or contract support) to find and replace the failed component and to return the system to service. Obviously, it is preferable to minimize operational down-time, costs and logistical footprint that result from insufficient system reliability.

Another frustrating issue that testers contend with in the reliability area is systems coming to test before they are sufficiently mature. Often, schedule considerations preempt methodical system technical development, and tests can begin while the system is still technically immature. Sufficient maturity in reliability is especially troubling, as test experience indicates. Looking at initial operational T&E (IOT&E) results, for which DOT&E reports to Congress, the trend is not good. From 2001 to 2005, the suitability performance rate for systems ranged from 33 percent to 60 percent of systems found not suitable in IOT&E. In the Army, from 1996 to 2006, 66 percent of systems failed to meet reliability requirements and, of those, 75 percent failed to meet one-half of the requirement. Navy testing in Fiscal Year 2007 resulted in more than half of its systems being found not suitable. A Fiscal Year 2007 breakdown of DT/OT events indicates that 43 percent of Air Force tests were slipped. In Fiscal Year 2006, 25 percent (two of eight) of the OTs that were started had to be stopped because of system deficiencies.

These unsatisfactory results add up to our forces not receiving the planned equipment improvements they need, because either the system fielding had to be delayed to fix suitability problems—most often the deficiencies are in reliability—or the choice was to field the system with its built-in lack of reliability. We know reliability deficiencies can compromise mission effectiveness, because as I mentioned previously, if an unreliable system cannot be counted on to perform when needed, then our warfighters will obviously doubt the system's performance, and this will erode overall mission success.

Deficiencies mean that part(s) of the system need to be reworked to get what was originally desired. In my experience in the private sector, it is this "rework" that is the big cost and schedule driver.

So, what can the test community do to reduce the rework problem? First and foremost, the deficiencies must be discovered and corrected as early as possible—IOT&E is too late. I have said that *"OT&E should be a time of confirmation, not discovery."* This is only possible if the systems engineering work of which reliability design and testing is an integral part is done up front. Emphasis on reliability testing needs to go beyond traditional tasks (that is, failure modes and effects analysis, failure reporting analysis and corrective action system, environmental stress screening and burn-in, and so forth) to include physics of failure modeling and simulation (that is, fatigue analysis tools, finite element modeling, dynamic simulation, heat transfer analyses and so forth) and reliability design testing. Reliability design testing includes Reliability Enhancement Testing/Highly Accelerated Life Testing (HALT), Accelerated Life Testing, and environmental survey tests. Without comprehensive lower-level testing (for example, HALT) on most or all critical subassemblies, and without significant integration and developmental testing, it is unlikely that high levels of reliability will be achieved.

The significance of the suitability problem can be defined and measured in terms of the cost over the life cycle and the cost to correct the problem if it moves past the design process. This is why DOT&E has made improving suitability its first priority and has sponsored studies to determine the costs of unreliability, as well as the return on investment (ROI) that is possible with targeted reliability engineering. The results are striking.

One study found that reliability goals did not appear to be informed management decisions or the initial engineering effort. Another study also found significant re–design effort after the initial design was complete and the systems were through their IOT&Es. For the purpose of the studies, the late effort to correct problems had a special benefit, namely, the budget justifications called out the amounts spent correcting reliability problems after developmental and operational tests. With the ability to track the budget to improve reliability and the ability to calculate the reduced life cycle operating and support costs, each group could calculate the ROI. The ROIs for investment in reliability improvements were all greater than 4:1. The median reliability ROI was 15:1.

In 2005, a representative of the Defense Supply Center reported that the Defense Logistics Agency (DLA) Reliability program had similar results. The programs were smaller and focused on component improvements for aviation components in already fielded systems. In total, DLA provided $36 million from Fiscal Year 2003 to Fiscal Year 2005, for which it estimates a 10-year savings of $496 million, broken down as follows:

- Twenty-seven Army projects with $14.1 million funding with $187 million in estimated savings;
- Forty-five Navy projects with $9.7 million funding and $207 million in estimated savings; and
- Twenty-one Air Force projects with $8.3 million funding and $102 million in estimated savings.

While these projects were small, a 13.8 ROI is consistent with the findings for the larger and system-level findings of our studies.

DoD's Reduction of Total Ownership Costs (R-TOC) program is a slightly different example of what ROIs are possible. Fiscal Year 2005 cost avoidances were reported to be $2.1 billion, and projected life cycle cost avoidances will exceed $76 billion. The R-TOC program is Office of the Secretary of Defense (OSD)-led and Service-supported. It seeks to facilitate both new technologies and management practices to improve readiness and reduce ownership cost. Funding for R-TOC was provided from DoD through out-of-POM cycle sweep-up funding through three Program Budget Decisions (PBDs). The Services were not required to set up and fund R-TOC projects. The DoD funding total was approximately $40 million in these PBDs. So the billions in savings resulted from an investment of approximately $40 million, plus intensive management attention to improve techniques and procedures.

The R-TOC program addresses already existing systems. What ROIs are possible if the investment is done as part of the up-front systems engineering effort? In the cases where the investment occurred after the initial design was complete and often after the IOT&E, calculating the ROI was possible because the reliability improvement occurred after the initial design was complete, so the cost was separate from the initial systems engineering effort. Still, the reduction in operations and sustainment (O&S) cost was in the 23- to 86-percent range. There is evidence that an 80-percent reduction in O&S is not unreasonable to expect when the life cycle support costs are considered from the very beginning and design choices made accordingly. In a simulation of a complex ground vehicle electronics system, one study found that reliability improvement is the most significant factor in reducing the cost of ownership among the factors examined. The factors were reliability, commonality of parts (number of different configurations allowed), support system performance, packaging (that is, the use of line-replaceable modules versus line-replaceable units) and maintainability. However, when all factors were considered together and assuming best possible trades were made, an 80-percent reduction in overall support cost might be possible—which can produce billion-dollar savings.

In one case (Force XXI Battle Command, Brigade-and-Below), the improvement in reliability decreased the expected 20-year support cost from $13.6 billion to $1.8 billion (an 86-percent reduction). In another case, the Air Force post-IOT&E investment in reliability improvements for the F-22 are expected to reduce the costs from $30 billion to $25 billion, based on the current expected buy of 182 total active inventory aircraft (with a 148 primary aerospace vehicle authorization) and a 24-year life. If the buy were bigger or the life extended (as is often the case for defense systems), the savings would be greater.

Because efforts and investments to improve reliability must happen before IOT&E and in the early developmental phases, DOT&E and USD(AT&L) have developed a key partnership that is working to identify and exploit opportunities to formulate new policies for improving reliability. These joint efforts have so far included: sponsorship of an updated DoD Reliability, Availability and Maintainability (RAM) Handbook: joint sponsorship of a congressionally mandated report on current T&E policies and practices and how they can be improved: and joint sponsorship of a Defense Science Board taskforce on Developmental T&E (DT&E) that will examine how to strengthen DT&E oversight. DOT&E and USD(AT&L) are also working together to provide some guidance for the development of the mandatory Key Performance Parameter for Materiel Availability.

Working with the Joint Staff and USD(AT&L), we have initial agreement on a method for developing and justifying RAM requirements. This will provide a sound basis for the requirement, and the logistical conditions for system employment that would be a valid basis for test. Another ongoing joint effort is to look at the system development contracting process—specifically the request for proposal to industry, and determine how to include reliability requirements in the system development statement of work.

So these are just a few of the ways that the T&E community has answered the call to remain focused on our brave airmen, soldiers, sailors and marines as they sacrifice and risk all to defend our nation against enemies that are determined to undermine and destroy it. To me, the striking characteristic of the national security community of which T&E is a part is how the old parochialisms seem to melt away as we all become united and focused on supporting our warfighters. It is in these times that we cease to become developmental testers, or operational testers, and instead become just plain testers, looking for the best way to meet the urgent operational needs of our men and women at war, and to do what makes the most sense to deliver them the best systems possible. In the final analysis, we do not serve the acquisition community; we serve the men and women who are protecting our freedoms with the equipment we deliver to them. ❑

DR. CHARLES E. MCQUEARY was sworn in as Director of Operational Test and Evaluation on July 27, 2006. A Presidential appointee confirmed by the U.S. Senate, he serves as the senior advisor to the Secretary of Defense on testing of Department of Defense weapon systems, prescribing policies and procedures for the conduct of operational and live fire test and evaluation. Prior to this appointment, Dr. McQueary was the first Under Secretary for Science and Technology at the Department of Homeland Security and confirmed by the U.S. Senate in March of 2003. In this position, he led the research and development arm of the department, utilizing the nation's scientific and technological resources to provide federal, state and local officials with the technology and capabilities to protect the homeland. Dr. McQueary is a former president of General Dynamics Advanced Technology Systems, Greensboro, North Carolina. He also has been president and vice president of business units for AT&T, Lucent Technologies, and director for AT&T Bell Laboratories. Early in his career at Bell Laboratories, Dr. McQueary served as head of the Missile Operations Department for the SAFEGUARD Antiballistic Missile Test Program, based at Kwajalein Atoll in the Marshall Islands. He later headed Bell Laboratories' Field Operations Department in Great Britain in support of a Navy oceanographic research station. He also served as the director of Undersea Systems Development Lab. Dr. McQueary is a former executive board member of the National Security Industrial Association and the American Defense Preparedness Association (ADPA) (combined to form the National Defense Industrial Association [NDIA]). He is a past chairman of the Undersea Warfare Systems Division of ADPA and a former member of the Navy League Industrial Executive Board, the Navy Submarine League, the Electronics Industries Association, the American Society of Mechanical Engineers and the American Association for the Advancement of Science. He is also the recipient of the NDIA Homeland Security Leadership Award. Dr. McQueary is a graduate of The University of Texas, Austin, where he earned a bachelor of science degree in mechanical engineering; master of science degree in mechanical engineering; and a Ph.D. in engineering mechanics as a National Aeronautics and Space Administration (NASA) Scholar (masters of science and Ph.D.) and member of five academic honor societies. The University of Texas has named Dr. McQueary a Distinguished Engineering Graduate.

NIST Program to Support T&E of Trace Explosives Detection

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Trace detection is a primary strategy for thwarting terrorism activities in the United States and abroad. The development of effective reference materials and methods for this purpose relies on fundamental knowledge regarding the size, mass, morphologies and chemical distributions in residues from explosives handling, personal exposure and sampling. The authors are working with the National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES) and the Department of Homeland Security (DHS) Transportation Security Laboratory to strengthen the chemical metrology system that supports the widespread operational deployment of explosive trace detectors (ETDs).

In this effort, available resources of microanalytical and trace detection instrumentation are being applied to investigate and build fundamental understanding in: (1) sampling of fingerprints and other residues containing trace explosives; (2) inkjet printing of explosive reference and calibration materials; and (3) dynamics of particle release, capture and vapor processes in portal-based ETDs. The following will highlight some NIST activities in these areas.

■ *Sampling of residues*—A methodology was developed to evaluate particle collection efficiency by swipe sampling of trace residues. Collection efficiencies were evaluated for fluorescent micrometer-sized polystyrene latex spheres with respect to particle size and mode of deposition, collection swipe, surface type and swiping force. The particles were placed on polytetrafluoroethylene (PTFE) or muslin surfaces using either a dry deposition technique, or by embedding the particles in an artificial sebum (skin oil) expected to be more representative of real residues. Test surfaces containing particles were prepared under controlled conditions and swiped with a slip/peel tester that allowed for the evaluation of frictional forces. Collection efficiencies were determined by optical imaging and particle counting, with some data shown in *Figure 1.*

Primary conclusions include: (1) major differences in collection efficiency exist for the two different sampling materials; (2) large particles are collected more efficiently than small particles; (3) many particles are detached but not collected; (4) the sebaceous particles are more efficiently collected off surfaces than the dry particles; and (5) applying greater downward force during swiping does not significantly improve collection efficiencies. These facts imply that collection efficiency may be best optimized by improving the design of col-

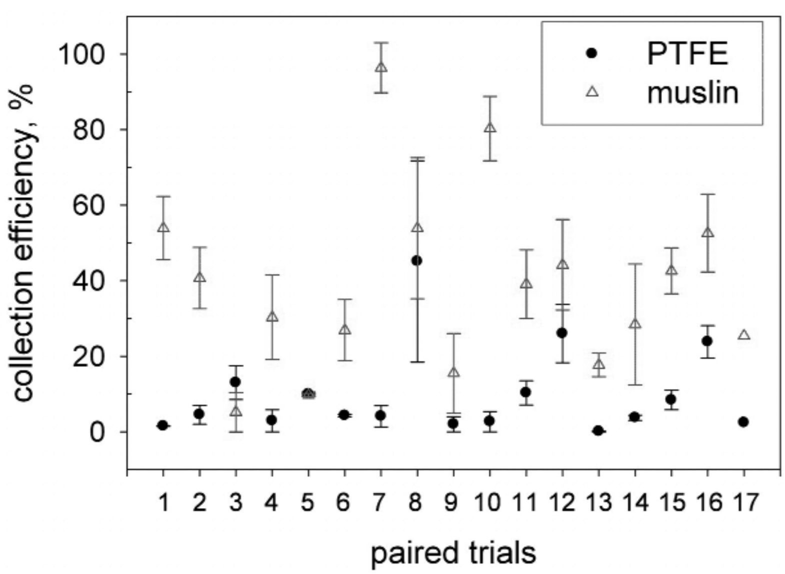

Figure 1. Paired comparison of sphere collection efficiencies for polytetrafluoroethylene (PTFE) versus muslin swipes across 17 different collection conditions (not specified here); (bars represent the standard uncertainties of the means)

lection surfaces in order to maximize the inherent adhesion to the particles, rather than by applying larger forces to detach the particles. These results have impacted sampling and screening protocols used at airports and other points of entry, thereby significantly improving explosives detection.

■ *Inkjet printing of testing and evaluation materials*—Many tens of thousands of ETDs are currently deployed, and the performance of each must be monitored frequently to verify operational readiness. Because vast numbers of reference materials are needed for this purpose, inkjet technology is being adapted as a means to print trace explosives on appropriate media. As exemplified in inkjet printing, piezoelectric nozzles offer precise and accurate control over the microdeposition of materials. Several piezoelectric systems for production of standard materials have been developed at NIST. The following section briefly describes two systems useful for the testing and calibration of trace explosive detectors.

The NIST vapor calibrator uses precise microdroplet injection and evaporation to introduce trace compounds into a calibrated airstream, where vapor signatures may be produced at fg/L to ng/L levels. *Figure 2* shows photoionization detection (PID) data from three pure fluid vapors: ethyl-2-hexanol, which has been linked with canine olfaction of plasticized explosives; isobutanol, a solvent used for preparing trace explosive standards; and methyl salicylate, a chemical warfare agent simulant. By injecting diluted solutions of explosives, concentrations have been generated that are appropriate for the calibration of ETDs, the training of canines, as well as the testing of absorptive materials designed to trap trace substances from air flows. An example is described in the next section.

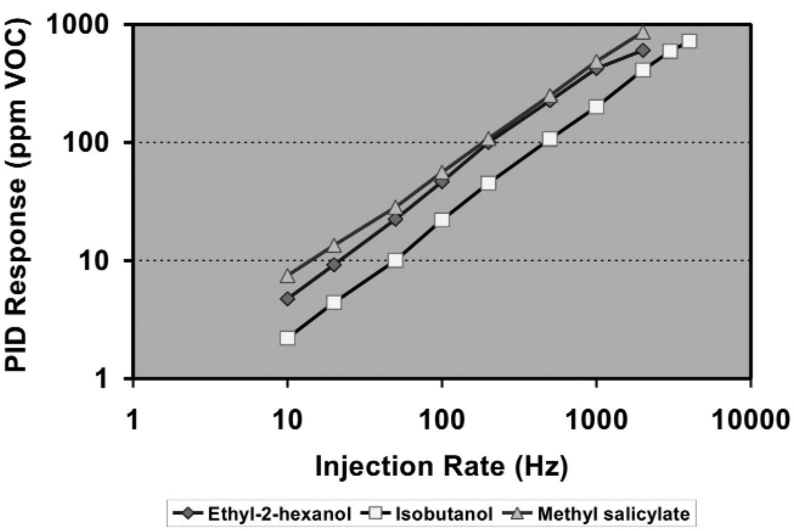

Figure 2. Responses of a photoionization detector (PID) to trace vapors of three volatile organic compounds (VOCs) injected individually at various rates in the NIST vapor calibrator

The Jetlab[1] is a drop-on-demand printing system with an XYZ-stage where substrates may be manipulated precisely under a piezoelectric nozzle. Methods have been developed to deposit trace explosives and other substances in patterns onto a variety of substrates, including sampling swipes, computer diskettes and luggage handles. The printing of bitmapped fingerprints has been demonstrated *(see Figure 3, next page),* which may be used to simulate residues found on objects at crime scenes for training purposes. The JetLab has been used to prepare reference materials containing trace amounts of composition C4, and have distributed these materials in an ongoing pilot study to intercompare ETDs deployed in varied locations. Results from intercomparisons have been extremely valuable for evaluating and improving the effectiveness of test methods and standards in the field.

NIST is developing "smart" reference swipes that provide feedback to the user. ETDs commonly use thermal desorption to liberate explosive vapors from sampled residues, so ETD reliability is dependent on desorption temperature and the co-location of the heat and deposit on the swipe material. Microdot arrays of thermochromic inks have been printed on these swipes, formulated to change color irreversibly at a specific temperature. After use in an ETD, a user with a low-power microscope may determine the location, temperature achieved and symmetry of the heated area of the swipe. This feedback provides a valuable assessment of sampling effectiveness for protocols involving swipe sampling and ETD measurements.

■ *Testing materials used in portal-based ETDs*—Many ETD technologies use preconcentration to increase detection sensitivity of the analyte. In some portal-based ETDs, particles dislodged by air jets are collected quickly on large filters, which are heated to release vapors

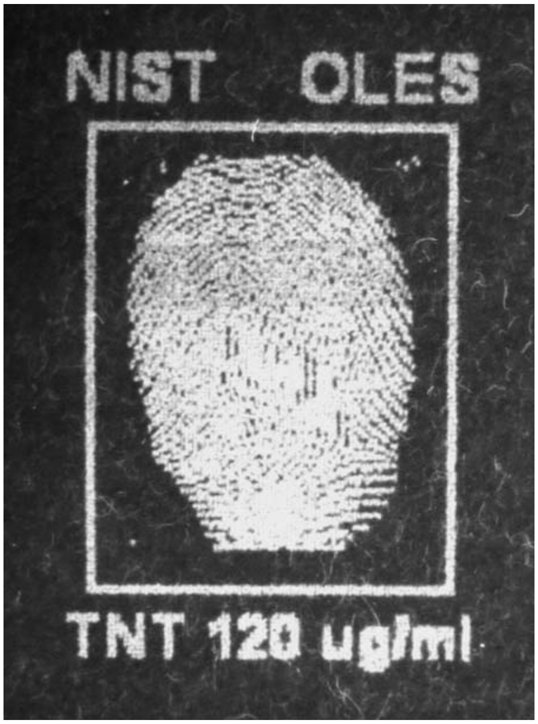

Figure 3. A bitmapped fingerprint, printed using microdroplets containing trinitrotoluene (TNT), artificial sebum and a fluorescent dye

that are subsequently adsorbed on small filters. These small filters, in turn, are heated to release the concentrated vapors for analysis. In an analogous process, some handheld vapor detectors sample a low flow of ambient air for prolonged periods to concentrate the analyte on sorptive materials and traps before analysis. In both cases, the sensitivity of detection depends on the vapor collection efficiency of the sorptive material utilized. Stainless steel filters are frequently used for the purpose of preconcentration, and the authors noted that the surface of this material develops oxide coatings (heat tint) after repeated thermal cycling.

To test the consequences of this surface alteration, stainless steel filter replicates were treated to produce oxide films on the fibers. These filters were installed on a temperature-controlled vapor collection platform and exposed to known trace amounts of cyclotrimethylenetrinitramine (RDX) using the vapor calibrator described previously. ETD measurements of these filters indicated that heat-generated iron/chromium oxide films do not significantly affect RDX vapor collection, while silanated surfaces reduce sorption and wall effects. Absorption data such as these are enabling improvements in designs of next-generation ETDs.

In summary, the goal of the NIST trace explosive metrology program is to develop measurements and standards that support the reliability of trace detection and enable the timely development of effective countermeasures to high-priority explosive threats. NIST has focused on developing fundamental measurements of particles, residues and vapors needed to improve sampling, test and evaluation materials, operational methods and technologies deployed for explosive detection. An experimental approach has been designed to determine particle collection efficiency during swipe sampling, and the authors have obtained results of high impact to agencies responsible for public safety.

Procedures also have been developed to deposit, by piezoelectric inkjet nozzles, known quantities of substances in patterns on a variety of media, useful for the production of large numbers of "smart" reference materials, and in the fabrication of training materials for first responders, security screeners and crime investigators. Another piezoelectric system, a vapor calibrator, has been developed that can deliver concentrations of trace explosives in air across at least six orders of magnitude. This has been applied to the calibration of explosive vapor sniffers and to challenge and evaluate the performance of next-generation materials in ETDs. ❑

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Endnote

[1]Certain commercial equipment, instruments or materials are identified in this article to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.