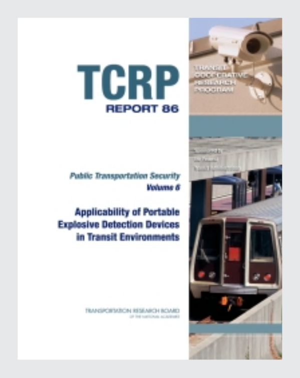


Applicability of Portable Explosive Detection Devices in Transit Environments

DETAILS

34 pages | | PAPERBACK
ISBN 978-0-309-42794-4 | DOI 10.17226/23367

AUTHORS

TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 86

Public Transportation Security

Volume 6

Applicability of Portable Explosive Detection Devices in Transit Environments

STEVEN G. HAUPT
SHAHED ROWSHAN
AND
WILLIAM C. SAUNTRY
Science Applications International Corporation
Vienna, VA

SUBJECT AREAS
Public Transit • Planning and Administration

Research Sponsored by the Federal Transit Administration in Cooperation with the Transit Development Corporation

TRANSPORTATION RESEARCH BOARD
WASHINGTON, D.C.
2004
www.TRB.org

TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, The National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

TCRP REPORT 86: Volume 6

Project J-10B(2) FY'02
ISSN 1073-4872
ISBN 0-309-06760-X
Library of Congress Control Number 2002109708

Price $19.00

NOTICE

The project that is the subject of this report was a part of the Transit Cooperative Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

To save time and money in disseminating the research findings, the report is essentially the original text as submitted by the research agency. This report has not been edited by TRB.

Special Notice

The Transportation Research Board of The National Academies, the National Research Council, the Transit Development Corporation, and the Federal Transit Administration (sponsor of the Transit Cooperative Research Program) do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the clarity and completeness of the project reporting.

Published reports of the

TRANSIT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at
http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation through research. In an objective and interdisciplinary setting, the Board facilitates the sharing of information on transportation practice and policy by researchers and practitioners; stimulates research and offers research management services that promote technical excellence; provides expert advice on transportation policy and programs; and disseminates research results broadly and encourages their implementation. The Board's varied activities annually engage more than 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

COOPERATIVE RESEARCH PROGRAMS STAFF FOR TCRP REPORT 86

ROBERT J. REILLY, *Director, Cooperative Research Programs*
CHRISTOPHER W. JENKS, *TCRP Manager*
S. A. PARKER, *Senior Program Officer*
EILEEN P. DELANEY, *Managing Editor*
ELLEN M. CHAFEE, *Assistant Editor*

TCRP PROJECT J-10B(2)
Field of Special Projects—Area of Security

WILLIAM J. FLEMING, *Massachusetts Bay Transportation Authority*
ERNEST R. "RON" FRAZIER, *AMTRAK, Wilmington, DE*
BEN GOMEZ, *Dallas Area Rapid Transit*
JOHN K. JOYCE, *Greater Cleveland Regional Transit Authority*
K. SCOTT KIMERER, *King County (WA) Sheriff/Metro Transit Police*
LISA A. MANCINI, *CSX Transportation, Jacksonville, FL*
FRANK T. MARTIN, *PBS&J, Tallahassee, FL*
MICHAEL J. WALKER, *Toronto Transit Commission*
PATRICIA WEAVER, *University of Kansas*
RICHARD WINSTON, *Chicago Transit Authority*
VINCENT P. PEARCE, *FHWA Liaison Representative*
LEWIS P. CLOPTON, *FTA Liaison Representative*
ROBERT D. JAMISON, *FTA Liaison Representative*
QUON KWAN, *FTA Liaison Representative*
TERRELL WILLIAMS, *FTA Liaison Representative*
ANTHONY VANCHIERI, *TSA Liaison Representative*
GREG HULL, *APTA Liaison Representative*
VIVIENNE WILLIAMS, *APTA Liaison Representative*
MIKE AUBERGER, *Atlantis Community Liaison Representative*
ALLAN J. DEBLASIO, *Volpe National Transportation Systems Center Liaison Representative*
PAUL GOLDEN, *DHS Information Assurance and Infrastructure Protection Liaison Representative*
KAREN HEAD, *Amalgamated Transit Union Liaison Representative*
DAN KNOTE, *Federal Railroad Administration Liaison Representative*
CHRISTOPHER A. KOZUB, *National Transit Institute Liaison Representative*
GEORGE MCDONALD, *Transport Workers Union Liaison Representative*
ED PRITCHARD, *Federal Railroad Administration Liaison Representative*
MATTHEW D. RABKIN, *Volpe National Transportation Systems Center Liaison Representative*
LENA TIMMONS, *Project ACTION Liaison Representative*
JOEDY W. CAMBRIDGE, *TRB Liaison Representative*
PETER SHAW, *TRB Liaison Representative*

AUTHOR ACKNOWLEDGMENTS

This report on the use of portable explosive detection devices (EDDs) is the result of contributions from a number of individuals, transit authorities, and federal agencies. The Transit Cooperative Research Program (TCRP) of the Transportation Research Board (TRB) funded the development of this report, and the Federal Transit Administration (FTA) sponsored its preparation. The panel for TCRP Project J-10B(2) served as the primary advisor for this study.

The information in this study is derived from the demonstration of commercial EDDs in public transit environments. The contribution of a number of metropolitan transit agency general managers, police chiefs, and other security representatives was critical in creating a document that reflects the needs of transit agency executives and managers for evaluating the feasibility of use of portable EDDs in public transit facilities.

The demonstration and conclusions in this study reflect the best judgment and experience of Science Applications International Corporation (SAIC), which conducted field demonstrations and researched and developed this report. The principal investigator of the project was Dr. Steven G. Haupt. The other primary authors are Dr. Shahed Rowshan and William C. Sauntry. The contents of this study were derived from laboratory and field tests in major transit agency facilities, interviews with transit security managers and personnel, and literature reviews, but the study does not represent the official view of any sponsor, transit administration, or federal agency.

FOREWORD

By S. A. Parker
Staff Officer
Transportation Research Board

With the current high level of security awareness in the transit environment and the large number of false bomb threats, law-enforcement and transit-security officials need tools to investigate threats before taking actions such as an evacuation order. Presently, trained dogs represent the best broad-spectrum, high-sensitivity sensory system for investigating bomb threats. Nonetheless, in addition to the use of trained dogs, state-of-the-art, technology-based tools, including portable explosive detection devices, are available for detecting the presence of explosives. Dogs can detect more items of interest than technology-based sensors can, and they can detect the presence of explosives, fuel, and disease at lower concentrations than technology-based sensors can. However, dogs can only work a short period of time before they are fatigued, and technology-based detection devices are not subject to fatigue.

Although some transit agencies deploy bomb-sniffing canine units, technology-based explosive detection devices have not been used on a routine basis in transit systems. *Applicability of Portable Explosive Detection Devices in Transit Environments,* the sixth volume of *TCRP Report 86: Public Transportation Security,* assessed the usefulness of portable explosive detectors in a transit environment. Commercially available portable explosive detection units were tested in the laboratory as well as in field tests in actual transit agency environments such as subway stations and platforms, bus stations, tunnels, and repair facilities. Training, implementation issues, and specific information on explosives detection are discussed herein.

This volume of *TCRP Report 86: Public Transportation Security* will be of interest to transit general managers; transit law-enforcement and security officials; and operations, training, and human-resources staffs. It will also be of interest to federal, state, and local law-enforcement representatives. This volume was prepared by Science Applications International Corporation, under TCRP Project J-10B(2).

Emergencies arising from terrorist threats highlight the need for transportation managers to minimize the vulnerability of passengers, employees, and physical assets through incident prevention, preparedness, response, and recovery. Managers are seeking to reduce the chances that transportation vehicles and facilities will be targets or instruments of terrorist attacks and to be prepared to respond to and recover from such possibilities. By being prepared to respond to terrorism, each public transportation agency is simultaneously prepared to respond to natural disasters such as hurricanes, floods, and wildfires, as well as human-caused events such as hazardous materials spills and other incidents.

This is the sixth volume of *TCRP Report 86: Public Transportation Security,* a series in which relevant information is assembled into single, concise volumes, each pertaining to a specific security problem and closely related issues. These volumes focus on the concerns that transit agencies are addressing when developing programs in response to the terrorist attacks of September 11, 2001, and the anthrax attacks that followed. Future volumes of the report will be issued as they are completed.

To develop this volume in a comprehensive manner and to ensure inclusion of significant knowledge, available information was assembled from numerous sources, including a number of public transportation agencies. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data and to review the final document.

This volume was prepared to meet an urgent need for information in this area. It records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. Work in this area is proceeding swiftly, and readers are encouraged to be on the lookout for the most up-to-date information.

Volumes issued under *TCRP Report 86: Public Transportation Security* may be found on the TRB website at http://www4.trb.org/trb/crp.nsf/All+Projects/TCRP+J-10.

CONTENTS

APPLICABILITY OF PORTABLE EXPLOSIVE DETECTION DEVICES IN TRANSIT ENVIRONMENTS

SUMMARY

With the current high level of security awareness in the transit environment and the considerable proportion of bomb threats that are hoaxes, law-enforcement and transit-security officials need decision-making tools to investigate threats before taking actions such as an evacuation order. The use of technology is one option for safely investigating bomb threats.

In addition to the traditional practice of using trained dogs, state-of-the-art tools are available for detecting the presence of explosives, including portable explosive trace-vapor detection devices. Some transit agencies deploy bomb-sniffing canine units, but the dogs can only work a short period of time before they are fatigued. Many of the technology-based detection devices are not subject to fatigue, but they have not been used on a routine basis in transit systems.

This report addresses the need to determine the usefulness of existing portable explosive detection devices (EDDs) in a transit environment. The audience of this report includes transit agency general managers, middle- to upper-level managers, transit-security and/or law-enforcement officials, and local or state law-enforcement representatives.

The Federal Aviation Administration (FAA) is the first transportation agency that has deployed EDDs (for use at airports). The technology is predicated on trace-vapor detection of explosive residues using ion mobility spectrometry.

The methodology for this research included selecting commercially available portable EDDs and testing them in the laboratory as well as in field tests in actual transit agency environments such subway stations and platforms, bus stations, tunnels, and repair facilities. The test method for the field tests was semi-quantitative and reproducible, and it tested the full cycle of detection capabilities from sample collection to identification. The test strategy was based on methods used by the Transportation Security Administration (TSA) Howard Center (formerly the FAA Technical Center), but was adapted to the needs of the study.

There are a number of explosive detection systems that are designed around vapor and trace detection. Unfortunately, the majority of modern explosive compounds display an extremely low vapor pressure and make vapor-based detection difficult. The vapor pressure is the gas phase pressure due to the material that is found in the air

above the explosive. Materials that are volatile have a very high vapor pressure and are inherently easier to detect. Materials that have a very low vapor pressure (like most explosives) are inherently harder to detect. For the purposes of this study, vapor detection capabilities were not tested.

This report investigated a number of currently available and emerging technologies that are suitable for portable instrumentation for explosives detection. Many of these technologies are based on trace or vapor detection and would include Ion Mobility Spectrometry (IMS), Surface Acoustic Wave (SAW) detection, electrochemical detection, and fluorescent polymers. One of the key parameters to be compared is the relative sensitivity of the equipment. The amount of material available in the gas phase or as a trace contaminant in typical applications is very small and makes detection very challenging.

IMS is one of the leading technologies for field portable trace detection and was the type of technology used in this study. It is used in a number of security-related applications to detect contraband items such as drugs, explosives, and chemical warfare agents (CWAs).

A comparison between the portable EDDs and canine units was made under this study. The canine nose is able to spatially locate the source of a scent, allowing the rapid search of a large area. In addition, canines are able to distinguish the presence of explosives in complex environments and are much less susceptible to the problems of masking interferents. The disadvantages of using dogs are the extensive training requirements and their inability to work for extended periods. Costs are approximately $10,000 to purchase a trained animal and a $2,000 annual cost for care and feeding. For information on using dogs for explosive detection, see *TCRP Report 86: Public Transportation Security—K9 Units in Public Transportation: A Guide for Decision Makers.*

In the decision-making process for transit agencies who are considering deploying portable EDDs, the acquisition, installation, training, operations, and maintenance costs associated with these devices are important factors. These costs will undoubtedly vary depending on the conditions and circumstances of the application. For example, screening vehicles entering tunnels or underground garages and screening packages or other possessions of transit riders on the platform are two different applications of the devices. Another consideration is comparing the costs of using portable EDDs to the costs of using intensive hand searches or dogs trained to detect explosive residues.

The onsite testing was undertaken at three major transit locations within the United States. The criteria for the transit site selection included system age, location, climate, and types of available systems. Collectively, the transit sites used to test portable EDDs were representative of the range of potential applications and reflected the nature of the perceived threat to transit systems. Specifically, the selected sites included diesel and compressed-natural-gas bus maintenance yards; diesel and electric rail (including commuter rail, subway, light rail, and street trolley); parking facilities (including garage and underground facilities); access points to transit operations (e.g., turnstiles, escalators, tunnels, and platforms); and other areas where suspicious packages may potentially be found.

The portable EDD used for testing was relatively simple to handle and operate. It was proven reliable in detecting trace explosives while operating under a wide range of conditions. The devices are lightweight and very transportable. They proved to be reliable (no systematic failures) and to be able to operate for extended periods. On average, it took an operator less than 2 minutes to complete each test.

One of the aims of this study was to uncover conditions that may affect these devices adversely, such as the existence of external fumes near cleaning closets, copy shops, hairdressers, restaurants, or around combusted diesel fuel. None of the external factors in these places seemed to significantly affect the outcome of tests. This report addresses a number of potential scenarios in the transit environment. In many of these situations, the trace detection equipment could offer meaningful aid. In others, the current technology is problematic. Some of the scenarios addressed in the report are listed below:

Abandoned or Lost Articles. In cases of suspicious packages, transit officials typically call explosive ordnance disposal (EOD) units to evaluate the package, but it would be very desirable to be able to perform a screening prior to calling officials. The equipment used in this study appears to be reliable and sensitive enough to be used as a screening tool, but it has some limitations. The portability, ease of operation, short setup time and sensitivity of the system makes it attractive for this application. However, taking swab samples is an issue when examining abandoned/lost articles because, in the case of a suspicious abandoned package, the operator may decide not to handle the package for safety reasons. In this case, the trace detection equipment provides little utility.

Screening. Passenger screening does not seem to be a feasible use for this type of system. Lining up passengers for screening, as is done in airports, would cause massive delays in commuter travel. In addition, a single station may have multiple entry points, leaving an attacker with the option to bypass the screening point.

Post-Blast Analysis. An application of the EDD is the use of the device to evaluate post-blast residue. The EDD may be a tool to aid in collection of evidence in the field. Information collected from interviews with transit officials suggested that this technology could provide significant help in investigating bomb crime sites. After a blast, railcar parts can be investigated for residues of explosives.

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of the research reported here was to demonstrate the capabilities of existing portable explosive detection devices (EDDs) in a transit environment, including subways and bus station platforms. The study addresses this objective combining three areas of expertise: (1) an in-depth understanding of transit operations and how EDDs can be used effectively without interfering with efficient operations, (2) scientific and technical expertise in the deployment and operation of portable EDDs, and (3) knowledge and experience in conducting field-operational tests to assess the efficacy of available portable EDDs in transit settings.

Research conducted for this study and reported here includes the following:

- The selected portable EDDs were tested in the transit environment, and the use of these devices to check suspicious packages was evaluated. A variety of transit and geographical environments were used in these tests.
- The intended use of these devices is to perform preliminary field tests to detect explosive materials. The ease of use was considered important because the intended operators are transit security personnel, not explosive ordnance disposal (EOD) units.
- The ability to screen vehicles at entrances to bus tunnels was evaluated.

In addition, this report makes recommendations for improvement or adaptation of the devices to the transit environment, discusses the cost of implementing and maintaining the instruments, and includes a comparison of portable detectors and canines.

1.2 AUDIENCE

This report is directed toward a range of audiences within the transit community with a collective interest in transportation security. General managers, middle- to upper-level managers, transit-security and/or law-enforcement officials, local or state law-enforcement representatives, all with a vested interest in the security of their respective transit networks, are the target audience for this report.

1.3 SCOPE

The project scope included the following:

- Establishing technical and operational objectives for explosive detection devices,
- Selecting demonstration sites and establishing demonstration protocols,
- Operating the equipment in the transit environment and documenting the test results,
- Recommending portable EDDs for application in the transit environment, and
- Estimating implementation and maintenance costs for portable EDDs.

1.4 METHODOLOGY

The method for the field demonstration was semi-quantitative, reproducible, and tested the full cycle of detection capabilities from sample collection to identification. The strategy was based on methods used by the Transportation Security Administration (TSA) Howard Center (formerly the Federal Aviation Administration [FAA] Technical Center), but was adapted to the study needs.

The research in this report involved the following general methodology:

- A literature search of the information available on portable explosive detection systems was conducted. The search included commercial detection technologies as applied by the government and private industries.
- Two leading explosive detection manufacturers were identified, and the test team attempted to borrow two portable EDDs from each company. Only one manufacturer loaned the test team the two portable EDDs. These units were the subject of the study.
- The test team completed training from the manufacturer and developed the demonstration protocol.
- A plan was developed for the onsite demonstration of the devices.
- The test team selected three transit agencies as test sites on the basis of a range of variables including location,

types of transit systems in the agency, age of the facility, and temperature and humidity conditions. The team conducted onsite field testing of the portable EDDs in the selected transit environments, evaluating the use of these devices to check suspicious packages.
- The test team interviewed security chiefs, field personnel, and/or contracted law enforcement at each transit agency to gain insight on the realities of deploying a portable EDD.
- The test team analyzed the data gathered through the onsite visits to develop a report on the findings and recommendations for improvement of the devices or their adaptation to the transit environment. The test team also estimated the costs for implementing and maintaining the devices including training and calibration requirements for effective operation

1.5 ASSUMPTIONS

The demonstration results are based upon the performance of two portable EDDs on loan from a manufacturer. The conclusions of this study are based on three case studies. On the basis of a range of variables, the demonstration team selected three transit agencies across the United States as test sites. The team conducted onsite field testing of the portable EDDs in the selected transit environments, evaluating the use of these devices to check suspicious packages.

The alarm levels of the instrumentation tested were found to be 10 nanograms (ng) for high explosives and about 70 ng for ammonium nitrate (AN) and were consistent with the manufacturer's specification. During this study, tests were conducted using sample quantities of explosives that were at, or even below, the manufacturer's specified alarm level.

CHAPTER **2**

EXPLOSIVE DETECTION DEVICES

2.1 PROPERTIES OF EXPLOSIVES

It is useful to first examine the physical properties that are unique to explosives and examine how these properties define the technical challenge in detecting improvised explosive devices (IEDs). Most portable detection equipment has been designed for airport security and is focused on finding modern plastic explosives that can create significant damage, even in small quantities. The majority of modern explosive materials primarily consist of solid, nitrogen-containing compounds, as listed in Table 1. However, rarely are the pure explosives used. The finished commercial and military products—such as C4, Semtex, detonating cord, and blasting fuses—are made using mixtures of materials such as those listed in Table 1 along with binding agents and other additives. Semtex, for example, is a mixture of plastic explosive hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), pentaerythritol tetranitrate (PETN), and binding agents (see Appendix A for a glossary of acronyms for explosives). Manufactured in the former Czechoslovakia and now in the Czech Republic, Semtex has been exported in large quantities to the Middle East and has been used in a number of high-profile terrorist bombings, including the 1988 Lockerbie (Scotland) bombing and the 1998 embassy bombing in Kenya.

There are a number of detection systems that are designed around vapor and trace contamination. Unfortunately, the majority of modern explosive compounds display an extremely low vapor pressure and make vapor-based detection difficult. The vapor pressure is the gas phase pressure due to the material that is found in the air above the explosive. Materials that are volatile have a very high vapor pressure and are comparatively easy to detect. Materials that have a very low vapor pressure, like most explosives, are harder to detect. Table 1 reports the vapor pressure for a number of explosives. The vapor pressure reported in Table 1 is the maximum pressure that forms in the air in a sealed system. The actual vapor pressure in an open container is actually less. The very low vapor pressure of explosives makes detection using vapor-based detection systems, or “electronic noses” very difficult.

As a means of mitigating the low vapor pressure, commercial explosives are marked with volatile nitrogen-containing markers that aid vapor-based detection. Both United States law and international convention require the addition of chemical markers to commercial explosives. The accepted markers and associated properties are shown in Table 2. The vapor pressure of these additives is orders of magnitude higher than the vapor pressure of explosives they are added to. While the relative concentration of these markers is low, the vapor pressure is so high that they are much easier to detect. For example, the relative vapor pressure of ethylene glycol dinitrate (EGDN) is 10 million times greater than the vapor pressure of RDX. Addition of these materials makes it easier to detect commercial explosives, and the markers are included in the threat library of most detection systems. However, military explosives and homemade materials do not contain these markers, and most detection systems do not solely rely on finding marker vapors.

While plastic explosives are not volatile, they are relatively sticky. Traces of material will reside on people working with explosives, as well as on clothes and packages. These trace quantities can be quite persistent and can be detected after an IED has been prepared. The total amount of material that will be found on the outside of an IED is difficult to predict, but has been estimated to be on the order of 100 micrograms (μg) (Rhykerd et al., 1999). This is a very small quantity, approximately the same amount of material found in a single grain of salt. While 100 μg is a very small quantity, it represents many thousands of liters of saturated air. For example, it would take approximately 1,800 liters of air saturated with RDX vapor to collect the equivalent amount of material found in a 100-μg trace sample. Because the residue material is easier to analyze, most detection systems, including the system tested in this research, rely on trace detection and not on vapor detection. In most systems, this means that a trace sample must be first collected from the test article. This is often performed by wiping down the surface of the test article with a fiberglass cloth that collects the sample. The cloth is then placed into the analyzer, where it is then heated to high temperatures to thermally desorb the sample. There are other methods of sample collection, including using vacuums and brushes. However, in all cases, sample collection requires physical contact with the article being tested.

Most of the instrumentation developed for aviation security has focused on detecting high explosives. These materials are considered the greatest threat to aviation security. However, there are a number of other materials that are used

TABLE 1 Common explosives

Explosive	Chemical Name	Chemical Composition	Molecular Weight (g/mol)	Vapor Pressure (ppb) 25°C/77°F	Density (g/cm^3)
TNT	2,4,6- trinitrotoluene	$C_7H_5N_3O_6$	227.13	9	1.65
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine	$C_3H_6N_6O_6$	222.26	0.006	1.82
HMX	octahydro-1,3,5,7-tetranitro-1,3,5,7-tetraazocine	$C_4H_8N_8O_8$	296.15	0.0001	1.96
PETN	pentaerythritol tetranitrate	$C_5H_8N_4O_{12}$	316.14	0. 0005	1.76

NOTE: g/ml = grams per mole, ppb = parts per billion.

(SOURCES: *Handbook of Chemistry and Physics,* 2004. Committee on Marking, Rendering Inert, and Licensing of Explosives et al., 1998)

in IEDs. Figure 1 shows the materials that were used in IEDs during a 5-year period from 1991 to 1996 (U.S. Department of the Treasury, 1996). While this list is not comprehensive, it is representative of what has been used in the past. Only approximately 20% of the IEDs found in this period consisted of traditional explosives (Military-1%, Black Powder-10%, Commercial-1%, Smokeless-8%, C4-0%). The most common material is flammable liquid, a material that is not detected by most security instrumentation. The firebomb used in the train incident in the South Korean city of Daegu, in February 2003, would not have been readily detected by the current generation of trace explosives detectors.

2.2 STATE OF TECHNOLOGY (U.S. AND INTERNATIONAL)

There are a number of current and emerging technologies that are suitable for portable instrumentation for explosives detection. Many of these technologies are based on trace or vapor detection; they include Ion Mobility Spectrometry (IMS), Surface Acoustic Wave (SAW) detection, electrochemical detection, and fluorescent polymers. One of the key parameters to be compared is the relative sensitivity of the equipment. The amount of material available in the gas phase or as a trace contaminate in typical applications is very small and makes detection very challenging. Higher sensitivity is desired. A comparison of some of the leading technologies, along with canine sensitivity, is shown in Table 3. A number of technologies listed are suitable for laboratory use only, but they are included for comparison. The suitability for field instrumentation is also indicated in Table 3.

2.2.1 IMS

IMS is one of the leading technologies for field portable trace detection. It is used in a number of security-related applications to detect contraband items such as drugs, explosives, and chemical warfare agents (CWAs). An illustration of an ion mobility sensor is shown in Figure 2 as a guide to the principle of operation.

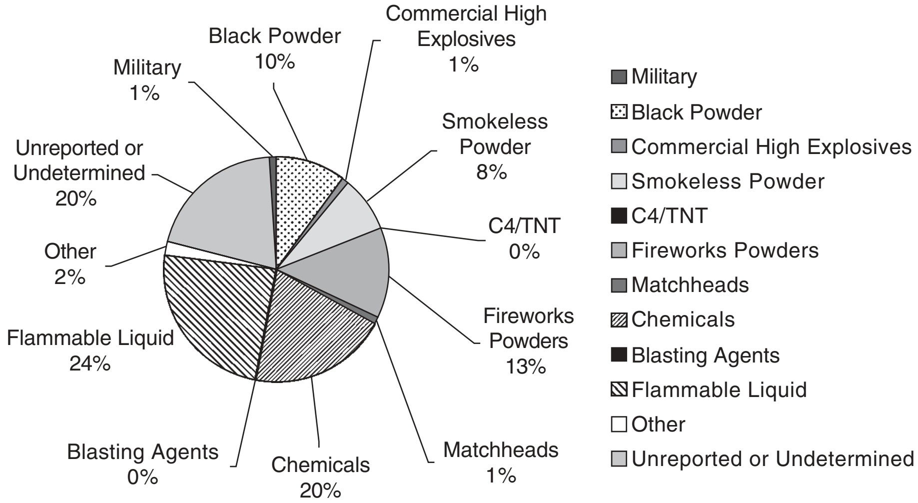
The IMS process takes place in the four distinct phases shown in Figure 3. In the first phase, the sample is vaporized into the gas phase. This is accomplished by heating the sample to evaporate it. In the "ionize" phase, the vapors are electrically charged, or ionized. In portable commercial systems, this is often accomplished using a small radioactive isotopic source. However, there are a number of other methods that can be used, including lasers and electrospray. In the example shown in Figure 2, a small Nickel 63 (Ni-63) radioactive source is used.

In the third phase, "separate," the gating grid releases the charged ions, allowing them to drift through the IMS chamber. The chamber is equipped with an electric field that draws

TABLE 2 Detection agents used in plastic explosives

Explosive Marker	Chemical Name	Minimum Concentration (percent mass)	Vapor Pressure (ppb)
EGDN	Ethylene glycol dinitrate	0.2	60,000
DMNB	2,3-dimethyl-2,3 dinitrobutane	0.1	27,000
p-MNT	Para-mononitrotoluene	0.5	>50,000
o-MNT	Ortho-mononitrotoluene	0.5	>200,000

(SOURCES: The Convention on the Marking of Plastic Explosives for the Purpose of Detection, signed in Montreal in 1991, available from the International Civil Aviation Organization, Committee on Marking, Rendering Inert, and Licensing of Explosives et al., 1998)



(SOURCE: U.S. Department of Treasury, 1996)

Figure 1. Materials used in IEDs from 1991 to 1996.

the ions to a detector. The time it takes for the ions to reach a collection plate is measured. In general, the larger and heavier ions travel slowly, whereas smaller ions arrive at the collector more quickly. Also, some materials are sticky and travel more slowly through the air on the basis of chemical composition.

When the ions reach the end of the drift region, they collide into the collector and generate electrical signals. The magnitude of the collector current, as a function of time, is roughly proportional to the number of ions arriving. The characteristic speed at which an ion moves through the drift region, called ion mobility, is a distinct fingerprint that identifies the original substance.

The attractive feature of IMS is that the measurement is carried out at atmospheric pressure, rather than under vacuum conditions. This makes it easier to build field portable equipment and provides significant cost savings. With very good sensitivity, ion mobility is capable of detecting and

TABLE 3 Vapor-based detection limits

Detection Method	Limits (pg/ml) for Vapor Sample	Suitable for Field Portable Instrument	Comment
High-Performance Liquid Chromatography Ultraviolet (HPLC-UV)	1,000	No	Suitable for laboratory use
Mass Spectroscopy	800	No	Leading instrument for laboratory use
High-Performance Liquid Chromatography	600	No	Suitable for laboratory use
Thermo-Redox/Electrochemical		Yes	Lower costs/higher false alarm rate
Thermal Energy Analysis (TEA)	30	Yes	None
Electron Capture Detectors (ECDs)	10	Yes	Less expensive, requires compressed carrier gas
Surface Acoustic Wave (SAW)	0.7–7	Yes	Promising emerging technology
Ion Mobility	0.05–.1	Yes	Predominant technology for field use
Amplifying Fluorescent Polymer	0.001	Yes	Promising emerging technology
Canine	N/A	N/A	Highest sensitivity

NOTE: pg/ml = picograms per mililiter

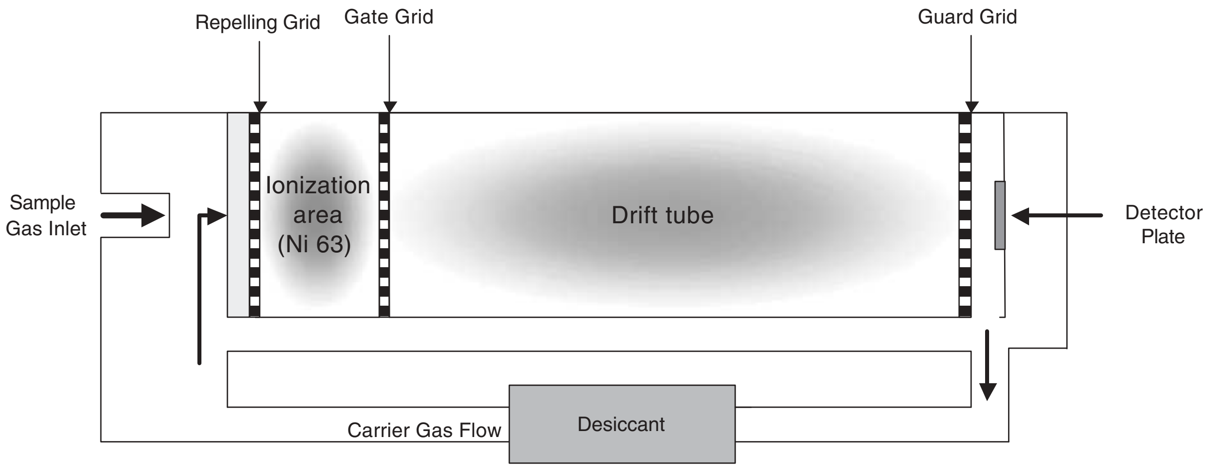


Figure 2. Ion mobility sensor.

identifying explosives. However, one limitation is that it is not capable of quantifying the amount of explosive material. It is difficult to determine how much explosive material is present in a sample. One disadvantage is that it is possible for innocuous material to display very similar drift times, and this can lead to a false alarm problem.

2.2.2 SAW

SAW sensors are an important technology for field analysis. Commercial instruments are available from a number of vendors for detection of both CWAs and toxic industrial chemicals (TICs). Many of these units are small, between 40 and 100 cubic inches, and cost in the range of $6,000 to $9,000.

The core of the SAW sensor is a piezoelectric crystal that is capable of converting an electric field into an acoustic wave. The surface of this crystal is coated with a polymer that adsorbs the explosives. The typical SAW sensor is operated at a base frequency between 250 and 500 MHz. As the polymer adsorbs the material of interest, there is a change in mass that results in a shift in frequency. This shift in frequency is the means by which the change in mass is detected and is the basis for the method of explosives detection. Often SAW devices will consist of an array of polymers to expand the threat library and as a means of reducing false alarms. Typical commercial units will have between three and eight coatings in the SAW array. A pattern recognition algorithm is then used to identify the materials of interest. While this technology is common for CWA detection and industrial material, it is currently an emerging technology for explosives detection.

There are recent developments at government laboratories, such as The Naval Research Laboratory (NRL), and commercial firms in developing this technology for explosives detection. NRL has an active program in synthesizing new polymers that are designed to detect explosives. In addition, a field portable device prototype has been demonstrated by one commercial entity. Figure 4 is the schematic diagram of SAW technology.

2.2.3 Electron Capture Detectors

Electron capture detectors (ECDs) are similar to IMSs. Like the IMS, the sample is first ionized using a small isotopic source such as Ni 63. However, rather than measuring the mobility of the ion, the system measures the affinity of the material to adsorb electrons. Another difference can be found in the carrier gas. The portable IMS systems typically use dry air as the carrier gas. However, the carrier gas in an ECD is an inert gas such as Helium or Argon. The cost of ECDs is slightly less than the typical portable IMS; the costs of consumables are slightly higher, due to the carrier gas. The sensitivity is not as good as IMS, and the false alarm rate is reported to be higher.

The principle behind the ECD is that the sample is mixed with the carrier gas and then is ionized by the isotopic source. The ionized sample then travels through a chamber that has an electric potential between an anode and a cathode. When clean carrier gas passes through the chamber, there is a fixed current.

1	2	3	4
VAPORIZE	***IONIZE***	***SEPARATE***	***DETECT***

Figure 3. The IMS process.

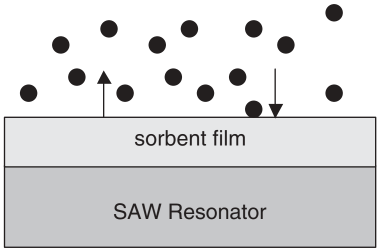


Figure 4. Schematic diagram of a SAW.

However, if materials that have a strong affinity to adsorb electrons enter the chamber, they reduce the standing current, and this forms the basis of detection. Materials that have a strong electron affinity include Nitro (NO_2) compounds, like explosives, and other materials such as halogenated compounds (halogenated compounds are materials that contain either fluorine, chlorine, bromine, or iodine). This lack of specificity means that the technique is incapable of identifying individual explosives, and there are a significant number of potential interferents. As a means of mitigating this problem, most systems are coupled with a gas chromatographic column to provide separation and identification.

2.2.4 Thermo-Redox Detectors

Thermo-redox systems are capable of detecting compounds that contain Nitro groups (NO_2). While this includes many explosives and explosive markers, it also includes a very large number of potential interferents. Costs are generally $20,000. The principle of operation is that the sample is first heated to release NO_2 molecules; these are then detected using an electrochemical detector. The system does not require a carrier gas other than ambient air. The disadvantages are that the system is only capable of detecting NO_2-containing compounds, is incapable of distinguishing between different explosives, and is vulnerable to a large number of potential interferents.

2.2.5 Amplifying Fluorescent Polymer

One emerging technology noted in this study is the use of fluorescent polymers to detect trinitrotoluene (TNT). While the work reported has centered on detection of land mines (the majority of land mines contain TNT), it is interesting to note that the sensitivity of this technology is exceptional. If this technology can be developed to detect other explosives, it could offer significant sensitivity advantages and could possibly allow operation in a vapor-detection mode. Because this technology is relatively new, there is not a commercial unit available for general explosives detection, and little information exists on costs.

The basis of detection is that the sensor contains a fluorophore that will emit light until the material of interest, TNT in this example, is attached to a receptor site. Once the material is adsorbed, there is a decrease in light signal that can be measured. What is unique to this technology is that a polymer is formed using fluorescent monomers that have conjugated backbone that acts as a conductor. In the case of the fluoropolymer, if an analyte molecule is adsorbed at any place on the chain, it suppresses the light formation of every monomer in the chain. This results in a significant amplification of signal, between 100 and 1,000 times that of the monomer fluorophore. Figure 5 is an outline of a fluorophore system.

2.2.6 Canine

A dog's ability to detect explosive material is truly remarkable. The sensitivity of a dog's nose is superior to most field portable instrumentation and has detection limits estimated to be on the order of a few parts per billion (ppb) to 500 parts per trillion (ppt) in sensitivity. Equally important, the canine nose is able to spatially locate explosive material, allowing the rapid search of a large area. In addition, canines are able to distinguish the presence of explosives in complex environments and are much less susceptible to the problems of masking interferents. The disadvantages of using dogs are the extensive training requirements and their inability to work for extended periods. Costs are approximately $10,000 to purchase a trained animal and $2,000 in annual cost for care and feeding.

Currently, 12 public transportation systems have either canine narcotics or explosives detection programs in operation (see Balog et al., 2002). Those systems without an organized canine program typically use the canine resources of local authorities when needed. Trained canines have the ability to sniff out the same explosives as the EDDs tested in this study, including TNT, RDX, PETN, nitroglycerin (NG), trinitro-

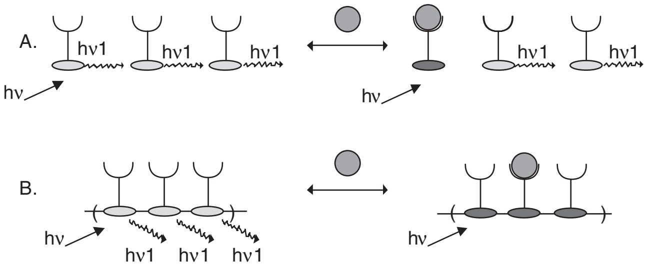


Figure 5. Outline of a fluorophore system. (A) A single fluorophore, such as Green Fluorescent Protein (GFP) extracted from a jellyfish, responds to a single analyte, decreasing light intensity. (B) In the case of the conjugated polymer system, the decrease is magnified. If the analyte is adsorbed anywhere on the chain, the signal is quenched among all the chromophores on the chain. This acts as an amplifying step and improves sensitivity by a factor of 100. The light of a given energy that is emitted by the polymer is represented (hv).

phenylmethylnitramine (Tetryl), and ammonium nitrate. *TCRP Report 86: Public Transportation Security—Volume 2: K9 Units in Public Transportation: A Guide for Decision Makers* has listed the general pros and cons of developing a canine program. Table 4 includes a summary of the pros and cons of the canine units in public transportation described in *TCRP Report 86: Public Transportation Security—Volume 2: K9 Units in Public Transportation: A Guide for Decision Makers.*

While testing at two of the sites, the test team engaged in conversations with members of the transit system's canine unit as to the advantages and disadvantages of the two systems of detection. In comparison to technology-based explosive detection, a trained canine has two distinct advantages: (1) exceptional mobility and (2) the ability to track a scent to its source. These advantages were actively demonstrated during testing at two of the three test sites (see Sections 3.2.2 and 3.2.3). Conversely, as noted in the National Institute for Justice's *Guide for the Selection of Commercial Explosives Detection Systems for Law Enforcement Applications* (Rhykerd et al., 1999), the primary disadvantages of canines in comparison with technology-based explosive detection include fatigue of the canine (thereby requiring breaks), the need for regular retraining, and the inability to communicate to the handler the type of explosive that is detected.

2.3 STATE OF RELATED RESEARCH

There are a number of reviews available that outline current and emerging detection technologies. *Handbook of Machine Olfaction: Electronic Nose Technology* (Pearce et al., 2003) provides a thorough technical review of existing and emerg-

TABLE 4 Canine explosive detection pros and cons

THE PROS	THE CONS
1. Good for public relations, supports outreach with community and media, and provides strong symbol for public safety. 2. Effective tool for deterrence and order maintenance, passengers generally like canine unit, criminals are often fearful of trained police dogs. 3. Supports a higher level of officer safety, criminal fear of dogs reduces resistance during apprehension. 4. More effective resource for facility searches, one K9 team can perform the work of four patrol officers. 5. Most effective resource available for non-repetitive detection of narcotics and explosives, no technology or other resource is better. 6. One canine team can perform dual functions, supporting both patrol and either drug or explosives detection. 7. Grants are currently available for dual-function patrol and drug-detection dogs.	1. Consequences of poor planning are exacerbated by the importance of initial decision making to program capabilities and performance. Bad decisions cannot easily be overcome. 2. Reliance on outside technical support is often necessary to start program, a major vulnerability for a system new to this function. Good help is hard to find. 3. High program start-up costs, not averaged evenly over time, places large emphasis on cost savings during the phase of project when spending is most essential. 4. Difficulty of finding good dogs, patrolling the transportation environment places additional strains on canines, selection testing is critical, but expensive and not ready made for public transportation. 5. Difficulty of selecting the right handler, public transportation systems with limited experience may value the wrong traits or fail to recognize potential shortcomings prior to a major investment. 6. Legal and public relations consequences of bites, the public has zero tolerance for what it may perceive as inappropriate force exerted by police dogs. 7. Demands of canine administration are high for a supervisor with other responsibilities, scheduling challenges limit availability of canines for service. 8. Success requires a long-term investment, several months to a year for results. 9. Constant effort is required to ensure that law enforcement and operations personnel are using the resources of the canine unit.

(SOURCE: Balog et al., 2002)

ing technologies that can be used for contraband detection, including detection of explosives. This review provides background in applications and a detailed outline of the technical capabilities and limitations of the current and emerging technologies. Particularly useful is the guide to commercial detectors and the outline of operating principles of emerging and established technologies.

The General Accounting Office has provided information on explosive detection devices that are commercially available and can be used to screen baggage, passengers, and cargo for the aviation industry in a report titled *Aviation Security: Commercially Available Advanced Explosives Detection Devices* (Dillingham, 1997). The report provides information on these devices and their underlying technologies, manufacturers, costs, capabilities, and other related information. The information gathered was used to aid the FAA in purchasing and installing various explosive detection technologies at airports in the United States.

Volumes I and II of the *Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders* (Fatah et al., 2000) was completed by the National Institute of Justice (NIJ) in June of 2000. The *Guide* provides information to aid emergency first responders in the selection of chemical agent and toxic industrial material detection techniques and equipment. The *Guide* is intended to be more practical than technical; it provides information on a variety of factors that can be considered when purchasing detection equipment, such as sensitivity, detection states, and portability.

In September 1999, the NIJ completed the *Guide for the Selection of Commercial Explosives Detection Systems for Law Enforcement Applications* (Rhykerd et al., 1999). This guide was intended to provide law-enforcement agencies with information that should aid them in the selection and use of explosives detection equipment. Much like this report, this NIJ guide highlights the capabilities of different technologies, and what technologies are likely to work best in various applications, by considering factors that are considered important to purchasers of detection equipment, including cost, sensitivity, portability, ease of use, and so forth.

2.4 EDD SELECTION

For this study, an IMS device was selected. This was based on its commercial availability and capability. The IMS process is described in Figure 6. The illustration in Figure 6 is included in the Smiths Detection *Sabre 2000 Basic Operator's Guide.* This configuration is specific to the device selected for this study and may differ from other IMS devices.

The environmental requirements of the device include most conditions encountered in indoor and outdoor operations. The operating environment temperature is from –10 °C/14 °F to 45 °C/113 °F. The relative humidity must not exceed 99% and must be noncondensing. The detection device operates on normal alternating current (AC) voltage at either 110 or 240 volts (Vs). The device also operates with a 12-V battery. The basic IMS process is described in Section 2.2.1; a specific description of the IMS process of the test unit follows.

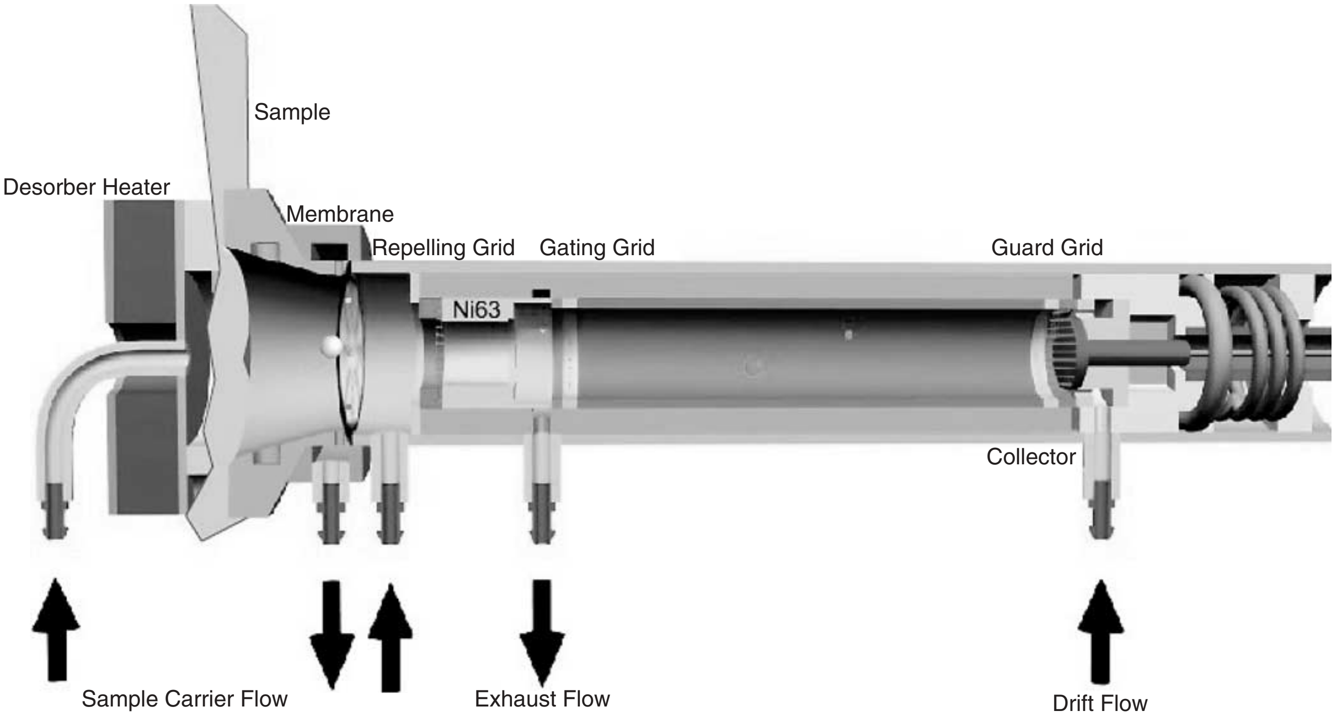


Figure 6. IMS process of tested device.

After the insertion of a swab into the device, the first phase, “vaporize,” is initiated. The particles collected on the swab are heated at a high temperature (190 °C/374 °F) by the desorber heater and transformed into vapors. The vapors then percolate through a membrane and enter the next phase. The vapors are electrically charged, or ionized, in the “ionize” phase using a sealed 15-millicurie Ni-63 radioactive source to form ionic clusters that have a specific mobility (Smiths Detection, n.d.).

The gating grid releases the charged ions, allowing them to flow through the IMS chamber in the third phase, “separate.” Larger and heavier ions such as cocaine and heroin will travel slowly, but smaller ions, such as amphetamines, arrive at the collector more quickly. When the ions reach the end of the drift region, they collide into the collector and generate electrical signals. The magnitude of the collector current, as a function of time, is proportional to the number of ions arriving at that moment (Smiths Detection, n.d.). The characteristic speed at which an ion moves, called ion mobility, is a distinct fingerprint that identifies the original substance.

After the device captures the travel time and the number of signals generated by the ions, it begins the “detect” phase to determine if the ions satisfy the criteria for the detection algorithm. Once the detection criteria are met, the device provides visual and audio alarms as well as the name(s) of the substance(s) detected, the degree of hit by way of bar graph (and a signal height), and the accuracy of detection.

The advertised detection sensitivity of the selected device is 10 ng of explosive particles. This means that the instrument can detect as little as 10 ng of most explosives. To better understand the detection sensitivity, see Figure 7. A single grain of table salt weighs approximately 1 milligram (mg). If that grain of table salt was divided into 1,000 equal portions, each would be 1 μg of salt. If 1 μg of salt were divided by 1,000, each portion would be 1 ng of salt.

2.5 COST FOR IMPLEMENTATION, MAINTENANCE, AND TRAINING

In the decision-making process for transit agencies considering the deployment of portable EDDs, the acquisition, installation, training, operations, and maintenance costs associated with these devices are important factors. These costs will undoubtedly vary depending on the conditions and circumstances of the application. Some of the different types of application of the devices include screening vehicles entering tunnels or underground garages and screening packages or other possessions of transit riders on the platform. Another consideration for transit agencies is comparing the cost of portable EDDs with the costs of intensive hand searches or the use of dogs trained to detect explosive residues.

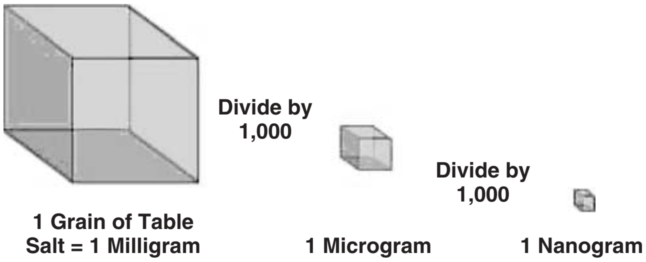


Figure 7. Sensitivity level of the selected device (not to scale).

The costs associated with the tested EDD are represented in Table 5 and are broken down into the device’s major components and their respective lifetimes.

The device does not need to be returned to the factory for any annual maintenance as long as it is kept clean and maintained properly. However, the manufacturer does offer a maintenance contract for the system to be sent back to the factory once a year. The maintenance cost is currently not available from the manufacturer. Proper maintenance includes changing the air-purification tubes and membranes when necessary.

To ensure similar performance of the portable EDDs in field tests for this research, the air-purification tubes and the membranes were replaced prior to testing at each of the three test sites. It should be noted that the replacement of these parts was ahead of schedule and was only necessary to provide testing consistency. The device is designed to allow for modular repair (9 modulars) for most components. If components such as the high-voltage power supply, the pumps, or the IMS module fail, the manufacturer recommends that the system be returned to the factory for servicing, with the cost of the service depending on the particular component failure(s). There is a standard 1-year warranty on the device.

2.6 PRELIMINARY TESTING

Preliminary testing and a field survey were conducted in preparation for the design of the field demonstration procedures. The purpose was to select test articles and develop reproducible procedures. The first task was to develop a method for placing trace quantities of explosives onto a test article. Each detector comes with a verification standard stick. This consists of a wax-like substance that is impregnated with trace quantities of explosives. It is used like a crayon to deposit trace amounts of explosive to challenge the detection system. This is a simple and convenient method of ensuring the instrument is operating. However, since the trace explosive is held in a heavy wax matrix, it is not representative of a sample found on the exterior of an IED. In addition, it is not possible to control the sample size with this technique. While it is useful as a confidence check source and in ensuring that the detection unit is functioning, a different method for preparing samples for the field demonstration was required.

The selected method for preparing samples was to use dry transfer strips developed by the TSA Howard Center. These dry transfer strips consist of a Teflon film that is coated with

TABLE 5 Pricing of selected portable detection device equipment

Component	Price	Lifetime
Portable EDD	\$20,000 – \$26,000	Dependent upon usage and maintenance.
Replacement Air--Purification Tubes	\$150 for a pack of 6	Dependent on the environment the system is being used in. The manufacturer states that a single tube can last for 7 days of operation, 24 hours a day, during normal (i.e., average humidity) conditions.
Replacement Membranes	\$40 for a pack of 5	Replaced only when the system is highly contaminated or the membrane is torn.
Replacement Calibration Standard	\$125	2 years if stored properly.
Replacement Battery	\$260 each	Can be recharged up to 2,000 times.
Swabs	\$50 for a can of 200	No shelf life, a single swab can be used up to 10 times unless it is dirty or contaminated.
Software	\$1,600	One-time cost until the release of new version.

a precise amount of explosive that can be quantitatively transferred to the test article. To transfer the trace explosive to the test article, the strip is simply rubbed onto the surface. This leaves a precise quantity of material with the same physical properties seen in residue found on IEDs.

The next step in developing the field demonstration protocol was to establish a test population. While the FAA has established test sets of baggage that represent what is seen at an airport, the items carried through the typical transit environment may not necessarily be the same. Therefore, a site survey was performed to identify what baggage and packages are seen at a transit site. It was found that briefcases, purses, shopping bags, and backpacks were most prevalent in the transit environment. Plastic handles and zippers were chosen as the test population for this research study.

In order to conduct field tests using an appropriate test set of items for ground transit terminals, it was first necessary to determine the composition of such a test set. A survey of transit sites was conducted to determine which items passengers in those environments typically carry. While much data of this type exist (collected by the FAA) for airline passengers, it was necessary to study the baggage and package population for ground transit environments.

Three observers surveyed three transit sites. They recorded observations on a data collection form that is included in Appendix C. Table 6 gives a summary organized by baggage category of the data collected. These data were obtained over a total period of 4 hours and 20 minutes at an intercity bus terminal; a combination trolley, bus, intercity-rail and commuter-rail stop; and a combination intercity-rail and bus stop. Days and times covered were a Thursday from 5:10 to 6:00 p.m. (intercity bus station), a Friday from 8:35 to 10:35 a.m. (trolley, bus, and commuter rail), and a Sunday from 12:30 to 2:00 p.m. (intercity rail and bus). It should be noted that no local peak-hour commuting was observed during these surveys. The briefcase count was therefore quite low, and more briefcases would be observed during peak commuting hours.

There was not a clear distinction among some of the baggage categories because of the wide variety of items included in each. For example, some purses are made to look like small backpacks, and some briefcases have shoulder straps and are carried on the back. Items recorded in the “Other” category included camera cases, tied boxes, portable radio/compact disc players, fanny packs, and even some unusual items such as a surfboard and a large footstool. Loose items carried in people’s hands, but not recorded above, included newspapers, maps, books, jackets, drinks, and canes. Bicycles, baby strollers, and wheelchairs were also observed.

As noted earlier, each of the categories scored contained a wide variety of items in terms of both size and construction material. Purses ranged in size from small change purses to large tote bags that rivaled the size of large suitcases. Backpacks ranged in size from very small children’s packs to very large camper/hiker styles. Shopping bags included open-weave plastic mesh bags, paper bags, and plastic bags. Items counted as luggage included soft-sided duffel bags as well as hard-

TABLE 6 Results of the site survey of baggage

Type of Item	Luggage	Shopping Bags	Briefcases	Backpacks	Purses	Other
Percent of Items	14%	13%	2%	35%	32%	4%

Figure 8. Test article (handle).

sided luggage, but the former was far more common than the latter. This diverse range of sizes and materials was noted.

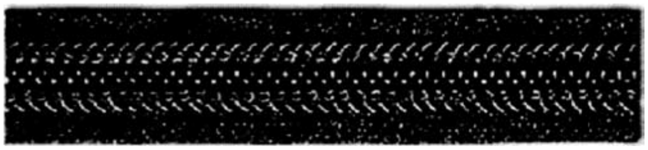


Figure 9. Test article (zipper).

Two test articles were selected for field testing. The first is shown in Figure 8 and is a plastic handle. This handle is 4 13⁄16 × 2 3⁄16 inches in size and typical of handles found on briefcases or small luggage. It is fabricated from virgin polyethylene. The second test article selected was a zipper that is typical of zippers on backpacks or purses, as shown in Figure 9. It is a size #5 plastic zipper, 7 inches long. Once test articles were selected, it was necessary to develop a reliable and repeatable method of marking them with explosives.

CHAPTER 3

TEST PROCEDURES AND RESULTS

3.1 FIELD-OPERATIONAL TESTING

Procedures were used in the preliminary field trials to test and evaluate the performance specifications, including the following:

- Detection probability;
- False alarm rate;
- Throughput rate; and
- Size, weight, and support requirements.

The goal of the field evaluation was to measure the effectiveness of the EDD under normal conditions and to determine if it was suitable for the transit environment. Ease of usage, operator interface, throughput, sensitivity, and reliability are important attributes that were monitored. Another feature that must be examined is the false alarm rate. One key goal of this study was to examine the false alarm rate when the system was deployed in a transit environment. During field testing, a false negative was recorded when a contaminated sample did not alarm. Conversely, false positives occurred when an alarm sounded on an uncontaminated sample.

Sampling included examining handles and zippers, which were contaminated with trace explosives. During these preliminary field tests, the detection system was challenged with articles contaminated with explosive simulant and articles not contaminated with trace explosives. A record of the detection/no detection reading, as well as the humidity, temperature, location, and the amount of time taken to examine the articles was made.

3.1.1 Demonstration Team

The test team consisted of two people. The *team leader* was responsible for recording all data, including the time and contaminating samples. The *device operator's* role was to set up the uncontaminated samples, perform the tests, and operate the portable EDD.

3.1.2 Training

A manufacturer's representative trained the field test team 2 months before field testing began. The training session duration was roughly 4 hours and covered a basic overview of IMS and trace-particle detection technologies, demonstrations of the device, and instructions for maintenance. The manufacturer's representative, using swabs contaminated with the supplied verification standard stick, performed demonstrations of the device. Following these demonstrations, the field test team performed multiple tests using the recommended procedures. After this, the instructor gave instructions for basic maintenance. The device is set up for modular repair by the user. The device has nine modules, all of which can be repaired by the user except the IMS module that contains the radioactive charge. That module must be sent back to the company for repair. At the conclusion of training, the instructor was briefed on the purpose of the study and answered a few questions regarding disruptions that may occur during testing, including possible false positives from combusted diesel fuel.

Organized training offered by the manufacturer for operating the device is a 1-day, instructor-led course. The course is divided into 12 individual modules covering such topics as reviewing narcotics and explosives, trace-particle detection technology, IMS, setup and start-up, collection and analysis, analysis of results, and basic maintenance of the device.

3.1.3 Field Test Sites

The onsite testing commenced at three major transit locations within the United States that will be referenced here as Test Sites A, B, and C. The criteria for the transit site selection included system age, location, climate, and types of available systems (bus, light rail, subway, regional rail, and so forth). Collectively, the transit sites used to test portable EDDs were representative of the range of potential applications and reflected the nature of the perceived threat to transit systems. Specifically, the selected sites included diesel and compressed-natural-gas bus maintenance yards; diesel and electric rail (including regional rail, subway, light rail, and street trolley); parking facilities (including garage and underground facilities); access points to transit operations (e.g., turnstiles, escalators, tunnels, and platforms); and other areas that may have suspicious packages.

All of the test sites provided the test team access to their facilities with escorts, who were transit system employees including field personnel and law enforcement. The transit agency escorts provided timely and knowledgeable information about topics such as typical bomb procedures, identification of test sites, provision of entry to secure areas, and possible deployment uses of portable EDDs. Work permits and/or badges were also provided to the test team to ensure access and safety.

The team tested a minimum of 50 sites throughout each of the three systems. A single station typically contained multiple test sites, such as platform, street, and mezzanine locations. Testing was done primarily in public areas, although the transit agency escorts allowed the test team to access restricted areas such as maintenance closets, control offices, and areas along the tracks. The restricted sites were viewed as potential sites for hiding suspicious packages and were therefore included in the testing. Sites with the potential to adversely affect the results of the detection device were of particular interest and were widely represented (i.e., sites near cleaning closets, bus stops, exhaust vents, and so forth). The test team used the transit agency representatives' knowledge of their facilities in the selection of test sites within each agency. The hours of testing ranged from 8 a.m. to 6 p.m.

3.1.4 Dry Transfer Strips

In this study, test articles were contaminated with small, yet quantifiable, quantities of actual explosives. This was accomplished by using dry transfer strips prepared by the FAA William J. Hughes Technical Center. These dry transfer strips consist of Teflon strips that are coated with very small but precisely known amounts of actual explosives. The strips were prepared by dissolving known quantitative amounts of the explosives of interest into a solvent and then pipetting the liquid to the surface of a Teflon strip. The solvent was then allowed to evaporate off the Teflon. To contaminate a test article, the dry transfer strip is rubbed along the surface of the test article. Because the explosive is on Teflon, the trace material is transferred easily to the test article. It is estimated that 95% of the trace explosive is transferred to the test article.

These dry transfer strips were prepared with 10-ng and 50-ng samples of Semtex (compound of PETN and RDX) and ammonium nitrate. The sample quantity is based on the advertised instrument sensitivity of 10 ng. While the test strips are coated with real explosives, the techniques are perfectly safe in the field because of the extremely low level of explosive concentration (ng = 10^{-9}). The strips are harmless and pose no threat to the test team or to the commuters.

3.1.5 Warm-Up

The operator's manual for the portable EDD being tested states that warm-up time is less than 15 minutes. The test team confirms that was true most of the time. At the last test site, however, most of the mornings included an extra 10 minutes (a total of 20–25 minutes) to clear nitrous oxide (NO3) from the system before the EDD was in READY mode. The presence of NO3 could have been from leftover contamination from the previous day's testing or from an abundance of NO3 in the air.

3.1.6 Verification

The test leader conducted operational checks of the equipment prior to testing using the verification standard stick provided with the device. The stick, resembling a crayon, consists of a wax-based substance, which contained trace amounts of various explosives (TNT, RDX, and PETN). A clean swab was inserted into the system to ensure that the system was free of any contamination. If the clean swab did not cause the device to alarm, it was considered to be ready for the confidence test. A small amount of the verification standard was then applied directly to a blank swab, which was then placed into the device. If a "Verific" alarm was observed, then the device was considered to be operational, and a clean blank swab was inserted to clear the device. If the "Verific" alarm failed, the process was repeated. If the expected result still did not appear, the device was recalibrated, and the process was repeated. During the field testing, a "Verific" alarm was always observed on the first try.

3.1.7 Field Test Supplies and Setup

The following is a primary list of the supplies used during the field tests.

- Portable EDD
- Verification standard stick
- Swabs
- Extension cords
- Handles and zippers
- Plastic bags
- Isopropyl alcohol swabs (for cleaning)
- Latex gloves
- Thermometer and barometer
- Stopwatch and clock

In false alarm testing using X-ray detection systems, the threat trace explosives are often moved from bag to bag within the sample set. This procedure ensures that the operator never knows what bag contains the threat, and this reduces bias in the tests. However, particle and vapor-based detection systems look for trace amounts of residual material, and, therefore, moving the trace explosives from bag to bag is not a recommended procedure. It is possible that the check source will leave a residue in a bag from which it has been removed, and all the test items could become contaminated rapidly. Therefore, for this study, the test area was prepared by placing two large plastic bags on the ground. This was to ensure that the test area was not contaminated. On the first bag, the team placed nine uncontaminated samples. The contaminated samples used for the tests were created by wiping a handle or zipper with the dry transfer strip, which had been treated with a small amount (10 ng or 50 ng) of Semtex or ammonium nitrate (see Figure 10). The two sets of samples were kept at least 2 feet apart to avoid cross contamination.

Figure 10. Dry transfer strip contaminating a handle.

At the request of the hosting transit authority, the device was checked before each day of testing to ensure that the audio alarm was disabled, and only the visual alarm was enabled. This was to avoid alarming the commuters by having the device set off alarms throughout the system.

3.1.8 Test Procedure

The testing procedure began with the setup of the site as depicted in Figure 11. Two bags were placed on the ground; nine uncontaminated samples were placed on one bag and one contaminated sample was placed on the other bag. The contaminated samples used for the tests were created by wiping them with the dry transfer strip on which the small amount (10 ng or 50 ng) of Semtex or ammonium nitrate had been evaporated. The time to set up was not included in the overall test duration. Upon completion of setup, the test leader signaled the beginning of time one (t1) and the device operator, using latex gloves, randomly selected one of the 10 samples to swab. The standard technique for swabbing samples was for the device operator to hold the swab in one hand and place the middle finger over the center of notches that are cut out of the swab along three of its edges. The majority of the handle or zipper was rubbed with pressure to remove particles from the surface of the sample. This is similar to the screening the TSA does at airports. There were four separate instrument operators in the three site visits, each using different pressure and varying speed during swabbing. Multiple operators were designated to better represent real world conditions, in which a single EDD may have multiple users. Next, the swab was inserted into the detection device sampling slot, thereby ending time one (t1). The side of the swab where the sample was collected must face the unit.

Time two (t2) began directly after t1, when the swab was inserted into the device. This time represents the time it takes for the EDD to analyze the swab, purge the air inside, and display the signal READY for analysis, at which time t2 ends. The total test duration was the time it took to complete all 10 tests. As displayed in the decision tree shown in Figure 12, the NO ALARM and ALARM results invoked different procedural actions depending on whether the sample was contaminated or not. The four results recorded during testing were ALARM, NO ALARM, FALSE NEGATIVE, and FALSE POSITIVE.

3.2 TEST RESULTS

Once a result was determined and displayed by the EDD, the data were recorded. Documentation of the test included detailed descriptions of test procedures; devices tested; test sets used; ambient conditions (e.g., temperature, humidity, and physical features of the test environment); and test results. The test team created a data collection spreadsheet in which the information was recorded manually in the field.

Figure 11. Typical setup for field testing.

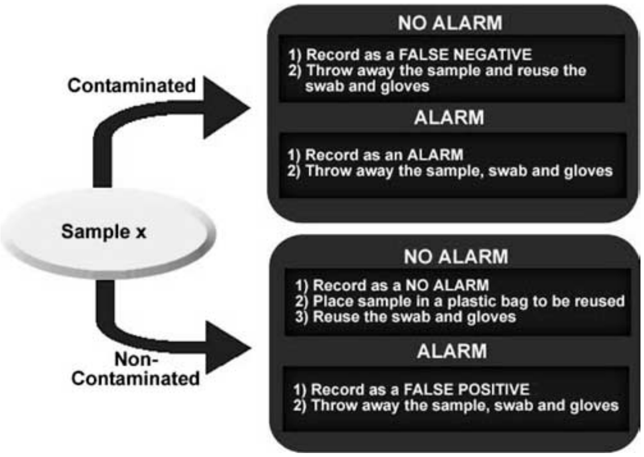


Figure 12. Procedural decision tree for field testing.

An example of the data collection spreadsheet is included in Appendix C.

The data from the spreadsheet were entered into a test database for the test sites to be synthesized and analyzed. The analysis focused on identifying statistically significant factors that affect the performance of portable EDDs in transit applications and on assessing the potential of these devices for operational deployment, including potential effects on routine transit operations. For assistance in deciphering of the results, consult the glossary of acronyms for explosives in Appendix A.

A total of 156 tests was performed throughout the three test sites, each test consisting of nine uncontaminated samples and one contaminated sample (i.e., handles or zippers). Within the "Notes" section of the data collection spreadsheet, the test leader recorded the general location of the test and a description of the environment, paying specific attention to any conditions that could cause false alarms. Possible disruption sites were identified by the observation team in consultation with local transit officials. This identification was based solely on the sites' proximity to areas that could have excessive levels of certain chemicals, such as nitrates. Nitrates may originate from sources such as cleaning agents; hair products; ink from printers, copiers, paints, and/or shoe polish; combusted diesel fuel; or fertilizers. Each of these possible nitrate sources was noticed at at least one of the three transit agencies. The reason for identifying possible areas of disruption is so that the team could determine if those areas cause an abundance of false alarms. Descriptions of the general locations along with a summary of areas that could cause disruptions are listed below.

- **Platform**—the landing alongside railroad tracks where commuters convene to wait for ground electric rail or diesel-powered regional rail.

  Possible Disruption Areas: on the platform next to a maintenance room or cleaning closet, or near any cleaning agents that were identified by smell or vision. Also, any testing performed on a regional rail platform where a diesel engine train was idling.
- **Mezzanine**—the area located before the platform, usually separated by turnstiles, stairs, or escalators; this area may include fare machines, telephones, or public service areas.

  Possible Disruption Areas: on the mezzanine next to a maintenance room or cleaning closet, or near any cleaning agents that were identified by smell or vision.
- **Street level**—the area outside the transit system, usually near the entry point from street level.

  Possible Disruption Areas: close to a street with heavy vehicle traffic or near active construction sites.
- **Bus depot/stop**—any bus stop, depot, or maintenance yard.

  Possible Disruption Areas: locations where combusted diesel fumes are expelled from idling buses.
- **On board a train**—any publicly accessible portion of a ground electric rail train car.

  Possible Disruption Areas: none of the tests on board trains were designated as producing adverse environments for testing.
- **Other**—these areas include most places not defined by the previous locations such as public waiting areas, public buildings, courtyards, hallways/tunnels, loading docks, trackside areas, emergency exits, and inside storage or maintenance rooms within the system.

  Possible Disruption Areas: near hair salons, copy centers, or construction areas using heavy equipment.

Table 7 shows the number of tests performed in each of the locations listed above, the number of those tests that were performed in areas of possible disruptions, the total number of false positives, and the number of false positives within areas of possible disruptions. Sections 3.2.1, 3.2.2, and 3.2.3, which discuss the results at Test Sites A, B, and C, respectively, include detailed discussion of false positive alarms.

3.2.1 Test Site A

Test Site A was a relatively new and clean system. The test locations included compressed-natural-gas bus transit and

TABLE 7 Summary of general test locations within the three test sites

Location	# of Tests	# of Tests with Possible Disruptions	% of Tests with Possible Disruptions	Total False Positives	# of False Positives at Location with Possible Disruptions
Platform	56	11	19.6%	9	-
Mezzanine	35	8	22.9%	3	3
Street Level	27	10	37.0%	5	5
Bus Depot/Stop	11	11	100.0%	1	1
On Board a Train	4	0	0.0%	-	-
Other	23	9	39.1%	-	-
TOTAL	156	49	31.4%	-	-

maintenance yards, above- and below-ground electric rail transit, diesel regional rail, parking facilities, subway turnstiles, escalators, tunnels, platforms, mezzanines, and street-level entries to the subway.

Table 8 provides a summary of Test Site A results. The *Number of Samples* row shows the total number of contaminated and uncontaminated samples (i.e., handles or zippers) tested at the first test site. In total, 51 tests were completed. Each test consisted of one contaminated sample and nine uncontaminated samples. The test team used 10-ng and 50-ng strips of Semtex as well as the verification stick provided by the device manufacturer as contaminants for the test samples. The *Alarms* row shows the number of correct alarms out of the total possible samples that were expected to alarm (i.e., contaminated samples). A breakdown of the individual alarm types is also listed. As mentioned, false negatives occur when a contaminated sample does not alarm. Conversely, false positives occur when an alarm trips on an uncontaminated sample. A false positive could occur on any of the contaminated or uncontaminated tests, but not the blank swabs inserted to clean the device after an alarm. The *Time 1 Average* row shows the average amount of time elapsed from swabbing the sample to receiving a result from the device. The *Time 2 Average* row shows the average amount of time it took after t1 ended for the device to be ready to analyze the next sample. The *Total Average Test Time* row shows sum of t1 and t2. Test Site A had an average test duration of 14 minutes. The average test duration is the amount of time to test all 10 samples and does not include time to set up.

3.2.1.1 False Negatives

Eight false negatives were recorded during testing at Test Site A. As noted in Table 9, six of the eight (75%) false negatives were recorded during testing with zippers. The provider of the dry transfer strips, FAA William J. Hughes Technical Center, claims that the transfer rate of a dry transfer strip is about 95%. However, due to the zipper's material, which was much smoother than the handle's material, it is possible that the transfer rate of the trace explosive from the dry transfer strip to the zipper was much less than the transfer rate to the coarse handle. A decreased transfer rate of the trace explosive to the zippers may have contributed to an increase in the number of false negatives. The total percentage of false negatives for the 10-ng tests was 67%, as compared with only 13% for the 50-ng tests. As mentioned, the advertised sensitivity limit of the device is 10 ng. The team presumes that three things may have contributed to the false negatives: (1) the known loss of explosive particles in the transfer from the dry transfer strip to the sample; (2) the possibility that the smooth surface of the zipper did not collect explosives as well as the handle during the contamination process; and, most notably, (3) the demonstration team was using the advertised minimum detection levels of the device during some of the testing (i.e., 10 ng of Semtex).

3.2.1.2 False Positives

In total, three false positives out of 510 tests (0.6%) were recorded during testing at Test Site A, all of which were nitroglycerin alarms and at the same test location within the system. This particular location was on the mezzanine level in the middle of a long hallway between the street and platform escalators. Testing took place underneath a fire-extinguisher case and next to a water drain. There was sporadic commuter traffic as subway trains entered and exited, but there were no unique characteristics of this test location that the team felt would warrant false positives. However, the test team was

TABLE 8 Summary information for Test Site A

Number of Samples:	350 Handles and 160 Zippers	
# of Test Locations:	51 locations	
Sample Preparation:	10ng & 50ng of Semtex dry transfer strips, verification standard stick	
Alarms:	43 of 51 (84%)	Alarm results: • C4/RDX – 16 alarms • SEMTEX – 12 alarms • PETN – 10 alarms • NG & PETN – 3 alarms • TNT & PETN – 2 alarms
False Negatives:	8 false negatives out of the 51 contaminated samples (16%)	
False Positives:	3 false positives out of 510 tests (0.6%)	
Time 1 Average:	27 seconds	
Time 2 Average:	15 seconds	
Total Average Test Time:	44 seconds	
Average Test Duration:	14 minutes	
Average Temp:	73.4°F	
Average Humidity:	49.7	

TABLE 9 False negative summary for Test Site A

Sample Description	# of Samples Contaminated	# of False Negatives	% False Negatives
10ng Semtex - Handle	3	1	33%
10ng Semtex - Zipper	3	3	100%
TOTAL - 10ng	6	4	67%
50ng Semtex - Handle	17	1	6%
50ng Semtex - Zipper	13	3	23%
TOTAL - 50ng	30	4	13%
Stick - Handle	15	0	0%
Stick - Zipper	0	0	0%
TOTAL - Stick	15	0	0%

using its last pair of latex gloves for this test and therefore was not able to follow standard procedure by changing gloves after each alarm. After purchasing new latex gloves, the test team returned to the same test location to perform another test to see if the false positives continued. The second test at this location returned no false positives.

3.2.2 Test Site B

Test Site B included some of the oldest and most diverse testing locations. Specifically, this site included diesel-bus transit and maintenance yards; diesel and electric rail (including regional rail, subway, light rail, and street trolley); parking facilities (including garage and underground facilities); access points to transit operations (e.g., turnstiles, escalators, tunnels, and platforms), and other areas surrounded by merchants, restaurants, and other public services. As shown in Table 10, the test team used 10 ng and 50 ng of Semtex to contaminate samples while testing at Test Site B. Fifty tests were completed with each test including nine uncontaminated samples and one contaminated sample. There was an increase in the number of false negatives at this test site, most of which occurred while testing at the device's minimum sensitivity level of 10 ng. Five false positives were recorded, and all were recorded at the same location. The average test times and durations were concurrent with those during testing at the first test site.

The transit authority at Test Site B provided the test team with an opportunity to observe their canine explosive detection capabilities. The canine testing took place in an enclosed transit authority locker room within the system. Handles and zippers, provided by the test team, were contaminated with 10 ng and 50 ng of Semtex and placed in locations such as closed lockers and closed desk drawers, and on countertops. Along with the contaminated samples, the test team's zip-locked trash bag of used samples and dry transfer strips was also hidden. Two canine units were brought in at different times shortly after the items were hidden. Within the presence of odors such as cigarette smoke and cooked food, the trainers instructed each of the dogs to search for explosives. Not only did each of the dogs signal the presence of explosives by passively sitting at the locations of the hidden items, but also, unexpectedly, the dogs signaled the presence of explosives at the desktop where the test team had contaminated the handles and zippers minutes before. Even though the test team was not testing the "sniffing" capability of the technology-based detection device, it is believed to be unlikely that the device would have performed as accurately as the canine units.

3.2.2.1 False Negatives

As shown in Table 11, 10 of the 15 false negatives (67%) occurred while testing a sample contaminated with 10 ng of Semtex. Since 10 ng is the advertised minimum sensitivity of the machine, this outcome was expected. The analysis must also consider that the transfer rate from the dry transfer strip to either the zipper or the handle is not 100%. Once again, the numbers show that the zipper had a higher false negative percentage. The 15 tests that resulted in false negatives occurred

TABLE 10 Summary information for Test Site B

Number of Samples:	410 Handles and 90 Zippers	
# of Test Locations:	50 locations	
Sample Preparation:	10ng & 50ng Semtex dry transfer strips	
Alarms:	35 out of 50 (70%)	Alarm results: • C4/RDX – 24 alarms • SEMTEX – 11 alarms
False Negatives:	15 false negatives out of 50 contaminated samples (30%)	
False Positives:	5 false positives out of 500 tests (1.0%)	
Time 1 Average:	28 seconds	
Time 2 Average:	14 seconds	
Total Average Test Time:	43 seconds	
Average Test Duration:	14 minutes	
Average Temp:	68.3°F	
Average Humidity:	39.1	

TABLE 11 False negative summary for Test Site B

Sample Description	# of Samples Contaminated	# of False Negatives	% False Negatives
10ng Semtex - **Handle**	11	8	73%
10ng Semtex - **Zipper**	2	2	100%
TOTALS - 10ng	13	10	77%
50ng Semtex - **Handle**	30	3	10%
50ng Semtex **- Zipper**	7	2	29%
TOTALS - 50ng	37	5	14%

at various locations—platforms, street and mezzanine levels, as well as inside tunnel walkways within the system. None of the locations seemed to pose any environmental conditions that may have adversely challenged the device while testing. It can be concluded that many of the false negatives were due to the same issues discussed in Section 3.2.1. The most apparent of these issues is that the 10 ng of explosive used to contaminate the samples during testing was pushing the minimum detection capabilities of the device.

3.2.2.2 False Positives

The device performed well at Test Site B with respect to false positives. There were 5 false positives recorded out of the 500 (1.0%) samples that were tested. All of these occurred in the same test location, during two separate test times, and they all had the same false positive result of triacetone triperoxide (TATP). The test location was at an outside street trolley stop next to a well-traveled intersection. Directly behind the covered trolley stop was an automobile shop. The shop's oil and transmission fluid dump tanks where roughly 15 feet away from the test location. The team's escorts mentioned that the trolley stops are usually power washed every couple of weeks, but because of the extended winter and freezing temperatures, the stops may not have been cleaned for a couple of months. The trolley stops may also have had a buildup of deicer used for the winter ice. Any one of these environmental abnormalities may have contributed to the false positive readings.

3.2.3 Test Site C

Test Site C included diesel and compressed-natural-gas bus transit and maintenance yards; diesel and electric rail (including regional rail, subway, light rail, and street trolley); parking facilities (including garage and underground facilities); access points to transit operations (e.g., turnstiles, escalators, tunnels, and platforms); and other areas that may potentially have suspicious packages.

At Test Site C, on the final day of testing, the team decided to test each of the two identical loaned explosive detection devices together. This testing was not scheduled in the initial project scope, but it was seen as possibly providing an answer to a question that would factor into analyzing the final data. The purpose of the "dual" testing was to check the sensitivity variance between the two machines to ensure that one machine was not alarming more than the other. The dual device-testing operations were identical to the single device testing. Overall, the dual testing returned similar results from the two machines. Of the 55 tests performed, 10 were performed using both machines. Six tests resulted in false negatives: one test by each machine during the same test at three different locations. In conclusion, it was found that the devices were calibrated similarly and produced similar results.

As shown in Table 12, the test team used 10-ng and 50-ng strips of ammonium nitrate and 50-ng strips of Semtex to contaminate samples while testing at Test Site C. Fifty-five tests were completed, with each test including nine uncontaminated samples and one contaminated sample. There was an increase in the number of false negatives at this test site, most of which

TABLE 12 Summary information for Test Site C

Number of Samples:	500 Handles and 50 Zippers	
# of Test Locations:	50 locations	
Sample Preparation:	10ng & 50ng of Ammonium Nitrate dry transfer strips, 50ng of Semtex dry transfer strips	
Alarms (correct alarms):	26 of 55 (47%)	• 5 – C4/RDX • 6 – SEMTEX • 1 – PETN • 14 – NITRATE
False Negatives:	28 of 55 (51%)	
False Positives:	10 false positives out of 550 tests (1.8%)	
Time 1 Average:	32 seconds	
Time 2 Average:	17 seconds	
Total Average Test Time:	49 seconds	
Average Test Duration:	15 minutes	
Average Temp:	70.0^{O}F	
Average Humidity:	55.6	

TABLE 13 False negative summary for Test Site C

Sample Description	# of Samples Contaminated	# of False Negatives	% False Negatives
50ng Semtex - Handle	12	3	25%
50ng Semtex - Zipper	4	2	50%
2x50ng Semtex - Handle	1	0	0%
TOTALS - Semtex	17	5	29%
50ngAN - Handle	32	21	66%
50ngAN - Zipper	1	0	0%
2x50ngAN - Handle	5	2	40%
TOTALS - AN	38	23	61%

occurred while testing at the device's minimum sensitivity level of 10 ng. Five false positives were recorded, all at the same location. The average test times and durations were concurrent with those during testing at the first test site.

The hosting transit authority of this test site also provided the team with the opportunity to challenge their canine unit's detection capabilities. This second instance of canine testing took place at an open-air bus stop in the middle of a breezy day. Multiple handles and zippers contaminated with 50 ng of ammonium nitrate as well as uncontaminated samples where hidden from the canine unit. Samples were hidden on support beams, behind and under benches, and underneath small rocks. After signaling that the test team was ready, the trainer instructed the canine to begin its search of the contaminated samples. Once again, the canine unit passively alarmed correctly on each of the contaminated samples, this time in breezy outdoor conditions.

3.2.3.1 False Negatives

Table 13 shows that 23 of the 28 false negatives (82%) occurred while testing a sample contaminated with ammonium nitrate. As mentioned, the sensitivity levels of the instrument are around 10 ng for most plastic explosives. However, nitrate is a common compound; it is found in cleaning agents; hair products; ink from printers, copiers, and/or shoe polish; combusted diesel fuel; and fertilizers. To avoid erroneous alarms, the manufacturer sets the device's alarm threshold for nitrates much higher to compensate for the abundance of nitrates found in everyday environments. In other words, the device's minimum detection capability for ammonium nitrate is closer to 50 ng or 60 ng rather than the typical 10 ng. This explains the many false negatives while testing with ammonium nitrate.

3.2.3.2 False Positives

There were 10 false positives recorded out of the 550 (1.8%) samples that were tested, 6 of which were in the same general location during the first two tests at this site, with the same test result of TATP. The first two tests were performed on the same platform at opposite ends. There was no unique characteristic of the location that the team felt would warrant a false positive. It should be noted that the team revisited the site 4 days later to see if the same results would occur. This time there were no false positives. During the second visit to this location, the team ventured outside to further investigate the environment for clues as to why there were initial false positive results. Directly above the station was a large field that had been recently mowed. In the middle of this field were air exchange vents for the subway platform. It is assumed that the nitrates from the landscape flowed to the platform through the air exchange vents after it was mowed. During testing at street level next to a bus stop at this location, the team did record another false positive of TATP. This false positive occurred while testing a sample contaminated with 50 ng of ammonium nitrate; however, since the result of TATP was incorrect, this test was considered to be a false positive.

CHAPTER **4**

CONCLUSIONS AND RECOMMENDATIONS

4.1 GENERAL OBSERVATIONS

The results of the field testing of the portable EDDs are summarized below: The trace detection equipment was operated under a wide range of conditions and performed well in the environment in which it was operated. It was proven reliable in detecting trace explosives. However, due to the sample collection method, it may not meet all the needs of the transit security force.

Transportability. The units are lightweight and very transportable. During this study they were carried from station to station and set up, on average, eight times a day. Operator fatigue in carrying the approximately 21 pounds of equipment (Detector, cord, battery, and wipes) was not noted. However, a soft-side carry case to hold the detector and accessories is recommended for field use.

Reliability of the Units. The portable EDDs tested in this study proved to be reliable. They had no systematic failures and were able to operate for extended periods. During this study, the instruments were operated in the field for a total of 140 hours over a 17-day period. In 1,600 individual tests, conducted under a wide range of conditions, no failures were noted.

One concern with portable instrumentation operating in the field is battery lifetime and the need to carry spares. However, in this study, all test sites had AC power available in the operating environment. The common availability of AC power allowed the operators to run the equipment on local power and charge the battery throughout the day. About one-third of the test was conducted outdoors, where the operators never had to suspend operations to change or recharge batteries because of the common availability of AC power throughout the operating environment. Extension of battery lifetime is not necessary, and the operators did not require spares in the field.

The units operated reliably under the ambient conditions test, both indoors and outdoors. The temperature ranges under the ambient conditions varied from a low of 16° C/60° F to a high of 32° C/89° F. The relative humidity ranged from 24% to 73%. It is necessary to swab a virtually dry surface; therefore, using the device in inclement conditions may not be recommended, and rainy weather may cause times of non-use.

Start-Up Time. Start-up of the unit usually took 10 to 15 minutes, although there were 5 days out of 17 (29%) that it took an extra 15 minutes to clear NO3 alarms that occurred on start-up.

Throughput. On average, it took the test team 14 minutes (840 seconds) to complete 10 tests. This does not include the warm-up time. Throughput time included the time to swab, analyze, run cleaning cycles to clear the machine, and to run blank swabs for 10 tests. All of these activities would be common in regular field use. Therefore, each test took, on average, 84 seconds to complete.

Ease of Use and Training Requirements. The equipment is relatively simple to operate. One minor problem noted was that under sunny conditions it was difficult to read the display when the equipment was operated outdoors. However, it is highly recommended that security personnel who are going to operate this equipment receive at least 1 day of training from the manufacturer. The cost and time commitment is minimal, and the training provides the operator with a solid foundation for using the equipment effectively. Currently, there are different training packages provided for the selected device. The cost can range from $1,500 to $2,800, depending on the type of training.

Ideally the training should take place at the transportation facility. Instruction needs to be provided in the areas of the following:

- General operating procedures,
- Replacement of consumables,
- Cleaning down the equipment,
- Use of the verification standard stick, and
- Operating parameters.

Maintenance Costs. At the time this report was published, the manufacturer had not established the need for an annual maintenance cycle.

Consumables. Consumables for the detection equipment tested include batteries, wipes, and filters. The cost of these for 1 week of heavy operations, as in this study, was estimated to be $90.

In addition to the consumables used by the detection equipment, it is also recommended that the operators use gloves. The trace detection equipment used in this study is very sensitive and susceptible to contamination. It is highly recommended that users wear latex gloves during operation of the equipment, particularly when verification standard sticks are used. While concern about allergic reaction to latex gloves is an increasingly reported problem, it was found that these gloves offered the best protection. In particular, the inexpensive nitrile gloves, which are finding increasing favor, can in fact be a contamination source and should not be used with this equipment.

False Positive Alarms. One aim of this study was to uncover adverse conditions that could affect the device's operation. These conditions might include operation where external fumes exist, such as near cleaning closets, combusted diesel fuel, copy shops, hairdressers, or restaurants. None of the external factors in these places seemed to significantly affect the outcome of tests. For example, test results were not affected during operations in bus maintenance shops with oil visibly covering the ground. The false positive alarm rate noted in this study was a relatively minor (1.7%) and is consistent with the false alarm rate seen at airports with trace detection equipment currently deployed. The false positive alarm rate did not represent a significant problem.

Site Survey. It is recommended to any transportation facility purchasing this equipment that a site survey be performed. That is, the equipment should be operated within the expected working environment, and the false positive alarm patterns should be noted. In one of the test facilities, it was noted that there were materials being used in a maintenance area that were not compatible with the instrument. In this one instance, the unit registered a number of false positive alarms associated with a repair/maintenance facility. It is presumed that there was a source of interfering material at this location that was responsible for the false positive alarms. It is recommended that such activities be identified by performing a site survey and be noted in local operating procedures.

False Negative Alarms. The alarm levels of the instrumentation tested was found to be 10 ng for the high explosives and about 70 ng for the ammonium nitrate. These levels are consistent with the manufacturer's specification. During this study, tests were conducted using sample quantities of explosives that were at, or even below, the manufacturer's specified alarm level.

4.2 APPLICATIONS OF THE PORTABLE INSTRUMENTATION

There are a number of potential circumstances in which portable EDDs could aid officials in the transit environment. In many of these situations, the trace detection equipment could offer meaningful aid. In others, the current technology is problematic.

4.2.1 Abandoned or Lost Articles

One problem faced by all transit authorities is the issue of evaluating lost or abandoned packages. The procedures for handling abandoned packages varied among the test locations in this study. However, most transit officials interviewed are making a visual evaluation and then determining if EOD units should be notified or if it is safe for the transit official to directly examine the abandoned object. In many cases, the object is handled and inspected without contacting law enforcement. In cases of suspicious packages, transit officials are calling EOD units to evaluate the package. While it would be very desirable to be able to perform a screening prior to calling officials, there are some equipment limitations.

The equipment used in this study appears to be reliable and sensitive enough to be used as a screening tool, but there are some limitations in using the equipment in this way. The portability, ease of operation, short setup time and sensitivity of the system makes it attractive for this application. However, taking swab samples is an issue when examining abandoned/lost articles.

In order to conduct a test, a swab must be rubbed by hand over the article being tested. This requires the operator to have to handle the package extensively, but it does not require the operator to open the package. In cases where the package has been evaluated by the transit official as likely to be harmless and the operator is going to open it or dispose of the article, it is not an issue to take a swab sample. The operator has already made the decision to handle the object. In this case, the use of the detection equipment provides a level of protection to the operator.

However, in the case of a suspicious abandoned package, the operator may make the decision not to handle the package for safety reasons. In this case, the trace detection equipment provides little utility. The extensive handling necessary with use of detection equipment may be deemed unsafe, and the official has little recourse other than calling for EOD to examine the object using dogs or X-ray equipment, neither of which requires handling the object. Deciding not to handle a package that is suspected to contain an IED precludes the use of virtually all trace detection systems that require a swab sample.

4.2.2 Screening

4.2.2.1 People Screening

It is possible to use portable detection equipment to screen passengers, but there are severe limitations with this use. The first limitation is the throughput. While the average inspection time of 84 seconds is not significant for inspecting an abandoned package, it is a considerable period of time for a commuter who needs to board a train, not to mention the amount of time spent waiting in line to be inspected. The open system is part of transit culture. Unless the culture changes, this type of use is not recommended. Because there are usually multiple entries to a single station, it makes no sense to line transit passengers up at one entrance for random checking of packages and bags before boarding (as is done in airports). An attacker could easily use an entry point where there is no screening. Further, the "just-in-time" nature of the subway does not leave commuters with the option to stop for a check. The delay caused by transit passenger screening could lead transit commuters to use other forms of transportation. That is not a desirable outcome.

4.2.2.2 Vehicle Searching

One potential application is to provide a level of inspection of vehicles as they enter tunnels or check points in the transit environment. The team randomly tested 30 vehicles in a parking lot to determine the device's performance with swabs of unknown particles. It is possible that false alarms could occur from elements on the vehicles, such as waxes and gas or oil residue, or other possible disruptions to the device. The tests were performed by swabbing only the outside of the vehicles; samples were taken from surfaces such as the door handles, door and trunk locks, and wheels. This type of screening may be suitable for this device. All tests returned the correct results, without false alarms. Ideally, an internal check of the vehicle should be performed as well. A limitation to use of this device for vehicle screening outdoors is that it can't be used in rain or snow. These weather conditions may result in downtime for the screening procedure.

4.2.2.3 Luggage/Cargo/Packages

Attention to train and bus security has increased steadily the past few years. Having baggage screeners operating on trains and buses in the same way that they operate in airports would create a costly dilemma of having to design passenger-screening areas in train and bus stations. As mentioned, the current just-in-time nature of commuter traffic on trains and buses may not permit the use of the portable EDD to screen passengers because there would need to be a certain level of queuing prior to boarding. Nonetheless, because the device can be set up in a relatively short amount of time and uses a small amount of space to operate, it could be useful in randomly screening passenger luggage just prior to loading it onto long distance bus or train trips. For instance, before loading luggage onto a bus, it is usually collected adjacent to the vehicle and loaded by an employee of the transit agency. While passengers are loading, an explosives screener could randomly test the luggage.

4.3 RECOMMENDATIONS FOR FURTHER DEVELOPMENT

A major concern in the application of the EDD in the transit environment was the sample collection. Rubbing the article with a swab is not recommended for all scenarios. A vapor-based system would help, in that it does not require the operator to touch the package.

4.3.1 Vapor-Based Detection

The greatest limitation of the equipment reviewed in this study was that the operator is required to handle the object to collect a swab sample. Improvements that could be made to change the sampling method are desirable. A vapor-based system, which would sample the air surrounding the package without touching it, would be superior. The problem is that modern explosives are not very volatile, and the existing equipment does not have the sensitivity to directly detect the explosive vapor. There are a number of possible approaches to developing equipment that can directly detect the explosive vapor.

The first approach is to develop more sensitive equipment. However, the equipment tested in this study is some of the most sensitive equipment available today. Making the equipment more sensitive will take extensive development time. The second approach is to develop new sample collection equipment to be used with the existing equipment.

4.3.2 Post-Blast Residue

An application of the EDD is the use of the device to evaluate post-blast residue. The EDD may be a tool to aid in collection of evidence in the field. The information collected from interviews with transit officials suggested that this technology could provide significant help in investigating bomb crime sites. Parts from a car after a blast can be investigated for residues of explosives.

REFERENCES

Balog, J., P. Bromley, J. Strongin, A. Boyd, J. Canton, and D. Mitchell. *TCRP Report 86: Public Transportation Security—Volume 2: K9 Units in Public Transportation: A Guide for Decision Makers.* Transportation Research Board, National Research Council, Washington, D.C., 2002.

Committee on Marking, Rendering Inert, and Licensing of Explosives, Board on Chemical Sciences and Technology, and Commission on Physical Sciences, Mathematics, and Applications. *Containing the Threat from Illegal Bombings: An Integrated National Strategy for Marking, Tagging, Rendering Inert, and Licensing Explosives and Their Precursors.* National Research Council, Washington, D.C., 1998.

The Convention on the Marking of Plastic Explosives for the Purpose of Detection, signed in Montreal in 1991(available from the International Civil Aviation Organization).

Dillingham, G. "Aviation Security: Commercially Available Advanced Explosives Detection Devices" (Memo to Honorable Wendell H. Ford, Committee on Commerce, Science, and Transportation, United States Senate). RCED-97-119R. General Accounting Office, April 24, 1997.

Fatah, A., J. Barrett, R. Arcilesi, K. Ewing, C. Lattin, M. Helsinki. *Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders* (NIJ Guide 100-00). National Institute of Justice, June 2000. Available at http://www.ojp.usdoj.gov/nij/pubs-sum/184449.htm.

Handbook of Chemistry and Physics. CRC Press, 2004.

Pearce, T., S. Schiffman, H. Nagle, and J. Garder (Eds.). *Handbook of Machine Olfaction: Electronic Nose Technology,* Wiley-VCH, Federal Republic of Germany, 2003.

Rhykerd C., D. Hannum, D. Murray, and J. Parmeter. *Guide for the Selection of Commercial Explosives Detection Systems for Law Enforcement Applications* (NIJ Guide 100-99). National Institute of Justice, September 1999.

Smiths Detection (formerly Barringer) Instruments Ltd. *Sabre 2000 Basic Operator's Guide,* n.d.

U.S. Department of the Treasury. "1996 Selected Explosives Incidents," Filler Material (handout). 1996.

APPENDIX A

GLOSSARIES

General Glossary of Acronyms

Acronym	Description
AC	Alternating current
C4	Military explosive mixture of RDX and plasticizer
CWA	Chemical warfare agent
DMND	2,3-dimethyl-2,3 dinitro butane, taggant for explosives
ECD	Electron capture detector
EDD	Explosive detection device
EGDN	Ethylene glycol dinitrate, taggant for explosives
EOD	Explosive ordnance disposal
FAA	Federal Aviation Administration
g/mol	Grams per mole
GFP	Green fluorescent protein
HMX	A plastic explosive, also known as octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HPLC-UV	High Performance Liquid Chromatography-Ultraviolet
IED	Improvised explosive device
IMS	Ion Mobility Spectrometry
mg	Milligram
µg	Microgram
MHz	Megahertz
ng	Nanogram
NIJ	National Institute of Justice
Ni 63	Nickel 63
NRL	The Naval Research Laboratory
o-MNT	Ortho-mononitrotoluene, an explosive taggant
pg/ml	Picograms per mililiter
p-MNT	Para-mononitrotoluene an explosive taggant
ppb	Parts per billion
ppt	Parts per trillion
SAIC	Science Applications International Corporation
SAW	Surface Acoustic Wave
TEA	Thermal Energy Analysis
TIC	Toxic industrial chemicals
TSA	Transportation Security Administration
V	Volt

Glossary of Acronyms for Explosives

Acronym	Full Name	Description
AN	Ammonium Nitrate	Ammonium Nitrate is an explosive that is also useful for fertilizer.
DNT	Dinitrotoluene	A byproduct in TNT product.
NG	Nitroglycerin	A liquid explosive.
NO3	Nitrous oxide	Nitrous oxide may form explosive compounds when exposed to combustible materials or oil, grease, and other hydrocarbon materials.
PETN	Pentaerythritol Tetranitrate	Primarily used in booster and bursting charges of small caliber ammunition, charges of detonators in some land mines, and as the explosive core of primacord.
RDX	Research Department Explosive	Chemically named cyclotrimethylenetrinitramine. RDX is a white crystalline solid usually used in mixtures with other explosives, oils, or waxes; it is rarely used alone. It is considered the most powerful of the military high explosives.
Semtex	Compound of RDX+PETN	Two main components of Semtex, RDX (Cyclonite) and PETN (Pentaerythrite Tetranitrate).
TATP	Triacetone Triperoxide	An unstable explosive used in IEDs due to the availability of the starting materials, acetone and hydrogen peroxide. Not used commercially or by the military due to poor stability and the dangers associated with it.
Tetryl	Trinitrophenylmethylnitramine	It is fairly sensitive, and it can be initiated from flame, friction, shock, or sparks. Tetryl is commonly used as a booster explosive where stable explosives need more than simply an initiator to cause them to detonate.
TNT	Trinitrotoluene	In a refined form, TNT is one of the most stable of high explosives and can be stored over long periods of time. It is relatively insensitive to blows or friction. It is the most common material in land mines.

APPENDIX B

BIBLIOGRAPHY

Army Soldier and Biological Chemical Command Program, 2000.

Balog, J., P. Bromley, J. Strongin, A. Boyd, J. Canton, and D. Mitchell. *TCRP Report 86: Public Transportation Security—Volume 2: K9 Units in Public Transportation: A Guide for Decision Makers.* Transportation Research Board, National Research Council, Washington, D.C., 2002.

Committee on Commercial Aviation Security. National Materials Advisory Board and Commission on Engineering and Technical Systems. *Detection of Explosives for Commercial Aviation Security.* National Research Council, Washington, D.C., 1993.

Committee on Marking, Rendering Inert, and Licensing of Explosives, Board on Chemical Sciences and Technology, and Commission on Physical Sciences, Mathematics, and Applications. *Containing the Threat from Illegal Bombings: An Integrated National Strategy for Marking, Tagging, Rendering Inert, and Licensing Explosives and Their Precursors.* National Research Council, Washington, D.C., 1998.

Davies, J., L. Blackwood, S. Davis, L. Goodrich, and R. Larson. "Design and Calibration of Pulsed Vapor Generators for 2,4,6 Trinitrotoluene, Cyclo-1,3,5-trimethylene-2,4,6-trinitramine, and Pentaerythritol Tetranitrate," *Anal. Chem.,* 65, 3004–3009, 1993.

Dillingham, G. "Aviation Security: Commercially Available Advanced Explosives Detection Devices (Memo to Honorable Wendell H. Ford, Committee on Commerce, Science, and Transportation, United States Senate)." RCED-97-119R. General Accounting Office, April 24, 1997.

Fatah, A., J. Barrett, R. Arcilesi, K. Ewing, C. Lattin, and T. Moshier. *An Introduction to Biological Agent Detection Equipment for Emergency First Responders* (NIJ Guide 101-00). National Institute of Justice, December 2001. Available at http://www.ojp.usdoj.gov/nij/pubs-sum/190747.htm.

Fatah, A., J. Barrett, R. Arcilesi, K. Ewing, C. Lattin, and M. Helsinki. *Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders* (NIJ Guide 100-00). National Institute of Justice, June 2000. Available at http://www.ojp.usdoj.gov/nij/pubs-sum/184449.htm.

Federal Aviation Administration (FAA). *Final Criteria for Certification of Explosives Detection Systems.* RIN 2120-AF95. 1998.

Grate, J. "Acoustic Wave Microsensor Arrays for Vapor Sensing." *Chem. Rev.,* 100, 2627–2648, 2000.

Handbook of Chemistry and Physics. CRC Press, 2004.

Johnston, J., M. Williams, L. Waggoner, C. Edge, R. Dugan, and S. Hallowell. "Canine Detection Odor Signatures for Mine-related Explosives." *SPIE,* 3392, 1998.

Longworth, T. and K. Ong. *Domestic Preparedness Program: Testing of Sabre 2000 Handheld Trace and Vapor Detector Against Chemical Warfare Agents Summary Report.* Report ECBC-TR. Soldier and Biological Command, AMSSB-RRT, Aberdeen Proving Ground, Maryland, August 2001.

Panel on Technical Regulation of Explosives-Detection Systems, National Materials Advisory Board, and Commission on Engineering and Technical Systems. *Configuration Management and Performance Verification of Explosives-Detection Systems* (Publication NMAB-482-3). National Research Council, Washington, D.C., 1998.

Pearce, T., S. Schiffman, H. Nagle, and J. Garder (Eds.). *Handbook of Machine Olfaction: Electronic Nose Technology.* Wiley-VCH, Federal Republic of Germany, 2003.

Rhykerd C., D. Hannum, D. Murray, and J. Parmeter. *Guide for the Selection of Commercial Explosives Detection Systems for Law Enforcement Applications* (NIJ Guide 100-99). National Institute of Justice, September 1999.

Smiths Detection (formerly Barringer) Instruments Ltd. *Sabre 2000 Basic Operator's Guide,* n.d.

Watson, G., and D. McGuire. *Detection of Explosives in Soil and Water with an Electronic Nose,* Paper presented at ACS meeting, Ontario, California, October, 5–7, 1999.

APPENDIX C

SAMPLE DATA COLLECTION SPREADSHEETS

Test #	Date	Device #	Time Begin	Time End	Humidity (%)	Temp	Test Details	T1	T2	Test Contaminant	Contaminated Sample	Alarm	Results	Notes
18	3/1/2003	20661	11:59	12:19	49	24.0	Handle 1	61	14	Semtex - 50 ng	FALSE	FALSE	NO ALARM	In a service corridor, outside of multiple doors- #42, staff security room, 427 rest room, 439 electrical room, on a cement floor.
							Handle 2	43	13		FALSE	FALSE	NGN	
							Handle 3	45	15		FALSE	FALSE	NO ALARM	
							Handle 4	44	16		FALSE	FALSE	NGN	
							Handle 5	44	15		FALSE	FALSE	NO ALARM	
							Handle 6	42	15		FALSE	FALSE	NGN	
							Handle 7	44	15		FALSE	FALSE	NO ALARM	
							Handle 8	39	15		FALSE	FALSE	NO ALARM	
							Handle 9	40	14		FALSE	FALSE	NO ALARM	
							Handle 10	37	15		TRUE	TRUE	SEMTEX 3	
													PETN-C	
													PETN-F	
													RDX-C	
													RDX-CS	
													RDX-N	
													VER-PF	
							BLANK	30	16		FALSE	TRUE	TATP 1	
											FALSE	FALSE	TATP-S	
							BLANK	24	16		FALSE	TRUE	TATP 1	
											FALSE	FALSE	TATP-S	

Test #	Date	Device #	Time Begin	Time End	Humidity (%)	Temp	Test Details	T1	T2	Test Contaminant	Contaminated Sample	Alarm	Results	Notes
							BLANK	37	15		FALSE	FALSE	NO ALARM	
							Zipper 9	42	14		FALSE	FALSE	NGN	
							Zipper 10	49	14		FALSE	FALSE	NO ALARM	
21	3/1/2003	20661	13:11	13:24	48	22.8	Handle 1	24	15	Semtex - 50 ng	TRUE	TRUE	SEMTEX 4	Inside the holding room on the lower platform. Outside of custodial room 132, on concrete.
													PETN-C	
													PETN-F	
													PETN-N	
													RDX-C	
													RDX-CS	
													RDX-N	
							BLANK	46	16		FALSE	TRUE	TATP 1	
											FALSE	FALSE	TATP-S	
							BLANK	43	16		FALSE	FALSE	NO ALARM	
							Handle 2	40	14		FALSE	FALSE	NGN	
							Handle 3	43	14		FALSE	FALSE	NO ALARM	
							Handle 4	41	14		FALSE	FALSE	NO ALARM	
							Handle 5	41	14		FALSE	FALSE	NGN	
							Handle 6	44	14		FALSE	FALSE	NO ALARM	
							Handle 7	45	14		FALSE	FALSE	NO ALARM	
							Handle 8	42	15		FALSE	FALSE	NGN	
							Handle 9	43	15		FALSE	FALSE	NO ALARM	

Test #	Date	Device #	Time Begin	Time End	Humidity (%)	Temp	Test Details	T1	T2	Test Contaminant	Contaminated Sample	Alarm	Results	Notes
							Handle 10	42	15		FALSE	FALSE	NGN	
22	3/1/2003	20661	14:54	15:10	50	21.0	Zipper 1	48	15	Semtex - 50 ng	FALSE	FALSE	NGN	Mezzanine level between escalators, medium breeze and heavy commuter traffic.
							Zipper 2	45	15		FALSE	FALSE	NO ALARM	
							Zipper 3	46	14		FALSE	FALSE	NO ALARM	
							Zipper 4	48	14		FALSE	FALSE	NGN	
							Zipper 5	45	14		FALSE	FALSE	NO ALARM	
							Zipper 6	43	14		FALSE	FALSE	NGN	
							Zipper 7	52	15		FALSE	FALSE	NO ALARM	
							Zipper 8	45	15		FALSE	FALSE	NGN	
							Zipper 9	47	15		FALSE	FALSE	NO ALARM	
							Zipper 10	42	15		TRUE	TRUE	C4/RDX 4	
													PETN-C	
													RDX-C	
													RDX-CS	
							BLANK	26	14		FALSE	TRUE	TATP 1	
											FALSE	FALSE	TATP-S	
							BLANK	39	15		FALSE	FALSE	NO	

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation