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Law Enforcement and Corrections Standards and Testing Program

Guide for the Selection of Commercial Explosives Detection Systems for Law Enforcement Applications

NIJ Guide 100-99

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FOREWORD

The Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. OLES's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

OLES is: (1) Subjecting existing equipment to laboratory testing and evaluation, and (2) conducting research leading to the development of several series of documents, including national standards, user guides, and technical reports.

This document covers research conducted by OLES under the sponsorship of the National Institute of Justice. Additional reports as well as other documents are being issued under the OLES program in the areas of protective clothing and equipment, communications systems, emergency equipment, investigative aids, security systems, vehicles, weapons, and analytical techniques and standard reference materials used by the forensic community.

Technical comments and suggestions concerning this report are invited from all interested parties. They may be addressed to the Office of Law Enforcement Standards, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8102, Gaithersburg, MD 20899-8102.

David G. Boyd, Director
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COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere	H	henry	nm	nanometer
ac	alternating current	h	hour	No.	number
AM	amplitude modulation	hf	high frequency	o.d.	outside diameter
cd	candela	Hz	hertz	Ω	ohm
cm	centimeter	i.d.	inside diameter	p.	page
CP	chemically pure	in	inch	Pa	pascal
c/s	cycle per second	IR	infrared	pe	probable error
d	day	J	joule	pp.	pages
dB	decibel	L	lambert	ppm	parts per million
dc	direct current	L	liter	qt	quart
C	degree Celsius	lb	pound	rad	radian
F	degree Fahrenheit	lbf	pound-force	rf	radio frequency
dia	diameter	lbf·in	pound-force inch	rh	relative humidity
emf	electromotive force	lm	lumen	s	second
eq	equation	ln	logarithm (base e)	SD	standard deviation
F	farad	log	logarithm (base 10)	sec.	section
fc	footcandle	M	molar	SWR	standing wave ratio
fig.	figure	m	meter	uhf	ultrahigh frequency
FM	frequency modulation	min	minute	UV	ultraviolet
ft	foot	mm	millimeter	V	volt
ft/s	foot per second	mph	miles per hour	vhf	very high frequency
g	acceleration	m/s	meter per second	W	watt
g	gram	N	newton	λ	wavelength
gr	grain	N·m	newton meter	wt	weight

area=unit^2 (e.g., ft^2, in^2, etc.); volume=unit^3 (e.g., ft^3, m^3, etc.)

PREFIXES

d	deci (10^{-1})	da	deka (10)
c	centi (10^{-2})	h	hecto (10^{2})
m	milli (10^{-3})	k	kilo (10^{3})
μ	micro (10^{-6})	M	mega (10^{6})
n	nano (10^{-9})	G	giga (10^{9})
p	pico (10^{-12})	T	tera (10^{12})

COMMON CONVERSIONS (See ASTM E380)

0.30480 m =1ft	4.448222 N = lbf
2.54 cm = 1 in	1.355818 J =1 ft·lbf
0.4535924 kg = 1 lb	0.1129848 N m = lbf·in
0.06479891g = 1gr	14.59390 N/m =1 lbf/ft
0.9463529 L = 1 qt	6894.757 Pa = 1 lbf/in^2
3600000 J = 1 kW·hr	1.609344 km/h = mph

Temperature: T• $_C$ = (T• $_F$ 32)×5/9
Temperature: T• $_F$ = (T• $_C$ ×9/5)+32

GUIDE FOR THE SELECTION OF COMMERCIAL EXPLOSIVES DETECTION SYSTEMS FOR LAW ENFORCEMENT APPLICATIONS*

This document includes a variety of information that is intended to be useful to the law enforcement community in the selection of explosives detection techniques and equipment for different applications. It includes a thorough market survey of all trace and x-ray based commercial detection systems known to the authors as of October 1998, including company contact information along with data on each system's cost, size, and uses. Information is also included on some additional novel detection technologies, and on such standard techniques as canine and physical search. Brief technical discussions are presented that consider the principles of operation of the various technologies. These may be ignored by readers who find them too technical, while those wanting additional technical information can obtain it from the extensive list of references that is included as an appendix. Other sections of the document present matrices listing the most highly recommended detection techniques for a variety of scenarios, a list of desirable characteristics for explosives detection equipment for law enforcement work with charts rating commercial systems against these criteria, and a standard test protocol for the evaluation of trace detection equipment. In addition to a reference list, the appendices include a section providing basic information about different types of explosives and explosions. Any law enforcement personnel having comments or questions are encouraged to contact the authors at Sandia National Laboratories.

1. INTRODUCTION

The primary purpose of this document is to provide law enforcement agencies with information that should aid them in the selection and utilization of explosives detection equipment. The document is thus more practical than technical, emphasizing advice about the capabilities of different technologies, and what technologies are likely to work best in various applications. A wide variety of factors are considered that may be important to purchasers of detection equipment, including cost, sensitivity, portability, ease of use, etc. Some technical information is included in sections describing how the various detection technologies work, but the level of detail is not great. Readers finding this material too technical can skip it while still making use of the rest of the document, and readers desiring more technical detail can obtain it from the suggested readings in Appendix A-1.

The remainder of this document is divided into several sections as follows:

Section 2 presents a market survey of currently available explosives detection equipment. In tables 4 and 6, specific information is listed on 26 trace detection systems and 90 x-ray based detection systems. To the knowledge of the authors, this information is complete as of October 1998. The information in these tables includes the type of detector or detection technology used in each system, cost, recommended uses, system size and weight, and vendor contact information. In the case of x-ray based systems, the cost information can only be approximate, because most vendors are hesitant to quote a specific price for these (usually expensive) systems. The table on trace detection systems also includes sensitivity information as provided by the manufacturer, *but it must be remembered that this information comes from the manufacturer and*

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* Inclusion of specific technologies in this document is not an endorsement by the authors or by Sandia National Laboratories. This document includes detectors known to the authors as of October 1998. Some technologies may not be included in the text due to oversight by the authors. Some detector characteristics described are not fully quantifiable, and in such cases, comparisons between detectors are necessarily subjective.

is not based on independent tests by a third party. Some independent test data exist for a few systems, and in the experience of the authors, the claims made by the manufacturers are usually not out of line with the system's true performance. However, all independent test results known to the authors are either classified or unclassified controlled nuclear information, so these results are not included in this document, which is intended for public release. Parties interested in what independent test data exist should contact the authors. Also included in section 2 are definitions of commonly used terms such as throughput rate and portability, a discussion of explosive vapor pressures and the issue of vapor sampling versus swipe (particulate) sampling in trace detection, and information on how the different trace and x-ray systems operate and what their general capabilities are. Finally, other techniques are discussed, including canine detection (already familiar to most law enforcement agencies, for drugs if not for explosives) and a few novel (though usually expensive and not always fully developed) detection technologies that have appeared in recent years.

Section 3 presents three matrices that give recommendations about what technologies and systems to use for a variety of applications. These matrices provide a quick reference point for anyone having a specific application in mind, and wanting to know what sort of detection system he or she should consider purchasing. Five factors are included in defining the applications in these matrices: system portability, presence or absence of an explosives background in the area where screening will be performed, throughput rate, the type of item to be screened (people, packages, vehicles, etc.), and system cost. As a general rule, these matrices do not point to a single system or technique that is considered "best" in each circumstance, but rather point to several options that may meet the user's needs. Needless to say, in some cases there may be several detection systems that can do the desired job, while under other circumstances there may be no system that does everything the potential purchaser would like it to do. The latter is unfortunately most often true when severe cost restraints are placed on the system to be purchased, as is usually the case in this era of rapidly advancing technology but extremely limited budgets for technology in law enforcement. It must be stressed that the matrices in section 3 are intended to point the reader in the right direction, and they are a starting point rather than a solution in choosing a detection system. They are not a substitute for detailed discussions with both the vendor(s) and a knowledgeable third party.

Section 4 discusses various characteristics and performance parameters that could be used to judge both trace and x-ray based detection systems, and defines ideal and nominal capabilities or characteristics for these systems. Defining these parameters is to some degree arbitrary since the "ideal" will of course depend upon the specific application. The definitions used are based on the best judgment of the authors and some feedback received from several law enforcement agencies, *but it is really up to each potential purchaser to determine what the requirements are for his or her application.* Tables 10 and 11 rate various commercial detection systems as ideal, nominal, or subnominal for the different parameters considered, and this allows the reader to focus on those parameters that are most important to him/her and to make rapid comparisons. Once again, these tables serve as a starting point for obtaining information and should supplement but not replace detailed discussions with the vendor(s) and outside experts.

Section 5 briefly discusses the issue of system calibration. Since calibration is very system specific, little can be said in general about this topic. The best advice is to discuss the calibration procedure thoroughly with the vendor of the equipment, and if possible learn it hands-on from the vendor at an onsite installation and training visit.

Section 6 provides a protocol for the testing and evaluation of trace detection systems. Such testing is also rather system specific, but this protocol has been made as generic as possible. The protocol should be of interest to users wanting to determine performance parameters for the specific unit they have purchased, and to those wanting to monitor the performance of the system over an extended period of time. The protocol also includes some basic information about sampling, ensuring a detector is free of contamination, etc. For some users in the law enforcement community, the protocol may be of little interest, and these users can skip section 6 without losing any content that is crucial to understanding the rest of the document.

Section 7 contains a brief warning about buying equipment that may not be based on sound scientific principles. Briefly stated, detectors that appear to make unprecedented claims about detection capabilities *may* be based on faulty science, and in extreme cases could prove to be fraudulent. When dealing with technologies that appear to be new and report exciting new capabilities, it is especially important to discuss the purchase with an outside expert before making a final decision.

Section 8 provides a brief summary and conclusions section.

Appendix A-1 provides a list of suggested readings relating to the topic of explosives detection.

Appendix A-2 provides a glossary of terms used in explosives detection, many of which may not be familiar to the average reader.

Finally, Appendix A-3 contains an introduction to different types of explosives, their uses, and their properties.

Any law enforcement agencies desiring more information about this document or explosives detection in general are invited to contact the authors[1] of this document. The contact points are as follows:

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2. MARKET SURVEY OF COMMERCIALLY AVAILABLE EXPLOSIVES DETECTION EQUIPMENT

In this section four different divisions of explosive detection technology are discussed. Covered in the greatest detail are (1) trace detection technologies and (2) x-ray based detection systems, since these are by far the most widely developed technologies. Canine detection, which is really a form of trace detection already very familiar to most law enforcement agencies, is discussed more briefly. Finally, some novel detection technologies are briefly discussed. Most of these novel technologies are not fully commercially developed, but they are mentioned here for the sake of completeness. Readers should note that they might become more readily available and also cheaper in the near future.

Before the specific technologies are discussed, four key characteristics that help describe explosive detection systems and applications are defined and addressed. These characteristics are portability, the type of item being screened, system cost, and throughput rate. Some of this material is covered further in section 4, but a brief introduction is necessary at this point.

2.1 Portability

Portability simply refers to the ease with which a detection system can be moved from one location to another. Depending on the application, portability may or may not be important. If a system needs to be carried by a detective who is screening a room for explosives, portability is clearly important. On the other hand, if it is only to be used as a dedicated system for screening people at a single entrance to a courthouse, portability is not important. In general, systems are divided into three categories: portable, semiportable, and fixed site. A system is considered portable if it weighs less than 9.1 kg (20 lb) and can be easily carried by one person (or, in the case of a canine, led by one person). It is considered semiportable if it does not meet these definitions, but can be moved easily by two people, fit in no more than two boxes, and be easily stored in the trunk of a police car. Systems that are too large or too heavy to meet the definition of semiportable are considered fixed-site systems. These can be very large and heavy, and include personnel portals and many baggage screening systems.

2.2 Type of Item Being Screened

Explosives detection can be used in a variety of applications. Two major categories are search applications and screening of individual items. Search applications involve situations where a bomb is suspected of being in a general area, but the exact location is unknown. This would include, for example, searching a building or property grounds for a bomb, once a bomb threat has been communicated. In most search applications, canine detection will be the detection method of choice because of the dog's rapid mobility and its ability to follow the scent to its source.

For screening of individual items, a wide variety of technologies can be useful in different situations. In general, the type of item screened will fall into one of four categories: people, hand-carried items, mailed or shipped items, and vehicles. Personnel screening involves detecting bombs or explosive material that is usually hidden under clothing. It can occur in many circumstances, ranging from suspect apprehension to screening large numbers of people entering a courthouse or some other facility. Screening of hand-carried items will usually occur alongside personnel screening. Specific items in this category include briefcases, backpacks, purses, hand-carried bags and packages, etc. Mailed and shipped items are used increasingly to transport bombs; these items can include letters, small packages, and large shipping crates. Vehicle screening can involve both single vehicles (e.g., suspect apprehension) and large numbers of vehicles at checkpoints. The vehicles involved can range from the smallest cars to fully loaded tractor-trailers.

2.3 Cost Range

Cost is one of the few characteristics associated with a detection system that can be fully quantified, and hence it is one of the easiest to get a handle on when comparing different systems. Obviously, a purchaser will want to know the exact cost of any system he or she is thinking about buying. Nevertheless, it is convenient when starting to look at different systems to divide them into low-, medium-, and high-cost ranges. The definitions of these ranges are given in table 1; note that they differ for trace systems and x-ray systems. Cost ranges are used when discussing x-ray systems. Often x-ray manufacturers are reluctant to quote an exact price until they have talked to the potential buyer.

Table 1. Cost ranges for trace and x-ray explosive detection systems

Category	Price Range $K	Price Range $K
	Trace	X-ray
Low	< 30	< 70
Medium	30 to 100	70 to 300
High	> 100	> 300

Note that most trace systems cost less than $75K (several less than $30K), while most x-ray systems cost more than $100K. The authors realize that all of these numbers may seem staggeringly high to most police departments, and that cost will usually be one of the most limiting factors in making a procurement decision. Nevertheless, the ranges listed are convenient reflections of current costs in state-of-the-art explosives detection equipment.

2.4 Throughput Rate

When screening individual items, throughput rate refers to the number of items that can be screened per unit time. It can also be expressed in terms of the time required to screen a single item. For example, if personnel are being screened at a checkpoint using a personnel portal that processes five people every minute, the throughput rate can be expressed as 5 persons/min, 300 persons/h, etc. Alternatively, the screening time can be expressed as 12 s per person. Throughput rate is typically an issue only when large numbers of items need to be screened rapidly. Table 2 quantifies high, medium, and low throughput rates for the items discussed in section 2.2.

Table 2. Throughput rates

Screening time	Category
> 60 s	Low
10 s to 60 s	Medium
< 10 s	High

2.5 Trace Explosives Detection

Explosive detection techniques can be divided generally into two categories: bulk detection and trace detection. In bulk detection, a macroscopic mass of explosive material is detected directly, usually by viewing images made by x-ray scanners or similar equipment. In trace detection, the explosive is detected by chemical identification of microscopic residues of the explosive compound. These residues can be in either or both of two forms: vapor and particulate. Vapor refers to the gas-phase molecules that are emitted from a solid or liquid explosive because of its finite vapor pressure. Particulate contamination refers to microscopic particles of solid material that adhere to surfaces that have, directly or indirectly, come into contact with an explosive material. Explosive vapor pressures and their implications for detection are discussed in the next subsection, while the following subsection considers particulate contamination. Thereafter, several additional subsections are included on the different trace detection technologies that are currently available for explosive detection. Note that one consequence of using trace detection is that a valid alarm may be recorded for the object (person, package, vehicle, etc.) being screened, even if the object does not contain a concealed bomb. This can happen if the object has been contaminated with trace explosive material for any number of reasons, legitimate or otherwise. For example, when screening people it is possible to record a positive alarm for nitroglycerin from a heart patient using nitroglycerin tablets for medication purposes. For this reason, alarm resolution is always a key issue when utilizing trace detection technologies.

2.5.1 Vapor Pressures of Explosives

To have a good understanding of the trace detection of explosives, it is important to understand the concept of vapor pressure. The vapor pressure of a solid or liquid substance at a given temperature is the gas phase pressure of the substance that exists at equilibrium above the surface of the solid or liquid. All solids and liquids emit a certain amount of vapor at all temperatures above absolute zero (-273 °C), and at a given temperature the amount of vapor emitted is characteristic of the particular substance. As an illustrative example, consider a piece of solid (2,4,6-trinitrotoluene (TNT)) placed in a jar with the lid closed. Before the TNT is placed in the jar, there is no TNT vapor present in the jar, but once the TNT is inside with the lid shut, the pressure of gas-phase TNT in the jar will increase as vapor molecules are emitted by the solid. Eventually, a state of dynamic equilibrium will be reached, where the number of vapor molecules emitted by the solid per unit time is the same as the number per unit time readsorbed by the solid and the walls of the jar. There will then be a constant pressure of TNT gas in the jar, and the quantitative value of this pressure is the vapor pressure of TNT at the prevailing temperature. Note that the vapor pressure of a chemical at a specific temperature is the maximum pressure of the gas that may exist above a solid or liquid. If the system has not yet reached equilibrium, the actual pressure of the vapor may be less than the vapor pressure, but never more.

For convenience, vapor pressures are often expressed not in true pressure units but as relative concentrations in saturated air. Such concentrations are proportional to the true vapor pressure, and they often provide a clearer picture of the amounts of vapor that are involved. Figure 1 shows the vapor concentrations in saturated air of several high explosives at room temperature (25 °C or 77 °F).

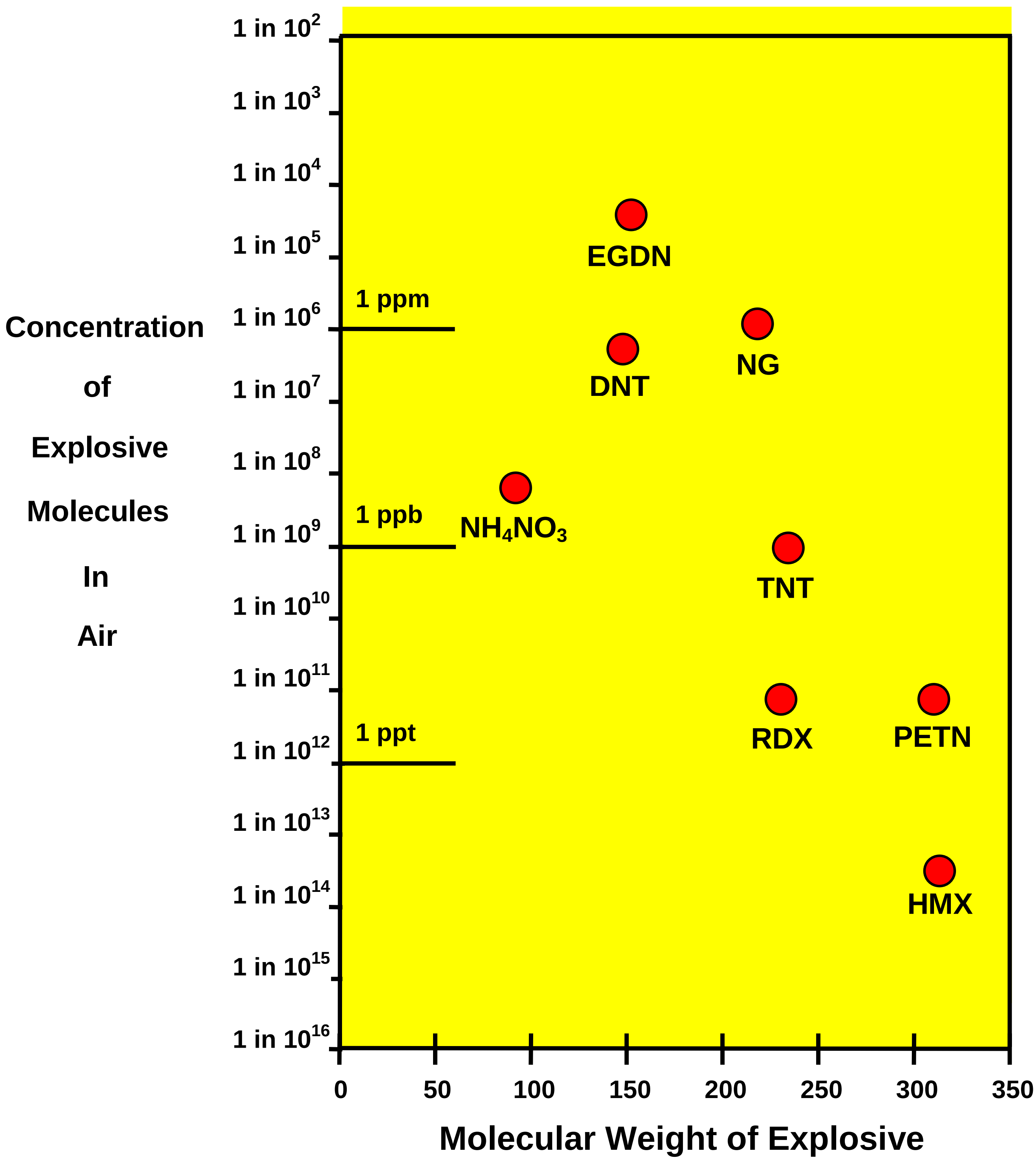

Figure 1. Vapor concentrations of neat high explosives in saturated air at 25 °C

Note that the vertical axis of figure 1 has an increasing logarithmic scale, so that each higher mark corresponds to a factor-of-ten increase in vapor pressure. The horizontal axis displays the molecular weights of the various compounds, and is not important in the following discussion. It can be seen that the vapor pressures of the explosives shown vary widely. For example, the vapor pressure of ethylene glycol dinitrate (EGDN) is about 10^9 times (or one billion times) higher than the vapor pressure of HMX (homocyclonite, or octogen). In general, the explosives can be broken into three groups based on their vapor pressures. The high vapor pressure explosives include EGDN, nitroglycerin (NG), and 2,4-dinitrotoluene (DNT). These explosives have saturated vapor concentrations in air close to or greater than one part per million (1 ppm), which means that at equilibrium there will be roughly one molecule of explosive vapor per every million air molecules. The medium vapor pressure explosives have saturated vapor concentrations in air near one part per billion (1 ppb), a factor of about 1,000 lower than the high-vapor-pressure explosives. The medium-vapor-pressure group includes TNT and NH_4NO_3 (ammonium nitrate). Finally, the low-vapor-pressure explosives have saturated vapor concentrations in air near or below the one part per trillion (1 ppt) level, approximately an additional factor of 1,000 lower than the medium-vapor-pressure explosives. The low-vapor-pressure group includes HMX, RDX (cyclotrimethylenetrinitramine or cyclonite), and pentaerythritol tetranitrate (PETN). These vapor pressures are for pure materials. Vapor pressures for mixtures containing these explosives may be even lower.

The relative values of the vapor pressures mentioned above have important implications for the trace detection of explosives. The high-vapor-pressure explosives are relatively easy to detect from their vapor using detectors such as ion mobility spectrometers or electron capture detectors. Thus dynamites, which usually contain EGDN and/or NG as an explosive ingredient, can usually be detected from their vapor. Detecting these compounds by swiping surfaces for particle contamination (see next section) is also possible in some cases, but it may be less effective than with lower-vapor-pressure explosives, because the high-vapor pressures cause small particles to evaporate rapidly. In other words, in the case of particle sampling, the evidence may not be present long enough to make a detection. The medium-vapor-pressure explosives can sometimes be detected from their vapor, but in many cases this will test the limits of sensitivity for gas-phase detection, and particle detection based on surface swiping is usually preferred. Ammonium nitrate is a somewhat special case because it is almost always used in quantities of hundreds or even thousands of pounds in devices such as car bombs, and not in small bombs that could be carried on a person or shipped through the mail. Thus when ammonium nitrate is used, there is likely to be lots of contamination present to make a swipe-based detection, and various bulk detection techniques (e.g., x-ray) should also be effective. The low-vapor-pressure explosives do not produce enough vapor to be detected from their vapor in any but the most exceptional circumstances, and efforts to detect these compounds using trace technology must focus on swipe collection of particulate material. This makes swiping the preferred collection technique when dealing with plastic explosives such as C-4, semtex, and detasheet, which contain RDX and/or PETN as the explosive ingredient.

The vapor pressure of a substance can be expressed as:

$$P_v = P_0 \exp^{(-\Delta G/RT)}$$

where P_v is the vapor pressure, P_0 is a constant with the same units as P_v, ΔG is the free energy of sublimation (for a solid) or vaporization (for a liquid) in units of J/mole, R is the gas constant in units of J/K● mole and T is the temperature in °K. An important point that can be gleaned from this equation is that P_v depends upon the temperature as discussed above, and in fact the value of P_v will increase exponentially with increasing temperature. Because of this exponential dependence, the effect of temperature on vapor pressure is quite dramatic. For example, for solid TNT near room temperature, the vapor pressure approximately doubles with every 5 °C (9 °F) increase in the temperature of the solid. Thus one cubic centimeter of air that is saturated with TNT vapor will contain about 0.096 ng of TNT at 25 °C, 0.19 ng of TNT at 30 °C, and 0.38 ng of TNT at 35 °C (1 ng = 10^{-9} g = one billionth of 1 g). This means that one possible way to increase the chances of a successful vapor detection if a package or suitcase is suspected of containing a bomb is to heat the object. However, this is not always possible, and it can lead to interference problems if the object also contains another material that is more vaporous than the explosive. It should be pointed out that the numbers given for TNT vapor are very small compared to the amount of TNT contained in a typical particle in a fingerprint, which might contain several micrograms of TNT (1 µg = 1,000 ng). For a high-vapor-pressure explosive such as NG, the vapor concentration in air will be about 1,000 times higher than in the case of TNT. Therefore, the amount of NG vapor in a cubic centimeter (ccm) of saturated air will start to approach the amount present in a typical piece of particle contamination.

A detailed report on the vapor pressures of several common high explosives has been published by Dionne et al. (Ref. 57 in App. 1). This study investigated the vapor pressures of TNT, RDX, PETN, NG, and NH_4NO_3 over a wide range of temperatures. In each case, an empirical formula was derived for the vapor pressure over a certain temperature range. For example, in the case of TNT, it was found that the vapor pressure could be calculated from:

$$\text{Log } P_v(\text{ppt}) = (-7243/T) + 25.56,$$

where Log P_v(ppt) is the base ten logarithm of the vapor pressure in units of parts per trillion (ppt), and T is the temperature in °K. This equation is valid for temperatures between approximately 21 °C and 144 °C. Similar equations for the other explosives, referred to collectively as the Dionne equations, provide a convenient means for estimating the vapor pressures of these explosives at different temperatures.

A final important point about vapor pressures and vapor detection of explosives involves the low-vapor-pressure plastic explosives based on RDX and PETN. It has already been pointed out that RDX and PETN have extremely low vapor pressures, and the vapor pressures of the plastic explosives containing these compounds are even lower, due to the presence of oils and plasticizing agents that give the plastic explosive its form and consistency. When these explosives are manufactured, they are often spiked with a high-vapor-pressure nitro-compound called a taggant. Common taggants include ortho-mononitrotoluene (o-MNT), para-mononitrotoluene (p-MNT), and dimethyldinitrobutane (DMDNB). These taggants have vapor pressures similar to NG or EGDN, and their presence makes vapor detection of plastic explosives possible. However, relying on vapor detection with plastic explosives is still very risky, because old or homemade samples of plastic explosives will not contain the taggant. Nevertheless, detection of one of the taggants using gas-phase sampling with a trace detection system should be interpreted as possibly indicating the presence of a plastic explosive.

2.5.2 Particulate Contamination

Particulate contamination, which can also be referred to simply as particle contamination, consists of microscopic solid particles, often with masses on the order of a few micrograms. Explosives in general tend to be rather sticky, and a person handling a macroscopic piece of the solid material will quickly transfer large amounts of such contamination to his or her hands. This material will then be transferred to any additional surfaces that are touched by the hands, which will likely include parts of the person's clothing as well as doorknobs, tabletops, and other objects he/she contacts. While it is hard to make generalizations, a typical fingerprint will contain many particles, often with a total mass on the order of 100 μg. For low- and medium-vapor-pressure explosives at room temperature, this amounts to more material than would be present in a liter of air saturated with vapor by a factor of 1,000 to 1,000,000. Thus, for these explosives, the ability to make detections based on particulate contamination is crucial, as was alluded to in the preceding section.

Particulate contamination is usually sampled by wiping the surface to be screened with a swipe pad provided by the manufacturer of the trace detection system being used. Once this is done, the swipe pad can be inserted into a sampling port on the instrument, and in a matter of seconds it can be analyzed for the presence of explosives. This works best with briefcases and similar small packages. When screening people, this sort of surface swiping will necessitate physical contact with the test subject, and in some situations this may be considered excessively invasive. It should be noted that while careful handling of the explosive and the proper use of disposable gloves can greatly reduce the spread of particulate contamination, reducing it to zero is extremely difficult. Most bomb builders and carriers will not have the expertise required to do a clean job, so this method of sampling has very wide applications.

2.5.3 Trace Technologies

The following subsections discuss specific trace detection technologies. A listing of different trace technologies and their acronyms is given in table 3.

Table 3. Trace detector technologies and their acronyms

Acronym	Detector Type
Color	**Color** Change of Test Paper
ECD	**E**lectron **C**apture **D**etector
FIS	**F**ield **I**on **S**pectrometer
GC/CL	**G**as **C**hromatograph / **C**hemi**L**uminescence
GC/ECD	**G**as **C**hromatograph / **E**lectron **C**apture **D**etector
GC/IMS	**G**as **C**hromatograph / **I**on **M**obility **S**pectrometer
GC/MS	**G**as **C**hromatograph / **M**ass **S**pectrometer
GC/SAW	**G**as **C**hromatograph / **S**urface **A**coustic **W**ave
IMS	**I**on **M**obility **S**pectrometer
TR	**T**hermo-**R**edox

2.5.3.1 Ion Mobility Spectrometry

Ion mobility spectrometry (IMS) is one of the most widely used techniques for the trace detection of explosives and other contraband materials. The principle of operation of an IMS is shown in figure 2. The spectrometer consists of two main sections: the ionization region and the drift region. In a typical IMS, ambient air is drawn into an inlet port at the rate of a few hundred cubic centimeters per minute (ccm/min). The purpose of the instrument is to analyze this air for explosives or other compounds of interest, which may be present in the air in the form of vapor or airborne particulate matter. The air first enters the ionization region, where electrons interact with the incoming molecules to form positive or negative ions. In the case of explosives, it is negative ions that are formed. The source of the ionizing electrons is a small, sealed piece of metal that has been coated with a radioactive material, usually nickel-63 ($63Ni^{28}$). Once ions are formed, they are periodically admitted into the drift region through an electronically shuttered gate. The ions are drawn through the gate by a static electric field, which pulls them towards a metal collection plate at the far end of the drift region. This "drift" of the ions from one end of the drift region to the other occurs at atmospheric pressure, with many collisions between the ions and the various molecules present. The time that it takes the ions to travel the length of the drift region is called the drift time, and is a complex function of the charge, mass, and size of the ion. Typical drift times are on the order of a few milliseconds (1 ms = 0.001 s). The current collected at the metal plate is measured as a function of time, and an IMS spectrum is a plot of ion current versus time, with different peaks representing different specific ions. An IMS spectrum of an air sample containing two types of explosives is shown in figure 3. Sometimes an additional gas called the dopant or carrier gas is admitted into the IMS to aid in the ionization process; very commonly methylene chloride or some other gas that easily forms chloride ions is used. Ions from this gas usually form the largest peak in the IMS spectrum, commonly known as the reactant ion peak or RIP, which serves as a reference peak.

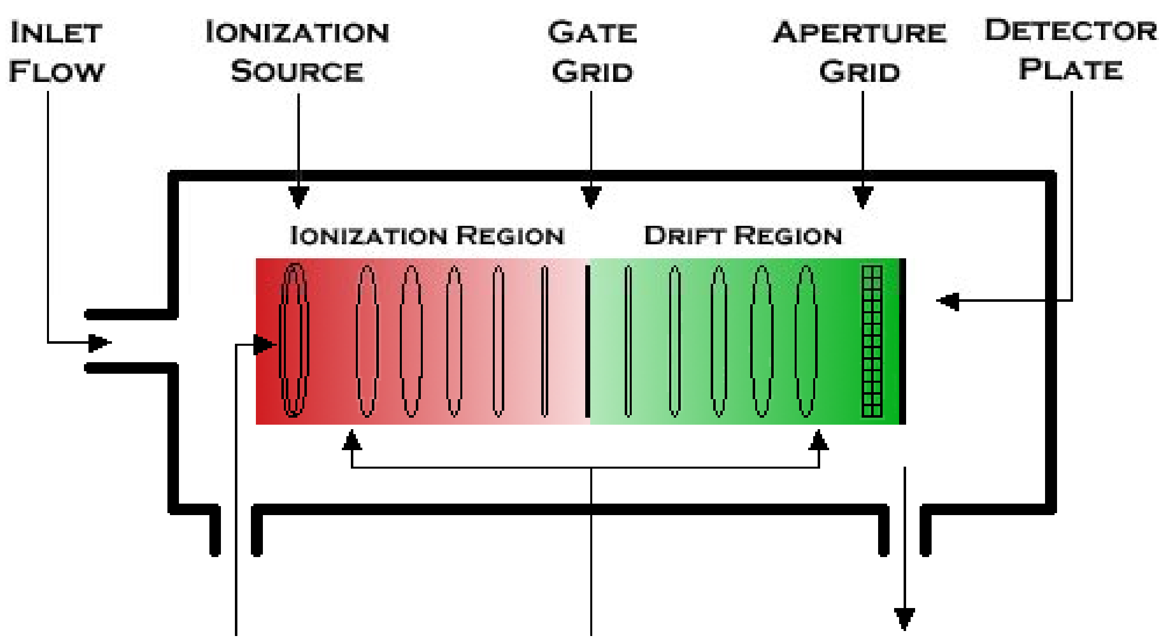

Figure 2. Schematic of ion mobility spectrometer (IMS) operation

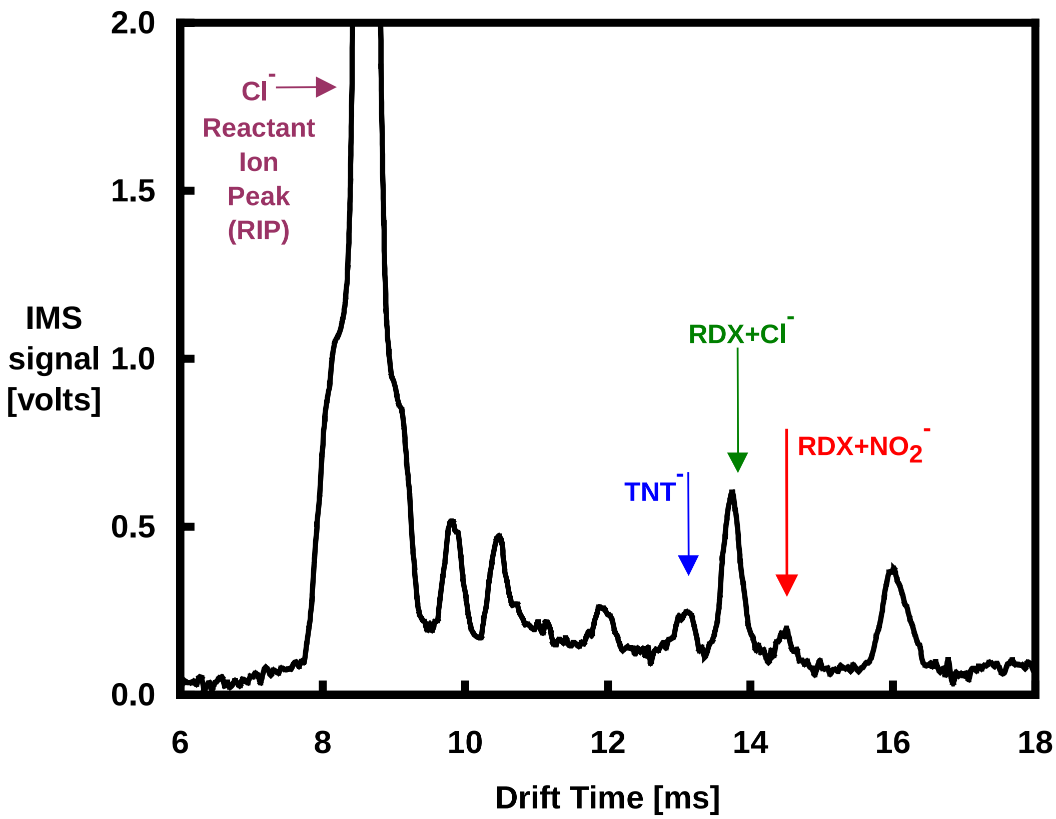

Figure 3. IMS spectrum, a plot of signal vs. drift time

There are a number of features of IMS that make it attractive for the trace detection of explosives. This technique has probably been more widely developed for commercial applications of trace explosives detection than any other. A number of companies market IMS systems, including Barringer, Graseby, and Ion Track Instruments (see table 4). By the standards of most technology-based explosives detectors, IMS systems are moderately priced, with several systems in the $30K to $50K range. Upkeep costs vary from system to system, but are moderate in most cases. Most IMS systems are small and portable enough to be moved around in the trunk of a police cruiser, and can be operated by a person with only a few hours of training. These instruments have response times of only a few seconds, the proven ability to detect a number of key explosives, subparts per billion sensitivity in some cases, and audio and visual alarms that tell the operator when an explosive has been detected, and what type. The most effective means for collecting a sample for presentation to one of these systems is surface swiping, but vacuum collection of samples is also possible with many systems. Figures 4-7 show photos of some commercial IMS systems.

Figure 4. Commercial IMS explosives detection system, Barringer Ionscan 400

Figure 5. ***Commercial IMS explosives detection system, Graseby Plastec***

Figure 6. Commercial IMS explosives detection system, Ion Track Instruments Vapor Trace

Figure 7. Commercial IMS explosives detection system, Intelligent Detection Systems ORION

Like all detection techniques, IMS also has certain weaknesses and drawbacks. As mentioned above, a radioactive material is used as the source of ionizing electrons in the ionization region. This source typically has a strength of about 10 mCi and does not pose any health risks if the system is operated properly, but simply having such a source may lead to some extra paperwork and regulatory oversight. Several attempts have been made to develop an IMS with a non-radioactive electron source such as a plasma discharge, but to date no such systems are commercially available. Most IMS systems do not run off batteries but rather require an electrical outlet, and this limits some field applications. There is a nontrivial warmup time, usually on the order of 10 min, associated with these systems. The drift time associated with a given ion is dependent on atmospheric pressure and can thus change during inclement weather or when the spectrometer is moved more than a few hundred feet in elevation. This requires little more than routine, periodic recalibration, but users need to be aware of this potential problem. Like other technology-based trace detection techniques, IMS systems cannot yet compete with canines in their ability to follow a scent to its source.

Another drawback of IMS in some applications is that the peak resolution is not outstanding, and two different ions of similar size and mass may appear to give only a single peak rather than two distinct peaks in an IMS spectrum. One method of attacking this problem is to prefraction the molecules entering the IMS by first passing the incoming gas through a gas chromatograph (GC). A GC column is essentially a hollow tube, usually packed with beads that are coated with a special chemical substance, referred to as the stationary phase. This coating interacts more strongly with some molecules than with others, so if a gas flow containing different types of molecules is admitted into the GC, molecules that interact more strongly with the stationary phase will take longer to pass through the column. This means that an originally random mixture of different molecules can be sorted by type, with each species exiting the GC at a different time. The time it takes a certain molecule to travel through the length of the GC column is referred to as the retention time. If two molecules have identical drift times in an IMS, they will almost certainly have different retention times in the GC, and their peaks can thus be temporally resolved because they will enter the IMS at different times. A combined system of this type is referred to as GC/IMS, and such instruments are marketed by Intelligent Detection Systems (see table 4) for approximately $75K.

2.5.3.2 Chemiluminescence

Most explosive compounds, including all of those shown in the preceding chart of gas phase concentrations in saturated air, contain either nitro (NO_2) or nitrate (NO_3) groups. The compounds commonly used as taggants in plastic explosives also contain NO_2 groups. Detectors based on chemiluminescence take advantage of this common property of most explosives by detecting infrared light that is emitted from electronically excited NO_2 molecules, denoted as NO_2^*. In a chemiluminescence system, explosive molecules are first pyrolyzed to produce nitric oxide (NO). The NO molecules are then reacted with ozone (O_3) in an evacuated reaction chamber maintained at a pressure of about 3 torr = 0.4 kPa. This reaction produces the excited state molecules, NO_2^*. A photomultiplier situated behind a red light filter is used to detect the infrared photons of a characteristic frequency that are emitted when the NO_2^* molecules decay to form unexcited NO_2. The signal output measured by the photomultiplier is directly proportional to the amount of NO present in the reaction chamber, and this signal is thus used to detect the presence of explosives in a chemiluminescence system. The overall sequence of reactions can be summarized as follows (where the chemical equations have not been balanced):

$$\text{Explosive molecules} \rightarrow NO \text{ (pyrolysis)}$$

$$NO + O_3 \rightarrow NO_2^*$$

$$NO_2^* \rightarrow NO_2 + \text{infrared photons}$$

Used alone, chemiluminescence is not capable of identifying what type of explosive molecule is present. Indeed, all that can be said is that a molecule must initially have been present that decomposed to yield NO molecules, and such molecules include not only explosives and taggants but also species found in fertilizers, some perfumes, and other potential interferents. For this reason, chemiluminescence detectors are not used alone but are fitted with a front-end gas chromatograph (GC), as described in the section on ion mobility spectrometry. The GC allows different molecules that are detected with the chemiluminescence detector to be specifically identified based on their GC retention times, and the resulting system is referred to as a GC/chemiluminescence (GC/CL) detector. Systems of this type are marketed by Thermedics (see table 4).

The best-known GC/chemiluminescence system is the Thermedics Egis. It is capable of analyzing samples in 18 s, and because of its high sensitivity and excellent selectivity it is a popular system with laboratory researchers and forensic analysts. However, its cost of approximately $150K is 2 to 3 times the cost of a typical IMS system. One nice feature of chemiluminescence detectors is that they do not utilize a radioactive ionization source, and thus avoid some of the paperwork and regulatory oversight that may be associated with IMS detectors. A drawback of chemiluminescence systems is their inability to detect explosives that are not nitro-based.

2.5.3.3 Electron Capture Detectors

An electron capture detector or ECD detects explosives and other types of molecules having high electron affinities. A schematic diagram of a typical ECD detector is shown in figure 8. In an ECD, a vapor sample is drawn into an inlet port, and this vapor mixes with a stream of inert carrier gas (usually helium or argon). The gas flow then travels through an ionization region to an exhaust line. In transit, the gas flow passes through a chamber with a radioactive material that acts as an electron source, as in an IMS. The source material is usually either nickel-63 (63Ni[28]) or tritium. The emitted electrons become thermalized through collisions with the gas in the chamber, and eventually are collected at an anode. Under equilibrium conditions, there is thus a constant standing current at the anode. The basic principle behind an ECD is that this standing current is characteristic of the gas mixture being drawn into the system. If the gas mixture originally consists, e.g., of helium and room air, the standing current will be reduced if the vapor of an explosive enters the chamber. This happens because the explosive molecules have a high electron affinity and thus a tendency to capture free electrons and form stable negative ions, leaving fewer electrons to reach the anode. Thus, a reduction of the measured standing current is evidence that an explosive or some similar species is present. As with a chemiluminescence detector, the ECD by itself cannot distinguish individual types of explosives from each other or certain interferents, so a gas chromatograph is placed on the front end to allow temporal identification of different explosives. Several companies market detectors of this type (see table 4), referred to as GC/ECD detectors. A photo of a commercially available GC/ECD device is displayed in figure 9.

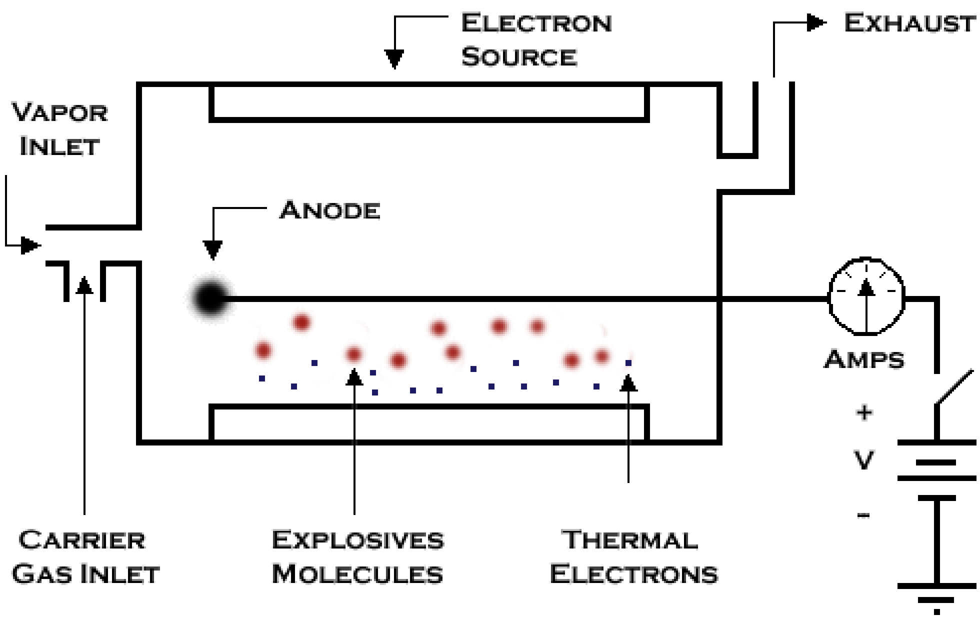

Figure 8. Schematic diagram of operation of an electron capture detector (ECD)

Figure 9. Commercial electron capture detector (ECD), Ion Track Instruments Model 97

This type of detector has a rapid response and typical sensitivities of about 1 ppb for most electron-capturing compounds. This sensitivity is somewhat less than the sensitivity of a typical IMS or chemiluminescence system, but it is still adequate for some applications. However, GC/ECD detectors usually cost less than IMS or chemiluminescence systems, with several systems available for $20K or less. These systems also tend to be smaller, lighter, and more easily portable. As with an IMS, the fact that the instrument has a radioactive ionization source can lead to some extra regulatory oversight. Another problem with ECD systems is that they require an ultrapure carrier gas, usually contained in a small cylinder, and the availability of this carrier gas can put limits on field applications.

2.5.3.4 Surface Acoustic Wave Sensors

Surface acoustic wave (SAW) sensors are usually coupled with a front end GC, as is the case with ECD and chemiluminescence detectors. The principal component of a SAW sensor is a piezoelectric crystal that resonates at a specific, measurable frequency. When molecules condense on the surface of this crystal, the resonant frequency shifts in proportion to the mass of material condensed. The frequency shift also depends upon the properties of the material being deposited, the surface temperature, and the chemical nature of the crystal surface.

In a typical system, the exit gas from the GC is focussed onto the SAW resonator crystal using a carefully positioned and temperature controlled nozzle. A thermoelectric cooler maintains the SAW surface at sufficiently low temperatures to ensure efficient trapping of the molecules of interest. The crystal surface can also be heated in order to desorb vapors and thus clean the surface. The temperature of the surface allows control of sensor specificity, by preventing adsorption of species with vapor pressures above a certain level. This feature is useful in distinguishing between high and low vapor pressure explosives. During sampling, vapors are concentrated in a cryo-trap before being desorbed into the GC for temporal separation.

SAW sensors are marketed by Electronic Sensor Technology, Inc. (see Table 4). Pictured in figure 10 is EST's Model 4100. Total analysis time, including sample concentration in the cryo-trap, is typically 10 s to15 s. The system is advertised to have parts per billion sensitivity to certain types of explosives. It is about the size of a large briefcase, and is operational within 10 min of startup. The cost is about $25K, similar to some GC/ECD systems.

Figure 10. Photo of a surface acoustic wave detector, the EST Model 4100

2.5.3.5 Thermo-Redox Detectors

Thermo-redox technology is based on the thermal decomposition of explosive molecules and the subsequent reduction of NO_2 groups. Air containing the explosive sample is drawn into a system inlet at a rate of approximately 1.5 L/min. The air is next passed through a concentrator tube, which selectively adsorbs explosive vapor using a proprietary coating on the tube's coils. The sample is then pyrolyzed to liberate NO_2 molecules, and these molecules are detected using proprietary technology. Those interested in additional information on this technology should contact Intelligent Detection Systems (see table 4), which now markets the thermo-redox based equipment formerly marketed by Scintrex.

The thermo-redox system currently marketed, the EVD-3000, is a hand-held unit that costs approximately $23K, pictured in figure 11. It can analyze both vapor and particle samples, and contains no radioactive source. Since only the presence of NO_2 groups is detected, this technology cannot distinguish among different explosives and potential interferences that contain NO_2 groups. Thus, the system identifies the presence of an “explosive-like” material, without identifying a specific explosive. Furthermore, the technology cannot detect explosives that do not contain NO_2 groups.

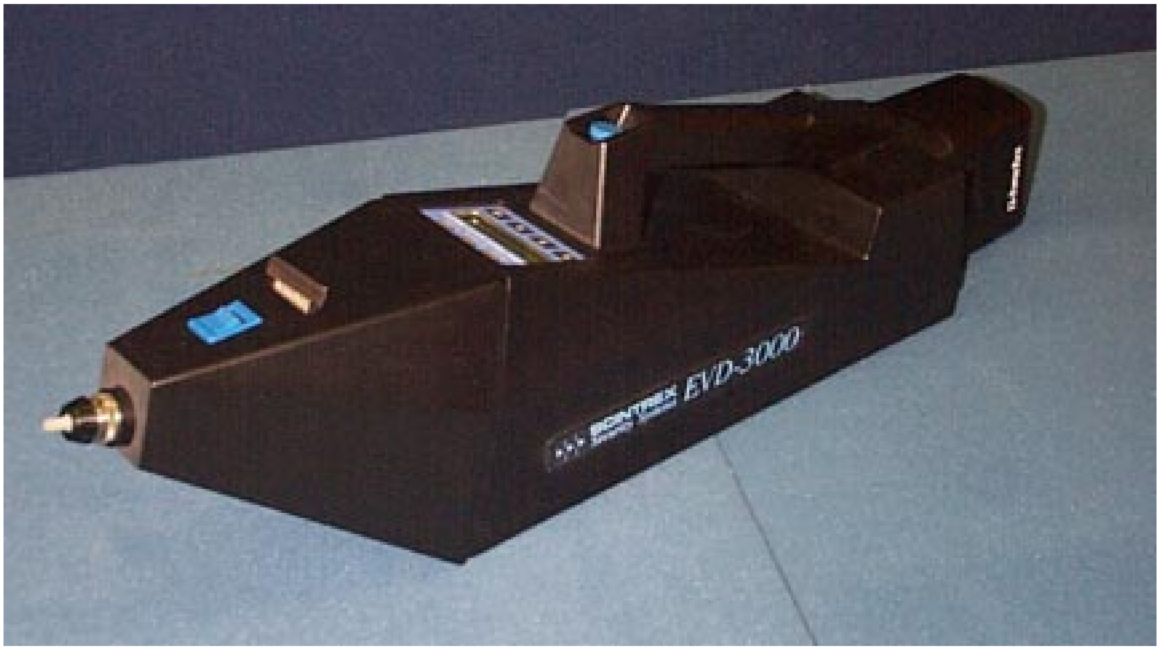

Figure 11. Photo of a Thermo-Redox detector, Sintrex/IDS EVD-3000

2.5.3.6 Field Ion Spectrometry

Field ion spectrometry (FIS) is a relatively new trace detection technology (1994) that is related to IMS. It incorporates a unique ion filter using dual transverse fields, which allows interferences to be eliminated electronically, without the use of GC columns, membranes, or other physical separation methods. FIS is similar to IMS in that it involves separating and quantifying ions while they are carried in a gas at atmospheric pressure. Furthermore, both systems utilize soft ionization methods that yield spectra where the species of interest produce the main features (i.e., under proper conditions there is little decomposition of the analyte).

In FIS, ions enter an analytical volume defined by a pair of parallel conducting plates where they execute two motions. The first is a longitudinal drift between the plates due to the bulk motion of a clean, dry carrier stream of air. The second is an oscillating motion transverse to the bulk flow velocity that occurs as the ions respond to an asymmetric, time-varying electric field imposed between the two plates. In response to the asymmetric field, the ions tend to migrate towards one of the plates where they will be neutralized. A second DC field is simultaneously established across the plates and can be used to balance or compensate for the drift introduced by the primary field. The DC field intensity needed to compensate for the AC field induced drift depends on the mobility of the particular ion under investigation, so that only specific ions can pass completely through the analytical volume and into the collection area for detection. Therefore, the device can be tuned to selectively pass only the ions of interest. Scanning the DC field intensity produces a spectrum of ion current versus field intensity that is known as an ionogram.

The sole manufacturer of FIS sensors is Mine Safety Applications (MSA) – see table 4. Their system, pictured in figure 12, can currently be purchased for about $30K. The sensor has no moving parts except for a small recirculation fan and no consumables except a replaceable calibrator and gas purification filters. The size of the system is 0.022.66 m^3 (0.8 ft^3), excluding a computer for control and display. The manufacturer has reported detection limits for explosives such as TNT, RDX, and PETN in the low picogram range. To our knowledge, there have not yet been any independent tests to verify this. A response time of 2 s for a single target molecule plus another 5 s for each additional target molecule has been reported. Like an IMS, an FIS uses a small radioactive source for ionization. Because of the newness of this technique, the current systems may be better adapted to laboratory research than to routine field applications, but this could change in the future.

Figure 12. Photo of a field ion spectrometer (FIS) by MSA

2.5.3.7 Mass Spectrometry

Mass spectrometry (MS) has long been one of the most powerful techniques available for laboratory chemical analysis. Although it is rarely used in routine field applications and may thus be of little interest to law enforcement agencies doing explosive detection, it is discussed briefly here for completeness and because of this widespread laboratory use. While there are different types of mass spectrometers, this is basically a magnetic filtering technique. Molecules are first ionized and then passed through a magnetic filter, which allows ions to be identified based on their charge-to-mass ratio. In some systems, the MS is connected to a front-end GC. Mass spectrometers have excellent specificity for identifying different ions, and some systems have sub-picogram sensitivity. Mass spectrometers tend to be expensive. Table 4 lists one mass spectrometer system that costs $70K, with an advertised sensitivity in the low parts per billion range for some analytes.

2.5.3.8 EXPRAY Field Test Kit

EXPRAY is a unique, aerosol-based field test kit for the detection of what the manufacturer refers to as Group A explosives (TNT, DNT, picric acid, etc.), Group B explosives (Semtex H, RDX, PETN, NG, smokeless powder, etc.), and compounds that contain nitrates that are used in improvised explosives. Detection of explosive residue is made by observing a **color** change of the test paper. EXPRAY can be used in a variety of applications, and although in some aspects it does not perform as well as many of the other trace detectors discussed in this section, it costs only $250. This very low cost, coupled with simplicity and ease of use, may make it of interest to many law enforcement agencies (see the EXPRAY kit in fig. 13).

The EXPRAY field kit[2] is comprised of the following items:

- one can of EXPRAY-1 for Group A explosives,
- one can of EXPRAY-2 for Group B explosives,
- one can of EXPRAY-3 for nitrate-based explosives (ANFO, black powder, and commercial and improvised explosives based on inorganic nitrates),
- special test papers which prevent cross contamination.

Figure 13. Photo of the EXPRAY Field Test Kit for explosives

Initially, a suspected surface (of a package, a person's clothing, etc.) is wiped with the special test paper. The paper is then sprayed with EXPRAY-1. The appearance of a dark violet-brown color indicates the presence of TNT, a blue-green color indicates the presence of DNT, and an orange color indicates the presence of other Group A explosives. If there is no reaction, the same piece of test paper is then sprayed with EXPRAY-2. The appearance of a pink color indicates the presence of Group B explosives, a group which includes most plastic explosives. If there is still no reaction, the same paper is then sprayed with EXPRAY-3. The appearance of pink then indicates the presence of nitrates, which could be part of an improvised explosive. If EXPRAY-2

[2] The EXPRAY kit pictured in figure 13 is available from Genesis Resource as Model M1553. The phone number for Genesis Research is (602) 838-6420.

is applied after a positive result with EXPRAY-1, a change to pink color indicates a double or triple base explosive. The chemistry associated with these color changes is proprietary. Note that the order of spraying is critical, and all three sprays should be used in order to perform a complete test.

The EXPRAY system has certain limitations. Obviously, it is not always possible to identify the specific type of explosive present when a positive result occurs. Sampling is entirely by surface swiping; there is no method for obtaining a vapor sample. Furthermore, not all types of explosives can be detected. Some nitrate esters and the chlorate group give a negative result. These include mixtures of potassium chlorate, sodium chlorate, and potassium nitrate with sugar, sulfur, and/or carbon. In addition, only the specific colors mentioned above can be judged a positive detection. Other discoloration is possible, but should be judged negative.

The manufacturer claims that EXPRAY can detect particles as small as 20 ng. However, tests performed at Sandia National Laboratories show limits of detection for TNT that are 10 to 20 times greater than this. Nevertheless, this kit is still sensitive enough to make detections in many real world situations.

2.5.4 Table on Commercial Trace Detectors

Table 4 gives information on various commercially available trace explosives detection systems. It must be emphasized that all information is subject to change, and the potential buyer should always check with the manufacturing company to obtain the most up-to-date information, including information on new systems. Companies can also provide advice on the suitability of their products for specific applications, though such advice will clearly not be disinterested. Bear in mind that all costs are approximate, and will depend to some degree on the exact options and accessories purchased.

Table 4. Trace explosives detection systems

#	Trace Detector	Cost in K$	Detector Type	Advertised Sensitivity	Use	Size / Weight	Phone
1	EXPRAY Field Test Kit Model M1553	0.25	Color	20ng of most nitrated high explosives	Personnel, package, and vehicle search	3 aerosol cans 1 lb.	(602) 838-6420
2	Ion Track Instruments Exfinder 152	5	GC/ECD	most nitrated high explosives	Personnel, package, and vehicle search	2"x2"x16" 1.5 lb.	(978) 658-3767
3	JGW International, Ltd. Graseby GVD4	5	GC/ECD	explosive vapor exceeding 1 part in 10^9	Personnel, package, and vehicle search	2"x3"x13" 1.6 lb.	(703) 352-3400
4	XID Corporation XID Model T-54	13	GC/ECD	0.01 parts per billion	Personnel, package, and vehicle search	4"x12"x17" 18 lb.	(201) 773-9400
5	JGW International, Ltd. Graseby GVD6	16	IMS	explosive vapor exceeding 1 part in 10^9	Personnel, package, and vehicle search	22"x4"x13" 21 lb.	(703) 352-3400
6	Ion Track Instruments Model 97	20	GC/ECD	most nitrated high explosives	Personnel, package, and vehicle search	14"x19"x6" 40 lb.	(978) 658-3767
7	Scintrex/IDS EVD-3000	23	TR	< 1 part per billion < 100 nanograms for particulate	Personnel, package, and vehicle search	4"x5"x20" 7 lb.	(613) 230-0609
8	Electronic Sensor Tech., Inc. EST Model 4100	25	GC/SAW	100 parts per billion	Personnel, package, and vehicle search	10"x20"x14" 35 lb.	(805) 480-1994
9	MSA Instrument Division FIS	29	FIS	10 to 1000 parts per trillion	Personnel, package, and vehicle search	24"x15"x13" 20 lb.	(800) 672-4678
10	JGW International, Ltd. Graseby PLASTEC	35	IMS	1 nanogram of TNT, NG, RDX, PETN	Personnel, package, and vehicle search	7"x14"x18" 38 lb.	(703) 352-3400
11	Ion Track Instruments ITMS Vapor Tracer	38	IMS	100 pg to 300 pg	Personnel, package, and vehicle search	13"x5"x5" 7 lb.	(978) 658-3767
12	Scintrex/IDS EVD-8000	43	GC/ECD	< 50 parts per trillion < 5 nanograms for particulate	Personnel, package, and vehicle search	8"x18"x24" 48 lb.	(613) 230-0609
13	Ion Track Instruments ITEMISER	44	IMS	100 pg to 300 pg	Personnel, package, and vehicle search	18"x21"x14" 43 lb.	(978) 658-3767
14	Barringer Instruments, Inc. IONSCAN 350	50	IMS	50 pg to 200 pg	Personnel, package, and vehicle search	22"x13"x12" 105 lb.	(908) 665-8200
15	Ion Track Instruments Model 85 Entry Scan	52	GC/ECD	1 part EGDN vapor in 10^{11} parts air	Personnel Portal (fixed checkpoint portal)	80"x33"x60" 600 lb.	(978) 658-3767
16	Ion Track Instruments Model 85 Dual scan	52	GC/ECD	1 part EGDN vapor in 10^{11} parts air	Personnel Portal (fixed checkpoint portal)	80"x33"x60" 600 lb.	(978) 658-3767
17	Barringer Instruments, Inc. IONSCAN 400	60	IMS	50-200 picograms	Personnel, package, and vehicle search	22"x13"x12" 60 lb.	(908) 665-8200
18	Intelligent Detection Systems ORION	70	GC/IMS	picograms to nanograms	Personnel, package, and vehicle search	40"x20"x30" 240 lb.	(613) 230-0609
19	VIKING Instruments, Inc. Spectra Trak	70	GC/MS	low parts per billion by volume	Portable Analytical Lab Instrument	24"x16"x21" 150 lb.	(703)968-0101
20	Intelligent Detection Systems ORION Mail Scanner	75	GC/IMS	picograms to nanograms	Mail Screening	40"x20"x30" 240 lb.	(613) 230-0609
21	Intelligent Detection Systems SIRIUS	75	GC/IMS	picograms to nanograms	Simultaneous narcotics and explosives	40"x20"x30" 240 lb.	(613) 230-0609
22	Thermedics Detection, Inc. EGIS Model 3000	150	GC/CL	all nitrogen based explosives plus taggants	Personnel, package, and vehicle search	51"x25"x26" 400 lb.	(508) 251-2030
23	Intelligent Detection Systems ORION Plus	155	GC/IMS	picograms to nanograms	Personnel, package, and vehicle search	40"x20"x30" 240 lb.	(613) 230-0609
24	Intelligent Detection Systems ORION Walk-Through	300	GC/IMS	picograms to nanograms	Personnel Portal (fixed checkpoint portal)	custom	(613) 230-0609
25	Intelligent Detection Systems V-bEDS	custom	GC/IMS	picograms to nanograms	Vehicle Screening Portal	custom	(613) 230-0609
26	Thermedics Detection, Inc. SecurScan Portal	300	GC/CL	all nitrogen based explosives plus taggants	Personnel Portal (fixed checkpoint portal)	84"x96"x90"	(508) 251-2030

2.6 X-ray Explosives Detection

X-ray technologies are used to search for explosives in a variety of situations. X-ray systems are most often used for screening luggage, packages, mail, and other relatively small items. All of the systems involve irradiation of a target item with x-rays, followed by detection of an image created by x-rays that are either transmitted or backscattered by the item. The process of personnel screening is problematic because of privacy concerns and the perceived health problems associated with x-rays, but there are currently two different x-ray based personnel scanners on the market in the U.S. Vehicle screening systems are also available, though these are large, expensive, and require passengers to exit the vehicle while it is being screened.

2.6.1 X-ray Technologies

The capabilities of x-ray systems range from those that produce a black and white picture to those that measure the effective atomic number (Z) of the screened items. The black and white images must be viewed and subjectively interpreted by an operator. Systems measuring effective Z can automatically alarm in the presence of materials that have an effective Z that is in the correct range for explosives. For most x-ray systems on the market, detection of a suspicious object is not automatic, and suspicious objects need to be identified by the person viewing the images. Two commercial x-ray systems for personnel screening (soft x-ray) are shown in figures 14-15. Many baggage-screening systems are also available and are similar to systems deployed at airport checkpoints. Such airport systems are undoubtedly familiar to the reader and are not pictured here.

Figure 14. X-ray explosives detection system for personnel, AS&E Body Search

Figure 15. X-ray explosives detection system for personnel, Rapiscan Secure 1000

Table 5. ***X-ray detector technologies and their acronyms***

Acronym	Detector Type
AA	**A**utomated **A**larm
B	**B**ackscatter
CT	**C**omputed **T**omography
DE	**D**ual **E**nergy
FI	**F**luoroscopic **I**maging
ISP	**I**mage **S**torage **P**anels
ST	**S**tandard **T**ransmission

X-ray imaging systems can be divided into two broad types of categories:

- systems that simply produce an image
- systems that detect explosive-like materials and may generate automatic alarms.

The simple black and white images from fluoroscopic imaging, image storage panel, and standard transmission systems cannot identify the actual explosive material, but do allow the operator to see wires, batteries, detonators and other bomb components. **Fluoroscopic imaging** refers to a transmission x-ray system, where the transmitted x-rays form an image of the objects investigated on a fluorescent screen. This is the simplest type of system, exposing the entire object with a cone of x-ray energy, often for extended periods. The fluorescent screen can be viewed in real time using a 45° mirror (to avoid standing in direct line with the x-rays), or can be used in conjunction with a video camera and a video **image storage panel**. Use of the camera and image storage panel minimizes the x-ray dose to the object being viewed, by allowing the image to be captured during a brief exposure. Even with a camera and storage device, this type of system is not film safe. The main reasons for the continued use of fluoroscopic imaging and image-storage panel systems are low cost and portability.

A higher level of technology is the **standard transmission** x-ray. These systems use a fan or flying-spot of x-rays to scan the object as it is carried past the scanner by a conveyor belt. A black and white image is produced directly with a linear array of sensing diodes. The resulting image is stored in digital memory and displayed on a TV or computer screen for operator viewing. These systems are often found at airport checkpoints, where carry-on bags are screened. While standard transmission systems deliver a smaller x-ray dose to the object being screened (they are film safe), they produce black and white transmission images similar to the fluoroscopic systems and are subject to the same detection limitations. Specifically, standard transmission systems cannot identify the actual explosive material, but do allow the operator to see wires, batteries, detonators and other bomb components. In order to provide an operator with identification of explosives-like (low-Z) materials, other x-ray technologies like backscatter, dual energy, or computed tomography may be employed. **Backscatter** systems produce an image from x-rays that are scattered from the screened object. Because low-Z materials are more efficient at scattering x-rays, explosive-like materials are imaged as bright in the backscatter image, while they are barely visible in the transmitted image. The backscatter system produces two images and both the backscatter and transmission images are displayed. The backscatter image is usually most effective for the detection of low-Z materials such as explosives, narcotics, and plastic handguns while the transmission image is most useful for viewing metals.

Backscatter systems cannot discriminate between various low-Z materials (e.g., between C-4 military plastic explosive and harmless plastic).

In order to specifically distinguish explosive-like materials from common low-Z materials, other technologies are employed. **Dual energy** x-ray systems yield superior material discrimination through comparison of the attenuation of x-ray beams at two energies. Thus, identification of low-Z materials can be achieved by using incident x-ray beams of two distinct energies. Materials of specific Z numbers (the same effective Z as explosives) can be clearly highlighted for the operator by adding color to the image. A material that has a high Z number (metals) is often colored green, while low-Z materials are colored orange, and materials with the same Z as explosives are red.

> Some standard transmission systems may have color instead of black and white displays. *Do not confuse dual-energy systems with colorized single energy transmission systems*, which do not color the image on the basis of Z number, but rather color the image based on the level of x-ray energy that is transmitted. These simple single-energy colorized systems have never been proven more effective than the single-energy black and white systems, although their displays may look similar to a dual-energy display.

Computed tomography (CT) is an even more sophisticated x-ray technique in which two-dimensional images ("slices") through an object are added together to produce a three dimensional image. Along with the three-dimensional image, the effective Z number is calculated and materials with the same Z number as explosives can be identified. This is essentially the same technique that may be familiar to the reader from medical CAT scans. Development of a dual-energy CT scanner is underway. This system may be capable of detection with lower false alarms than the single-energy CT scanners.

Any system that can determine that low-Z materials are present can have an **automated alarm** function added. Systems that have been converted into automated detection systems include backscatter, dual energy, and the CT. In fact, CT systems are most useful as automated detection systems because the image they produce may be difficult for the operator to interpret (the image is often heavily distorted).

2.6.2 Table on Commercial X-ray Detectors

Table 6 lists commercially available x-ray detection systems that can be used to detect explosives. Note that most of these systems are not easily portable, and are intended for screening at fixed checkpoints rather than for field use. Since costs vary widely depending on options and accessories selected, specific prices are not quoted, but rather the price category of each system is listed. Low cost is defined as less than $70K, medium cost as $70K to $300K, and high cost as greater than $300K. Again, it is very important to have thorough discussions with the vendors before making a purchase decision.

Table 6. X-ray explosives detection systems

#	X-ray Detector	Cost in K$	Detector Type	Use	Size / Weight	Phone
	PORTABLE					
1	LIXI, Inc - LIXI	Low	FI	Mail, Small Package Search, EOD	10"x18"x6" 6 lb.	(630) 620-4646
2	MINXRAY, Inc. - ISPS	Low	ISP	Portable Viewing of Suspicious Packages	7"x15"x26" 7 lb.	(847) 564-0323
3	MINXRAY, Inc. - 80ST	Low	ISP	Portable Viewing of Suspicious Packages	7"x15"x26" 7 lb.	(847) 564-0323
4	SAIC - RTR-3	Low	FI	Portable Viewing of Suspicious Packages	34"x15"x15" 55 lb.	(619) 546-6000
5	SAIC - CDS-20021	Low	FI	Handheld Contraband Detector	7"x2"x3" 2.6 lb.	(619) 546-6000
6	Vidisco Ltd. - µ - Ray 150	Low	FI	Portable Systems for small package, mail search, EOD	18"x26"x9" 20 lb.	(703) 536-0255
7	Vidisco Ltd. - foXray 150	Low	FI	Portable Systems for small package, mail search, EOD	18"x26"x9" 41 lb.	(703) 536-0255
8	Vidisco Ltd. - A-600	Low	FI	Portable Systems for small package, mail search, EOD	18"x26"x9" 20 lb.	(703) 536-0255
9	MINXRAY, Inc. - FSU6	Low	FI	Field Inspection System	9"x15"x34" 80 lb.	(847) 564-0323
	PACKAGE					
10	American Science and Engineering, Inc – 66Z	Low	B	Mail, Packages, and Baggage Search	69"x30"x83" 1700 lb.	(508) 262-8700
11	American Science and Engineering, Inc – 101GT	Low	B	Mail, Packages, and Baggage Search	69"x30"x83" 1700 lb.	(508) 262-8700
12	American Science and Engineering, Inc – 101GTA	Low	B	Mail, Packages, and Baggage Search	69"x30"x83" 1700 lb.	(508) 262-8700
13	Control Screening - Mailguard	Low	FI	Mail, Small Package Search	30"x22"x23" 350 lb.	(412) 837-5411
14	Control Screening - Guardray	Low	FI	Mail, Small Package Search	74"x40"x29" 1300 lb.	(412) 837-5411
15	EG&G Astrophysics - MINISCAN	Low	FI	Mail and Small Package Inspection	41"x22"x20" 350lb.	(310) 513-1411
16	EG&G Astrophysics - Torrex II	Low	FI	Mail and Large Parcel Inspection	73"x38"x30" 1525 lb.	(310) 513-1411
17	EG&G Astrophysics – LINESCAN 110	Low	ST(DE)	Mail, Hand-Carry, Package Inspection	76"x33"x48" 1500 lb.	(310) 513-1411
18	EG&G Astrophysics - LINESCAN 210	Low	ST(DE)	Mail, Hand-Carry, Package Inspection	76"x33"x48" 1500 lb.	(310) 513-1411
19	EG&G Astrophysics - LINESCAN 215	Low	ST(DE)	Mail, Hand-Carry, Package Inspection	76"x33"x48" 1385 lb.	(310) 513-1411
20	EG&G Astrophysics - LINESCAN 222	Low	ST only	Mail, Hand-Carry, Package Inspection	76"x33"x48" 398 lb.	(310) 513-1411
21	Rapiscan Security Products – Rapiscan 19	Low	ST	Table Top Package Search	75"x31"x25" 308 lb.	(562) 427-0515
22	SAIC - Cabinet Postal Parcel Inspection System	Low	FI	Inspection of Mail, Hand carried Items	72"x36"x66" 1000 lb.	(619) 546-6000
23	Vidisco Ltd. – eXaminer-	Low	FI	Mail, handbags, parcels, briefcase inspection	31"x14"x40" 330 lb.	(703) 536-0255
24	Vidisco Ltd. – MIC-80A	Low	FI	Mail, handbags, parcels, briefcase inspection	30"x21"x74" 790 lb.	(703) 536-0255
25	XID Corporation - MailSafex	Low	FI	Mail, Small Package Search	30"x22"x22" 190 lb.	(201) 773-9400
26	XID Corporation - MailScope 500	Low	FI	Mail, Small Package Search	30"x22"x22" 190 lb.	(201) 773-9400
27	Control Screening - Dynavision 910	Low-Medium	ST(DE)	Parcel, Package, and Luggage Search	48"x31"x60" 890 lb.	(412) 837-5411

Table 6. X-ray explosives detection systems–Continued

#	X-ray Detector	Cost in K$	Detector Type	Use	Size / Weight	Phone
	PACKAGE (continued)					
28	Control Screening - Dynavision 925	Low-Medium	ST(DE)	Large Parcel, Package, and Luggage Search	48"x44"x119" 1600 lb.	(412) 837-5411
29	Control Screening - Dynavision 400A	Low-Medium	ST(DE)	Parcel, Package, and Luggage Search	48"x31"x42" 650 lb.	(412) 837-5411
30	Heimann Systems - HI-Scan 6040-A	Low-Medium	DE	Hand Carried Luggage, Packages	33"x49"x79" 900 lb	(908) 603-5914
31	Heimann Systems - HI Scan 7555-A	Low-Medium	DE	Hand Carried Luggage, Packages	80"x33"x50" 880 lb.	(908) 603-5914
32	Heimann Systems - PS 5030	Low-Medium	DE	Hand Carried Luggage, Packages	22"x25"x47" 280 lb.	(908) 603-5914
33	Rapiscan Security Products - Rapiscan Model 320	Low-Medium	DE	Small Package Search	33"x53"x101" 1230 lb.	(562) 427-0515
34	Rapiscan Security Products - Rapiscan Model 322	Low-Medium	DE	Package Search	41"x58"x101" 1365 lb.	(562) 427-0515
35	Rapiscan Security Products - Rapiscan Model 324	Low-Medium	DE	Large Package Search	53"x47"x136" 1562 lb.	(562) 427-0515
36	Rapiscan Security Products - Rapiscan Model 326	Low-Medium	DE	Large Package Search	52"x64"x120" 1805 lb.	(562) 427-0515
37	Rapiscan Security Products - Rapiscan Model 327	Low-Medium	DE	Large Package Search	55"x82"x155" 3080 lb.	(562) 427-0515
38	Rapiscan Security Products - Rapiscan Model 328	Low-Medium	DE	Large Package Search	56"x84"x155" 2465 lb.	(562) 427-0515
39	Rapiscan Security Products - Rapiscan Model 330	Low-Medium	DE	Large Package Search	83"x53"x130" 2310 lb.	(562) 427-0515
40	American Science and Engineering, Inc - 101Z	Medium	B	Large Package and Baggage Inspection	50"x49"x103" 1630 lb.	(508) 262-8700
41	American Science and Engineering, Inc - 101ZZ	Medium	B	Large Package and Baggage Inspection,	50"x49"x103" 3600 lb.	(508) 262-8700
42	American Science and Engineering, Inc - EXR-ZZ	Medium	B	Package Inspection Real -Time Image Analysis	80"x51"x150" 3500 lb.	(508) 262-8700
43	Heimann Systems - HI-Scan 5170-A	Medium	DE	Check-in luggage, Bulk items,	120"x60"x48" 1000-4000 lb.	(908) 603-5914
44	Heimann Systems - CS 5070	Medium	DE	Check-in luggage, Bulk items Counter System (CS)	120"x60"x48" 1000-4000 lb.	(908) 603-5914
45	Heimann Systems - HI-Scan 9075-TS	Medium	DE	Check-in luggage, Bulk items Terminal System (TS)	120"x60"x48" 1000-4000 lb.	(908) 603-5914
46	EG&G Astrophysics – LINESCAN 107	Medium -High	ST(DE)	Large Package, Luggage Inspection	160"x80"x80" 3435 lb.	(310) 513-1411
47	EG&G Astrophysics - LINESCAN 111	Medium -High	ST(DE)	Large Package, Luggage Inspection	160"x80"x80" 2800 lb.	(310) 513-1411
48	EG&G Astrophysics - LINESCAN 112	Medium -High	ST(DE)	Large Package, Luggage Inspection	160"x80"x80" 1730 lb.	(310) 513-1411
49	EG&G Astrophysics - LINESCAN 231	Medium -High	ST(DE)	Large Package, Luggage Inspection	160"x80"x80" 3435 lb.	(310) 513-1411
50	EG&G Astrophysics - LINESCAN 232	Medium -High	ST(DE)	Large Package, Luggage Inspection	160"x80"x80" 7600 lb.	(310) 513-1411
51	EG&G Astrophysics - LINESCAN 237	Medium -High	ST(DE)	Large Package, Luggage Inspection	160"x80"x80" 3235 lb.	(310) 513-1411
52	EG&G Astrophysics - Z-Scan – 10 (small)	Medium -High	DE, AA Dual View	Package Inspection	58"x51"x114" 2600 lb.	(310) 513-1411
53	EG&G Astrophysics - Z-Scan – 12 (medium)	Medium -High	DE, AA Dual View	Package Inspection	58"x69"x156" 3800 lb.	(310) 513-1411

Table 6. X-ray explosives detection systems–Continued

#	X-ray Detector	Cost in K$	Detector Type	Use	Size / Weight	Phone
	PACKAGE (continued)					
54	EG&G Astrophysics - Z-Scan – 7 (large)	Medium -High	DE, AA Dual View	Package Inspection	75"x68"x152" 4600 lb.	(310) 513-1411
55	Heimann Systems - HI-Scan 11080-TS	Medium -High	DE	Large boxes, parcels, bulk items, and freight	10'x10'x10' 4400-10000lb.	(908) 603-5914
56	Heimann Systems - HI-Scan 85120-TS	Medium -High	DE	Large boxes, parcels, bulk items, and freight	10'x10'x10' 4400-10000lb.	(908) 603-5914
57	Heimann Systems - HI-Scan 100170-TS	Medium -High	DE	Large boxes, parcels, bulk items, and freight	10'x10'x10' 4400-10000lb.	(908) 603-5914
58	Rapiscan Security Products – Rapiscan Model 520	Medium -High	DE	Small Package Search	33"x53"x101" 1230 lb.	(562) 427-0515
59	Rapiscan Security Products – Rapiscan Model 522	Medium -High	DE	Package Search	41"x58"x101" 1365 lb.	(562) 427-0515
60	Rapiscan Security Products – Rapiscan Model 524	Medium -High	DE	Large Package Search	53"x47"x136" 1562 lb.	(562) 427-0515
61	Rapiscan Security Products – Rapiscan Model 526	Medium -High	DE	Large Package Search	52"x64"x120" 1805 lb.	(562) 427-0515
62	Rapiscan Security Products – Rapiscan Model 527	Medium -High	DE	Large Package Search	55"x82"x155" 3080 lb.	(562) 427-0515
63	Rapiscan Security Products – Rapiscan Model 528	Medium -High	DE	Large Package Search	56"x84"x155" 2465 lb.	(562) 427-0515
64	Rapiscan Security Products – Rapiscan Model 530	Medium -High	DE	Cargo Search	83"x53"x130" 2310 lb.	(562) 427-0515
65	Vivid Technologies Inc. - H-1	Medium -High	DE	Package and Luggage Search	63"x52"x127" 1600 lb.	(617) 890-8188
66	Vivid Technologies Inc. - APS	Medium -High	DE	Package and Luggage Search	36"x49"x101" 1086 lb.	(617) 890-8188
67	Vivid Technologies Inc. - VIS	Medium -High	DE, AA	Package and Luggage Search, no operator input	56"x73"x140" 4200 lb.	(617) 890-8188
68	Vivid Technologies Inc. - VIS-W	Medium -High	DE, AA	Package and Luggage Search adds workstation to VIS	56"x73"x140" 4200 lb.	(617) 890-8188
69	Vivid Technologies Inc. - VDS	Medium -High	DE, AA	Package and Luggage Search requires operator input	56"x73"x140" 4200 lb.	(617) 890-8188
70	Heimann Systems - HI-Scan 10050 EDS	High	DE, AA	Checked Baggage Search	65"x78"x117" 4400 lb.	(908) 603-5914
71	In Vision Technologies. Inc. - CTX-5000	High	CT, AA	Package and Luggage Search	80"x75"x174" 9400 lb.	(415) 578-1930
	PERSONNEL					
72	American Science and Engineering, Inc - Body Search	Medium	B	Personnel Inspection	46"x127"x120" 4120 lb.	(508) 262-8700
73	Nicolet Imaging Systems - Secure 1000	Medium	B	Personnel Search	11.1 sq. ft.,80" H 650 lb.	(619) 635-8600
	VEHICLE OR CARGO					
74	American Science and Engineering, Inc - 101XL	Medium	B	Large Cartons and Palletized Cargo Inspection	103"x96"x120" 3830 lb.	(508) 262-8700
75	EG&G Astrophysics - LINESCAN 226	Medium -High	ST(DE)	Large Package, Luggage Inspection	96"x114"x288" 8000 lb.	(310) 513-1411
76	Rapiscan Security Products – Rapiscan Model 532	Medium -High	DE	Cargo Search	105"x75"x135" 4735 lb.	(562) 427-0515

Table 6. X-ray explosives detection systems–Continued

#	X-ray Detector	Cost in K$	Detector Type	Use	Size / Weight	Phone
	VEHICLE (continued)					
77	Rapiscan "System 2000"	High	DE	Large Scale Systems for border crossings, sea ports	Custom	(562) 427-0515
78	Heimann Systems - HI-CO-SCAN	High	DE	Vehicle and Cargo search	63'X43'x151' Bldg.	(908) 603-5914
79	American Science and Engineering, Inc - CargoSearch	High	B	Vehicle, and Cargo Inspection	Custom Bldg.	(508) 262-8700
80	American Science and Engineering, Inc - ContainerSearch	High	B	Vehicle and Cargo Inspection	Custom Bldg.	(508) 262-8700
81	American Science and Engineering, Inc - MobileSearch	High	B	Mobilized, Vehicle and Cargo Inspection	Custom Large truck	(508) 262-8700
82	EG&G Astrophysics – Cargo Inspection System	High	ST(DE)	Fully Loaded Trucks and 20'&40' Containers	Custom Bldg.	(310) 513-1411
	MOBILE PACKAGE (mounted in a vehicle)					
83	Rapiscan Security Products - X-ray Van	Medium -High	DE	Mobile Package Search	233"x90"x80" Van	(562) 427-0515
84	American Science and Engineering, Inc - 101Van	High	B	Mobilized, Large Package Inspection	Custom Van	(508) 262-8700
85	American Science and Engineering, Inc - 101 Trailer	High	B	Mobilized, Large Package Inspection	Custom Trailer	(508) 262-8700
86	EG&G Astrophysics – LINESCAN Trailer	High	ST(DE)	Mobilized Package Inspection	8'x13'x6' 5240 lb.	(310) 513-1411
87	EG&G Astrophysics – LINESCAN AutoVan	High	ST(DE)	Mobilized Package Inspection	22'x8'x10' 10,000 lb.	(310) 513-1411
88	Heimann Systems - ScanTrailer	High	DE	Mobile screening systems	80"x32" tunnel opening	(908) 603-5914
89	Heimann Systems - ScanVan IV	High	DE	Mobile screening systems	80"x32" tunnel opening	(908) 603-5914
90	Heimann Systems - Scanmobile	High	DE	Mobile screening systems	80"x32" tunnel opening	(908) 603-5914

Low cost is defined as less than $70K, medium cost is defined as $70K to $300K, and high cost is defined as above $300K.

2.7 Canine Detection

Trained canines provide a reliable and time-proven method for detecting concealed explosives. There is in principle no explosive compound that dogs cannot be trained to sniff out, and dogs used in the U.S. military are typically trained to detect nine different explosives. Compared to technology-based “sniffer” systems, dogs have the advantages of (1) superior mobility and (2) the ability to rapidly follow a scent directly to its source. Because of these advantages, canines are an excellent choice for explosives detection applications that involve a significant search component. Such applications include the search of vehicles, warehouses, luggage and cargo, aircraft, buildings, offices, and areas exterior to buildings such as parking lots, property perimeters, etc. Dogs are not usually used to search people because of the liability issues involved should a dog bite someone. Disadvantages of canines compared to trace technologies include: limited duty cycle (i.e., a dog works about 1 h before requiring a break), the need for regular retraining, and the inability to communicate to the handler the type of explosive that is detected.

Law enforcement agencies can obtain canines from various civilian contractors. The best contact point is probably a law enforcement agency in the same area that already utilizes canines. The purchase cost is typically $5K to $10K per dog, and the initial training usually costs an additional $6K to $12K. This training typically involves two people and lasts up to three months. Once a dog has been procured, monthly training sessions are required. These are often performed in-house, so that the main cost is the time of the personnel involved. Feeding and caring for a dog (veterinary bills, etc.) typically costs approximately $1.6K per year.

2.8 Novel Detection Techniques

This section lists several additional explosives detection techniques that have received at least some commercial development. Since most of these techniques are still in the process of development, it is especially important to contact the companies involved to obtain the latest information.

(1) Thermal Neutron Activation (TNA): This technique is based on the interaction of neutrons with the nitrogen atoms contained in an explosive compound. A system of this type is produced by Science Applications International Corporation (SAIC), phone: (800)962-1632, fax: (619)646-9718. The system is capable of detecting a number of explosives and has been used to screen check luggage in airports. However, it is very large 1363.6 kg (3,000 lb) and costs approximately $900K. Smaller and cheaper systems may be developed in the future, as the technology progresses.
(2) Pulsed Fast Neutron Analysis (PFNA): This new and promising technique is also being developed by SAIC, which should be contacted if additional information is desired. It is also based on the interaction of neutrons with the explosive material, which results in the emission of gamma rays with characteristics that are indicative of the specific material. Preliminary testing has shown that many materials, including but not limited to explosives, yield unique signatures when this technique is applied. It has been used primarily for luggage screening.
(3) Quadrupole Resonance: This is a promising new technology that has been extensively developed by Quantum Magnetics, Inc., phone: (619)566-9200. This technique uses pulses of radio-frequency energy to excite nitrogen nuclei within an explosive material, which then

(4) emits photons of characteristic frequency when they relax. A number of systems are available for screening mail, packages, boxes, etc. Cost varies from $65K to $400K depending on the system selected.

(5) Portable Isotopic Neutron Spectroscopy (PINS) Chemical Assay System: This system has been jointly developed by EG&G Ortec (phone: (423)482-4411) and the Idaho National Engineering and Environmental Laboratory. It is also based on irradiation of the explosive material with neutrons to produce gamma rays of a characteristic energy. It is designed primarily for field use in military applications, where it identifies explosives, nerve agents, and blister agents associated with firing ranges and munitions burial sites.

3. SUGGESTED TECHNOLOGIES FOR PORTABLE, SEMI-PORTABLE, AND FIXED-SITE APPLICATIONS

This section presents three matrices (tables 7-9) that provide suggestions on which explosives detection technologies are likely to work best in a variety of different circumstances and applications. The emphasis is on what methods will work best in general, and not on what specific system should be purchased from a specific manufacturer. When two or more technologies will work equally well, all are listed. Note that high technology solutions are not always the best solutions. In a number of cases, canine detection or physical search (manual search) by police officers or security guards may prove more effective.

3.1 How to Choose Explosives Detection Technology for Specific Applications (Tables 7-9)

The three matrices consider five factors that law enforcement personnel will want to weigh in making a procurement decision:

- Degree of Portability: Table 7 is for portable applications, table 8 for semiportable applications, and table 9 for fixed-site applications. The definitions of portable, semi-portable, and fixed-site are as given in section 2.1.
- Presence or Absence of an Explosives Background: For some applications that are primarily at a fixed site, the presence of background explosives contamination at the site could present problems. For example, if a detector is to be deployed near a bunker where explosives are stored, there will probably be a considerable amount of particulate contamination in the general area, transported by wind, people's feet, etc. In such cases, it may be undesirable to use trace detection and perhaps also canine detection in the area, because the contamination will lead to many nuisance alarms that need to be resolved. Bulk detection technologies or physical search are often preferable in such situations.
- Item to be Screened: There are four categories of items – people, hand-carried items, mailed items, and vehicles, as discussed in section 2.2.
- Throughput Rate: Alternatives are provided for low, medium, and high throughput rates, as defined in section 2.4.
- System cost: Low-, medium- and high-cost range alternatives are considered, with the cost ranges defined as in section 2.3. Recall that the cost ranges are defined differently for trace and x-ray systems, in order to reflect the realities of the current market.

3.2 Practical Notes Concerning Tables 7-9

- If a low-cost option is listed, it can also be used in principle for the situation defined by the medium-cost and high-cost boxes just below it. However, it is sometimes the case that there is a trade-off between cost and performance, and sensitivity or some other performance characteristic may suffer if the cheapest possible system is chosen.
- In some checkpoint screening applications, a high throughput rate may make it impossible to uniformly screen all items passing through the checkpoint. In these cases, a possible option is random screening. Random screening means that only a randomly chosen fraction of the passing items will be screened for explosives. For example, with a personnel portal, every fifth person passing the checkpoint might be screened, rather than all persons. The advantage of random screening is that it can reduce a high throughput situation to a medium or low throughput situation and thus provide more time to screen the individual items that are

screened, while still retaining some deterrent effect. The disadvantage, obviously, is that it becomes possible for a bomb to pass through the checkpoint in an item that is not screened. In general, uniform screening is to be preferred to random screening whenever possible, but random screening is always an alternative. In tables 7-9, random screening is recommended only in cases where uniform screening would almost certainly be too slow.

- Shaded boxes in the three matrices represent combinations of cost and throughput rate where it is difficult or impossible to perform uniform screening with current technologies. In many cases, these combinations are also unlikely to occur. For example, it will probably never be necessary to screen people with a high throughput rate using a portable system. A portable system for personnel screening is needed only for applications such as searching an apprehended suspect in the field, and in such an application a high throughput rate is not needed. The officers involved can, within reason, take as much time as they need to search the suspect.
- Metal detection is listed in a few places in these matrices where options are rather limited, but it must be remembered that metal detection is of limited value in searching for explosives. It can find primers and metallic bomb components, but not the explosives themselves.
- In the matrices, the range of recommended trace or x-ray systems in a particular situation is given by using the numbers assigned to detection systems in tables 4 and 6. Thus, for example, "Trace 1-7" indicates that any of the first seven systems listed in table 4 might be a satisfactory choice for the given situation.

Readers of this document are encouraged to study tables 7-9, and focus on those circumstances they believe will be most important to their intended applications. Once again, it must be emphasized that these matrices serve as a starting point, and not an endpoint, in choosing an appropriate detection system. Obtaining product literature, speaking with the vendor(s), and holding discussions with an outside expert are still necessary to make the best-informed decision possible.

Table 7. Matrices for law enforcement - <u>portable</u>: easily carried by one person

Item Screened	Cost	Explosives Background: Low Throughput	Explosives Background: Medium Throughput	Explosives Background: High Throughput	No Explosives Background: Low Throughput	No Explosives Background: Medium Throughput	No Explosives Background: High Throughput
People	**Low**	Physical Search or Handheld Metal Detector			Trace (1-8)		
	Medium				Trace (10,11)		
	High						
Hand-Carried Item	**Low**	x-ray (1-9)			Trace (1-8) or x-ray (1-9)	Trace (1-8)	
	Medium				Trace (10,11)	Trace (10,11)	
	High						
Mailed Item	**Low**	x-ray (1-9)			Trace (1-8) or x-ray (1-9)	Trace (1-8)	
	Medium				Trace (10,11)	Trace (10,11)	
	High						
Vehicle	**Low**	Physical Search			Canine with Trace (1-8) supplement		
	Medium				Canine with Trace (10,11) supplement		
	High						

Shaded boxes represent cases that are unlikely to arise. The use of truly man-portable systems will be largely limited to field applications rather than to screening at fixed checkpoints, and in such field applications throughput rate will not be an issue. In rare cases where a portable system is desired for higher throughput applications, applying the suggested low throughput technology in a random fashion is one possible solution. Contact the authors of this document for further information and advice.

Table 8. Matrices for law enforcement - <u>semiportable</u>: Can fit in the trunk of a police car

Item Screened	Cost	Explosives Background: Low Throughput	Explosives Background: Medium Throughput	Explosives Background: High Throughput	No Explosives Background: Low Throughput	No Explosives Background: Medium Throughput	No Explosives Background: High Throughput
People	**Low**	Physical Search or Handheld Metal Detector	Random Physical Search or Handheld Metal Detector		Trace (1-8)		Random Trace (1-8)
	Medium				Trace (10-13,17)		Random Trace (10-13,17)
	High						
Hand-Carried Item	**Low**	Physical Search or x-ray (1-9)	Random Physical Search		Trace (1-8) or x-ray (1-9) or Canine	Trace (1-8) or Canine	Random Trace (1-8) or Canine
	Medium				Trace (10-13,17)	Trace (10-13,17)	
	High						
Mailed Item	**Low**	Physical Search or x-ray (1-9)	Random Physical Search		Trace (1-8) or x-ray (1-9) or Canine	Trace (1-8) or Canine	Random Trace (1-8) or Canine
	Medium				Trace (10-13,17)	Trace (10-13,17)	
	High						
Vehicle	**Low**	Physical Search		Random Physical Search	Canine		Random canine
	Medium						
	High						

Shaded boxes indicate situations where semiportable technologies have difficulty meeting the throughput requirement. In such cases, some form of random screening may be recommended.

Table 9. Matrices for law enforcement - fixed location, dedicated systems

<table>
<tr><th rowspan="2">Item Screened</th><th rowspan="2">Cost</th><th colspan="3">Explosives Background</th><th colspan="3">No Explosives Background</th></tr>
<tr><th>Low Throughput</th><th>Medium Throughput</th><th>High Throughput</th><th>Low Throughput</th><th>Medium Throughput</th><th>High Throughput</th></tr>
<tr><td rowspan="3">People</td><td>Low</td><td rowspan="2">Physical Search or Handheld Metal Detector</td><td rowspan="2" colspan="2">Random Physical Search or Handheld Metal Detector</td><td colspan="2">Trace (1-8)</td><td>Random Trace (1-8)</td></tr>
<tr><td>Medium</td><td colspan="2">Trace (10-21)</td><td>Trace (15,16)</td></tr>
<tr><td>High</td><td colspan="3">x-ray (72,73)</td><td colspan="2">Trace (22-24,26), x-ray (72,73)</td><td>Trace (24,26), x-ray (72,73)</td></tr>
<tr><td rowspan="3">Hand-Carried Item</td><td>Low</td><td>Physical Search or x-ray (1-26)</td><td colspan="2">x-ray (10-26)</td><td colspan="2">Trace (1-8), x-ray (1-26) or Canine</td><td>Random Trace (1-8) or Canine</td></tr>
<tr><td>Medium</td><td colspan="3">x-ray (27-45)</td><td colspan="2">x-ray (27-45) or Trace (10-14,17-21)</td><td>x-ray (27-45)</td></tr>
<tr><td>High</td><td colspan="3">x-ray (46-71)</td><td colspan="2">x-ray (46-71), Trace (22,23)</td><td>x-ray (46-71)</td></tr>
<tr><td rowspan="3">Mailed Item</td><td>Low</td><td>Physical Search or x-ray (1-26)</td><td colspan="2">x-ray (10-26)</td><td colspan="2">Trace (1-8), x-ray (1-26) or Canine</td><td>Random Trace (1-8) or Canine</td></tr>
<tr><td>Medium</td><td colspan="3">x-ray (27-45)</td><td colspan="2">x-ray (27-45) or Trace (10-14,17-21)</td><td>x-ray (27-45)</td></tr>
<tr><td>High</td><td colspan="3">x-ray (46-71)</td><td colspan="2">x-ray (46-71), Trace (22,23)</td><td>x-ray (46-71)</td></tr>
<tr><td rowspan="3">Vehicle</td><td>Low</td><td rowspan="2" colspan="2">Physical Search</td><td rowspan="3">Random Physical Search</td><td rowspan="2" colspan="2">Canine</td><td rowspan="3">Random canine</td></tr>
<tr><td>Medium</td></tr>
<tr><td>High</td><td colspan="2">x-ray (78-82)</td><td colspan="2">x-ray (78-82)</td></tr>
</table>

Shaded boxes represent cases where no current technology is rapid enough to perform screening of all incoming items. In such cases, some form of random screening is recommended.

4. DESIRABLE CHARACTERISTICS FOR EXPLOSIVES DETECTION EQUIPMENT FOR POLICE WORK

Sections 4.1 and 4.2 present tables and discussion dealing with desirable characteristics for trace and x-ray explosives detection equipment that might be used in law enforcement work. In the case of trace detection systems, 22 different characteristics are discussed in table 10. A much smaller number of defining characteristics for x-ray systems is in table 11.

4.1 Trace Systems

In looking at desirable characteristics for detection systems, a useful approach is to define "ideal" and "nominal" characteristics, and then to classify each detector (when possible) as ideal, nominal, or subnominal with regards to that particular characteristic. While the definitions of ideal and nominal are necessarily somewhat arbitrary and application dependent, this categorization allows comparisons to be made easily and rapidly. However, it must be remembered that a law enforcement agency needs to procure a system based on the characteristics that are most important to it, and these will vary widely. In other words, there is no "one size fits all" method of choosing detection equipment for law enforcement work. For some applications, it may be crucial that a system meet the "ideal" standard for one or more characteristics, while for other characteristics a subnominal rating may be perfectly acceptable. Note that no system in table 10 meets all of our ideal characteristics, and it is very likely that no system will meet any other set of "ideal" specifications that might be defined. *The enumeration of "ideal" and "nominal" characteristics in this section should not be construed as providing a list of requirements; it is intended only to provide information.* As with the matrices in section 3, this table should serve only as a starting point in making a procurement decision. Furthermore, it must be remembered that some of the characteristics considered are not fully quantifiable, and in such cases the associated "ratings" (ideal, nominal, subnominal) are necessarily subjective and could be open to debate. With these caveats in mind, the following characteristics are considered:

(1) **System Size**: Ideal capability: The system can be easily carried by one person. Nominal capability: The system fits easily in the trunk of a standard police car. Comments: At present, few commercial systems meet the ideal capability. The two that do are the Scintrex/IDS EVD-3000 and the ITI Vapor Tracer. Most commercial trace detection systems meet the nominal capability, though a few of the larger ones such as the Thermedics EGIS do not. Obviously, personnel portals also do not meet the nominal capability.

(2) **System Weight**: Ideal capability: The system consists of one piece that weighs less than 9.1 kg (20 lb), so it can easily be hand-carried by a single operator. Nominal capability: The system can be contained within two crates or packages, each with a weight of 22.73 kg (50 lb) or less. Comments: Only a few commercial trace detection systems meet the ideal capability, but most meet the nominal capability.

(3) **Cost**: Ideal capability: The system costs less than $30K. Nominal capability: The system costs less than $100K. Comments: Most of the commercial systems now available cost $75K or less. Few are less than $25K, although some like the Scintrex/IDS EVD-3000 and the ITI Vixen are. These two systems are based on thermo-redox and ECD technology. Those technologies are typically less sensitive compared to systems employing chemiluminescence or IMS technology. The typical cost for IMS systems is $40K to $75K.

(4) **<u>Explosives Detected</u>**: <u>Ideal capability</u>: The system can detect TNT, RDX, PETN, NG, EGDN, DNT, ANFO (ammonium nitrate), double base smokeless and black powders, and common taggants such as DMDNB and mononitrotoluenes. <u>Nominal capability</u>: The system can detect TNT, RDX, PETN, NG, and black powder. <u>Comments</u>: These are the common high explosives that police officers are likely to encounter in everyday situations. Some less common explosives that are likely to be very rare in real-life situations are not considered here. Little emphasis is placed on chemical taggants because (a) there is lots of untagged plastic explosive material around (C-4, semtex), and (b) it is assumed that most sample collection will utilize surface swiping, in which case the explosives are easily detected without taggants. Most commercial systems do not detect all explosives equally well in practice. For example, IMS systems can detect nitrate-based explosives such as ANFO and black powder, but not as effectively as they detect TNT, RDX, etc. All of the commercial systems that the authors are familiar with can detect the nominal list; most can detect the ideal list.

(5) **<u>Ruggedness</u>**: <u>Ideal capability</u>: The system is encased and protected to withstand wind, dust, and rain. It must also withstand the routine shocks and vibration associated with transporting it. <u>Nominal capability</u>: The system is generally rugged for field applications, but will not be operated during inclement weather (and thus exposure to dust, rain, and severe winds will be minimized). It must also withstand the routine shocks and vibration associated with transporting it. <u>Comments</u>: All current systems meet the nominal capability. Some testing would be needed to determine which systems meet the ideal capability.

(6) **<u>Field Operation (Power)</u>**: <u>Ideal capability</u>: The system can operate on batteries. <u>Nominal capability</u>: The system can operate from a standard 110 V AC power outlet. <u>Comments</u>: While battery operation is ideal, many commercial systems do not offer this option. All systems meet the nominal capability.

(7) **<u>Maintenance</u>**: <u>Ideal capability</u>: Nominal maintenance required, perhaps every six months, and can be performed by a law enforcement officer. <u>Nominal capability</u>: Monthly replacement of consumable chemicals, filters, etc. <u>Comments</u>: Most systems will meet the nominal capability.

(8) **<u>System Calibration</u>**: <u>Ideal capability</u>: A simple calibration procedure should be provided by the manufacturer and well documented in a manual. Under normal weather conditions, not more than one recalibration should be required per day, assuming continual operation of the equipment. <u>Nominal capability</u>: As for the ideal case, except that recalibration up to once per hour is permissible, assuming continual operation of the equipment. <u>Comments</u>: Most current systems meet the ideal capability under normal weather conditions. However, pressure changes during storms can rapidly change peak positions in IMS spectra, resulting in the need for frequent recalibration during inclement weather. This may be a problem with some other technologies as well. Police departments may wish to consider questions such as “How many days a year are there severe storms in this region?” before purchasing a system. Note also that moving an IMS system to a new elevation may also require recalibration, due to the pressure change involved. For most systems, this will not be an issue if the elevation change is less than $\pm$ 91.44 m ($\pm$ 300 ft).

(9) **<u>Start-up Time</u>**: <u>Ideal capability</u>: Less than 10 min from a warm start, and less than 20 min from a cold start. <u>Normal capability</u>: Less than 1 h from a cold or warm start. <u>Comments</u>: For most systems, the start-up time will be considerably less if the system has been turned off briefly after running for a long time (warm start) than if it has been turned off for a long time (cold start). Thus, it may be desirable to have a system running continually at

headquarters, and turn it off only when it needs to be transported to a nearby locale. This would certainly result in quicker start-ups in field applications.

(10) **Sample Collection Mode**: Ideal capability: All target explosives can be detected using vapor (vacuum) collection. Nominal capability: All target explosives can be detected using swipe collection. Comments: It has been our general experience that IMS and chemiluminescence systems have the sensitivity to detect all the target explosives in a vapor collection mode (though the authors have relatively little experience with ANFO and black powder). The ECD and thermo-redox systems fail to detect at least some of the explosives in this collection mode. Data concerning vapor collection with GC/SAW systems and some less commonly used technologies was not reviewed. All systems should be adequate when collecting samples via swiping surfaces. For most applications, surface swiping should be permissible. However, there are a few applications where vacuum collection may be preferable. For example, obtaining samples from a suspect's clothing is perhaps best done by vacuuming, since physical contact with the suspect (swiping his clothing) might be considered excessively invasive (i.e., a violation of his right to privacy, or unreasonable search without probable cause, etc.). Surface swiping will also lead to greater concern about cross contamination of samples.

(11) **Sample Collection Time**: Ideal capability: Ten seconds to 5 min (variable depending upon how the sample is obtained). Nominal capability: One minute to 5 min (variable depending upon how the sample is obtained). Comments: All systems known to the authors can meet the ideal capability.

(12) **Sample Analysis Time**: Ideal capability: The system gives an "answer" less than 30 s after a sample is inserted into the instrument. Nominal capability: The system gives an "answer" less than 2 min after the sample is inserted into the instrument. Comments: Most if not all commercial trace detection systems meet the ideal capability. In general, this means that sample collection rather than sample analysis will usually be the rate limiting step.

(13) **Limits of Detection**: Ideal capability: Can detect 100 μg of each target explosive in the vapor collection mode at least 95 percent of the time. Nominal capability: Can detect 100 μg of each tarrget explosive in the swipe collection mode at least 95 percent of the time. Comments: The 100 μg figure is chosen because this is approximately the amount of particle residue contained in a typical fingerprint. Some current systems meet the ideal capability for all target explosives, while virtually all of them meet the nominal capability. For swipe collection, the true detection limit will depend to at least some degree on the surface the explosive is deposited on. Note that for ANFO the detection limit is likely to be less important than for the other explosives, because ANFO is almost always used in very large quantities.

(14) **Alarm and User Notification of Detection**: Ideal capability: The system has both an audio and a visual alarm, and tells the user what type of explosive has been detected. A spectrum may be displayed, but the system must not require the user to interpret the spectrum in any way. Nominal capability: The system should have an audio alarm or a visual alarm. It will tell the operator that an explosive or explosive-like material has been detected, but will not identify the type (in this sense, it will be similar to an explosives sniffing canine). Comments: Most trace detection systems meet the ideal capability. A few, like the Scintrex/IDS EVD-3000, meet only the nominal capability.

(15) **False Positive Rate**: Ideal capability: Less than 1 percent in laboratory tests. Nominal capability: Less than 5 percent in laboratory tests. Comments: These numbers should be based on laboratory tests because it ought to be possible to obtain clear-cut answers by

doing the proper studies. Until such studies are performed, no definite answers can be given. However, all systems can meet the nominal capability, and many will probably meet the ideal capability.

(16) **Nuisance Alarm Rate**: Ideal capability: Less than 1 percent when handled by police officers that are reasonably clean but may have had recent contact with firearms and ammunition. Nominal capability: Less than 5 percent when handled by police officers that are reasonably clean but may have had recent contact with firearms and ammunition. Comments: Nuisance alarms are alarms caused by true detections, but where the material detected is only innocuous contamination that does not result from the presence or handling of an illegal bomb or any other threat item. Some systems could give nuisance alarms when handled by law enforcement personnel that have been in contact with weapons.

(17) **Probability of Detection**: Ideal capability: Greater than 99 percent for a swiped fingerprint. Nominal capability: Greater than 95 percent for a swiped fingerprint. Comments: Testing needs to be done to determine these values, but all systems should meet the nominal capability and several will meet the ideal capability. A swipe-friendly (smooth and hard) surface with deposited explosive is assumed. Note that this capability sets the false negative rate, since the false negative rate is simply one minus the probability of detection.

(18) **Data Storage**: Ideal capability: The data obtained can be stored in the system and printed out later. Nominal capability: Data can be saved if the system is connected to a computer at the time of data collection. Comments: Most current trace detection systems meet the nominal capability.

(19) **Ease of Use**: Ideal capability: No factory training required. Could be operated by an average police officer with one day of training. Nominal capability: No factory training required. Could be operated by an average police officer with no more than three days of training. Comments: This is a very important criterion, but it is also subjective and difficult to define. Most current trace detection systems probably meet the ideal capability as defined here.

(20) **Legal Issues**: Ideal capability: The system should be certified to meet certain judicial standards, such as the Dow and Frye standards. There should be a proven history of data obtained with the system standing up in court. Nominal capability: There must be a reasonable expectation that the data obtained with the system can stand up in court, based on the record of similar instruments. Comments: Some detectors, such as the Barringer Ionscan, have undergone certain forms of legal certification. Probably all of the detectors considered could get such certification. Determination of the current legal status of each instrument should be based on up-to-date conversations with the vendor.

(21) **Drug Detection**: Ideal capability: The system can also detect key illegal drugs such as cocaine, heroine, marijuana, and methamphetamine when operated in the proper mode. Nominal capability: No drug detection capability. Comments: It is up to each law enforcement agency that procures a detector to decide if they would like to use it as both an explosives detector and a drug detector. Most IMS-based systems can perform drug detection, but only when operated in a mode where explosives cannot be detected. Thus, these systems can detect drugs and explosives, but not at the same time. The chemiluminescence, ECD, and thermo-redox systems cannot detect drugs.

(22) **Radioactivity**: Ideal capability: The system contains no radioactive source. Nominal capability: The system can contain a sealed radioactive ionization source with a strength of less than 50 mCi. Comments: Chemiluminescence detectors contain no radioactive source and hence meet the ideal capability. GC/SAW and thermo-redox detectors also

contain no radioactive source. On the other hand, IMS and ECD detectors have a radioactive source. Several companies are doing research to develop nonradioactive IMS sources (Corona Discharge IMS), but none are commercially available yet and it is not certain how soon these will be available for reliable field use. The potential problem with these radioactive sources is one of paperwork and convenience, than one relating to human health, because the low energy electrons emitted are easily stopped by skin. Police departments need to be sure that if they purchase a detector with a radioactive source, they can transport it freely within their area of operation. Keeping a logbook of where the system goes each day is probably reasonable and even desirable, but any paperwork that is required beyond this would be a burden and could inhibit rapid field deployment. Most commercial detectors will be acceptable for police use with regards to this issue.

4.2 X-ray Systems

Table 1, dealing with desirable characteristics for x-ray based detection systems, is somewhat different than table 10. Most significantly, there are far fewer characteristics that are considered. Two of the most important are the capability to detect low-Z materials and the presence of an automatic alarm. For both characteristics, each system has this capability as a standard feature (+), has it available as an option (=), or does not have it (-). Mobility is also considered, with each system classified as portable (P), mobile (M – mounted in a vehicle), or for use at a fixed site (F). Cost ranges are listed as defined earlier. Note that two cost ranges are listed for some systems (e.g., Low/Med); this means that the cost range may change depending upon what options are purchased. Once again, this table is intended only to provide information, and it can only be a starting point in making a procurement decision.

Table 10. Characterization of commercial trace explosive detection systems

Manufacturer - Model	Detector Type	Cost k$	Size	Weight	Explosives Detected	Ruggedness	Field Power Operation	Maintenance	System Calibration	Start-up Time	Collection Mode	Limits of Detection	Alarm and Notification	Data Storage	Ease of Use	Legal Certification	Drug Detection	Radioactive Source
1 EXPRAY – Field Test Kit Model M1553	Color	0.25	+	+	=	+	+	+	+	+	=	=	=	+	+		+	+
2. Ion Track Instruments - Exfinder 152	ECD	5	+	+	–	=	+	=	+	+	+	–	=	–	+		=	=
3. JGW International, Ltd. - Graseby GVD4	ECD	5	+	+	–	=	+	=	+	+	+	–	=	–	+		=	=
4. XID Corporation – XID Model T-54	ECD	13	+	+	+	+	+	–	+	+	+	–	=	–	+		=	=
5. JGW International, Ltd. - Graseby GVD6	IMS	16	+	+	+	=	+	=	+	+	+	–		–	+		=	=
6. Ion Track Instruments - Model 97	ECD	20	+	=	–	+	+	–	+	+	+	–	=	–	+		=	=
7. Scintrex/IDS – EVD-3000	TR	23	+	+	+	+	+	–	+	+	+	=	=	=	+		=	+
8. Electronic Sensor Technology, Inc. - EST Model 4100	GC/SAW	25	=	=	+	=	=	–	+		–	=	+	=	+		=	+
9. MSA Instrument Division – FIS	FIS	29	=	=	+	–	=	–	+	=	–	+		=	=		+	=
10. JGW International, Ltd. - Graseby PLASTEC	IMS	35	+	=	+	+	+	+	=	=	+	+	+	=	+	=	=	=
11. Ion Track Instruments - ITMS Vapor Tracer	IMS	38	+	+	+	+	+	=	+	=	+	+	+	=	+		+	=
12. Scintrex/IDS – EVD-8000 (1)	ECD	43	=	=	+	+	+			=	+	=	=	+	=		=	+
13. Ion Track Instruments – ITEMISER	IMS	44	=	=	+	=	=	=	+	–	+	+	+	+	+	=	+	=
14. Barringer Instruments, Inc. – IONSCAN 350	IMS	50	–	–	+	+	+	=	+	=	+	+	+	=	+	+	+	=
15. Ion Track Instruments - Model 85 Entry Scan	GC/ECD	52	–	–	–	–	–	–	+	+	+	–	=	–	+		=	=
16. Ion Track Instruments - Model 85 Dual scan	GC/ECD	52	–	–	–	–	–	–	+	+	+	–	=	–	+		=	=
17. Barringer Instruments, Inc. – IONSCAN 400	IMS	60	=	=	+	+	+	=	+	+	+	+	+	=	+	+	+	=
18. Intelligent Detection Systems – ORION	GC/IMS	70	–	–	+	=	=	–	+	=	+	+	+	+	+		=	=
19. VIKING Instruments, Inc. - Spectra Trak	GC/MS	70	–	–	+	=		–	+	+	–	+	+	+	–		+	+
20. Intelligent Detection Systems – ORION Mail Scanner	GC/IMS	75	–	–	+	=	=	–	+	=	+	+	+	+	+		=	=
21. Intelligent Detection Systems – SIRIUS	GC/IMS	75	–	–	+	=	=	–	+	=	+	+	+	+	+		=	=
22. Thermedics Detection, Inc. - EGIS Model 3000	GC/CL	**150**	–	–	+	–	=	–	+	–	+	+	+	=	=	+	=	+
23. Intelligent Detection Systems – ORION Plus	GC/IMS	**155**	–	–	+	=	=	–	+	=	+	+	+	+	+		=	=
24. Intelligent Detection Systems – ORION Walk-	GC/IMS	**300**	–	–	+	=	=	–	+	=	+	+	+	+	+		=	=
25. Intelligent Detection Systems - V-bEDS	GC/IMS	–	–	–	+	=	=	–	+	=	+	+	+	+	+		=	=
26. Thermedics Detection, Inc. – SecurScanPortal	GC/CL	**300**	–	–	+	–	–	–	+	–	+	+	+	=	=	=	=	+

Ideal (+) Nominal (=) Sub-Nominal (–) Unknown ( )

(1) The EVD-8000 has separate sampling and analysis units. The sampling unit is small and portable.

Table 11. Characterization of commercial x-ray explosives detection systems

Manufacturer Model	Use	Technology	Cost	Portability	Detect low-Z materials	Automatic Alarm	Web address. http://www.
PORTABLE							
1. LIXI, Inc – LIXI	Small packages	FI	Low	P	–	–	lixi.com/
2. MINXRAY, Inc. – ISPS	Small packages	ISP	Low	P	–	–	(800) 221-2245
3. MINXRAY, Inc. - 80ST	Small packages	ISP	Low	P	–	–	(800) 221-2245
4. SAIC - RTR-3	Small packages	ST	Low	P	–	–	saic.com/
5. SAIC - CDS-20021	Small packages	B	Low	P	–	–	saic.com/
6. Vidisco Ltd. - μ - Ray 150	Small packages	ST	Low	P	–	–	vidisco.co.il/
7. Vidisco Ltd. - foXray 150	Small packages	ST	Low	P	–	–	vidisco.co.il/
8. Vidisco Ltd. - A-600	Small packages	ST	Low	P	–	–	vidisco.co.il/
9. MINXRAY, Inc. - FSU6	Small packages	FI	Low	P	–	–	(800) 221-2245
PACKAGES							
10. American Science and Engineering, Inc - 66Z	Small packages	B	Low	F	+	–	as-e.com/
11. American Science and Engineering, Inc - 101GT	Small packages	B	Low	F	+	–	as-e.com/
12. American Science and Engineering, Inc - 101GTA	Small packages	B	Low	F	+	–	as-e.com/
13. Control Screening - Mailguard	Small packages	Fl	Low	F	–	–	controlscreening.com/
14. Control Screening - Guardray	Small packages	Fl	Low	F	–	–	controlscreening.com/
15. EG&G Astrophysics - MINISCAN	Small packages	Fl	Low	F	–	–	egginc.com/
16. EG&G Astrophysics - Torrex II	Small packages	Fl	Low	F	–	–	egginc.com/
17. EG&G Astrophysics - LINESCAN 110	Small packages	ST(DE)	Low	F	=	–	egginc.com/
18. EG&G Astrophysics - LINESCAN 210	Small packages	ST(DE)	Low	F	=	–	egginc.com/
19. EG&G Astrophysics - LINESCAN 215	Small packages	ST(DE)	Low	F	=	–	egginc.com/
20. EG&G Astrophysics - LINESCAN 222	Small packages	ST	Low	F	–	–	egginc.com/
21. Rapiscan Security Products -Rapiscan 19	Small packages	ST	Low	F	–	–	rapiscan.com/
22. SAIC - Cabinet Postal Parcel Inspection System	Small packages	Fl	Low	F	–	–	saic.com/
23. Vidisco Ltd. – eXaminer-	Small packages	Fl	Low	F	–	–	vidisco.co.il/
24. Vidisco Ltd. – MIC-80A	Small packages	Fl	Low	F	–	–	vidisco.co.il/
25. XID Corporation - MailSafex	Small packages	Fl	Low	F	–	–	egginc.com/
26. XID Corporation - MailScope 500	Small packages	FI	Low	F	–	–	egginc.com/

Table 11. Characterization of commercial x-ray explosives detection systems–Continued

Manufacturer Model	Use	Technology	Cost	Portability	Detect low-Z materials	Automatic Alarm	Web address. http://www.
PACKAGES (continued)							
27. Control Screening - Dynavision 910	Packages	ST(DE)	Low/Med	F	=	–	controlscreening.com/
28. Control Screening - Dynavision 925	Large packages	ST(DE)	Low/Med	F	=	–	controlscreening.com/
29. Control Screening - Dynavision 400A	Packages	ST(DE)	Low/Med	F	=	–	controlscreening.com/
30. Heimann Systems - HI-Scan 6040-A	Packages	DE	Low/Med	F	+	=	heimannsystems.com/
31. Heimann Systems - HI Scan 7555-A	Packages	DE	Low/Med	F	+	=	heimannsystems.com/
32. Heimann Systems - PS 5030	Packages	DE	Low/Med	F	+	=	heimannsystems.com/
33. Rapiscan Security Products - Rapiscan Model 320	Small packages	DE	Low/Med	F	+	–	rapiscan.com/
34. Rapiscan Security Products - Rapiscan Model 322	Packages	DE	Low/Med	F	+	–	rapiscan.com/
35. Rapiscan Security Products - Rapiscan Model 324	Packages	DE	Low/Med	F	+	–	rapiscan.com/
36. Rapiscan Security Products - Rapiscan Model 326	Large packages	DE	Low/Med	F	+	–	rapiscan.com/
37. Rapiscan Security Products - Rapiscan Model 327	Large packages	DE	Low/Med	F	+	–	rapiscan.com/
38. Rapiscan Security Products - Rapiscan Model 328	Large packages	DE	Low/Med	F	+	–	rapiscan.com/
39. Rapiscan Security Products - Rapiscan Model 330	Large packages	DE	Low/Med	F	+	–	rapiscan.com/
40. American Science and Engineering, Inc - 101Z	Large packages	B	Med	F	+	–	as-e.com/
41. American Science and Engineering, Inc - 101ZZ	Large packages	B	Med	F	+	–	as-e.com/
42. American Science and Engineering, Inc - EXR-ZZ	Large packages	B	Med	F	+	+	as-e.com/
43. Heimann Systems - HI-Scan 5170-A	Large packages	DE	Med	F	+	=	heimannsystems.com/
44. Heimann Systems - CS 5070	Large packages	DE	Med	F	+	=	heimannsystems.com/
45. Heimann Systems - HI-Scan 9075-TS	Large packages	DE	Med	F	+	=	heimannsystems.com/
46. EG&G Astrophysics – LINESCAN 107	Large packages	ST(DE)	Med/Hi	F	=	–	egginc.com/
47. EG&G Astrophysics - LINESCAN 111	Large packages	ST(DE)	Med/Hi	F	=	–	egginc.com/
48. EG&G Astrophysics - LINESCAN 112	Large packages	ST(DE)	Med/Hi	F	=	–	egginc.com/
49. EG&G Astrophysics - LINESCAN 231	Large packages	ST(DE)	Med/Hi	F	=	–	egginc.com/
50. EG&G Astrophysics - LINESCAN 232	Large packages	ST(DE)	Med/Hi	F	=	–	egginc.com/
51. EG&G Astrophysics - LINESCAN 237	Large packages	ST(DE)	Med/Hi	F	=	–	egginc.com/
52. EG&G Astrophysics - Z-Scan – 10 (small)	Small packages	DE	Med/Hi	F	+	+	egginc.com/
53. EG&G Astrophysics - Z-Scan – 12 (medium)	Packages	DE	Med/Hi	F	+	+	egginc.com/
54. EG&G Astrophysics - Z-Scan – 7 (large)	Large packages	DE	Med/Hi	F	+	+	Egginc.com/
55. Heimann Systems - HI-Scan 11080-TS	Large packages	DE	Med/Hi	F	+	=	heimannsystems.com/

Table 11. Characterization of commercial x-ray explosives detection systems–Continued

Manufacturer Model	Use	Technology	Cost	Portability	Detect low-Z materials	Automatic Alarm	Web address. http://www.
PACKAGES (continued)							
56. Heimann Systems - HI-Scan 85120-TS	Large packages	DE	Med/Hi	F	+	=	heimannsystems.com/
57. Heimann Systems - HI-Scan 100170-TS	Large packages	DE	Med/Hi	F	+	=	heimannsystems.com/
58. Rapiscan Security Products - Rapiscan Model 520	Small packages	DE	Med/Hi	F	+	–	rapiscan.com/
59. Rapiscan Security Products - Rapiscan Model 522	Packages	DE	Med/Hi	F	+	–	rapiscan.com/
60. Rapiscan Security Products - Rapiscan Model 524	Packages	DE	Med/Hi	F	+	–	rapiscan.com/
61. Rapiscan Security Products - Rapiscan Model 526	Large packages	DE	Med/Hi	F	+	–	rapiscan.com/
62. Rapiscan Security Products - Rapiscan Model 527	Large packages	DE	Med/Hi	F	+	–	rapiscan.com/
63. Rapiscan Security Products - Rapiscan Model 528	Large packages	DE	Med/Hi	F	+	–	rapiscan.com/
64. Rapiscan Security Products - Rapiscan Model 530	Large packages	DE	Med/Hi	F	+	–	rapiscan.com/
65. Vivid Technologies Inc. - H-1	Large packages	DE	Med/Hi	F	+	+	vividusa.com/
66. Vivid Technologies Inc. - APS	Large packages	DE	Med/Hi	F	+	+	vividusa.com/
67. Vivid Technologies Inc. - VIS	Large packages	DE	Med/Hi	F	+	+	vividusa.com/
68. Vivid Technologies Inc. - VIS-W	Large packages	DE	Med/Hi	F	+	+	vividusa.com/
69. Vivid Technologies Inc. - VDS	Large packages	DE	Med/Hi	F	+	+	vividusa.com/
70. Heimann Systems - HI-Scan 10050 EDS	Large packages	DE	Hi	F	+	+	heimannsystems.com/
71. In Vision Technologies. Inc. - CTX-5000	Large packages	CT	Hi	F	+	+	invision-tech.com/
PERSONNEL							
72. American Science and Engineering, Inc - Body Search	Personnel	B	Med	F	+	–	as-e.com/
73. Nicolet Imaging Systems - Secure 1000	Personnel	B	Med	F	+	–	nicimg.com/
VEHICLE OR CARGO							
74. American Science and Engineering, Inc - 101XL	Cargo	B	Med	F	+	–	as-e.com/
75 EG&G Astrophysics - LINESCAN 226	Cargo	ST(DE)	Med/Hi	F	=	–	egginc.com/
76. Rapiscan Security Products - Rapiscan Model 532	Cargo	DE	Med/Hi	F	+	–	rapiscan.com/
77. Rapiscan "System 2000"	Vehicle and cargo	DE	Hi	F	+	–	rapiscan.com/
78. Heimann Systems - HI-CO-SCAN	Vehicle and cargo	DE	Hi	F	+	=	heimannsystems.com/
79. American Science and Engineering, Inc - CargoSearch	Vehicle and cargo	B	Hi	F	+	–	as-e.com/
80. American Science and Engineering, Inc - ContainerSearch	Vehicle and cargo	B	Hi	F	+	–	as-e.com/

Table 11. Characterization of commercial x-ray explosives detection systems–Continued

Manufacturer Model	Use	Technology	Cost	Portability	Detect low-Z materials	Automatic Alarm	Web address. http://www.
VEHICLE OR CARGO (continued)							
81. American Science and Engineering, Inc - MobileSearch	Vehicle and cargo	B	Hi	M	+	–	as-e.com/
82. EG&G Astrophysics – Cargo Inspection System	Vehicle and cargo	ST(DE)	Hi	F	+	–	egginc.com/
MOBILE PACKAGE							
83. Rapiscan Security Products -X-ray Van	Large package	DE	Med/Hi	M	+	–	rapiscan.com/
84. American Science and Engineering, Inc - 101Van	Large package	B	Hi	M	+	–	as-e.com/
85. American Science and Engineering, Inc - 101 Trailer	Large package	B	Hi	M	+	–	as-e.com/
86. EG&G Astrophysics – LINESCAN Trailer	Large package	ST(DE)	Hi	M	+	–	egginc.com/
87. EG&G Astrophysics – LINESCAN AutoVan	Large package	ST(DE)	Hi	M	+	–	egginc.com/
88. Heimann Systems - ScanTrailer	Large package	DE	Hi	M	+	=	heimannsystems.com/
89. Heimann Systems - ScanVan IV	Large package	DE	Hi	M	+	=	heimannsystems.com/
90. Heimann Systems - Scanmobile	Large package	DE	Hi	M	+	=	heimannsystems.com/

Yes (+) Optional (=) No (–) Unknown ( )

P – portable; F – fixed site; M – mobile.

4.3 A Practical Example of How to Use Tables 7-11

Consider a law enforcement officer responsible for responding when suspicious packages are reported. Assume that any technology that the officer would use must be portable, easily carried by one person. Table 7 (**Portable**) is selected, because the additional technologies listed in table 8 (semiportable) and table 9 (fixed-site) are too cumbersome for this application. The **Hand-Carried Item** description fits the suspicious package, so the second set of three rows of table 7 is selected. In most cases, there will be **No Explosives Background**, so the right half of table 7 is used, for that second set of three rows. This area contains nine combinations: one for each combination of three costs and three throughputs. In those nine areas in table 7, all the High Throughput boxes are shaded. These are shaded because it is unlikely that an officer would have to screen items at a high throughput in a field situation. In this example of a suspicious package, there is only one suspicious package to screen, so a relatively **Low Throughput** rate can be accepted. The **Low Throughput** column has now been selected, where it intersects with the **Hand-Carried Item** rows in table 7. The only variable left to consider is the cost of the technology.

In the Low cost ($0K to $30K trace; $1K to $70K x-ray), several Trace (1-7) and x-ray (1-9) technologies are listed. These numbers refer to table 4 for Trace systems and to table 6 for x-ray systems. (Consider only the trace systems to simplify this example.) Looking up the name of Trace system number 6 in table 4, the Scintrex/IDS EVD-3000, pictured in figure 11 is found. The EVD-3000 costs $23K according to the table, and it weighs 3.18 kg (7 lb). If there is uncertainty about how it rates against Trace systems 1-4, table 10, Characterization of Commercial Trace Explosive Detection Systems, can be consulted.

In table 10, look at the columns labeled **Maintenance** and **Limits of Detection**. The EVD-3000 has subnominal (black) maintenance characteristics as does Trace system number 3, while numbers 1, 2, and 4 have nominal (blue) maintenance characteristics. But when the Limits of Detection column is reviewed, the EVD-3000 is the only one of these five systems that is nominal, while the other systems, numbers 1-4, are rated sub-nominal. So, a judgment has to be made whether maintenance or detection is more important to consider. Assume that better limits of detection are desired. Then the EVD-3000 would be selected over the other four trace systems. (If the $23K price tag was too high, a department might choose one of the cheaper systems, 1-5, on that basis.)

What if better limits of detection are needed? What if the EVD-3000 only rated **nominal**, while we wanted an **ideal rating**? Go back to table 7, and look at the available options. The higher cost selections have not yet been considered. Trace systems number 8 and 9 are listed in the Medium cost ($30K to $100K) box. Comparing systems 8 and 9 in table 10, system 9 has more pluses, i.e., ideal attributes than 8, and only costs $3K more. Look at that system for comparison with the EVD-3000.

Trace system number 9 is found in table 4, where it is listed as the Ion Track Instruments ITMS Vapor Tracer, pictured in figure 6. The Vapor Tracer costs $38K and weighs 3.18 kg (7 lb) according to that table. Its characterization from table 10 is that the Vapor Tracer has a nominal maintenance rating and an ideal limits of detection rating. If the main consideration is detection limit, and if $38K is an acceptable price for the organization, then the Vapor Tracer would be selected over the EVD-3000.

5. CALIBRATION OF EXPLOSIVES DETECTION SYSTEMS

Commercially available explosives detection systems operate using different principles, and it is difficult to make generalizations about appropriate calibration procedures. One generalization that can be made is that all systems made by reputable companies should come with a detailed user's manual, and this manual should give a recommended procedure for system calibration. Depending on the system, the recommended calibration procedure may not be fully quantitative; the emphasis is usually on ascertaining that the system works at some minimal level. The manufacturer should normally be questioned about calibration and maintenance before a system is purchased. In most cases, a company representative can provide onsite training when the system is first purchased, giving one or more employees at the purchasing site an opportunity to receive hands-on training from an expert operator. The importance of such training can hardly be overstressed.

Commercial trace detection systems use a variety of sample types for calibration, but all calibration procedures involve challenging the system with a minute amount of one or more of the target explosives. Several systems come with sampling pads that have already been spiked with known amounts of certain explosives. These can be inserted into a sampling port for analysis, and the lack of a detection from such a pad would indicate that the system is not working properly. If a detection is made, the intensity of the signal can provide a semi-quantitative measure of the system's sensitivity to the explosive involved, though it would be more accurate to use sampling pads spiked with explosives from freshly made standard solutions. At least one commercial system comes with a lipstick-like substance that contains trace quantities of several different explosives. This system can be tested by challenging it with a sampling pad onto which a small amount of the "lipstick" has been rubbed. Some systems that are used primarily for gas phase sampling come with small vials of material that emit vapors when opened, and can be tested by holding the open vial up to the system's sampling inlet. Such systems could perhaps be calibrated more accurately using one of the explosives vapor generators that have been described in the literature [1-4], but a calibration of this type would be expensive and time consuming, and is probably beyond the scope of most law enforcement work.

Bulk detection systems such as x-ray scanners are often calibrated and tested by challenging them with a threat object hidden in a piece of luggage or some other type of hand-carried item. This is not always a straightforward process, because many systems do not alarm automatically but rather require a person to determine whether a threat item is present on a displayed screen image. Thus human factors are involved and the calibration process is not perfectly defined. When looking for explosives, it is desirable not to work with real explosive materials, because for bulk testing it would be necessary to work with a macroscopic sample that is capable of detonation. For this reason, a material called a simulant is often used in place of the actual explosive. A simulant is simply an innocuous material that has similar properties to the explosive when probed with the type of incident radiation the system uses. For example, if a transmission x-ray system is being used to study detection of detasheet, a good simulant would be any material that has an x-ray mass absorption coefficient similar to detasheet. In the past, Vivid Technologies Inc., has sold simulant materials suitable for the testing of dual-energy transmission x-ray detection systems. Other manufacturers may also have identified simulant materials that they would be willing to sell, or provide with the systems that they sell.

Other calibration measurements for x-ray systems include those using a step wedge. The step wedge as defined by the American Society of Testing and Materials (ASTM) is a series of steps of aluminum with a series of thin wires of various gauges attached beneath. The purpose of this test device is to determine that the system can produce different distinct image intensity levels for each step while clearly displaying the smallest specified wire beneath each step.
Typical x-ray systems can image a minimum of 34AWG solid copper wire through a minimum of 10 steps. Many modern systems can perform at higher levels with 38AWG and 20 steps are common.

PROTOCOL FOR THE EVALUATION OF COMMERCIAL TRACE DETECTION SYSTEMS

This document describes standard procedures for testing various important performance benchmarks of commercial, trace explosives detection systems. These benchmarks include probability of detection, detection limit, false-negative rate, false-positive rate, nuisance-alarm rate, interference response, throughput rate, sampling time, analysis time, and total processing time. Note that other test protocols have been developed by various agencies and organizations, and interested readers can contact the authors for further information.

6.1 Introduction

The tests described in this document are intended to be general enough for application to all or most commercial trace detectors. Consequently, comparisons between the performance of various detectors and documentation of existing detectors in service might be made uniform or convenient. However, these tests are not replacements for user's manuals, and readers should become thoroughly familiar with the instrument through reading the user's manual provided by the manufacturer. If any instructions provided in this protocol contradict instructions given in the user's manual, operators should follow the instructions given in the user's manual, or at the very least contact the company marketing the equipment to discuss the matter.

A procedure not included here, because it is very instrument specific, is that of instrument calibration, including the setting of alarm levels for various explosives. All calibrations should follow the procedures given in the user's manual. When a system is purchased, most vendors will provide some onsite training so that the calibration procedure can be learned directly from an expert operator employed by the company.

6.2 The Basics of Instrument Operation

(I) Blank Samples: Verifying Freedom From Contamination

When presenting any chemical detection system with a sample (also known as "challenging" the system), it is imperative that the system is clean (free of the substance being detected prior to the challenge). If the system is contaminated, an apparent detection may result from the contamination that was already present in the system and not from the sample being analyzed. Clearly, this could lead to false-positive results. For example, in a portal system that screens people for explosives, it might be concluded that a certain person has had contact with explosives, when in fact he has not.

For this reason, trace detectors must be certified as clean after a positive response or alarm shows the presence of explosive material. In addition, the system must be verified as clean before analyzing the first sample. This is done by challenging the system with blank samples that are known not to contain explosive material. For example, if swipe pads for sample collection are being used, pads that have come straight out of the package supplied by the vendor and have not been exposed to any explosive can be tested. Thus at the start of each period of use of the instrument and after the processing of any sample that results in an alarm, challenge the system with a blank to see whether or not an alarm is recorded. If no alarm is recorded, proceed to process additional samples. (When doing rigorous testing, it might be desirable to run as many as three blanks between samples.) If an alarm is recorded, it almost surely results from contamination of the system. In this case, keep challenging the system with blanks until no alarm is recorded. In extreme cases of exposure to very large explosive masses, it might be necessary to let the system sit for several hours with the detector at a high temperature in order to purge the system of all the explosive contamination.

(II) Collecting the Explosive Material: Swipe Versus Vapor Collection

With most commercial trace explosives detection systems, there are two common means of collecting samples: swipe collection and vapor collection. In swipe collection, a sampling pad (usually supplied by the manufacturer) is wiped across a surface suspected of having residue of explosive material. This surface could be a tabletop, the outside of a package, a piece of luggage, clothing, and so forth. The sampling pad is then inserted into a sampling port on the instrument for analysis. In contrast, vapor collection involves the use of a small hand-held vacuum to collect airborne vapors or particles. Typically, vacuuming is performed just above the surface to be investigated. A collection filter is located inside the inlet of the vacuum, and air is drawn through this filter. The explosive material will be trapped on the filter. The filter is then removed and analyzed by the system in a manner similar to the analysis of a swipe sample. Vapor sampling of this sort is generally less sensitive than swipe sampling, but it is advantageous for screening people because it is not necessary to touch the person being screened. Thus, taking samples with vapor collection is regarded as less invasive than collecting swipe samples.

(III) Explosives Solutions and Proper Handling

Successful work with trace explosives detectors usually requires detection of explosive residues, amounts of material that are so small that the actual sample cannot be seen by the human eye. Most trace detectors will show a positive response to amounts of explosive material on the order of a few nanograms or less (one nanogram equals one billionth of one gram). Even in the preparation of solutions of known composition and content (standardized solutions), only microscopic amounts of material are needed to perform instrument testing. One benefit of this is that the usual hazards of working with explosives are obviated, since such tiny amounts of explosive cannot produce a detonation.

A common method of handling microscopic amounts of explosive material is to use explosives dissolved in volatile organic solvents. For example, a typical solution might be TNT dissolved in methanol at a concentration of 1 ng of TNT per microliter of methanol. (Such solutions can often be purchased directly from commercial chemical suppliers.[3] Once obtained, the solutions can be used as received, or further diluted to provide lesser concentrations.) A known amount of explosive can be obtained from such a solution by withdrawing a known volume of solution (typically measured in microliters by a syringe) and then depositing this volume onto a sampling pad. A typical calculation is:

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[3]An example of this type of supplier is AccuStandard, Inc., 125 Market Street, New Haven, CT 06513, Phone: (800) 442-5290.

$$\text{Amount of explosive in nanograms (ng)} = \text{Volume of solution in microliters } (\mu l) \times \text{Concentration in ng}/\mu l.$$

Other terms for mass and volume may be used so long as the units are consistent throughout the formula. The volatile solvent will evaporate rapidly at room temperature and the measured amount of explosive material will remain on the sampling pad. While a thorough discussion of the proper handling of chemical solutions is beyond the scope of this document, always make sure that the work area is free of explosive residues, the syringes and glassware that are used are clean, and in particular that a syringe used to measure out a dilute solution is not contaminated with a more concentrated solution.

(IV) Logbook and Record Keeping

An easily overlooked aspect of making trace chemical measurements is record keeping on a sample and on the instrument used for analysis. In both laboratory and field use, a record of who, when, where, what, and why should be kept. This record or logbook is essential for legal purposes and other uses such as instrument maintenance.

Table 12. An example of a logbook page

Analysis No.	Date	Time	Room Temp (°C) BaroPress (mmHg) Flow (ml/min)	Description	Initials
3253	17 May 1998	0810	25/644/250	Blank sample	CAB
3254	17 May 1998	0823	25/644/250	10 ng Standard of TNT-from 3 uL of solution T-26753	CAB
3255	17 May 1998	0830	25/644/250	Blank sample	CAB
3256	17 May 1998	0923	25/644/250	Swipe sample (no. A436) from left fender screen for TNT and RDX	CAB
3257	17 May 1998	1045	25/644/250	Vapor sample (no. A383) from Carpet screen for narcotics	FNW
3258	17 May 1998	1418	25/644/250	Swipe sample (no. G23) from holster, screen for NG	FNW
3259	18 May 1998	0834	25/658/250	Blank sample	FNW
	19 May 1998	0953		Instrument disabled for scheduled replacement of sieve packs	CAB

Notice that consecutive analysis numbers are given for each use of the instrument and that the sample's identity is recorded elsewhere in the Description column. Moreover, the table above is an example of minimum content for a logbook. Other details might include where the data are stored, a reference to the origin of the standards, etc. In addition, the results from the calibrations might be maintained elsewhere (see Sec. VII) in a type of maintenance record to anticipate or schedule routine repair and upkeep of instruments. Experimental parameters such as temperature and pressure should be included in the logbook as shown in the fourth column; these will show only minor changes in laboratory use, but may show wide variations in field use.

(V) Data Storage and Backup

Trace detectors may be connected to small computers where results of analyses are processed and findings are displayed. The level of technology on these detectors may range from hand-held units with on-board computers without data storage capabilities to laboratory models with modern computers and large storage capacities. In instances where analysis results are stored, efforts should be made to copy the results to another storage medium and the results archived for future use. The organization and records for such archives should be well maintained and secure, particularly for legal purposes. The possible corruption of records through technology failures (copying errors) or other failures (misplace records or damaged disks) must be avoided. In addition, hardcopy records might be maintained as the ultimate backup.

(VI) Control Charts and Long-Term Instrument Performance

A routine procedure with trace detectors should be the use of blanks and standards to guarantee freedom of contamination and proper responses to known amounts of chemicals. This determines the quantitative response of the detector and if it changes over time. Often loss in performance for a detector is seen in the quantitative response and can suggest need of maintenance. All trace detectors require routine maintenance, so the frequency and cost of such service should be anticipated. One helpful tool is the control chart. A control chart is a graph of calibration results of an instrument on a daily, weekly, or monthly basis. Some control charts may span years. In the control chart shown in figure 16, the response of an IMS based detector to 5 ng of TNT was monitored (given a certain amount of normal variability) from the middle of June until the middle of July. Such control charts are often created and kept by specialized personnel whose responsibility is to inventory and maintain field instruments or by regular laboratory personnel operating the detectors daily. Field or enforcement personnel should not ordinarily be responsible for this somewhat tedious aspect of instrumentation use.

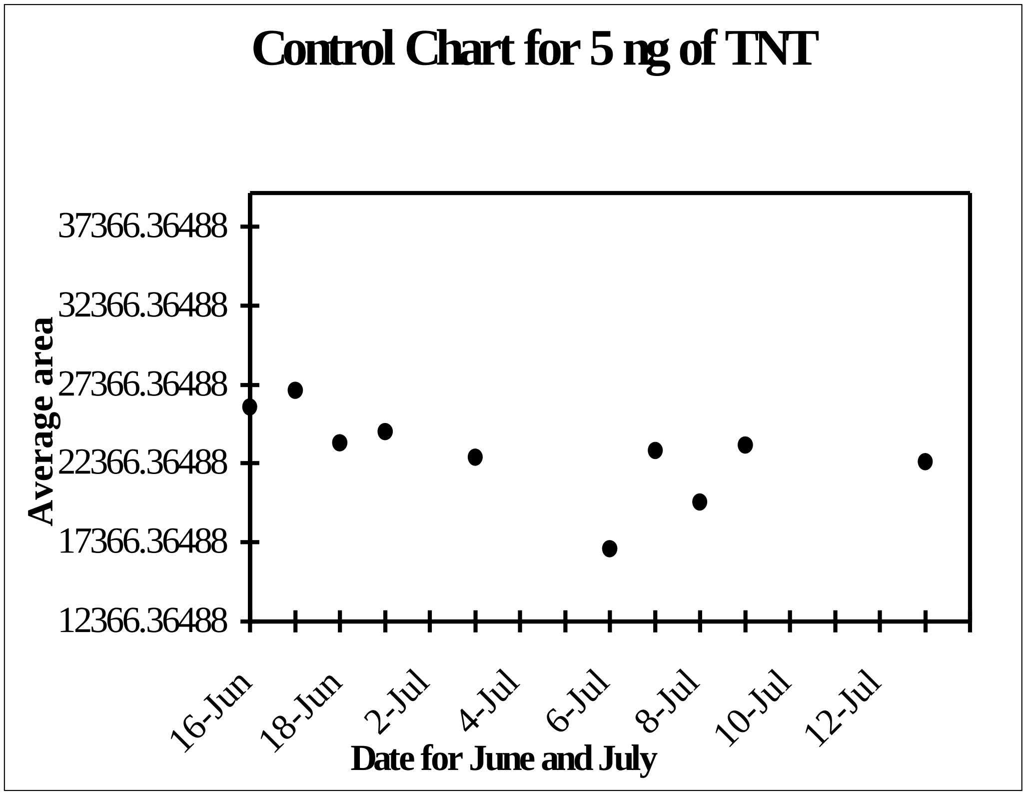

Figure 16. Control chart using 5 ng of TNT from June 16, 1998 to July 13, 1998

<u>(VII) Experimental Parameters</u>

Experimental parameters are those quantities and conditions that define or describe the conditions under which an analysis or measurement occurred. When testing a commercial trace detection system, the experimental parameters will include both system operating parameters (e.g., detector temperature, alarm level, etc.) and external parameters (ambient temperature, ambient pressure, etc.). When determining detector performance, the values of all experimental parameters should be recorded. Changing any experimental parameter could change the final value of Probability of Detection [P(d)] or any other experimentally determined quantity, so the value of the experimentally determined quantity is only meaningful if all experimental parameters are defined. Some experimental parameters will have a large impact on the experimentally measured quantity, while others will have little or no impact. Minor changes in external parameters such as ambient temperature usually will have only a small impact. During any testing to characterize a detector's performance, the experimental parameters should be carefully monitored.

6.3 Protocol for Characterizing a Trace Explosives Detector

This protocol includes procedures for determining the following benchmarks, each of which will be described in the sections below:

- Probability of Detection
- Detection Limit
- False-Negative Rate
- False-Positive Rate
- Nuisance-Alarm Rate
- Interference Tests
- Throughput Rate
- Sampling Time
- Analysis Time
- Total Processing Time

6.3.1 Probability of Detection - P(d)

P(d) should be determined or defined for each type of sample collection. The procedure outlined below concerns the most common method for explosives screening where a known amount of explosive from a solution is deposited directly onto a sampling pad. However, a very similar procedure could be followed to determine a P(d) based on other types of sampling.

1. See that the system is turned on, calibrated, and that the alarm level is properly set.
2. Using a syringe, place a known amount of explosive in a solution of a volatile solvent onto the center of a sampling pad (e.g., 1 ng of TNT in 1 μL of acetonitrile). Use the type of sampling pad recommended by the manufacturer for that instrument.
3. Wait for the solvent to evaporate.
4. Present the sampling pad to the instrument as appropriate for that system. For many systems, this will mean inserting the pad into a heated sample port on the instrument. For others, this may mean rubbing the sampling pad over an inlet where material is sucked into the system.
5. Observe the system response, and record whether or not an alarm occurs. You will probably want to save the spectrum produced for future reference.
6. Present the system with clean pads (a blank), and observe whether or not an alarm is recorded for the explosive in question. If three consecutive clean pads produce no alarm, the system can be assumed to be clean and can again be challenged with a pad containing explosive material.
7. Repeat this procedure for a total of 20 measurements. P(d) is then = [number of alarms recorded/20].

P(d) can also be measured for the following sampling methods: (i) known explosive mass deposited onto a designated surface, then swiped; (ii) known explosive mass deposited onto a surface, then vacuumed; (iii) known vapor dose directed into sampling pad (perhaps contained in a vacuum device); and (iv) known vapor dose directed into an instrument using a vapor generator. Not all of these modes are possible with every instrument.

6.3.2 Detection Limit (DL)

The DL is defined here as the lowest mass of explosive material with a P(d) of 0.9 or higher, i.e., the lowest amount that will cause the system to alarm on > 90 percent of the challenges. Note that this is dependent upon where the alarm level is set for a particular system.

In principle, it is desirable to test the detection system with a variety of different masses for a given explosive, and the lowest mass that gives a P(d) of 90 percent or greater will be the DL. general procedure is outlined below. Once again the example of known explosive masses deposited directly onto a sampling pad of the appropriate type is used.

1. See that the system is turned on and properly calibrated, and that the alarm level is set at the appropriate level.
2. Challenge the system with a blank sample pad to verify that it is clean. If no alarm is recorded, proceed to the next step. If an alarm is recorded, repeat this step until no alarm is recorded. To save pads, this step may be repeated with the same pad initially if desired, but always challenge the system with at least one new clean pad and obtain a result of "no alarm" before moving on to the next step.
3. Challenge the system with a sample mass that is suspected of being well above the DL. This might take some guesswork, but the system manual and a little experience can be of assistance. If an alarm is recorded, move to the next step. If no alarm is recorded, the mass chosen was too small. After running a blank sample to verify system cleanliness, double the mass, and see if an alarm is recorded. Repeat this procedure until an alarm is recorded.
4. Perform a P(d) test for the mass where the alarm is recorded, as described above in the section on **Probability of Detection**. If P(d) for this mass is 90 percent or greater, this can serve as the starting point for the test performed in step (5). If P(d) is less than 90 percent, double the mass and again perform a P(d) test. Repeat this procedure until a mass is found that is above the DL, i.e., that has a P(d) of at least 90 percent.
5. Once such a point above the DL has been found, perform a series of tests where the system is challenged with ten different masses, ranging from no explosive to the mass determined in step (4) in equal increments. For example, if it was determined in step (4) that a mass of 2 ng was above the DL, the masses tested should be (0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 ng). Start with the lowest mass (no explosive) and work upwards, performing two tests for each mass and recording whether or not alarms are recorded. Make sure that a clean blank sample is run and that no alarm is recorded following each challenge with explosive material.
6. Find from the test in step (5) the lowest mass for which two alarms were recorded, and run a P(d) test with twenty challenges at this mass. This mass should be very close to the DL. If P(d) for this mass is found to be less than 90 percent, perform a P(d) test at the next highest mass, and keep moving up in mass until a mass is tested where P(d) is greater than 90 percent. If, on the other hand, P(d) is greater than or equal to 90 percent for the mass chosen initially, move down to the next lowest mass and perform a P(d) test, and continue to move down until a mass is reached with P(d) less than 90 percent. Once this procedure is complete, the lowest mass tested with P(d) > 90 percent can be taken as the DL.

The DL can be determined more precisely by testing at additional explosive masses between the DL determined above and the mass immediately below it where P(d) < 90 percent. However, in practice, this more precise determination will rarely be worth the effort.

6.3.3 False-Negative Rate

For a given set of experimental conditions, the false-negative rate is simply one minus the probability of detection. Thus, if P(d) = 0.8, the false negative rate is 0.2, or 20 percent. All experimental parameters must be identical for this to hold true. If any parameter is changed, determine a new P(d) before calculating the false negative rate.

6.3.4 False-Positive Test

The following test procedure can be followed for a laboratory test of the false-positive rate. The example of clean sampling pads, though vapor tests with clean air could be used in some cases, is used.

1. Make sure the system is turned on, calibrated, and that the alarm level is set properly.
2. Challenge the system with a clean sample pad. If no alarm is recorded, the system can be assumed to be clean and the testing can begin. If an alarm is recorded, continue to challenge the system with clean pads until no alarm is recorded three consecutive times.
3. Challenge the system with clean sample pads 20 times, and record each time whether an alarm is recorded and for what explosive. If an alarm is recorded, interrupt the test by challenging the system with blank pads that are not counted towards the total of twenty. When three consecutive pads produce no alarm, the system can be taken to be clean again. At this point, continue where you left off in the test sequence of twenty pads.

The false-positive rate is then [number of alarms in the test sequence of twenty pads/20].

A similar and somewhat more useful test could also be performed to determine the false-positive rate under realistic field conditions. However, in this case the situation becomes more complicated, because "false positives" obtained in the field may actually be due to real explosives contamination. If this is so, they should be classified as "nuisance alarms" rather than "false alarms." Therefore, some form of alarm resolution (questioning of people screened or further chemical analysis of samples) needs to be conducted in order to correctly classify the alarms. Alternatively, all alarms can simply be classified as "false positives," and the false-positive rate thus determined will represent an upper limit on the actual false alarm rate.

6.3.5 Nuisance-Alarm Rate

Nuisance-alarms are alarms that result from the actual detection of an explosive, but where the explosive material present originates from an innocuous source rather than from a threat item. For example, when screening people for explosives at a checkpoint, a nitroglycerin alarm could result because the test subject is a heart patient with nitroglycerin tablets, rather than a terrorist attempting to smuggle a bomb containing nitroglycerin. Similarly, an alarm for TNT could result from a construction worker employed at a blasting site, an alarm for black powder or some related substance could result from anyone having recently handled firearms for a legitimate reason, etc. In law enforcement applications, nuisance alarms could result for some explosives detection systems if these are operated by officers frequently handling firearms, or working in or visiting areas where there may be explosive contamination.

A nuisance-alarm rate can be determined in the same way as a false-positive rate, but the tests will need to be performed in a real-world operating environment rather than in a laboratory. For example, if using a system to screen persons entering a courthouse, it would be possible to determine a nuisance-alarm rate by careful examination and questioning of all persons giving alarms. Based on these followup investigations, the alarms can be divided into (i) actual detections of bombs or individuals having handled bombs, (ii) nuisance-alarms, and (iii) false-positives.

6.3.6 Interference Tests

Interferences (or interferents) are chemicals that may interfere with the detection of explosives using a trace detection system. They can do this by either masking the presence of explosives when an explosive is present, or by giving rise to false positives when no explosive is present.

Since interference may produce either false-positives or false-negatives, two different tests are outlined to check for each of these effects. The common sampling procedure of placing a known amount of explosive in solution onto a swipe pad is used as an example, but a similar procedure could be followed based on other sampling methods.

To check for false-positives caused by interference, follow this procedure:

1. Make sure that the explosives detection system is on, properly calibrated, and that the alarm level is set as desired.
2. Challenge the system with clean sampling pads until no alarm is recorded on three consecutive challenges.
3. Place a known amount of the potential interferent onto the center of the appropriate sampling pad. Use an amount that is at least 100X the DL for an explosive that has been tested with the system. For most materials, this step will most easily be accomplished by using a solution of the material in some volatile solvent. However, for solid materials (e.g., lipstick), this test could be performed crudely (and nonquantitatively) by simply smearing the material across the sampling pad.
4. Challenge the system with the sampling pad containing the material being tested for interference. If no alarm is recorded for explosives, the material is not an interferent that is capable of producing false-positives.
5. Repeat step (4) with at least two more sample pads containing the material, to make sure the result is correct. Before each test, challenge the system with a clean sampling pad to assure that it is not contaminated.

To check whether or not a potential interference can create a false negative (that is, mask the presence of an explosive), use the following procedure:

1. See that the system is on, properly calibrated, and that the alarm level is set as desired.
2. Challenge the system with a clean sampling pad to assure that it is not contaminated.
3. Take a clean sampling pad. Deposit onto the center of this pad a known amount of the explosive of interest that is approximately twice the DL. Also deposit into the pad a known amount of the potential interference to be studied (preferably the same mass as for the explosive).
4. Challenge the system with this pad and see if an explosive alarm is recorded. If no alarm is recorded, the substance studied is an effective interferent.
5. After clearing out the system, repeat the test with half as much interference, and continue this process until the explosive can again be detected. This gives an idea of how much interference is required to mask the presence of the explosive.

6. If an alarm is recorded, keep repeating the test while increasing the amount of interference used, until either the explosive can no longer be detected or the experiment becomes impractical. If even then the explosive can be detected, the material present is not an effective interferent.

6.3.7 Throughput Rate

The throughput rate is the number of distinct samples that can be processed in a given period of time. It is usually expressed in units such as samples per minute or samples per hour. It needs to be determined by challenging the system with a large number of samples over a considerable period of time, in order to obtain an accurate average value. Note that the throughput rate includes the time needed to collect the samples. Clearly, the throughput rate will depend upon the sampling process, and will be different for swipe collection and vapor collection. It can also change for differing swiping procedures or differing vapor collection procedures, depending upon how the process is defined. The term "throughput rate" can refer to any sort of item being screened or processed: people, packages, vehicles, mail, etc.

In general, the maximum possible throughput rate can be determined by following this procedure:

1. Collect a large number of the appropriate sampling media (e.g., swipe pads).
2. See that the detection system is turned on, calibrated, and has the alarm level properly set.
3. Challenge the system with a clean sampling pad to make sure that it gives no alarm.
4. Start timing with a stopwatch. Follow the steps listed below for 5 min or for the time it takes to process ten samples, whichever is greater. Use only blank samples in this test, to make sure that no time is lost due to detection system clear down time. The experiment will then give a measure of the optimum throughput rate for the sampling process chosen.
5. Obtain a sample according to the chosen procedure (e.g., swipe a clean tabletop), challenge the detector with it, and record the result (alarm or no alarm).
6. Repeat step (5) until 5 min are up or 10 samples have been processed. Work deliberately and continuously, but do not rush.
7. Stop the watch and record the finishing time. The throughput rate is the number of samples processed divided by the total time. For example, if 30 samples are processed in 3 min, the throughput rate is ten samples per minute.

6.3.8 Sampling Time

The sampling time is the time needed to acquire a sample and to present it to the explosives detection system for analysis. Like the throughput rate, it can only be determined accurately by averaging over a large number of measurements. Since by definition

$$\text{total processing time} = \text{sampling time} + \text{analysis time},$$

the sampling time is perhaps best determined by determining the other two quantities (see below) and solving the above equation. Obviously, the sampling time will vary depending on the method of sampling chosen.

6.3.9 Analysis Time

The analysis time is the time required for the system to analyze a sample with which it has been challenged, including the time needed to produce an alarm and the corresponding readout. For most trace detection systems, this time can be determined by continuously challenging the system with the same sample (e.g., swipe pad) that is either clean or contains explosive material, waiting for the system to complete the analysis between each challenge, and then dividing the total time elapsed by the number of challenges.

6.3.10 Total Processing Time

The total processing time is the time needed to collect and analyze one sample with the detector in question. It is equal to the sum of the sampling time and the analysis time. It should also be equal to the reciprocal of the throughput rate. For example, if the throughput rate is five samples per minute, the total processing time should be 1/5 min per sample, or 12 s per sample.

7. WARNING: DO NOT BUY BOGUS EXPLOSIVES DETECTION EQUIPMENT

From time to time, there are new devices that enter the market. Most companies make reasonable claims, and their products are based on solid scientific principles. Claims for some other devices may seem unreasonable or may not appear to be based on solid scientific principles. An old truism that continues to offer good advise is "If it sounds too good to be true, it probably is not true." If there are any questions as to the validity of a device, caution should be used and thorough research must be performed before a purchase is made. Money can be wasted and even lives may be risked. Although there may be other types of nonoperational devices around, dowsing devices for explosives detection have emerged during the past couple of years.

There is a rather large community of people around the world that believes in dowsing: the ancient practice of using forked sticks, swinging rods, and pendulums to look for underground water and other materials. These people believe that many types of materials can be located using a variety of dowsing methods. Dowsers claim that the dowsing device will respond to any buried anomalies, and years of practice are needed to use the device with discrimination (the ability to cause the device to respond to only those materials being sought). Modern dowsers have been developing various new methods to add discrimination to their devices. These new methods include molecular frequency discrimination (MFD) and harmonic induction discrimination (HID). MFD has taken the form of everything from placing a xerox copy of a Poloroid photograph of the desired material into the handle of the device, to using dowsing rods in conjunction with frequency generation electronics (function generators). **None of these attempts to create devices that can detect specific materials such as explosives (or any materials for that matter) have been proven successful in controlled double-blind scientific tests.** In fact, all testing of these inventions has shown these devices to perform no better than random chance.

Mostly these devices are used to locate water and now are used extensively by treasure hunters looking for gold and silver. In recent years some makers of these dowsing devices have attempted to cross over from treasure hunting to the areas of contraband detection, search and rescue, and law enforcement. The Quadro Tracker is one notable example of this cross-over attempt. This device was advertised as being a serious technology with a realistic sounding description of how it worked (close examination showed serious errors in the scientific sounding description). Fortunately, the National Institute of Justice investigated this company and stopped the sale of this device for these purposes, but not before many law enforcement agencies and school districts wasted public funds on the purchase of these devices.

Things to look for when dealing with "new technologies" that may well be a dowsing device are words like molecular frequency discrimination, harmonic induction discrimination, and claims of detecting small objects at large distances. Many of these devices require no power to operate (most real technology requires power). Suspect any device that uses a swinging rod that is held nearly level, pivots freely and "indicates" the material being sought by pointing at it. Any device that uses a pendulum that swings in different shaped paths to indicate its response should also arouse suspicion. Advertisements that feature several testimonials by "satisfied users," and statements about pending tests by scientific and regulatory agencies (but have just not happened yet) may be indications that the device has not been proven to work. Statements that the device must be held by a human to operate usually indicate dowsing devices. Statements that the device requires extensive training by the factory, the device is difficult to use, and not everyone can use the device, are often made to allow the manufacturer a way of blaming the operator for the device's failure to work. Another often used diversion is that scientists and engineers cannot understand the operation of the device or the device operates on principles that have been lost or forgotten by the scientific community.

In general, any legitimate manufacturer of contraband detection equipment will eagerly seek evaluation of their device's performance by scientific and engineering laboratories. Any doubt that a device is legitimate can quickly be dispelled by making a call to any of the known agencies whose business it is to know about security-related technology.

8. CONCLUSION

Many details regarding commercially available explosives detection equipment have been included in this document. The reader should first determine his or her own intended applications, and thus narrow the problem, to avoid being overwhelmed by the amount of information in this document and the number of systems from which to choose. Having decided on the most important application, a decision of which system to buy can start by consulting table 7, 8, or 9, depending on the desired system portability. Finding the appropriate boxes in the chosen table based on the other conditions defining the application and purchase, several possibly acceptable systems can be chosen in most cases. These systems can then be looked up in table 4 (trace systems) or table 6 (x-ray systems), and, if necessary, additional information about the system characteristics can be obtained from tables 10 and 11. This process should allow the identification of one or more systems that should be investigated further. At this point, it would be appropriate to contact the vendor or the authors of this document for additional information and discussions.

One point that needs to be remembered is that explosives detection technologies are constantly being improved and expanded, so information can become dated rather quickly. For this reason, it is especially important to consult with product vendors and outside experts before making a major procurement decision. Such discussions are a great aid in making informed procurement decisions, and can save time, effort, and money.

APPENDIX A-1. SUGGESTED READINGS

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APPENDIX A-2. GLOSSARY OF TERMS

Alarm: a signal given by an EDS that indicates to the operator that a detection of explosive material has been made. For a technological system such as an IMS the alarm might be either audio (e.g., a buzzer sounds) or visual (e.g., a message on a computer screen). In the case of a canine, the alarm is some form of behavior by the dog which the handler interprets as a detection.

Alarm resolution: the process by which an operator determines whether an alarm is the result of a threat item being present, or whether in fact there is no threat item present.

Alarm threshold setting: the signal level above which an EDS is set to alarm. An EDS may make a detection of an amount of explosive below the alarm threshold setting, but it will then be assumed that the signal obtained is either (1) a nuisance alarm or (2) noise.

Ammonia dynamites: a class of dynamites in which a portion of the nitroglycerin is replaced by ammonium nitrate and nitroglycol. These dynamites are lower in cost and less sensitive to shock and friction than straight dynamites.

Ammonia-gelatin dynamites: gelatin dynamites where part of the nitroglycerin/nitrocellulose gel is replaced by less costly ammonium nitrate.

Ammonium nitrate: an explosive compound, NH_4NO_3. It is the main ingredient of ANFO, and of some water-gel explosives.

Analyte: in analytical chemistry, the compound that is being studied, analyzed, or identified.

ANFO: a mixture of ammonium nitrate and fuel oil, often used in vehicle bombs.

Astrolite: a commercially available two-part explosive. One component is a liquid and the other is a solid.

Attenuation coefficient: a measure of how much an incident probe (e.g., electromagnetic radiation) is attenuated as it passes through a given substance.

Atomic explosion: an explosion caused by the breaking up (fission) or joining together (fusion) of atomic nuclei. This is the type of explosion occurring when a nuclear weapon is detonated.

Atomic number: the total number of protons in the nucleus of an atom, equal to the nuclear charge. Represented by the symbol Z.

Backscatter x-ray system: any x-ray system that detects objects (including explosives) based on the images produced from reflected x-rays.

Binary explosive: an explosive material containing two different explosive compounds.

Black powder: a low explosive which is a mixture of potassium nitrate (KNO_3), charcoal, and sulfur. It is frequently used in mail bombs and pipe bombs.

Blasting agent: a chemical composition or mixture, consisting mainly of ammonium nitrate, which will detonate when initiated by high explosive primers or boosters. Blasting agents contain no nitroglycerin and are relatively insensitive to shock and friction.

Blasting cap: a device containing a small amount of primary high explosive, used for detonating a main charge of secondary high explosive.

Blasting slurries: a blasting agent consisting of NCN mixtures in a gel-like consistency.

Blast pressure wave: the wave of hot, very high-pressure gases traveling outward from an explosive detonation. The effect of this wave decreases as distance from the point of explosion increases.

Bomb: any device containing explosive or incendiary material that is designed to explode or ignite upon receiving the proper external stimulus.

Bombing: an illegal detonation or ignition of an explosive or incendiary device.

Bomb detection: the discovery and identification of bombs that are being smuggled, or used for some illicit purpose. Bomb detection differs from explosives detection in that the detection may or may not be based on the detection of the explosive material in the bomb. The detection may be based on the detection of some other bomb component, such as metal parts that are identified using metal detection.

Bonding agent: a material that is added to a chemical mixture in order to help bind the components together.

Boosters: secondary explosives placed between the primary high explosive (blasting cap) and the main explosive charge, with the purpose of amplifying the detonation wave from the primary high explosive.

Brisance: the destructive fragmentation effect of a charge on its immediate vicinity.

Bulk explosives detection system: any EDS which directly detects a macroscopic solid mass of explosive material. This is often (but not always) accomplished using x-ray technology, with the explosive material being observed as an object on the x-ray image. Bulk detection is in contrast to trace detection, where the explosive material is detected from vapor or particulate residue. In contrast to a trace detection system, a bulk detection system will never detect explosives if only residue is present.

C-3: a military plastic explosive, composed of approximately 80 percent RDX and 20 percent plasticizer. Also known as composition C-3, it was the predecessor to C-4.

C-4: a military plastic explosive composed primarily (approximately 90 percent) of RDX. Also known as composition C-4.

Canine detection: the detection of explosives, narcotics, or other types of chemical compounds through the use of a dog that is trained to sniff out these substances.

Carrier gas: In IMS technology, the carrier gas (also called dopant) is a gas which is added to the inlet air flow containing the sample. The purpose of the carrier gas is to enhance the ionization process, and in some cases to make the sample molecules easier to detect via the formation of a chemical adduct (i.e., a species consisting of the sample molecule attached to a carrier gas molecule or fragment).

Cavity charge: a shaped charge.

Certification: a process through which an EDS is tested and, if it performs successfully, is judged to be suitable for certain applications.

Cf: Californium, a radioactive element that emits neutrons and can be used as a neutron source.

Chemical explosion: an explosion caused by the extremely rapid conversion of a solid or liquid explosive into gases having a much greater volume than the original material.

Chemiluminescence: a trace detection technique in which explosives are detected via light that is emitted from NO molecules in a chemically excited state. The excited state NO molecules are formed through deliberately induced decomposition of the nitro (NO_2) groups in the original explosive compound.

Combustible: a material capable of igniting or burning.

Commercial explosives detection system: any EDS that can be purchased on the open market.

Composition B: a plastic explosive that contains approximately equal amounts of TNT and RDX.

Computer tomography, computed tomography: an x-ray technique in which transmission images (“slices”) taken at many different angles through an object are put together to produce a three-dimensional image of the object.

Contraband: any item or material that is smuggled into an area or facility where it is prohibited. For example, in a prison contraband might include weapons, explosives, and narcotics.

Conical-shaped charge: a cone-shaped explosive charge, employed to cut or punch a hole through a target.

Cordeau Detonant: a brand name for detonating cord.

CT: computer tomography.

Deflagration: a subsonic process by which explosives release their energy through a rapid burning or autocombustion process, this process being sustained by the energy release from the material. Low explosives explode via deflagration, and under some circumstances high explosives do also. The terms explosion and deflagration are sometimes used synonymously, with both being in contrast to detonation.

Density: the mass of a substance per unit volume, usually expressed in units of grams per cubic centimeter (gr/cm^3).

Detacord: a brand name for detonating cord.

Detasheet: a plastic explosive with a sheet-like structure, containing PETN as the explosive ingredient.

Detonating cord: a cord-like synthetic explosive product, containing PETN as the explosive ingredient.

Detonating Fuse: a brand name for detonating cord.

Detonation: the supersonic process by which a high explosive decomposes and liberates its energy from shock wave compression.

Detonation velocity: the speed at which the shock wave travels through an explosive material.

Detonator: a device, such as a fuse or blasting cap, used to set off explosives.

Dielectric constant: the ratio of electric flux density produced by an electric field in a given material, compared to the density produced by the same field in vacuum. Also called permittivity.

Ditching dynamite: a form of straight dynamite widely used in commercial blasting operations. It is characterized by a high detonation velocity of over 5,185 m/s (17,000 ft/s).

DNT: 2,4-dinitrotoluene, a high explosive compound with a rather high vapor pressure (near one part per million). Molecular formula $C_7H_6N_2O_4$; molecular weight = 182.

Dopant: carrier gas.

Double-beam backscatter x-ray system: a backscatter x-ray system in which there are two x-ray sources and two detectors, so that both sides of an investigated article can be looked at simultaneously.

Dual-axis x-ray system: an x-ray system in which the object under investigation is examined with two x-ray beams coming in at two different angles.

Dual-energy x-ray system: an x-ray system in which the object under investigation is simultaneously irradiated with x-ray beams of two different energies. This allows a wider range of target materials to be detected than if only one beam of one energy were used.

Dynamite: a solid synthetic explosive material, widely used in blasting operations. Dynamite usually contains nitroglycerin as a major explosive component.

ECD: electron capture detector.

Eddy current: a current that is induced around a closed conducting loop by the application of an external magnetic field. Eddy currents currently form the basis of most portal metal detectors.

EDS: explosives detection system.

Effective atomic number: for a substance made up of more than one element, the apparent atomic number that results if the substance is treated as if it were composed only of a single element. It is closely related to the weighted average of the atomic numbers of the constituent elements.

EGDN: ethylene glycol dinitrate. This is a high vapor pressure high explosive that is one of the main explosive ingredients in certain types of dynamite. Its molecular formula is $C_2H_4N_2O_6$; molecular weight = 152.

Electric blasting cap: a blasting cap that is initiated by passing electric current through a bridge wire, thus igniting the primary explosive present in the cap.

Electroluminescent image panel: a panel that is capable of converting electric energy into light.

Electron capture detector: a type of explosives detector wherein gas phase explosives molecules capture electrons from an electron-emitting source to form negative ions. The presence of an explosive is then deduced by observing a decrease in the electron current delivered from the emitting source to a detector.

Electronegativity: the tendency of a molecule to attach an electron.

Explosive bombing: the illegal explosion of a device containing high or low explosive material.

Explosive mixture: a low explosive material composed of a mixture of a combustible and an oxidizer.

Explosives: Explosives are compounds or mixtures of compounds which when subjected to the appropriate stimulus (heat, shock, friction, etc.) undergo extremely rapid chemical changes that result in the evolution of large volumes of highly heated gases and exert pressure upon the surrounding medium. Explosives can be thought of as energy packets that can release their energy in the microsecond timeframe.

Explosives detection system: any device, person, or animal which serves the purpose of detecting explosives. Examples include an ion mobility spectrometer, an x-ray scanner for screening luggage, a trained canine with a handler, and a security guard conducting manual inspection of backpacks and briefcases.

Explosive train: a series of explosions specifically arranged to produce a desired outcome.

EXPRAY: a commercially available, aerosol-based field test kit, able to detect most explosives. Detection is based on color changes of a special paper when it is treated with one of three types of aerosol spray.

False alarm: any alarm of an EDS which occurs when no explosive material or explosive residue is really present. Such alarms may be caused by chemically similar innocuous compounds, or by system malfunction.

False negative: an indication from an EDS that a person or item being screened for explosives is free of explosive material, when in fact the person or item does have/contain explosives.

False positive: an indication from an EDS that a person or item being screened for explosives has/contains explosive material, when in fact the person or item does not have/contain explosive material.

Flex-X: a military name for Detasheet.

Fluorophore: material capable of fluorescence.

Fluoroscopic imaging: use of a fluorescent screen to view the contents of an opaque object, with the contents appearing as shadows formed by transmission of x-rays through the object.

Forensics: In the sense used herein, the science of trace explosives analysis as related to criminal investigations or other law enforcement work.

Fragmentation bomb: a bomb such as a pipe bomb where explosive material is placed inside a metal or other solid casing, with the casing breaking into fragments that are hurled about the area at high velocity when the bomb explodes.

Free-running explosives: group of blasting agents consisting of NCN in small pellet or granular form.

Ft/s: feet per second, the standard unit for detonation velocities.

Gamma rays: high-energy electromagnetic radiation emitted by certain atoms when they are properly stimulated, as in the technique of TNA.

Gelatin dynamites: a class of dynamites with an explosive base of water-resistant gel, formed by combining nitrocellulose and nitroglycerin.

Granulation: the grain size of an explosive powder, such as black powder.

Guncotton: nitrocellulose.

Handler: the individual controlling a dog that is trained to sniff out explosives or narcotics.

HE: high explosive.

High explosives: explosives that are capable of detonation. Common examples include TNT, RDX, PETN, NG, and EGDN.

High-explosive train: an explosive train involving high explosives.

High-order detonation: complete detonation of an explosive at its highest possible detonation velocity.

HMX: a high explosive, chemically related to RDX. HMX (Her Majesty's Explosive) is an eight membered ring of alternating carbon and nitrogen atoms, with nitro (NO_2) groups attached to the nitrogens. Molecular formula $C_4H_8N_8O_8$, molecular weight = 296. HMX has an extremely low vapor pressure and hence is very difficult to detect using any vapor sniffing technique.

Hydrazine: liquid component of the two-part explosive Astrolite. Hydrazine is also used in rocket fuel.

Hygroscopic: readily absorbing moisture, as from the atmosphere.

Immunochemical: relating to antibody-based techniques applied to trace chemical detection.

Improvised device: a homemade device filled with explosive or incendiary material and containing the components necessary to initiate the device.

Incendiary device: a device constructed with flammable materials designed to produce a burning effect.

Incendiary thermal effect: the burning effect of an explosion. It is relatively insignificant compared to the blast pressure effect.

Infrared radiation: electromagnetic radiation that is less energetic than visible light and more energetic than microwaves.

Instantaneous combustion: a colloquial term for detonation. Detonation is in reality not truly instantaneous, but occurs in a matter of microseconds.

Interference, interferent: any chemical compound that serves to mask the presence of an explosive from a given explosives detection system.

Ion mobility spectrometer (IMS): a trace chemical detector which detects explosives and other chemical compounds using the technique of ion mobility spectrometry.

Ion mobility spectrometry: a technique for the trace detection of explosives and other chemical compounds. In this technique, compounds are first ionized, then identified based on the time that it takes them to travel through a region with an applied electric field.

Jet: the extremely hot, swiftly moving bundle of gases and concentrated power resulting from a directionally directed explosion.

Jet-Axe: a commercially available linear-shaped charge, used to cut through doors, roofs, and walls to obtain access into a building.

Kine-Pak: a commercially available two-part explosive, having excellent shock resistance even after mixture of the two components.

KV: kilovolts, a unit of energy.

KVp: kilovolts potential, x-ray source voltage descriptor.

Lead azide: a primary high-explosive compound, $Pb(N_3)_2$.

Lead styphnate: a primary high explosive, often used in blasting caps, $C_6H_3N_3O_9Pb$.

Linear-shaped charge: a type of shaped charge used to cut or slice a target.

Low explosives: explosives which do not detonate, but rather explode via the process of deflagration.

Low-explosive train: an explosive train employing only low explosives.

Low-order detonation: incomplete detonation of an explosive, or detonation at less than maximum detonation velocity.

Magnetic moment: a property of the nucleus of atoms that have a non-zero nuclear spin. These atoms are affected by the application of an external magnetic field, and can give rise to an NMR spectrum.

Mail bomb: any bomb that is sent through the postal service in a letter or package. It is usually designed to detonate when the letter or package is opened.

Mass spectrometer: an instrument that performs mass spectrometry.

Mass spectrometry: a chemical analysis technique in which the molecules to be studied are first ionized and then separated and identified based on their charge-to-mass ratio. Mass spectrometry is performed under conditions of high vacuum, in contrast to IMS which is performed at atmospheric pressure.

Mechanical explosion: an explosion caused by the buildup of excessive pressure inside a solid container, the pressure buildup resulting from the application of heat and hence vaporization of a material inside the container.

Mercury fulminate: a primary high-explosive compound, $Hg(OCN)_2$.

Metal detection: the detection of metals and other conducting materials, usually based on the detection of eddy currents in an applied magnetic field.

Microgram: one millionth of one gram, usually written as µg.

Microrem: a unit of radiation dosage, equal to one millionth of a rem.

Microsecond: one millionth of 1 second, usually written as µs.

Microwaves: electromagnetic radiation that is less energetic than infrared radiation but more energetic than radio waves.

Military dynamite: an explosive (not a true dynamite) used in military construction and demolition work. It is composed of 75 percent RDX, 15 percent TNT, 5 percent motor oil, and 5 percent cornstarch.

Military explosives: explosives manufactured primarily for military applications. Examples include TNT, tetrytol, and C-4.

Milking: a dangerous process by which nitroglycerin is extracted from dynamite.

Milligram: one-thousandth of one gram, usually written as mg.

Millimeter waves: electromagnetic radiation (microwaves) having a wavelength on the order of a few millimeters.

Mine detection: the detection of land or sea mines that are buried or submerged. The detection may be made using metal detection, explosives detection, or some other detection technique.

Nanogram: one-billionth of one gram, usually written as ng.

NCN: nitro-carbo-nitrates.

Negative-pressure phase: the time period following an explosion and after the passing of the outward-going blast pressure wave, during which the pressure at a given point is below atmospheric pressure and air is sucked back into the area. Also called the suction phase. It is less powerful than the positive-pressure phase, but of longer duration.

Nerve agents: chemical agents that harm humans by attacking the nervous system.

Neutron: an elementary particle; along with protons and electrons, one of the three particles that make up atoms. Used as a probe to look for explosives in the technique of thermal neutron activation. Neutrons are neutral (i.e., they have no electrostatic charge).

NG: nitroglycerin.

Nitro-carbo-nitrates: a type of blasting agent, composed primarily of ammonium nitrate and oil.

Nitrocellulose: a cotton-like polymer treated with sulfuric and nitric acids, and used in the manufacture of certain explosives.

Nitroglycerin, nitroglycerine: a high vapor pressure (vapor pressure approximately one part per million) high-explosive compound that is the explosive ingredient in certain types of dynamite. Molecular formula $C_3H_5N_3O_9$; molecular weight = 227.

NMR: nuclear magnetic resonance.

Nonelectric blasting cap: a blasting cap in which the primary explosive material is set off using a flame.

Nuclear detection system: any bulk explosives detection system based on the properties of the nuclei of the individual atoms within the explosives material, including TNA, NMR, and QR systems.

Nuclear magnetic resonance: a bulk explosives detection technique based on the magnetic properties of the hydrogen atoms within the explosive being detected.

Nuisance alarm: In trace detection, an alarm caused by the detection of explosive material, but where the detection results not from a bomb or other contraband explosives but rather from a nonthreat item. For example, in a portal that screens personnel for explosives, detection of NG on a heart patient using NG tablets would be a nuisance alarm. A nuisance alarm is different from a false alarm, since in the case of a false alarm no explosive material is actually present.

Oxidizer: any substance that chemically reacts with another substance to increase its oxygen content.

Particulate: contamination in the form of residual particles attached to clothing, furniture, luggage, skin, or some other surface.

Parts per billion: a quantitative measure of pressure and certain other quantities. When used in reference to explosives vapor pressures, one part per billion means that under equilibrium conditions the air above the explosive material will contain one molecule of explosive vapor for every billion molecules in the air itself.

Parts per million: a measure of explosive vapor concentration analogous to parts per billion, but a thousand times more concentrated. Thus one part per million of explosives vapor in air means one molecule of explosive vapor per every million molecules in the air itself.

Parts per trillion: a measure of explosives vapor concentration analogous to parts per billion, but a factor of one thousand less concentrated. Thus one part per trillion of explosives vapor in air means one molecule of explosive vapor per every trillion molecules in the air itself.

Pentolite: a commonly employed booster explosive, composed of 50 percent TNT and 50 percent PETN.

Percussion primer: a primer that converts mechanical energy into a flame, such as the primer that is set off by the firing pin in a gun.

PETN: pentaerythritol tetranitrate, a common high explosive. It is used in plastic explosives such as Detasheet and Semtex, and has a low vapor pressure (a few parts per trillion at room temperature and atmospheric pressure). Molecular formula $C_5H_8N_4O_{12}$; molecular weight = 316.

PFNA: pulsed fast neutron analysis.

Phosphor: any substance that can be stimulated to emit light by incident radiation.

Picogram: one-trillionth of 1 gram, usually written as pg.

PINS: portable isotopic neutron spectroscopy.

Pipe bomb: a homemade bomb in which explosive material is packed into a section of (usually metal) pipe. Upon explosion, the pipe may shatter, and the propelled fragments thus produced can do much damage to people and property.

Pixel: the smallest resolvable spot on a computer or television screen.

Plastic explosives: high-explosive materials that have the general consistency of plastic. They are usually composed of RDX and/or PETN, along with a small amount of oil or plasticizing agent. Examples include C-4, Detasheet, and Semtex.

Portable isotopic neutron spectroscopy: a portable explosives detection system based on the emission of gamma rays when a material is bombarded with neutrons from a Cf source.

Portal: a walk-through, booth-like structure which serves the purpose of screening personnel for contraband. Examples include the metal detection portals currently deployed in airports, and various types of explosives detection portals that are now on the market or in development.

Positive-pressure phase: the brief time after a detonation in which the local pressure is much greater than atmospheric pressure, due to the outward-moving blast pressure wave.

Post-blast analysis: analysis of the site of an explosion to attempt to identify the type of explosive that was used.

Potassium chlorate: an explosive compound, $KClO_3$.

Potassium nitrate: a crystalline compound, KNO_3, used in the manufacture of explosives, pyrotechnics, and propellants.

Preconcentrator: any mechanical device designed to collect a dilute trace chemical sample and concentrate it, prior to delivery into a detector.

Prill: the loose, powder form of an explosive (as opposed to gel form) or a compressed pellet thereof. The readymade ANFO explosive is also marketed under the name “Prills.”

Primacord: a brand name for detonating cord.

Primary explosives: high-explosive compounds or mixtures that, when present in small quantities, can convert the process of deflagration into detonation. Primary explosives are used to induce detonation of a secondary explosive.

Primer: a cap or tube containing a small amount of primary explosive and used to detonate a secondary main charge.

Primex: a brand name for detonating cord.

Probability of detection - P(d): the probability that a certain EDS can detect a certain amount of a given type of explosive under a particular set of conditions. If a positive detection is always made under these conditions, the probability of detection would be 100 percent. If a detection is made only half the time, the probability of detection would be 50 percent. In general, a large number of experimental trials need to be conducted to accurately determine this parameter.

Propellants: explosive compounds or mixtures used for propelling projectiles or rockets.

Pulsed Fast Neutron Analysis: a nuclear screening technique which measures the elemental composition of the object being scanned through neutron interaction with elemental constituents of the object, resulting in characteristic gamma rays.

Pyrodex: a low-explosive material used as a filler in some improvised devices. Developed by Hodgdon Powder Company, this propellant is available in powder or pellet form. Pyrodex has 30 percent more power than common black powder.

Pyrotechnics: physical mixtures of fuel and oxidizer powders, used to produce light (e.g., fireworks), sound, heat, or smoke.

Q: quality factor, electronics-related term defining the selectivity of a resonant circuit.

QR: quadrupole resonance.

Quadrupole resonance: a bulk explosives detection technique in which the material under investigation is probed using rf radiation. This results in excitation of the nuclei of nitrogen atoms, which emit photons of a characteristic frequency when they relax. The resulting signal is specific for a certain type of nitrogen-containing compound.

Random screening: performing explosives detection on a randomly chosen fraction of a large number of people or items. For example, a security checkpoint might wish to screen every fourth person entering a secure facility. Random screening has the advantage of providing a deterrent against the illicit transport of explosives into a given area, while at the same time being less time consuming than uniform screening.

RDX: a high explosive, cyclotrimethylenetrinitramine, also known as cyclonite. The abbreviation RDX stands for “research and development explosive.” RDX is the main ingredient of C-4, and is also used in Semtex. It has a low vapor pressure (low parts per trillion at room temperature and atmospheric pressure). It consists of a six-membered ring of alternating carbon and nitrogen atoms, with nitro (NO_2) groups attached to the nitrogen atoms. Molecular formula $C_3H_6N_6O_6$; molecular weight = 222.

RF: radio frequency.

Safety fuse: a flame-producing source used in some nonelectric blasting caps.

Saltpeter: potassium nitrate.

Secondary explosives: high-explosive compounds or mixtures that are generally initiated to detonation by intense shock. Secondary explosives are generally less sensitive than primary explosives, but pack more explosive power.

Secondary high-explosive boosters: explosives which provide the detonation link in an explosive train between the very sensitive primary high explosives and the comparatively insensitive main charge high explosives.

Secure area, secure facility: any area or facility where access is restricted by appropriate entry controls. Entry normally involves some form of identity verification for the entering individual. It may also include contraband screening.

Security checkpoint: any checkpoint at an entrance to a secure area that administers some sort of entry control. It may also involve screening for contraband, including explosives.

Semtex: a type of plastic explosive, normally containing both RDX and PETN.

Shaped charge: specially shaped explosive charges that are used to cut or punch holes in solid materials such as steel and concrete.

Shock wave: a sharp discontinuous pressure disturbance traveling faster than the speed of sound. A shock wave is created when a high explosive detonates.

Shrapnel: precut or preformed objects (e.g., metal fragments, nails) placed in or attached to a bomb. When the bomb explodes, these objects are hurled at high velocity, with much potential damage to people and property.

Single-energy transmission x-ray scanner: an x-ray scanner using only a single x-ray beam, in which the portion of the beam that penetrates the object under investigation is detected and used to produce the x-ray image.

Smokeless powder: an explosive material (double-base propellant) in powder form, often containing nitroglycerin (typically 40 percent by weight) as the explosive ingredient.

Sodium chlorate: an explosive compound, $NaClO_3$.

Sodium nitrate: a chemical compound, $NaNO_3$. It is sometimes added to dynamite to increase the oxygen content and hence improve combustion.

Specificity: the ability of a chemical analysis technique to distinguish similar chemicals from one another. The greater the specificity, the more certain the identification of a particular compound can be.

Straight dynamites: a class of dynamites containing nitroglycerin as the explosive base.

Tandem mass spectrometry: a technique of chemical analysis, also referred to as mass spec/mass spec, or simply MS/MS. Essentially, it involves sending analyte molecules through two mass spectrometers consecutively, in order to increase the specificity of the system.

Tetramino nitrate: a highly sensitive primary high explosive, which can be formed from the reaction of ammonium nitrate with brass or bronze tools.

Tetryl: a high-explosive compound, similar in structure to TNT. Molecular formula $C_7H_5N_5O_8$; molecular weight = 287.

Tetrytol: a military explosive composed of approximately 75 percent tetryl and 25 percent TNT.

Thermal neutron: a neutron having an energy that is typical of neutrons at room temperature.

Thermal neutron activation: a bulk explosives detection technique, in which explosives are detected by the emission of characteristic radiation (gamma rays) that occurs when the explosive material is irradiated with thermal energy neutrons.

Threat: the event or occurrence which a protective measure is intended to guard against.

Threat consequence: the results of a particular threat event occurring, including death or injury to personnel, and damage to property.

Threat item: the item that an EDS is designed to detect, i.e., a bomb or contraband explosives material.

Threat probability: the likelihood of a particular threat event actually occurring, on a scale of 0 percent (no probability of occurring) to 100 percent (certainty that the event will occur).

Throughput rate: the rate at which an EDS can process the people or objects being screened. It is generally expressed in units such as people per hour for a personnel portal, or bags per hour for an x-ray baggage scanner.

TNA: thermal neutron activation.

TNT: 2,4,6-trinitrotoluene, a common high explosive with a moderate vapor pressure (near one part per billion at room temperature and atmospheric pressure). Molecular formula $C_7H_5N_3O_6$; molecular weight = 227.

Tovex: a trade name for certain water-gel based explosives.

Trace explosives detection system: any EDS that detects explosive materials by collecting and identifying trace residue from the material. This residue may be in the form of either vapor or particulate. Trace detection is in contrast to bulk detection.

Two-part explosives: explosives that consist of two separate components, which are sold together in separate containers and need to be mixed together prior to detonation.

Ultraviolet light: electromagnetic radiation that is less energetic than x-rays but more energetic than visible light.

Uniform screening: Performing explosives detection on all persons or items passing through a given security checkpoint, applying the same screening process to all of them. Uniform screening is in contrast to random screening.

Vapor generator: any device designed to produce calibrated amounts of vapor of a particular compound.

Vapor pressure: the quantity of vapor (usually expressed in terms of a concentration) of an explosive compound that exists above the compound in air at equilibrium under a specified set of conditions.

Water-gel explosives: explosive mixtures (slurries) consisting of saturated aqueous solutions of ammonium nitrates and other nitrates.

Wavelength: a property of electromagnetic radiation that is inversely proportional to its energy.

Working lifetime: the time period during which a given EDS is useful. For both a canine and an IMS, a typical working lifetime might be on the order of 10 years.

X-ray absorption coefficient: the fraction of incident x-rays that is absorbed by a given material.

X-ray backscatter coefficient: the fraction of incident x-rays that is backscattered (i.e., reflected) by a given material.

X-rays: high-energy electromagnetic radiation with wavelength in the approximate range of 0.05 angstroms to 100 angstroms (one angstrom = 1 A = 100 billionths of one centimeter). Less energetic than gamma rays.

X-ray transmission coefficient: the fraction of incident x-rays that pass through a given material.

Z: symbol for atomic number.

APPENDIX A-3. EXPLOSIVES: NATURE, USE, EFFECTS, AND APPLICATIONS

The purpose of this appendix is to provide a general understanding of the nature of explosions and explosives. It is intended not as a textbook or technical manual, but as a source of background information for police, security, and other law enforcement officials finding themselves involved in the prevention and control of the illegal use of explosives.

EXPLOSIONS

TYPES OF EXPLOSIONS

An explosion can be broadly defined as the sudden and rapid escape of gases from a confined space accompanied by high temperatures, violent shock, and loud noise. The generation and violent escape of gases is the primary criterion of an explosion and is present in each of the three basic types of explosions: 1) mechanical, 2) chemical, and 3) atomic.

Mechanical Explosion

The mechanical explosion is illustrated by the gradual buildup of pressure in a steam boiler or pressure cooker. As heat is applied to the water inside the boiler, steam, a form of gas, is generated. If the boiler or pressure cooker is not equipped with some type of safety valve, the mounting steam pressure will eventually reach a point when it will overcome the structural or material resistance of its container and an explosion will occur. Such a mechanical explosion would be accompanied by high temperatures, a rapid escape of gases (steam), and a loud noise.

Chemical Explosion

A chemical explosion is caused by the extremely rapid conversion of a solid or liquid explosive compound into gases having a much greater volume than the substances from which they were generated. When a block of explosive detonates, the produced gases will expand into a volume 10,000 to 15,000 times greater than the original volume of the explosive. The expansion of these generated gases is very rapid, reaching velocities of approximately 8.05 km (5 miles) per second. Temperatures generated by the conversion of a solid into a gas state may reach 3000 °C to 4000 °C. The entire conversion process takes only microseconds and is accompanied by shock and loud noise.

Atomic Explosion

An atomic explosion may be induced either by fission, the splitting of the nuclei of atoms, or fusion, the joining together under great force of the nuclei of atoms. During nuclear fission or fusion, a tremendous release of energy, heat, gas, and shock takes place. The atomic bombs dropped on Japan in World War II were rated as equivalent to 18,140 t (20,000 tons (20 kT), or 18.18 million kg (40 million pounds), of TNT in explosive power, yet the amount of fissionable material required to produce this energy weighed approximately 1 kg (2.2 lb). With today’s technology, even greater yields are possible with smaller amounts of fissionable material.

NATURE OF CHEMICAL EXPLOSIONS

The explosives normally encountered by law enforcement personnel are chemical in nature and result in chemical explosions. In all chemical explosions, the changes which occur are the result of combustion or burning. Combustion of any type produces several well-known effects: heat, light, and release of gases. The burning of a log and the detonation of a stick of dynamite are similar because each changes its form and, in so doing, produces certain effects through combustion. The real difference between the burning of the log and the detonation of the dynamite is in the time duration of the combustion process.

Deflagration (Rapid Combustion)
An example of deflagration or rapid combustion is illustrated by the internal combustion automobile engine. Inside the cylinder of the engine, combustible fuel (gasoline) is mixed with a combustion supporter (air), and the mixture is raised close to its ignition temperature by compression. When a flame from the spark plug ignites the mixture, rapid combustion or deflagration occurs. Deflagration is merely a rapid form of combustion, and ordinary combustion is simply a slow form of deflagration. The speed of the burning action constitutes the difference between combustion, deflagration, and detonation.

Detonation (Instantaneous Combustion)
Detonation can be defined as “instantaneous combustion”. However, even in detonation, the most apid form of combustion, there must be some time interval in order that the combustion action can be transferred from one particle of the explosive compound to the next. Therefore, there cannot be “instantaneous” combustion, but the extreme rapidity of the process, as compared to that of ordinary combustion and explosion, warrants the use of the term.

The velocity of this “instantaneous combustion” has been measured for most explosives and is referred to as the detonation velocity of the explosive. Detonation velocities of high explosives range from approximately 2,743 m/s (9,000 ft/s) to over 8,382 m/s (27,500 ft/s). As an illustration of detonation velocity, if a 8.05 km (5 mile) 80,467 m (26,400 ft) length of garden hose were filled with RDX (detonation velocity 8,382 m/s (27,500 ft/s)) and initiated at one end, the detonation would reach the other end of the 8.05 km (5 mile) long hose in less than 1 s.

A high-order detonation is a complete detonation of the explosive at its highest possible velocity. A low-order detonation is either incomplete detonation or complete detonation at lower than maximum velocity. Low-order detonations may be caused by any one or a combination of the following factors: 1) initiator (blasting cap) of inadequate power, 2) deterioration of the explosive, 3) poor contact between the initiator and the explosive, and 4) lack of continuity in the explosive (air space).

EFFECTS OF AN EXPLOSION

When an explosive is detonated, the block or stick of chemical explosive material is instantaneously converted from a solid into a rapidly expanding mass of gases. The detonation of the explosive will produce three primary effects and several associated secondary effects which create great damage in the area surrounding the explosion. The three primary effects produced are blast pressure, fragmentation, and incendiary or thermal effects.

Blast Pressure Effect
When an explosive charge is detonated, very hot, expanding gases are formed in a period of approximately 1/10,000 of a second (100 μs). These gases exert pressures of about 635 metric ton (700 tons) per square inch on the atmosphere surrounding the point of detonation and rush away from the point of detonation at velocities of up to 11,265 km (7,000 mph), compressing the surrounding air. This mass of expanding gas rolls outward in a circular pattern from the point of detonation like a giant wave, weighing tons, smashing and shattering any object in its path. The further the pressure wave travels from the point of detonation, the less power it possesses until, at a great distance from its creation, it dwindles to nothing. This wave of pressure is usually called the blast pressure wave.

The blast pressure wave has two distinct phases which will exert two different types of pressures on any object in its path. These phases are the positive pressure phase and the negative or suction phase. The negative phase is less powerful, but lasts three times as long as the positive phase. The entire blast pressure wave, because of its two distinct phases, actually delivers a one-two punch to any object in its path. The blast pressure effect is the most powerful and destructive of the explosive effects produced by the detonation of high explosives.

Secondary Blast Pressure Effects: Reflection, Focusing, and Shielding of the Pressure Wave. Blast pressure waves, like sound or light waves, will bounce off reflective surfaces. This reflection may cause either a scattering or a focusing of the wave. A blast pressure wave will lose its power and velocity quickly when the detonation takes place in the open. For example, assume that a block of explosive is detonated in the open, and the blast wave dissipates at a distance of 30.48 m (100 ft) from the point of detonation. If the same charge had been placed inside a large diameter sewer pipe or a long hallway and detonated, the blast pressure wave would have been still measurable at 6.096 m (200 ft) or more. This is due to the reflection of the blast wave off the surfaces surrounding it, and the reflected wave may actually reinforce the original wave by overlapping it in some places.

Since the reflected wave is a pressure wave, it will exert physical pressure. Similarly, a blast pressure wave may be focused when it strikes a surface which acts as a parabolic reflector just as sound waves can be focused and directed.

Shielding occurs when the blast pressure wave strikes an immovable object in its path. If a square, solid concrete post 60.96 cm (2 ft) thick is placed in the path of the blast pressure wave and a wine glass is placed behind this post, the blast pressure wave will strike the post, and the post will, in effect, cut a hole in the pressure wave, leaving the wine glass undamaged.

When dealing with detonations which have taken place inside buildings, many unusual effects due to reflection or shielding will be noted. These effects account for such strange things as the entire wall of the structure being blown out, but a mirror on the opposite wall remaining intact.

Secondary Blast Pressure Effects: Earth and Water Shock. When an explosive charge is buried in the earth or placed underwater and detonated, the same violent expansion of gases, heat, shock, and loud noise results. Since earth is more difficult to compress than air, and water is not compressible at all, the detonation will seem less violent. Nevertheless, the energy released is exactly the same as would result from a detonation in the open air. The effect of this violence is, however, manifested in a different manner. The blast wave is transmitted through the earth or water in the form of a shock wave, which is comparable to a short, sharp, powerful earthquake. This shock wave will pass through earth and water just as it does through air, and when it strikes an object such as a building foundation, the shock wave will, if of sufficient strength, damage that structure much as an earthquake would. An explosive charge detonated underwater will produce damage at greater distances because, unlike earth, water is not compressible and cannot absorb energy. As a result, it transmits the shock wave much faster and farther, and consequently produces greater damage within a larger area.

Fragmentation Effect

A simple fragmentation bomb is composed of an explosive placed inside a length of pipe which has the end caps screwed into place. When the explosive is detonated not only will the blast pressure effect produce damage, but shattered fragments of the pipe will be hurled outward from the point of detonation at great velocity. The average fragment produced by the detonation of a bomb will reach the approximate velocity of a military rifle bullet 822.96 m/s (2,700 ft/s) a few feet from the point of detonation. These bomb fragments will travel in a straight line of flight until they lose velocity and fall to earth or strike an object and either ricochet or become imbedded.

When an encased explosive such as a pipe bomb detonates, the rapidly expanding gases produced by the explosion cause the casing to enlarge to about one and one-half times its original diameter (material dependent) before it ruptures and breaks into fragments. Approximately, half the total energy released by the explosion is expended in rupturing the case and propelling the broken pieces of the casing outward in the form of fragments. Fragments resulting from the detonation of a high-explosive filler have a stretched, torn, and thinned configuration due to the tremendous heat and pressure produced by the explosion. In contrast, the detonation of a pipe bomb containing black powder, a low explosive, would produce fragments that are larger in size than those resulting from a high-explosive detonation, and they would not have a stretched and thinned configuration.

Precut or preformed objects such as nails, ball bearings, or fence staples, which are placed either inside the bomb or attached on the outside are referred to as shrapnel. Shrapnel serves the same purpose and has the same effect on personnel, material, and structures as fragmentation. One advantage of using shrapnel is that part of the energy released by the explosion, which would normally have been expended in fracturing the bomb casing into fragments, is used instead in propelling the preformed, separate pieces of shrapnel. Consequently, the use of shrapnel inside or attached outside a bomb results in an increase in blast damage by cutting, slicing, or punching holes in materials near the detonation point.

Incendiary Thermal Effect

The incendiary thermal effect produced by the detonation of a high or low explosive varies greatly from one explosive to another. In general, a low explosive will produce a longer time period of incendiary thermal effect than will a high explosive. A high explosive will, on the other hand, produce much higher temperatures. In either case, the duration of the effect is measured in fractions of seconds. The incendiary thermal effect is usually seen as a bright flash or fireball at the instant of detonation. If a high-explosive charge is placed on a section of earth covered by dry grass and then detonated, only a vacant patch of scorched earth will remain. However, if a low-explosive charge is placed on the same type of earth and detonated, more than likely a grass fire will result.

Unless highly combustible materials are involved, the thermal effect plays an insignificant part in an explosion. Should combustible materials be present and a fire started, the debris resulting from the explosion may provide additional fuel and contribute to spreading the fire. When fires are started inside a structure which has been bombed, they usually are traceable to broken and shorted electrical circuits and ruptured natural gas lines rather than to incendiary thermal effects. Incendiary thermal effects are generally the least damaging of the three primary detonation effects.

COMPOSITION AND BEHAVIOR OF CHEMICAL EXPLOSIVES

An explosive is a chemically unstable material which produces an explosion or detonation by means of a very rapid, self-propagating transformation of the material into more stable substances, always with the liberation of heat and with the formation of gases. Shock and loud noise accompany this transformation.

The primary requisite of a chemical explosive is that it contains enough oxygen to initiate and maintain extremely rapid combustion. Since an adequate supply cannot be drawn from the air, a source of oxygen must be incorporated into the combustible elements of the explosive, or added by including other substances in the mixture. These sources of oxygen are called oxidizers.

Explosive Mixtures

In the case of deflagrating substances, as contrasted to detonating substances, the combustible and oxidizer are blended mechanically. The result of this type of blending is known as an explosive mixture. Mechanical blending is generally used when manufacturing low explosives or propellants such as pistol and rifle powders. Propellants are materials that burn to produce gases used to perform mechanical work, such as propelling a projectile or pushing a piston. In some cases, a bonding agent such as water is added to the mixture to form a paste. When dry, the paste mixture is broken into pieces and ground to produce a finer mixture than would result from simply blending the separate ingredients.

Explosive Compounds

The first requirement of a detonating substance is that the bond between the combustible and the oxidizer must be as close as possible. Since mechanical mixing does not provide a close enough relationship, detonating explosives must be chemically blended. For example, in creating the chemical compound nitroglycerin, glycerin is poured slowly into nitric acid forming a new compound whose elements are bound tightly together. All high explosives, in contrast to low explosives, are composed of chemical compounds consisting of tightly bonded combustibles and oxidizers.

Classification by Velocity

The classification of explosives by the velocity of explosion or detonation is a convenient and widely used system for distinguishing between two major groups of explosives.

Low Explosives. Those explosives known as low explosives have rates of detonation below 999.7 m/s (3,280 ft/s). For example, black powder has a rate of approximately 399.9 m/s (1,312 ft/s). Low explosives are used primarily as propellants, because a mechanically mixed explosive charge minimizes the danger of bursting the weapon in which it is used. In a mechanical mixture the burning is transmitted from one grain of low explosive to the next, and

the gases produced build up as the powder burns. This causes low explosives, in terms of performing work, to exert a rapid pushing effect rather than a shattering effect as do high explosives. Low-explosives are used in blasting operations and are also frequently the filler for homemade pipe bombs.

A bomb using low explosives is made by confining pistol, rifle, or black powder in a length of pipe with end caps. When the confined powder is ignited, the rapidly produced and confined gases will create increasing internal pressures until the pipe container bursts and is torn apart by the pressure. Unlike high explosives, low explosives may be started on the combustion path by the application of a simple flame or acid/flame reaction and do not require the shock of a detonating blasting cap.

High Explosives. This type of explosive is designed to shatter and destroy. The detonation rate of high explosives is above 999.7 m/s (3,280 ft/s). There is a wide range in the detonation velocities of high explosives, extending from some dynamites at 2,743.2 m/s (9,000 ft/s) up to RDX at 8,382 m/s (27,500 ft/s).

High explosives differ from low explosives in that they must, in general, be initiated by the shock of a blasting cap. When low explosives begin their combustion, the burning travels from particle to particle because of the granular form of the explosive. This results in the deflagration of the material. High explosives detonate, which has been described as instantaneous combustion. When a blasting cap is detonated in a stick or block of high explosive, it delivers an extremely sharp shock to the explosive. This shock breaks the bonds of the molecules of the chemically bonded explosive material and oxidizers. The disruption of the molecules is transmitted as a shock wave radiating outward in all directions from the point of initiation. This internal shock wave is known as a detonation wave, and it causes each molecule it strikes to rupture. The rupture of each molecule causes the wave to move faster until, in a very short time and distance, the explosive material is detonating at its maximum rate. When a high explosive detonates, the speed at which the detonation wave progresses through the explosive is called the detonation velocity. It is usually expressed in feet or meters per second.

Applications of Explosives

The varying velocities of explosives have a direct relationship to the types of work they can perform. The differences in velocity determine the type of power exerted by high or low explosives. Low explosives have pushing or heaving power and high explosives have, because of the rapid expansion of their gases, shattering power. Thus, an expert in the use of explosives will select a high or low explosive depending on the type of work to be performed. For example, if a large boulder is blocking a dirt roadway, the experienced blaster might dig a hole under the boulder and place a black powder 399.9 m/s (1,312 ft/s) charge in the hole. When the black powder charge is functioned, it will heave the boulder, virtually intact, off the roadway. If the blaster wishes to reduce the boulder to rubble so that it may be removed, he might place a TNT

010.4 m/s (23,000 ft/s) charge on or under the boulder. When the TNT charge is functioned, the boulder will be shattered into many smaller pieces.

Another characteristic of explosives related to work performance is the fact that the forces created by a detonating explosive will be given off directionally at a 90° angle from the surface of the explosive. Consequently, if the explosive is cut or shaped to provide 90° surfaces along a predetermined plane, the explosive forces can be focused directionally, and will produce a greater effect, ounce for ounce, than the same explosive employed as a mass.
This improved effectiveness is caused by the focusing of the hot gases released by the detonating explosive. The extremely hot, swiftly moving bundle of concentrated power is called the "jet" and performs in much the same manner as the white-hot flame of a cutting torch.

A significant advance in the employment of explosives to accomplish specific work was achieved with the development of shaped or cavity charges that focus explosive forces. These specially shaped explosive charges are employed to cut or punch holes in steel, concrete, and other materials.

There are two basic types of shaped charges, the conical-shaped charge and the linear-shaped charge. Conical shaped charges are employed to cut or punch a hole through the target, while linear shaped charges are used to cut or slice a target.

Until recent years, the military were the primary users of shaped charges. Military shaped charges used in military projectiles, rockets, and mines were employed to destroy tanks and reinforced concrete bunkers. Today shaped charges are widely used in industry and by public safety personnel. One of the latest uses of the linear-shaped charge is as an explosive entry tool employed by fire fighters and public safety officers to cut through steel fire doors, roofs, and light structural walls. This shaped charge is manufactured under the name "Jet-Axe," and consists of a linear-shaped charge contained in a polystyrene box. The box is placed against the target and the shaped charge is detonated, providing an entry hole to the building.

Two different sizes of prepackaged shaped charges are utilized by the armed forces in demolition and breaching operations against steel or reinforced concrete structures. The 6.82 kg (15-lb) M2A3 shaped charge and the 18.2 kg (40-lb) M3 shaped charge each contain a 50/50 pentolite/ composition B mixture. The armed forces also use various other shaped charges, both linear and conical, for special purposes, but these generally are small hand-packed charges employing composition C-3 or C-4 as the explosive filler.

EXPLOSIVE TRAINS

An explosive train is a series of explosions specifically arranged to produce a desired outcome, usually the most effective detonation or explosion of a particular explosive. The simplest explosive trains require only two steps, while the more complex trains of military munitions may have four or more separate steps terminating in detonation. Explosive trains are classified as either low (propellant) or high, depending upon the classification of the final material in the train.

Low-Explosive Trains
A round of small arms ammunition is a simple example of a two-step low-explosive train. The components in this train are a percussion primer and a propellant charge. The primer converts the mechanical energy of the weapon's firing pin into a flame. The flame ignites the propellant charge, and the gases produced by the resulting explosion drive the bullet through the bore of the weapon.

When low explosives, such as smokeless powder and black powder, are used in the construction of pipe bombs, a simple two-step explosive train is again required. A length of safety fuse, which is a slow-burning time fuse filled with black powder, is inserted into the pipe and the opposite end of the fuse is ignited with a match. The safety fuse transmits the flame, after a delay, to the low explosive inside the pipe. When it is ignited, the low explosive inside the pipe explodes, and the confined gases produced tear the pipe apart, resulting in both blast and fragmentation. The majority of low explosives require only a simple two-step train.

High-Explosive Trains
The nature of high-explosive trains is affected by the broad range of sensitivity found within the category of high-explosive compounds. Sensitivity refers to the amount of external force or effect needed to cause detonation. Some explosives are so sensitive that lightly brushing a small piece of explosive with a feather will cause it to detonate. On the other hand, other explosives may be placed on an anvil and struck with a sledge hammer and will not detonate.

For the sake of safety, the extremely sensitive explosives are always used in very small quantities, while the comparatively insensitive explosives are used in bulk quantities. This natural division, by sensitivity, produces two groups within the category of high explosives. The most sensitive explosives are referred to as primary high explosives, and the more insensitive compounds are termed secondary high explosives.

Primary High Explosives. Explosives known as primary high explosives are among the most powerful as well as the most sensitive of all chemical explosives. This combination of power plus sensitivity makes them very hazardous to handle. The primary high explosives, because of their sensitivity, may be initiated by applying shock, friction, flame, heat, or any combination of these conditions. Due to their high detonation velocities, the primary high explosives are able to create extremely powerful detonation waves capable of causing complete instantaneous detonation of other less sensitive explosives. For this reason they are used as the first step in high-explosive trains and are packaged for this purpose as blasting caps and military fuse detonators.

When used in both electric and nonelectric blasting caps, the primary high explosives are detonated by heat or flame. In military fuses, the primary high explosive is usually initiated by shock of impact or heat-producing friction. The more commonly used primary high explosives are lead styphnate, lead azide, mercury fulminate, and diazodinitrophenol, which have detonation velocities ranging from 5,029 m/s (16,500 ft/s) for mercury fulminate to 6,614 m/s (21,700 ft/s) for diazodinitrophenol.

Secondary High Explosives. Compared to the primary high explosives, the secondary high explosives are relatively insensitive to shock, friction, flame, or heat and are, therefore, less hazardous to handle and use. However, as a result of their relative insensitivity, the secondary high explosives must be initiated or detonated by a very strong explosive wave. Consequently, primary explosives are used to detonate secondary explosives.

Secondary explosives comprise the largest single class of explosives and have detonation velocities ranging from 2,743.2 m/s (9,000 ft/s) for some dynamites to 7,925 m/s (26,000 ft/s) for military composition C-4.

Boosters. Since there is a wide range of sensitivity found among the secondary high explosives, some of the more insensitive explosives cannot be detonated unless the detonation wave of the primary high explosive blasting cap is amplified or boosted. This amplification is accomplished through the use of a different and slightly more sensitive secondary explosive between the primary first step and the main explosive charge.
The progression of the detonation wave from a small amount of a sensitive primary high explosive, through a slightly larger amount of a less sensitive secondary high-explosive booster, to a large amount of very insensitive secondary high explosive main charge illustrates detonation through a basic three-step explosive train.

Typical High-Explosive Trains. The explosive train normally used in work with high explosives is a two- or three-step train. An example of a simple two-step train is an electric blasting cap containing a primary high explosive, and a stick of dynamite, as a secondary high explosive. The blasting cap is detonated by the heat generated by passing an electrical current through the fine wire imbedded in the primary high explosive inside the cap. The detonation wave from the blasting cap would cause the detonation of the dynamite. A simple three-step explosive train could be a length of safety fuse filled with black powder, a nonelectric blasting cap, and a stick of dynamite. The burning black powder in the safety fuse would produce a flame that would detonate the blasting cap, a primary high explosive, which would in turn detonate the dynamite, a secondary high explosive.

The number of steps in the explosive train is not always a matter of choice. As noted previously, some high explosives are so insensitive that the detonating wave from the blasting cap is not powerful enough to cause detonation. In such instances, a booster must be employed to amplify and strengthen the wave from the blasting cap.

Regardless of how many steps it contains, the firing train is nothing more than a series of explosions arranged to achieve a desired end result. If the explosive train is broken or interrupted, detonation of the main charge will not occur.

Some common explosives likely to be encountered by public safety personnel will be discussed next with information on the physical characteristics of the explosive material and its normal use and packaging. In addition, certain blasting accessories used to detonate the explosives will be discussed.

Low Explosives

Black Powder. The average composition of black powder is saltpeter (potassium nitrate), 75 parts by weight; sulfur, 10 parts by weight; and charcoal, 15 parts by weight. There has been, however, a wide variation in the black powder formulas that have been used over the years. The black powder mixture ranges in color from coal black to rusty brown and in form from a fine powder to granules as large as 1.27 cm (1/2 in) in diameter. The burning speed of black powder, and therefore to a certain extent its strength, is controlled by the size of the granulation. Large grains of powder burn more slowly than fine grains and are consequently less sudden in their action.

Black powder does not deteriorate with age, even if it has been submerged in water. Once black powder dries out, it is just as effective and dangerous an explosive as it was the day it was manufactured.

Sensitivity to friction, heat, impact, and sparks makes black powder one of the most dangerous explosives to handle. It is particularly sensitive to both electrically and nonelectrically generated sparks and should, therefore, be handled with wooden or plastic tools. As a further precaution, the body should be grounded before black powder is handled.

Because of its slow action and consequent heaving or pushing effect, black powder was for years the sole commercial blasting agent. Though it has been replaced by dynamite in most blasting applications, black powder is still used for certain special operations. For this purpose it is manufactured in varying granulations to enable the customer to match the powder to the specific application, and packaged in 11.36 kg (25-lb) metal kegs. For commercial blasting, black powder is also pressed into cylinders measuring 5.08 cm (2 in) by 3.175 cm (1 1/4 in). Some cylinders have a 0.9525 cm (3/8-in) hole through their center so that an electric squib may be inserted or so that the cylinders may be laced together on a length of fuse. In cylinder form, black powder is usually wrapped in paper to form a stick about 20.32 cm (8 in) in length and packed in 11.36 kg (25 lb) and 22.73 kg (50 lb) cases for sale.

As a blasting charge, black powder has about half the strength of TNT, and because the basic ingredients can be readily acquired in any community, it has become the favorite homemade explosive of bombers in the United States. Black and smokeless powder, whether homemade or commercial, will probably be the explosives most often encountered in pipe bombs. When confined inside a pipe and provided with a safety fuse, no blasting cap is needed to initiate the powder, because the flame from the end of the fuse is sufficient to cause the explosion of the bomb. It should be noted that any sparks resulting from an attempt to dismantle a pipe bomb may produce the same results. Therefore, a discovered pipe bomb should only be handled by specially trained personnel.

Perhaps the most common use of black powder in routine work with explosives is in the manufacture of safety fuse. Since its burning rate can easily be regulated in production, black powder is widely used as the core burning powder in the safety fuse used commercially, and by the military to provide a uniform delay time prior to an explosion.

Safety fuse is used for detonating explosives nonelectrically. Normally, its purpose is to transmit a flame at a continuous and uniform rate to a nonelectric blasting cap. There are two common burning rates for safety fuse. The most frequently encountered fuse burns at the rate of 40 s per 0.305 m, while a less common type is designed to burn at the rate of 30 s per 0.305 m.

Although safety fuse is designed for use with nonelectric blasting caps, it may, as previously noted, be used by bombers as a direct means of initiating a low explosive main charge. A delay element in itself, the safety fuse can be used to allow the bomber time to leave the scene of the incident. When employed in bombings, a portion of the spent fuse will usually survive the explosion and may be located not far from the point of detonation.

- **Commercial Safety Fuse**. There are numerous brands of commercial safety fuse, but their only essential difference is in the type of exterior water proofing materials and color markings. Commercial safety fuse is approximately 0.508 cm (0.2 in) in diameter, about the size of a lead pencil, and comes in 15.24 m (50 ft), paper wrapped, rolls or coils. It is colored orange for general use, black for use in salt mines, and white for use in coal mines.

- **Military Safety Fuse**. The U.S. military uses two types of safety fuse, one called “safety fuse” and the other called “M 700 time fuse.” They are interchangeable in use and similar in construction.

- **Improvised Safety Fuse**. Fusing can be made from a common fireworks fuse, or by saturating ordinary cotton cord with certain liquid chemical compounds that provide uniform burning when dry. Even the use of rag wicks in fire bombs such as the “Molotov cocktail” can be considered a form of improvised fusing. Since most improvised fuses burn at erratic rates, they can hardly be considered “safety” fuses.

Smokeless Powder. Smokeless powder is the world standard propelling powder for small arms, cannons, and, in a slightly different form, rockets. All low explosives currently used as propellants have a nitrocellulose base and are commonly referred to as smokeless powders. Various organic and inorganic substances are added to the nitrocellulose base during manufacture to give improved qualities for special purposes, and these variations are distinguished by such terms as double-base, flashless, and smokeless, as well as by various commercial trade names or symbols.

Smokeless powders are produced by dissolving guncotton (nitrocellulose) in a mixture of ether and alcohol to form a mass called a colloid. The colloid has the consistency of melted glue, and is squeezed into macaroni-shaped tubes that are subsequently cut into short lengths. The ether and alcohol used to dissolve the guncotton are evaporated, leaving a hard substance. The small cylindrical powder grains resulting from this process are used as rifle ammunition powders.

Pistol powders, unlike rifle powders, do not generally have cylindrical grains. Instead, they are manufactured in the form of very fine, thin wafers, flakes, or balls. These shapes insure the shorter burning time necessary for full combustion in weapons with short barrels. Shotgun powders are similar to pistol powders in that they burn more rapidly than rifle powders. In fact, most shotgun powders are straight nitrocellulose in composition.

Like black powder, smokeless powders vary widely in both form and color. The majority of rifle and pistol powders are black in color and are formed into rods, cylindrical strips, round flakes, or irregular grains. Shotgun powders may be translucent round or square flakes, orange to green in color, or may be black irregularly shaped granules. Smokeless powders of all types are sold in tin flasks, glass jars, plastic containers, and kegs of varying weights up to 11.36 kg (25 lb).

Unconfined smokeless powder burns with little or no ash or smoke and, when confined, its rate of burning increases with temperature and pressure. For this reason, it is frequently used in the construction of pipe bombs. It should be noted that smokeless powder manufactured for use in small arms ammunition is usually glazed with graphite to facilitate machine loading and prevent the accumulation of static electricity. Many of these powders are as sensitive to friction as black powder, and the precautions used in handling black powder should be observed for smokeless powders.

Primary High Explosives

Primary high explosives are sensitive, powerful explosives used in blasting caps, military fuse detonators, and detonating cord to detonate main charges or secondary high explosives.
Blasting Caps. Blasting caps are used for initiating high explosives and contain small amounts of a sensitive primary high explosive. Although they are manufactured to absorb a reasonable amount of abuse under normal conditions, they must be protected from shock, extreme heat, impact, and rough treatment to prevent accidental detonation. Blasting caps are functioned either electrically or nonelectrically.

Electric Blasting Caps. Electric blasting caps are used when a source of electricity, such as a blasting machine or battery, is available. The electric cap is constructed from a small metal tube or shell which is closed at one end. The cap contains a base load of a sensitive high explosive, a pressed intermediate charge of extremely sensitive explosive, and a loose ignition charge. The electrical firing element consists of two plastic insulated leg wires (also called lead wires), an insulated plug which holds the two wires in place, and a small diameter corrosion-resistant bridge wire attached across the terminals of the leg wires below the plug. This assembly is double crimped into the cap shell.

Upon application of electric current, the bridge wire heats to incandescence and ignites the loose ignition mixture. The resulting heat or flame sets off the extremely sensitive intermediate charge which, in turn, detonates the base charge.

Commercial electric blasting caps come in a variety of sizes, with the Number 6 and Number 8 blasting caps being the most common. Number 6 blasting caps are approximately 2.8575 cm (1 1/8 in) long, with an outside diameter of 0.635 cm (1/4 in). Number 8 blasting caps have the same diameter and are about 3.175 cm (1 1/4 in) long. Electric blasting caps with leg or lead wires 7.315 m (24 ft) long or less are normally packed 50 to a carton and 500 caps to the case. Leg or lead wires, which come in lengths ranging from 1.22 m to 91.44 m (4 ft to 300 ft), are made of 22 gauge copper wires for lengths up to 7.315 m (24 ft) and 20 gauge copper for longer lengths. Most commercial blasting caps employ lead wires of two different colors to facilitate making electrical connections.

Most electric blasting caps have a short circuiting shunt on the exposed ends of the leg wires to act as a guard against static electricity and to prevent accidental firing.

Special types of electric blasting caps are manufactured for seismographic work, open hearth steel furnaces, and other tasks requiring very short delays. The delays built into these special blasting caps range from 0.5 ms to 1.5 ms and are indicated by tags attached to each blasting cap.

Nonelectric Blasting Caps. Nonelectric blasting caps are small metal tubes or shells, closed at one end, which contain a charge of one or more of the very sensitive primary high explosives. They are designed to detonate from the flame provided by a safety fuse or other flame-producing device. Nonelectric blasting caps have a charge of sensitive high explosive in the base of the cap, with a priming load of extremely sensitive explosive in front of the base charge, and an ignition load superimposed upon the priming explosive. In functioning, the burning safety fuse ignites the ignition charge, which sets off the priming explosive, which, in turn, detonates the base charge.

The most common commercial nonelectric blasting caps are Number 6 and Number 8 with aluminum or copper shells. Number 6 caps are 3.4925 cm (1 3/8 in) long and Number 8 are 3.81 cm (1 1/2 in) long with outside diameters of approximately 0.635 cm (1/4 in). Some nonelectric caps may be larger. For example, the standard issue U.S. Army Corps of Engineers Special Number 8 blasting cap is 5.969 cm (2.35 in) long and 0.612 cm (0.241 in) in diameter. The larger size must accommodate the larger base charge required to detonate the less sensitive military explosives. Nonelectric blasting caps are packaged in a variety of containers, including metal cans, cardboard boxes, and wooden boxes.

The explosives normally employed in both electric and nonelectric blasting caps are the following:

- **Lead Azide.** Lead azide is an excellent initiating agent for high explosives and is used extensively as the intermediate charge in the manufacture of blasting caps. It is inferior to mercury fulminate in detonating the less sensitive main charge explosives like TNT, but is superior as an initiator for the more sensitive booster explosives such as tetryl, RDX, and PETN. Lead azide is extremely sensitive to heat, shock, friction, and static electricity. The form of lead azide normally used in blasting caps and fuse detonators is dextrinated lead azide. It is white to buff in color and is manufactured in the form of rounded aggregates having no visible crystal faces.

- **Lead Styphnate.** Lead styphnate is a relatively poor initiating explosive, and is used primarily as an ingredient of priming compositions and as a cover charge for lead azide to make the lead azide more sensitive to detonation. It is used as the ignition charge in blasting caps. Lead styphnate is light orange to reddish-brown in color and its crystals are rhombic in shape. This explosive is extremely sensitive to heat, shock, friction, and static electricity.

- **RDX or PETN.** These secondary explosives are typically used as the output charge in blasting caps. They are very powerful and have a high brisance value.

Detonating Cord. Detonating cord is a round flexible cord containing a center core of primary high explosive. The explosive core of the detonating cord is protected by a sheath of various textiles, waterproofing materials, or plastics.

The function of the protective sheath is to prevent or minimize damage to the explosive core from abrasion or moisture. Various colorings and textile patterns are used to identify different strengths and types of detonating cord.

While detonating cord has a general resemblance to safety fuse in that it has the same diameter and is supplied in rolls or coils, detonating cord is always distinguishable by its white powder core of PETN (pentaerythritol tetranitrate), an extremely powerful explosive. Pure PETN is white in color, but the addition of desensitizers may change its color slightly from pure white to light gray. PETN has no identifiable odor.

Detonating cord is frequently known by a brand name such as Primacord, Primex, Detacord, Detonating Fuse, or Cordeau Detonant. Most of the common detonating cords are of the high energy military type, which contains about 60 gr of PETN per foot. Detonating cords up to 400 gr per foot are manufactured for special purposes. There are other lower energy detonating cords designed for specific applications, especially for operations in developed areas where a diminished noise level is desired. For example, one low-energy cord, Detacord, has been developed with a core of only 18 gr of PETN per foot. Other low-energy cords include Mild Detonating Fuse and E-Cord, both with reduced core loading per foot.

Detonating cord is used to detonate charges of high explosives in the same manner as blasting caps and for the same purpose. The detonating cord with its primary high-explosive core may be tied around, threaded through, or knotted inside explosives to cause them to detonate.

Detonating cord is most commonly used when a simultaneous detonation of a number of explosive charges is planned and when it is not practical to use electrical circuits for this purpose. For example, to simultaneously detonate 10 dynamite charges placed 60.96 m (200 ft) apart in a straight line would require a minimum of about 548.64 m (1,800 ft) of electric firing wire and a considerable amount of time to prepare and test the electrical circuit. In contrast, a single line of detonating cord can be laid out from the firing point in a path that will pass near all of the dynamite charges. This long line is known as a trunk line. Shorter lengths of detonating cord, called down lines or branch lines, are attached to the charges and tied into the trunk lines.

When a blasting cap is attached to one end of the trunk line and detonated, the detonating wave produced is transmitted through the trunk line and all the down lines to detonate the dynamite charges simultaneously. The detonating wave travels at approximately 6,400 m (21,000 ft) or nearly 6.44 km (4 miles) per second.

Secondary High-Explosive Boosters

Secondary high-explosive boosters are explosives that provide the detonation link in the explosive train between the very sensitive primary high explosives (blasting caps) and the comparatively insensitive main charge high explosives, which are also called primer explosives or simply primers. The explosives packaged for use as boosters are relatively sensitive and must be handled carefully. Most, for example, will detonate on sharp impact such as that resulting from a small arms bullet. Due to this sensitivity, boosters are normally used in small amounts ranging from several grams up to a 0.5 kg (1 lb) in weight.

Boosters are usually cylindrical in shape with the explosive encased in a light metal, cardboard, or plastic container. Generally there is an opening in the end of the booster container to permit the insertion of a blasting cap or to allow the threading of detonating cord. Boosters packaged in metal containers are usually employed in wet blasting operations, such as seismic prospecting or underwater channel cuttings. Cardboard and plastic encased primers or boosters of varying sizes are generally used in dry blasting operations, where they are often strung or laced on a length of detonating cord and lowered into a borehole. After the placing of the booster, insensitive main charge explosives in prill (loose) or slurry (liquid-gel mix) form are poured into the borehole. When the charge is fired, the boosters ensure complete detonation of the main charge explosives.

Several secondary high explosives are commonly used as primers or boosters. These explosives are frequently mixed for booster use and, in some instances, are cast together in a homogeneous mixture or are formed with one type of explosive cast around or over the other. Common explosives used in boosters include:

- **Pentolite.** Pentolite is a very commonly employed booster explosive. It consists of a homogeneous mixture of 50 percent PETN and 50 percent TNT. Cast pentolite varies in color from gray to yellow and has a detonation velocity of 7,315 m/s (24,500 ft/s).

- **RDX.** Alone and mixed with other explosives, RDX is used in several commercial primers and boosters. The Titan Booster 25 is designed primarily for underwater work. It consists mainly of RDX in a 11.43 cm by 1.5875 cm (4 1/2 in by 5/8 in) aluminum tube with a cap well located at one end, giving the appearance of an oversized blasting cap.

- **PETN.** Described earlier as a filler for detonating cord, PETN is also used as a booster. It is most commonly used to boost ammonium nitrate and other cap insensitive explosives.

- **Tetryl.** Tetryl is the most common military booster. It is yellow in color, but may appear gray if graphite has been added. Tetryl is a very powerful explosive with a satisfactory initiating power which is also used in the manufacture of primary and secondary charges for blasting caps. When used as a booster, tetryl is usually found in pellet form.

Secondary High-Explosive Main Charges

Dynamite. Dynamite is the explosive most widely used for blasting operations throughout the world. In the past, dynamite has been relatively easy to obtain by theft or through legal purchase in the United States. While dynamites are generally used in earth-moving operations, they differ widely in their explosive content and, therefore, in their strength and sensitivity. Commercial dynamites are made of either liquid nitroglycerin, ammonium nitrate, or nitroglycol (EGDN), along with oxidizers and a binding material.

The percentage strength of commercial straight dynamite is the gauge by which the strength of all other commercial dynamite variations are measured. This measurement is based upon the percentage of nitroglycerin by weight present in its formula. This percentage value can be misleading, however, in determining actual blasting power. For example, a 60 percent dynamite is not necessarily three times as powerful as one marked 20 percent, because the nitroglycerin is not the only energy-producing ingredient present in the total composition.

Unless it is packaged loose in boxes or bags for specialized applications, dynamite will usually be found in cylindrical form, or sticks, wrapped in colored wax paper. These sticks or cartridges are obtainable in a variety of lengths and diameters. The most common sizes range from 2.8575 cm (1 1/8 in) to 3.81 cm (1 1/2 in) in diameter and are about 20.32 cm (8 in) long. In less common larger sizes, dynamite cartridges may be 10.16 cm to 15.24 cm (4 in x 6 in) in diameter and up to 96.52 cm (38 in) in length. Because of the wide variety of formulas, ingredients, and packaging, dynamite is not always easy to identify. Consequently, any packaging materials available should be retained as a means of determining the actual composition and strength of recovered dynamite.

In addition to its illegal use in bomb construction, dynamite also provides a source of liquid nitroglycerin for use in safe and vault burglary. Through a dangerous operation called milking, nitroglycerin is obtained by boiling, heating, or straining the dynamite through a fine fabric such as silk. The boiling process is also referred to as sweating, with the separated nitroglycerin being skimmed from the surface of the pot. In any event, the resulting nitroglycerin is almost always impure and highly unstable.

Although dynamite is available in an almost unlimited number of sizes, shapes, strengths, and packages, there are essentially only five basic types of dynamite in use today.

Straight Dynamites. The explosive base of straight dynamite is liquid nitroglycerin absorbed in a mixture of various carbonaceous materials, such as wood pulp or ground meal. Sodium nitrate is added primarily to supply oxygen for complete combustion of the carbonaceous materials, thereby increasing the strength of the explosive.

Straight dynamite, because of the nitroglycerin content, has a heavy, pungent, sweet odor, which is its most outstanding identification feature. Inhalation of straight dynamite fumes, even for short periods of time, will usually cause a persistent and severe headache.

When removed from its wrapper, straight dynamite is light tan to reddish-brown in color. While they vary in texture, the straight dynamites can be described as loose, slightly moist, oily mixtures, much like a mixture of sawdust, clay, and oil. Straight dynamites have been manufactured in percentage ratings of 10 percent to 60 percent, with the more common ratings being 30 percent, 40 percent, 50 percent, and 60 percent.

Straight dynamites are rarely used in general blasting work because of their high sensitivity to shock and friction and their high flammability. When detonated, they produce toxic fumes, which makes them unsuitable for use underground or in confined spaces. Because of their high nitroglycerin content, straight dynamites are the most hazardous of the dynamites to handle and store. Boxes or sticks of straight dynamite in storage must be periodically inverted to prevent the nitroglycerin content from settling to the bottom and leaking out of the stick. Public safety personnel should be extremely cautious of any dynamite that appears to be deteriorating or leaking any oily substance. In such cases, the material should be moved only by trained bomb technicians.

A form of straight dynamite that is widely used in commercial blasting operations is known as ditching dynamite. Ditching dynamite is manufactured in a 50 percent grade in sticks 3.175 cm by 20.32 cm (1 1/4 in by 8 in) for use in ditch blasting. The principal characteristic of ditching dynamite is its high detonation velocity of over 5,181.6 m/s (17,000 ft/s), which imparts a powerful shock wave and produces a large earth-shattering effect.

Ammonia Dynamites. In the manufacture of ammonia dynamites, a portion of the nitroglycerin content is replaced by ammonium nitrate and nitroglycol (EGDN). This produces a dynamite which is lower in cost and less sensitive to shock and friction than straight dynamite. Since it has a less shattering effect, ammonia dynamite is more suitable for pushing or heaving kinds of work such as quarry operations, stump or boulder blasting, and hard pan gravel or frozen earth blasting. Due to these characteristics, ammonia dynamites are probably the most widely used explosives of the dynamite family.

Ammonia dynamites are generally manufactured in percentage strengths, from 20 percent to 60 percent, with detonation velocities in the range of 2,133.6 m to 2,743.2 cm (7,000 ft/s to 9,000 ft/s). However, special purpose formulas producing velocities from 1,981 m/s to 3,718 m/s (6,500 ft/s to 12,200 ft/s) can be obtained.

When the wrapper is removed, ammonia dynamite will appear light tan to light brown in color and will have a pulpy, granular, slightly moist, oily texture. It has the same odor as straight dynamite because of its nitroglycerin content and may produce severe headaches after short periods of contact.

Gelatin Dynamites. Gelatin dynamites have a base of water resistant “gel” made by dissolving or colloiding nitrocellulose with nitroglycerin. The gel varies from a thick, viscous liquid to a tough, rubbery substance. Gelatin dynamite avoids two of the disadvantages of straight ammonia dynamite in that it is neither hydroscopic or desensitized by water. Since it is insoluble in water and tends to waterproof and bind other ingredients with which it is mixed, gelatin dynamite is well suited for all types of wet blasting work. Because of its density, it is also used extensively for blasting very hard, tough rock or ore.

Gelatin dynamites and semi-gelatin dynamites are manufactured in percentage strengths from 20 percent to 90 percent. It is an inherent property of gelatin dynamite to detonate at two velocities. Unconfined, it will usually detonate at about 2,133.6 m/s (7,000 ft/s), but when confined gelatin dynamites will detonate in the range of 3,962.4 m/s to 6,705.6 m/s (13,000 ft/s to 22,000 ft/s), depending upon the strength of the dynamite employed.

Ammonia-gelatin Dynamites. These dynamites retain most of the characteristics and qualities of gelatin dynamite, but derive a portion of their strength from the use of less costly ammonium nitrate. Ammonia-gelatin dynamites are manufactured in percentage strengths of 25 percent to 90 percent with detonating velocities ranging from about 3,962.4 m/s (13,000 ft/s) to 5,181.6 m/s (17,000 ft/s).

Military Dynamites. Military dynamite is not a true dynamite. It is manufactured with 75 percent RDX, 15 percent TNT, 5 percent SAE 10 motor oil, and 5 percent cornstarch. It is packaged in standard dynamite cartridges of colored wax paper and is marked either M1, M2, or M3 on the cartridge. This marking identifies a cartridge size difference only, since all military dynamite detonates at about 6,096 m/s (20,000 ft/s).

Military dynamite is used as a substitute for commercial dynamites in military construction, quarry work, and demolitions. It is equivalent in strength to 60 percent straight dynamite.

Since it contains no nitroglycerin, military dynamite is safer to store and transport than true dynamite, and is relatively insensitive to heat, shock, friction, or bullet impact. These qualities permit safer combat operations while providing the pushing or heaving action not available from standard combat demolition explosives. When removed from its wrapper, military dynamite is yellow-white to tan in color and is a granular substance which crumbles easily and is slightly oily. It does not have a noticeable characteristic odor, nor does it cause the headaches typical of the true dynamites.

Ammonium Nitrate. Ammonium nitrate is one of the least sensitive and most readily available main charge high explosives. It ranges in color from white to buff-brown or gray, depending upon its purity, and has a salty taste. Ammonium nitrate is usually found in the form of small compressed pellets called prills. While it is extensively used as a blasting agent and by the military as a cratering charge, it is also an ingredient in the manufacture of certain dynamites and is widely employed as a fertilizer.

Even a high-explosive grade of ammonium nitrate generally requires the use of a booster for detonation. For military cratering charges, TNT is used as the booster, while in commercial applications RDX-filled boosters or primers are usually employed. The normal detonation velocity of ammonium nitrate is approximately 3,352.8 m/s (11,000 ft/s). Due to its hygroscopicity and the fact that it loses power and sensitivity in direct proportion to its moisture content, explosive charges composed of ammonium nitrate are usually packaged in some form of waterproof container.

Its use as a commercial fertilizer makes ammonium nitrate readily accessible to anyone. While the grade of ammonium nitrate used as fertilizer is naturally inferior as an explosive charge, it can be sensitized by the addition of fuel oil. The mixture is referred to as "prills and oil" or ANFO (ammonium nitrate and fuel oil), and its use is fairly widespread because of its low cost and availability.

Ammonium nitrate should be handled with some degree of caution, because it is a strong oxidizing agent and has the ability to increase the combustibility of other flammable materials with which it comes in contact. If it is recovered as the result of a bombing incident, brass or bronze nonsparking tools should not be employed because they react with the ammonium nitrate to form tetramino nitrate, which is as sensitive an explosive as lead azide.

Blasting Agents

A blasting agent is an insensitive chemical composition or mixture, consisting largely of ammonium nitrate, which will detonate when initiated by high-explosive primers or boosters. Since they contain no nitroglycerin, blasting agents are relatively insensitive to shock, friction, and impact and are, therefore, safer to handle and transport.

One group of blasting agents are called nitro-carbo-nitrates (NCN). NCN is manufactured mainly of ammonium nitrate and oil, with special ingredients added to reduce static electricity and prevent hardening of the agent during storage. It is packaged in sealed waterproof cans, asphalt laminated paper, and flexible plastic bags which provide water resistance as long as the containers are not opened or damaged. Container sizes range from 10.16 cm to 27.94 cm (4 in to 11 in) in diameter, 40.64 cm to 60.96 cm (16 in to 24 in) in length, and weigh from 6.136 kg to 38.636 kg (13.5 lb to 85 lb). NCN is similar to 50 percent or 60 percent blasting gelatin in strength, but is much less sensitive. NCN cannot normally be detonated with a blasting cap or detonating cord alone, but requires a high-explosive booster.

Free-running explosives consisting of NCN, either with or without the addition of high explosives, make up another group of blasting agents. Because of their granular or small pellet form, the free-running agents can be poured around rigid explosive charges to fill all of the available space in the borehole. They are also useful for pouring into rough, irregular, or partially blocked holes, and some free running blasting agents can be submerged underwater for a period of time without loss of effectiveness. Sometimes an orange dye is added to the agent to facilitate visibility.

A final common group of blasting agents are called blasting slurries. These consist of NCN mixtures, with or without the addition of TNT, in a gel-like consistency. Some of the blasting slurries have powdered metals, such as aluminum, added to increase their performance. The blasting slurries, because of their consistency, can be poured into irregular or wet boreholes to fill all available space with explosive. Like all of the previously discussed blasting agents, the blasting slurries require a primer or booster for detonation.

Two-Part Explosives

Kine-Pak and Kine-Stick explosives are two-part explosives, consisting of ammonium nitrate and nitromethane, which are inert until mixed. When mixed and detonated with a Number 6 cap, Kine-Pak generates 50 percent more shock energy than 75 percent dynamite. Following mixture and prior to detonation, it is some 20 times less shock or impact sensitive than dynamite. The Kine-Pak and Kine-Stick explosives were developed as a direct replacement for dynamites and commercial PETN-RDX boosters, and are manufactured by the Atlas Powder Company.

Liquid Explosive - Astrolite. Astrolite is a liquid explosive developed for commercial and military applications. Although it is almost twice as powerful as TNT, Astrolite cannot be detonated until its two separate components are mixed.

Astrolite comes in two plastic bottles labeled Astropak. The smaller bottle contains a dry solid component (proprietary, but assumed to be ammonium nitrate), and the larger bottle contains a liquid-filled can (slightly aqueous hydrazine) in the bottom. To form the explosive, the contents of the small bottle are poured into the larger bottle and the top replaced. By pressing down on the bottle cap, cutters automatically puncture the liquid-filled can. By inverting and shaking the bottle, the two components are mixed and are ready for detonation with a standard blasting cap. The liquid can be detonated in its container or poured into crevices in the ground, cracks in rocks, or into other containers. Astrolite is clear in color and smells strongly of ammonia. Additional information on Astrolite may be obtained from the Explosives Corporation of America, Excca Building, Issaquah, WA 98027.

Military Explosives

Explosives made for military use differ from commercial explosives in several respects. Military explosives, designed to shatter and destroy, must have high rates of detonation and, because of combat conditions, must be relatively insensitive to impact, heat, shock, and friction. They must also possess high power per unit of weight, must be usable underwater, and must be of a convenient size, shape, and weight for troop use.

Trinitrotoluene (TNT). TNT is probably the most widely used military explosive in the world. Alone or in combination with other explosives, it is frequently used as a main charge in artillery projectiles, mortar rounds, and aerial bombs. As one of the moderately insensitive military explosives, TNT cannot be detonated by heat, shock, or friction and is, in fact, safe even when impacted by a bullet. It will usually burn rather than detonate if consumed by fire.

The TNT most often encountered by public safety personnel will probably be in the form of the 0.638 cm (1/4-lb), 1.27 cm (1/2-lb), and 0.4545 kg (1-lb) blocks. These blocks are normally packed in 22.727 kg (50-lb) wooden boxes for storage or transportation. When TNT is removed from the cardboard container, it is light yellow to light brown in color and gradually turns dark brown after several days' exposure to sunlight. Detonated TNT gives off a dirty gray smoke.

Tetrytol. Tetrytol is used as an alternative to TNT by the armed services and is composed of about 75 percent tetryl and 25 percent TNT. It is light tan to buff in color and has a detonation velocity of about 7,315.2 m/s (24,000 ft/s).

Tetrytol is manufactured for the military both as part of the M1 chain demolition package and as the M2 demolition block. When the present stocks are exhausted, no more tetrytol will be procured by the U.S. military services.

Composition C-3. Composition C-3 is a plastic explosive containing approximately 80 percent RDX and 20 percent explosive plasticizer. It is a yellow putty-like substance which has a distinct, heavy, sweet odor. When molded by hand in cold climates, C-3 is brittle and difficult to shape. In hot climates it is easy to mold, but tends to stick to the hands. C-3 will most likely be encountered by public safety personnel in the form of demolition blocks.

Composition C-4. Composition C-4 is an improved version of the C-3 explosive. It contains 90 percent RDX and has a greater shattering effect than the earlier C-3. C-4 is white to light tan in color, has no odor, and detonates at about 7,315.2 m/s (24,000 ft/s).

Sheet PETN (Flex-X). Sheet PETN, called Flex-X by the military and Detasheet commercially, is a demolition charge consisting of 63 percent PETN with nitrocellulose and plasticizer added. It comes in the form of sheets, with each sheet having a pressure-sensitive adhesive backing, making it possible to apply the sheet to almost any dry surface.

Commercially, sheet PETN is used for explosive forming, cutting, and metal hardening. The military sheet is supplied only in an olive green color, but commercial sheets may range from pink to brownish-red.

Improvised Explosives

When manufactured explosives are not available, it is relatively easy to obtain all of the ingredients necessary to improvise explosive materials. The list of existing materials and simple chemical compounds which can be employed to construct homemade bombs is virtually unlimited. The ingredients required can be obtained at local hardware or drug stores and are so commonplace that their purchase rarely arouses suspicion.

Starch, flour, sugar, or cellulose materials can be treated to become effective explosives. Powder from shotgun shells or small arms ammunition, match heads, firecracker powder, and ammonium nitrate fertilizers can all be accumulated in sufficient volume to create a devastating main charge explosive. To explode or detonate the improvised main charge, some means of initiation is required. The most common methods of ignition of improvised explosives are summarized below:

- **Blasting Caps.** Blasting caps, when available, provide the most successful means of causing the complete detonation of improvised explosives.

- **Percussion Primers.** Shotgun, rifle, or pistol ammunition primers have served as initiators in mechanically functioning bomb assemblies, particularly with explosives that are sensitive to heat.

- **Flashbulbs.** Although not explosive by nature, carefully prepared flash bulbs or light bulbs can be used as initiation devices when placed in contact with explosive materials that are sensitive to heat and flame. They can be functioned electrically to provide the necessary heat required to ignite black powder, smokeless powder, and other heat-sensitive explosive or incendiary mixtures.

Possible improvised main charge explosives are listed below:

- **Match Heads.** A main charge explosive consisting of ordinary match heads confined inside a steel pipe will produce an excellent explosion. Bombs filled with match heads are extremely sensitive to heat, shock, and friction, and must be handled with care.

- **Smokeless Powder.** Smokeless powder, obtained from assembled cartridges or purchased for hand reloading, is widely employed as a main charge, particularly in pipe bombs.

- **Ammonium Nitrate Fertilizer.** Fertilizer grade ammonium nitrate mixed with fuel oil or potassium nitrate and charcoal makes an excellent main charge explosive. A booster would be required for detonation.

- **Potassium/Sodium Chlorate.** Potassium chlorate or sodium chlorate and sugar mixtures are widely used as incendiary and explosive materials. Though essentially incendiary compounds, these mixtures will explode with a violence comparable to 40 percent dynamite when initiated in confinement.

Nitroglycerin

Although nitroglycerin is not often employed as a main charge either in its manufactured or improvised state, it is the main explosive component of straight dynamite and is found in lesser concentrations in a number of other explosives. Other applications include medical use, oil and gas well drilling, and the blowing open of safes and vaults by criminals. Liquid nitroglycerin may also be encountered as leakage from badly deteriorated dynamite.

Nitroglycerin is an oily liquid which is not mixable with and is about 1.6 times heavier than water. It may be anything from clear and colorless to amber in color and has been found looking almost milky. Brown fumes in a bottle of nitroglycerin are due to nitric acid and indicate decomposition and, thus, increased hazard. It is almost odorless, although there may be an acrid odor due to the presence of acid.

In a pure state, nitroglycerin is very sensitive to heat, shock, and friction. Sensitivity increases markedly by the application of heat. When frozen, nitroglycerin is less sensitive than when it is in a liquid state, but in a semifrozen state it becomes extremely sensitive due to the internal crystal stresses brought about by freezing or thawing action. Even under ideal conditions, nitroglycerin is an extremely dangerous explosive to handle and can explode from such causes as a slight jarring, overheating, or chemical reaction with container materials and impurities. In certain cases, it has been known to detonate for no apparent reason at all.

About the National Institute of Justice

The National Institute of Justice (NIJ), a component of the Office of Justice Programs, is the research agency of the U.S. Department of Justice. Created by the Omnibus Crime Control and Safe Streets Act of 1968, as amended, NIJ is authorized to support research, evaluation, and demonstration programs, development of technology, and both national and international information dissemination. Specific mandates of the Act direct NIJ to:

- Sponsor special projects, and research and development programs, that will improve and strengthen the criminal justice system and reduce or prevent crime.
- Conduct national demonstration projects that employ innovative or promising approaches for improving criminal justice.
- Develop new technologies to fight crime and improve criminal justice.
- Evaluate the effectiveness of criminal justice programs and identify programs that promise to be successful if continued or repeated.
- Recommend actions that can be taken by Federal, State, and local governments as well as by private organizations to improve criminal justice.
- Carry out research on criminal behavior.
- Develop new methods of crime prevention and reduction of crime and delinquency.

In recent years, NIJ has greatly expanded its initiatives, the result of the Violent Crime Control and Law Enforcement Act of 1994 (the Crime Act), partnerships with other Federal agencies and private foundations, advances in technology, and a new international focus. Some examples of these new initiatives:

- New research and evaluation are exploring key issues in community policing, violence against women, sentencing reforms, and specialized courts such as drug courts.
- Dual-use technologies are being developed to support national defense and local law enforcement needs.
- The causes, treatment, and prevention of violence against women and violence within the family are being investigated in cooperation with several agencies of the U.S. Department of Health and Human Services.
- NIJ's links with the international community are being strengthened through membership in the United Nations network of criminological institutes; participation in developing the U.N. Criminal Justice Information Network; initiation of UNOJUST (U.N. Online Justice Clearinghouse), which electronically links the institutes to the U.N. network; and establishment of an NIJ International Center.
- The NIJ-administered criminal justice information clearinghouse, the world's largest, has improved its online capability.
- The Institute's Drug Use Forecasting (DUF) program has been expanded and enhanced. Renamed ADAM (Arrestee Drug Abuse Monitoring), the program will increase the number of drug-testing sites, and its role as a "platform" for studying drug-related crime will grow.
- NIJ's new Crime Mapping Research Center will provide training in computer mapping technology, collect and archive geocoded crime data, and develop analytic software.
- The Institute's program of intramural research has been expanded and enhanced.

The Institute Director, who is appointed by the President and confirmed by the Senate, establishes the Institute's objectives, guided by the priorities of the Office of Justice Programs, the Department of Justice, and the needs of the criminal justice field. The Institute actively solicits the views of criminal justice professionals and researchers in the continuing search for answers that inform public policymaking in crime and justice.