Sandia National Laboratories

Survey of Commercially Available Explosives Detection Technologies and Equipment

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Some information included within this survey on commercially available explosives detection systems and technologies is derived from information received in response to a request for information placed in the *Commerce Business Daily* on August 5, 1997. Sandia National Laboratories does not warrant, guarantee, or endorse any of the products mentioned in this survey.

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Chapter 1. Introduction

Purpose of This Document

This document is intended to give a comprehensive overview of currently available explosives detection methods and technologies, in terms that are understandable to an intelligent layman who has no prior experience in this field. Funded by the National Institute of Justice (NIJ) and produced by Sandia National Laboratories (SNL) through the National Law Enforcement and Corrections Technology Center (NLECTC)–Rocky Mountain, this study is intended to inform law enforcement agencies about relevant aspects of explosives detection and to provide them with some basis for making procurement decisions. As a procurement guide, this document is not complete in and of itself, but it provides a useful foundation of information. Law enforcement agencies wishing to procure explosives detection equipment are encouraged to contact the authors of this document and the commercial contacts listed in the various chapters for additional consultation.

Facts Regarding 1995 Bombing Incidents That Occurred in the United States and Its Territories as Reported by the FBI Explosives Unit-Bomb Data Center

The FBI Laboratory Division's Explosives Unit and Bomb Data Center joined forces in October 1994. Some of their responsibilities include the following:

- Oversee the technical training of all public safety bomb disposal personnel at the Hazardous Devices School, Redstone Arsenal, Huntsville, Alabama.
- Provide explosives-related technical and operational support for special events.
- Conduct research and development for enhanced render safe procedures and technical equipment for bomb disposal personnel.
- Collect, collate, and distribute technical and statistical information about improvised explosive, incendiary, and hoax devices; render safe procedures; perform explosives research; and provide information about bomb technician equipment.
- Forensically examine bombing evidence to identify bomb components. Also, tests are conducted on new and unusual bomb components to check their validity.
- Provide training in bombing investigations and explosive device recognition. A post-blast investigators school is available to public safety personnel with investigative responsibilities in

bombing cases along with bomb technician seminars.

- Maintain a large computer reference library for identification and comparison purposes. This combines the text of FBI Laboratory reports with evidentiary photographs of bombing cases and allows the retrieval of information based upon any aspect of the forensic examination.

The importance of explosives detection can be appreciated by looking at statistics on recent bombings in the United States. The following information reported by the FBI Explosives Unit-Bomb Data Center (FBI EU-BDC) is a compilation of data from several government agencies, as well as more than 650 State and local bomb squads. The definitions provided are the basis for the statistics reported below.

Definitions

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

Explosive bombing. The illegal detonation of a device constructed with high- or low-explosive material.

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

Improvised device. A homemade device filled with an explosive or incendiary material and the components necessary to initiate the device.

Low-explosive fillers. These include black/smokeless powder, Pyrodex, match heads, pyrotechnics, fireworks, and improvised and chemical mixtures.

High-explosive fillers. These include dynamite, primers and boosters, ANFO (ammonium nitrate and fuel oil), TNT (trinitrotoluene), C-4, blasting caps and detonators, water gel, and binary/2-part explosives.

Statistics

There were 2,577 total bombings (includes explosive and incendiary, actual and attempted) reported to the FBI EU-BDC in 1995. This is an 18.5-percent decrease from 1994.

Total bombing incidents by region for 1995 numbered 206 in the East, 730 in the North Central region, 765 in the South, and 876 in the West. These geographical regions are defined by the FBI EU-BDC.

Further breakdown of the 2,577 total bombings shows 1,562 actual explosive bombings and 417 attempted explosive bombings. Likewise, actual incendiary bombings numbered 406 with 192 attempted incendiary bombings. These numbers reflect an 18-percent to 26-percent decrease compared to bombings in 1994, except for a 7-percent increase in attempted incendiary bombings.

Devices were successfully detonated or ignited in 76 percent of the bombing incidents. Explosive bombings accounted for 77 percent of the incidents, while incendiary bombings, or fire bombings, accounted for 23 percent of bombing incidents in 1995.

The use of improvised explosive devices declined 19 percent, from 1,916 in 1994 to 1,562 in 1995.

Pipe bombs accounted for 31 percent of all improvised explosive devices.

Low-explosive fillers were used in 87 percent of all improvised explosive devices with black/smokeless powder/Pyrodex accounting for 36 percent.

The most common known high-explosive fillers used in improvised explosive devices were blasting caps and detonators, which accounted for 2 percent of the total.

There were a total of 481 hoax devices in 1995, which is a 16-percent increase over 1994. Twenty-four percent of hoax devices were directed at commercial/retail targets.

Bombings were responsible for 193 deaths and 744 injuries in 1995. These numbers are significantly higher than those of 1994 because the bombing of the Murrah Federal Building in Oklahoma City killed 168 people and injured 518.

Bombings caused property damage in excess of $105 million in 1995, with $100 million of this destruction attributed to the Oklahoma City bombing.

Applications of Explosives Detection

If an agency seeks to acquire an explosives detection system, it is vital to first ask the question, “In what application or applications will this system be used?” The application must determine the system that is selected, and not vice versa. A number of applications of explosives detection are potentially of interest to law enforcement agencies, including the following:

(1) Routine screening of large numbers of personnel. This application occurs primarily at the entrances to buildings or facilities, when it is desired to screen all incoming persons to determine whether or not they have explosives in their possession. This could occur at courthouses, police stations, prisons, jails, schools, and other government facilities that are routinely entered by large numbers of people.

(2) Screening of large numbers of vehicles. This typically occurs at entry points or checkpoints such as police roadblocks with uniform screening of vehicles, vehicular entrances to secure facilities or facilities where a bomb threat is anticipated, and customs/border checkpoints. Note that the screening of vehicles includes, by definition, the screening of people and packages contained within those vehicles.

(3) Screening of large numbers of hand-carried items. This includes briefcases, backpacks, purses, suitcases, packages, etc. This application normally occurs in conjunction with application (1) above, and in most cases different detection systems are used to screen the people and their hand-carried items.

(4) Mail screening. This involves the screening of letters and packages arriving at a police station or some other government facility and typically involves large-volume screening.

(5) Screening of small numbers of selected people, vehicles, or items. This occurs in several specialized applications that can occur in law enforcement work. One example is the screening of a suspect after arrest or apprehension. Another is the investigation of a suspicious item (for example, an abandoned package found outside a building where a bomb threat has been communicated). In these cases, the volume of people/items to be screened is small, so that more time can be spent screening a single person or item than in applications (1) through (4).

(6) Bomb search. This typically involves the screening of a room, building, or some other limited area when there is a reason to believe a bomb may be present; for example, when a bomb threat has been communicated. This application clearly places a premium on being able to screen a relatively large area in a short period of time, since the area to be searched is potentially much larger than in the applications listed above.

(7) Forensic applications. This includes post-blast analysis at bombing sites, identification of explosives at crime scenes or other investigated sites, and identification of explosives on items seized as evidence. In many cases, the analysis is performed at a laboratory that is external to the investigating law enforcement agency. The analysis is performed by trained experts, rather than by the investigating police officers.

(8) Special situations or events. This includes any significant events which, by their nature, may require increased security measures with regard to explosives. Examples would include courthouses during major, highly publicized trials (e.g., the trial relating to the Oklahoma City bombing), visits by VIPs (e.g., the President, the Pope), and major international sports events (e.g., the Olympics).

(9) Protection of special infrastructure features. This includes structures such as bridges, dams, and utilities plants, especially during periods when there is reason to believe that there is an increased probability of terrorist attacks.

In many cases, a law enforcement agency may want to perform several of these explosives detection applications. In these cases, it must be determined which applications have the highest priority and to what degree the applications can utilize the same detection equipment.

Factors To Be Weighed in Determining the Best Detection System for a Given Application

Once the desired application of explosives detection has been identified, there are a number of factors that need to be weighed in determining what sort of detection system to acquire. These factors include, but are not necessarily limited to, the following:

(1) The explosives to be detected and the desired sensitivity levels. While it is obviously desirable to be able to detect any type of explosive, some types will be more commonly encountered than others. For example, mail bombs that have been sent in the United States usually use black powder, rather than the harder to obtain (and more difficult to detect) plastic explosives. Thus, if mail screening is the primary application, a detection system that works well for black powder and similar high-vapor-pressure explosives may be adequate, even if it does a poor job with plastics. It is almost always the case, particularly with trace explosives detection systems, that some types of explosives are more easily detected than others. The desired sensitivity level may also be important. There are many cases where two different detection systems can detect the same type(s) of explosive, but where the lower limit of detection for one system is significantly lower than that of the other system.

(2) System cost. In this time of limited budgets and hard financial choices, system cost is often a major factor in determining what sort of explosives detection system to purchase. Depending on the type of system and the degree of sophistication that is desired, commercial detection systems can range from approximately $20,000 to greater than $1 million in cost. It is often necessary to choose between the purchase of one very sophisticated system and the purchase of several cheaper and less sophisticated ones. Maintenance costs must be factored in when determining total system cost. Several maintenance plans are available from the various detection systems manufacturers, ranging from a per call to a scheduled preventative maintenance option. Maintenance costs can vary depending upon the complexity of the system, number of systems at a particular location, and the specific plan chosen. These costs can be as high as 10 percent of the original system cost on a yearly basis. Cost normally has a bearing on some of the other parameters listed in this section, such as system sensitivity and ease of use.

(3) Health/public safety issues. If the application will involve screening people for explosives, then the potential health effects of the screening process need to be taken into account. Even if it is demonstrable that there is no real hazard to human health, the public perception that there is a problem may present a significant barrier to the use of a technology. The prototypical example is the use of personnel screening systems that use low-dose x-ray technology to detect bombs and other contraband items. While the x-ray dosages involved are trivial and one such system has been approved for sale in the United States by the Food and Drug Administration, the general public dread of x-rays has thus far limited the use of such systems. In the United States, these systems have been restricted primarily to use in correctional facilities, where the inmates or persons visiting inmates are screened. In these applications, there is essentially a captive audience that has little choice but to submit to the screening process. For wider applications, extensive education of the public may be necessary before the technology can be applied.

(4) Privacy issues. The privacy of an individual whose person or possessions are being screened may also be an issue. Screening people with low-dose x-ray scanners is again a good example, since the x-ray image produced can show a rather revealing image of the person’s body. Once again, the reactions of the people to be screened may need to be considered before a system is purchased. This can become a constitutional/legal issue.

(5) Ease of use. Explosives detection systems vary dramatically in their complexity and ease of use, from highly technical laboratory systems that will be used primarily by experts in performing forensic analysis to field portable units that could be used by any police officer with a few hours of training. For most commercially available systems, the company that sells the system will provide some training when the unit is purchased. In the case of canine detection, an individual known as a handler works exclusively with the canine, and that person and the dog train together on a regular basis.

(6) Portability. Some explosives detection systems, such as canines and the smaller commercial trace detection systems, are easily portable, while others, such as portals and most x-ray baggage screeners, are large and are intended primarily for dedicated, repetitive use at a single location. Clearly, this is an important consideration relating to the application desired.

(7) System speed (throughput rate). In high-volume applications such as (1) through (4) in the preceding section, the speed with which the system can process the items being screened can be of great importance. This is often referred to as the throughput rate and expressed in units such as persons per minute, packages per hour, etc. In many high-volume applications, the need for a high throughput rate can be mitigated or eliminated by going from uniform to random screening, i.e., by screening a randomly selected fraction of all personnel entering a facility rather than all of the persons entering the facility.

There are often tradeoffs among these different system parameters. In general, system sensitivity increases with increasing cost. Increased portability often means lower cost but reduced sensitivity compared to a larger, dedicated system. The ways in which these various factors are weighed against one another to select a specific system for purchase are necessarily arbitrary. Most often, a single overriding factor such as cost or throughput rate sets some initial bounds that severely limit the choices available. Nevertheless, it is highly desirable to think about all of the issues listed in this section before a system is purchased.

Threat Probability Versus Threat Consequence

The applications listed earlier in this chapter are rather self-evidently related to specific threats. For example, the routine screening of large numbers of people entering a building is aimed at the specific threat of someone trying to carry a bomb into that building, and mail screening is aimed at detecting mail bombs before they detonate (an exception is forensic applications, which normally occur after an explosion has occurred or relate to the trace analysis of a nonthreat item). In choosing an explosives detection application, one must keep in mind the threat that one is seeking to prevent. There are really two different aspects of the threat that are important, and though neither can be measured precisely, both must be considered. These are the threat probability and the threat consequence. The threat probability is simply the likelihood (or perceived likelihood) that a particular threat will actually take place. The threat consequence is the damage that the event would be expected to cause if it did occur, including loss of life, injuries, and damage to property. It is important to consider both of these aspects, because they are largely independent of one another. For example, an incident such as the Oklahoma City bombing is quite unlikely to occur within a given jurisdiction, but the consequences of such a bombing are obviously very high if and when the bombing occurs. On the other hand, the chances of a single person within that jurisdiction receiving a mail bomb are substantially higher, but the potential consequences of such an incident, though serious, are much less severe. In choosing what explosives detection applications are of primary importance, one of the significant considerations involves the relative importance of the perceived threat probability and the likely threat consequence. There is some arbitrariness involved in this consideration, but it is crucial in deciding what threat(s) to protect against.

The Remainder of This Document

Each of the subsequent chapters contained in this document provides an overview of a given technique of explosives detection, or of a set of related techniques. The emphasis is on providing nonexpert readers with information on what is currently commercially available. Appendix I consists of basic information on explosions and explosives. Appendix II is a procedural outline on the manual search of vehicles. A glossary of commonly used terms relating to explosives and explosives detection, which may not be familiar to the nonexpert reader, is found in appendix III. Finally, appendix IV lists several references and resources for further reading and more detailed information about explosives and explosives detection technologies and equipment.

Chapter 2. Explosives Trace Detection Equipment and Technologies

The technologies and equipment presented in this section represent the state-of-the-art, commercially available explosives trace detection equipment. The term trace refers to both vapor and particulate sampling of the explosives. The distinction made here is that trace detection equipment is passive in that it only detects the vapors or microscopic particles emitted from the explosives compared to an active interrogator, or bulk detecting system, which uses a source of radiation (x-rays, gamma rays, radio frequencies, or magnetic field) to stimulate a response from explosives. In addition, a discussion of personnel portals, some of which are still in the prototype and testing stage of development, is included.

Prior to acquiring an appreciation for the capabilities of some of the present-day explosives detection systems, some understanding of the detection problem is needed. The principal problem in the detection of explosive vapors is the very low vapor pressures of some of the explosives of interest, which directly relate to the amount of explosive available in the air to collect as a vapor sample. The compound EGDN (ethylene glycol dinitrate), the most vaporous compound in nitrated dynamite, has a vapor pressure of 64 parts per million (1 PPM is 1 part in 10^6 parts of air). TNT has a vapor pressure of 6 parts per billion (6 parts in 10^9 parts of air). PETN (pentaerythritol tetranitrate) and RDX (cyclonite) are the explosive components found in Detasheet® and C-4, respectively, and have a vapor pressure of 6 parts per trillion (6 parts in 10^{12} parts of air), which is analogous to 6 seconds in 32,000 years. These vapor pressure numbers are for saturated head space vapor. In other words, if the explosive were confined in an airtight container at room temperature and allowed to equilibrate, thereby coating all available surfaces (the required times for the various explosives to reach this equilibrium state will vary), the resulting undisturbed vapor pressures are the numbers reported above. In real-world situations, with uncontrolled air currents, temperature fluctuations, etc., the actual vapor pressure can be orders of magnitude less. This property combines with others such as high electronegativity, thermal instability, and a high affinity for adsorbents (stickiness), to present a real challenge in the successful detection of these molecules.

Detection Technologies

Electron-Capture Detector (ECD)

The electron-capture detector (ECD) is an ionization chamber in which electrons are produced from a radioactive cathode, usually tritium or nickel-63. These electrons are injected into a stream of inert carrier gas (helium or argon), where they lose their energy by inelastic collisions with the carrier gas molecules and become thermalized. These thermal electrons are collected by an anode that produces a constant (standing) current. When an electron-capturing compound (such as an explosive) is introduced into the carrier gas, the standing current is reduced. ECDs have a fast response, a sensitivity of about 1 ppb for most electron-capturing compounds, and are comparatively low in cost. However, the ECD is not compound specific, i.e., it cannot tell with certainty what type of electron capturing compound is present. There are also some common nonexplosive substances that give rise to ECD signals, such as atmospheric oxygen, many substituted hydrocarbons such as Freon™, fertilizers, and some household cleaners.

In order to make the electron-capture detector more specific, some explosive detectors combine gas chromatography with ECD. In gas chromatography, components of volatile compounds are separated in a column containing a stationary phase, through which a stream of inert gas passes continuously. As the different compounds interact differently with the stationary phase, they emerge from the column at different retention times. The detection system looks at these retention times in conjunction with the ECD output and makes a determination of whether an explosive is present or not. The cost for an ECD-based explosives detection system is approximately $20,000.

Chemiluminescence

The chemiluminescence principle is based on the detection of infrared light emitted from electronically excited NO_2^*. The electronically excited NO_2^* results from the reaction of nitric oxide (NO) with ozone (O_3). Most explosives contain NO_2 groups that can be pyrolized to produce nitric acid. In a chemiluminescence detector, the ozone reaction generally takes place in an evacuated reaction chamber maintained at a pressure of about 3 torr. A photomultiplier situated behind a red light filter is used to detect the infrared light emitted from the NO_2^*. The red filter is in place to block any light with spectral frequency higher than the near infrared. The signal output from the photomultiplier is directly proportional to the amount of NO present in the reaction chamber. It is this signal that is used to detect the presence of explosives in a chemiluminescence system.
The chemiluminescence detector alone is not explosive type specific. Therefore, another technology, such as gas chromatography, needs to be used before the detector to selectively

separate the explosive compounds for proper identification. Technical advances in high-speed gas chromatography make it possible to do the required separation of the explosive compounds and subsequent detection in less than 18 seconds.

Chemiluminescence technology is typically higher in cost than other explosives detection technologies (around $150,000), but has excellent sensitivity and selectivity when combined with high-speed gas chromatography. A wide range of explosives are detectable, including EGDN, NG (nitroglycerin), ANFO, TNT, DNT (dinitrotoluene), RDX, and PETN. No radioactive source is required for detector operation, and this may reduce both time and paperwork when transporting the system.

Ion Mobility Spectrometry (IMS)

Ion mobility spectrometry (IMS) was created between 1965 and 1970 from studies on ion-molecule chemistry at atmospheric or elevated pressure with mass spectrometers and from ionization detectors for airborne vapor monitoring. A conventional ion mobility spectrometer consists of two main areas: the reaction region and the drift region. In the reaction region, atmospheric pressure carrier gas (clean, dry air) is ionized by collision of beta particles from a weak nickel-63 source with nitrogen and oxygen. These reactant ions then undergo ion/molecule reactions with the explosive molecule. The explosive molecules also undergo other ion forming reactions such as adduct formation and dissociation reactions.

Under the influence of an electric field, the mixture of reactant and product ions reaches a shutter grid that separates the reaction region and the drift region. The shutter grid is made up of sets of thin mesh wires with a bias voltage between them. With the bias voltage applied, the ions are attracted to the gating grid and lose their charge. Then the grid bias is briefly turned off, and ions are transmitted into the drift region of the cell. The ions are then focused and accelerated by an electric field (typically 1,000 to 3,000 volts) along the drift region (typically 8 centimeters) to arrive at the collector electrode (typically in a time of 10 to 20 milliseconds). The smaller, compact ions have a higher mobility than the heavier ions, and therefore traverse the region and collide with the collector plate in a shorter time. The collector current is then amplified; its magnitude, as a function of time, is proportional to the number of ions arriving at that moment.

In an IMS explosives detection system, times required for ions of specific explosives to drift down the IMS tube are precisely known and are programmed into the system’s microprocessor. The microprocessor monitors the collector electrode signal at the programmed drift times to detect the presence of explosive molecule ions. Typical analysis cycles require 5 to 8 seconds from introduction of sample to alarm notification. Some systems combine IMS with a front-end gas chromatography (GC) in order to optimize selectivity.

Ion mobility spectrometry detection systems tend to be mid-range in price ($40,000 to $60,000), costing more than the ECD-based detectors but less than the chemiluminescence detectors. Limits of detection for most explosives are in the sub-nanogram range with few interferents known to give false alarms. IMS technology can also be applied to drug detection and the chemical/ biological warfare (C/B) arena. Several manufacturers presently offer drug detection as a standard or optional feature on their IMS detectors. Be aware that in many cases the unit must be powered down momentarily to switch between the drug and explosives detection modes. Future trends in IMS technology are to continue miniaturization of detection instruments and incorporate a nonradioactive ionization source.

Gas Chromatography/Surface Acoustic Wave (GC/SAW)

Another type of technology used for explosives detection utilizes a portable gas chromatograph (GC) equipped with a surface acoustic wave (SAW) detector. In a SAW-based GC system, the SAW resonator crystal is exposed to the exit gas of a GC capillary column by a carefully positioned and temperature-controlled nozzle. When condensable vapors entrained in the GC carrier gas impinge upon the active area between the resonator electrodes, a frequency shift occurs in proportion to the mass of the material condensing on the crystal surface. The frequency shift is dependent upon the properties (mass and the elastic constants) of the material being deposited, the temperature of the SAW crystal, and the chemical nature of the crystal surface.

A thermoelectric cooler maintains the SAW surface at sufficiently low temperatures to ensure a good trapping efficiency for explosive vapors. This cooler can be reversed to heat the crystal in order to clean the active surface (boil off adsorbed vapors). The temperature of the SAW crystal acts as a control over sensor specificity based upon the vapor pressure of the species being trapped. This feature is useful in distinguishing between relatively volatile materials and sticky explosive materials.

During a sampling sequence, vapor samples are drawn through the GC inlet from a preconcentrator and then pumped through a cryo-trap. The cryo-trap is a metal capillary tube held at a temperature low enough to trap explosive vapors, while allowing more volatile vapors to pass through. After passing through a second cryo-trap the sample is injected into the GC column and separated in time by normal column operation for species identification. As the constituent vapors exit the column, they are collected and selectively trapped on the surface of the SAW crystal, where the frequency shift can be correlated to the material concentration.

Total analysis time, including preconcentration of the vapors, is typically 10 to 15 seconds. Sensitivity to picogram levels of explosives has been shown by the manufacturer of the only commercially available system. The system is portable, about the size of a large briefcase. Cost is similar to an ECD system, and the system is operational within 10 minutes of setup.

Thermo-Redox

The detection principle of thermo-redox technology is based on the thermal decomposition of the explosive molecules and the subsequent reduction of the NO_2 groups. Air containing the explosive sample is drawn into the system through an inlet at a flow of approximately 1.5 liters per minute. The air is then passed through a sample concentrator tube, which selectively adsorbs explosive vapor molecules using a proprietary coating on the tube’s coils. The introduced sample is then pyrolyzed to release the NO_2 group, which is then transferred to a membrane separator/sensor assembly. The membrane separator provides additional discrimination against potential chemical interferences. Then the gases are passed across the sensing surface of the detector and a small signal is generated.

Signals from the detector are collected, amplified, and delivered to the microprocessor, which determines the strength and time at which positive signals are obtained. The verification of explosive vapors is accomplished by comparing the strength of the signal from the detector with the time from the start of the analysis cycle. If both the signal strength and time requirements are met, a positive detection alarm results.

This detection system requires neither special carrier gases nor a radioactive source and is available in a relatively low cost ($23,000), handheld package. This technology lacks the ability to distinguish between specific types of explosives. In other words, an alarm could signal the detection of any of the detectable explosives, such as NG, TNT, many of the taggants, RDX, or PETN. Furthermore, thermo-redox cannot detect RDX and PETN by vapor sampling because of the very low vapor pressures of these compounds.

Field Ion Spectrometry (FIS)

Field ion spectrometry (FIS) is a new technology (less than 5 years old) that has been developed for trace detection of narcotics, explosives, and chemical warfare agents. This new technology incorporates a unique ion filter using dual transverse fields, which allows interferences to be electronically eliminated without the use of GC columns, membranes, or other physical separation methods.

FIS is related to ion mobility spectrometry in that it is a technique for separating and quantifying ions while they are carried in a gas at atmospheric pressure. In addition, both methods utilize soft ionization methods that yield spectra, in which the species of interest produce the main features.

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 plates. In response to the asymmetric field, the ions tend to migrate toward 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 species 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.

In actual operation, the air sample to be analyzed is drawn directly into the sensor's ionizing cavity. Once ionized, analyte ions are electrically separated from the bulk sample and a steady flow of clean, dry air carries the ions through the spectrometer. All ions except those of interest are dispersed to the sensor's walls, permitting only a selected group to reach the detector. The ionogram recorded by sweeping the compensation voltage is similar to the output of a gas chromatograph or an ion mobility spectrometer.

The sensor has no moving parts except for a small recirculation fan and no consumables except for the replaceable calibrator and gas purification filters. The size of the instrument is 0.8 cubic feet, excluding a computer for control and display. The sole manufacturer of the FIS has reported limits of detection in the low picograms for common explosives such as RDX, PETN, and TNT. In addition, a response time of 2 seconds for a single component and approximately 5 seconds for each additional component is advertised. To date, there are no independent test data available for the FIS. The instrument's estimated selling price is $20,000 for a single component analyzer, plus an additional $1,000 per extra component.

Mass Spectrometry (MS)

Mass spectrometry (MS) is mentioned here as a trace detection technique because it has been shown to be a very powerful analytical laboratory tool for explosives detection, even though it is not commercially available specifically for that use. In particular, its strength is low to sub-picogram detection limits with unusually high specificity. Oak Ridge National Laboratory has done considerable research and development with tandem mass spectrometry and with interfacing the most efficient ionization source to a mass spectrometer system for explosives vapor detection. However, most of the MS work has been geared toward laboratory type analyses and operations, and thus the system is quite complex and not field deployable.

More recently, several companies have advertised portable systems based on mass spectrometry, such as GC/MS, which can provide analysis in the lab or on the road. These systems can provide extensive analysis of air, gas, soil, solid, liquid, and water samples. However, these instruments are quite complex and relatively expensive, and they are not designed specifically for explosives detection. Furthermore, typical analysis cycle times are several minutes, as opposed to seconds, as with some of the other trace detection systems.

Sampling Techniques for Explosives Trace Detection Equipment

The explosives trace detection systems using the previously described detector technologies all require or utilize similar techniques in sampling. Trace detection sample acquisition can be accomplished either by vapor sampling or by swiping a surface to collect a particulate sample.

Most commercially available explosives detectors use a portable “dustbuster” type air vacuum for vapor sampling. Depending on the brand of instrument, the sampling filter that is placed in the vacuum may be either Teflon®, fiberglass, specially treated paper, or some kind of special fabric. No matter what material is used, the general idea is to pull air through the sampling medium, trapping the explosive molecules on the filter. Then the sampling medium is removed from the vacuum and placed in the detector for thermal desorption and subsequent analysis. Considerable research has been invested in determining the optimal airflows and the ideal filter material for the various commercially available explosives detection systems.

The second method of sampling afforded by most of the explosives detection systems is particulate or swipe sampling. Given the fact that a single particle can contain a microgram or more of explosive material, swiping the suspect surface can yield a much larger sample than vacuuming for a vapor sample. This is why all the manufacturers recommend swipe sampling if at all possible. The typical procedure is to wipe the suspect surface with the supplied swipes using a glove to prevent contamination of equipment and other sampling media. Then the swipe is placed in the detector and heated to evolve the trapped explosives molecules. The materials used for these swipes are typically paper or cloth. One manufacturer uses a reusable metal screen for surface swiping. Most other systems recommend that once a detection has been made, the swipes should not be reused, but disposed of properly. Since the price of these swipes can range from $0.01 to $1 per swipe, depending on the manufacturer, cost may be a factor in determining the right system for a given application.

In closing, we cannot overemphasize that you should consult with the manufacturer of the explosives detection system. They all have specific sampling guidelines for specific applications. Several have well-written procedures for using the acquired samples, if necessary, for evidence in a court of law.

Trace Detection Personnel Portals

Several contraband explosives detection personnel portals are either in the prototype/testing stage or are commercially available at this time. All of these systems incorporate detectors that have been previously described, namely ion mobility spectrometry, electron capture detection, and fast gas chromatography/chemiluminescence. A brief description of each portal system follows.

Model 85 Entry Scan Portal

The Model 85 Entry Scan Mark II portal, manufactured by Ion Track Instruments (ITI), has been used by the Nuclear Regulatory Commission (NRC) for personnel screening in several of their facilities for the past 10 years. During operation, a large sample airflow is blown horizontally across the person or object being screened. The air drawn in on the intake side of the archway then passes through a perforated wheel trap where the explosive vapors are deposited. Two heaters then heat the wheel to desorb the explosive, which is carried to an electron capture detector (containing a 10 mCi Ni-63 source) by a flow of argon. As the wheel trap continues to rotate, it is cooled by a small fan, which completes the sampling cycle. The detection of an explosive is indicated by a digital meter reading and by an audible signal and red indicator light.

The ITI Model 85 has three modes of operation for explosives detection. The first is the high sensitivity mode requiring 12 seconds for a complete sample and analysis cycle. This is the most sensitive mode and is advertised to have a good sensitivity to TNT and EGDN. The second mode of operation is the fast mode, which has a 6-second cycle period that reduces the detection capability for low-vapor-pressure explosives substantially. Finally, the walk-through mode accomplishes screening without requiring the subject to remain under the archway. Some problems in alarm resolution have been encountered in this mode since the alarm does not sound until 5 seconds after the subject has exited the portal.

This system is the oldest of the commercially available portal systems. The ITI Model 85 has good sensitivity to dynamite and several of the proposed taggants. This system, however, was not designed to detect the low vapor pressure compounds such as RDX- and PETN-based explosives. The system requires pure argon for operation and costs approximately $50,000.

SecurScan™ Portal

The SecurScan™ is a walk-through trace explosives detection system developed by Thermedics Detection, Inc. The SecurScan™ collects a sample as an individual walks through an array of wands fitted into the archway. The wands brush against the subject’s body, vacuuming his or her clothing and removing any explosive vapor or particulate traces that may be present. After the sample has been collected, it is concentrated by filtering it from the high volume of air from the wands. The concentrated sample is then desorbed into the chemistry module where it is trapped for injection into the fast GC system and detected by chemiluminescence.

The SecurScan™ system can process people at the rate of 10 per minute. Several sensors have been engineered into the system to fully automate operation, including a CCD (charge coupled device) camera to help resolve alarms. To date, the SecurScan™ has undergone extensive laboratory evaluations and some airport testing. For further information on the test results, system availability, and pricing contact Thermedics Detection directly.

Federal Aviation Administration/Sandia National Laboratories Portal

A walk-through portal for the trace detection of contraband explosives is in its final stages of testing at Sandia National Laboratories. The portal is designed to screen personnel without any direct physical contact, and in this respect is similar to the metal detectors that are already widely used in airports and accepted by the general public. The airflow sampling utilized is capable of collecting explosives material in both vapor and particulate form, the latter being potentially present on the exterior of a person’s clothing in the form of contamination.

Once a subject has entered the portal, air is blown down from the top of the portal and along the subject’s body for 5 seconds and is collected at two slots at the base of the portal. At the same time, brief puffs of air are used to slightly ruffle the subject's clothing to aid in dislodging particulate, which may contain explosive molecules. The air then flows into a preconcentrator, which is essentially a molecular filter, allowing air to pass through to be exhausted while collecting heavy organic molecules such as explosives onto a screen. The screen is then heated to desorb the collected explosive molecules back into the gas phase, and the resulting explosives-enriched air is then pulsed into an IMS for detection. Two identical preconcentration/IMS detection systems, one in front and one in back, are used to sample the front and back side of the subject.

The Sandia portal is fully automated and has undergone extensive laboratory testing to fine tune its responses to some of the lower vapor pressure explosives. The system is currently scheduled for airport testing in September 1997. No information on system availability or cost can be given at present. Please contact Sandia National Laboratories, Department 5848, for more information.

ORION Walk-Through

CPAD Technologies, Inc., a Canadian company specializing in chemical detection systems, has developed the ORION Walk-Through explosives detection portal. The portal system consists of a stand-alone portable detector system based on gas chromatography/ion mobility spectrometry and a detachable personnel booth.

A gentle stream of air passes from toe to head as a person walks through the open booth. The system can be discretely incorporated into existing architecture or openly displayed as a deterrent. The GC/IMS detector plugs into the sampling booth when needed for personnel portal screening, or it can stand alone for other explosives trace detection applications. CPAD reports that the ORION detection system can detect EGDN, NG, AN (ammonium nitrate), TNT, RDX, and PETN in the picogram to nanogram range. (Also, as an option the system can detect the International Civil Aviation Organization [ICAO] taggants, i.e. DMNB [dimethylnitrobenzene], OMNT [ortho-mononitrotoluene], and PMNT [para-mononitrotoluene]). Typical analysis time for all detectable compounds is 10 seconds. Note that the sensitivity and explosives detected are for the basic detector system, the ORION, not the ORION Walk-Through. The portal detection limits may well be different than those quoted for the ORION detector only. Contact CPAD Technologies for more information on availability, system owners, and cost.

Table 1. Explosives Trace Detection Systems

System	Technology	Use	Company
IONSCAN® Model 400 Model 350	Ion Mobility Spectrometry (IMS)	Personnel, package, and vehicle search	Barringer Instruments, Inc. 908–665–8200
ITMS Vapor Tracer ITEMISER	Ion Trap Mobility Spectrometry	Personnel, package, and vehicle search	Ion Track Instruments, Inc. 978–658–3767
Model 97 Exfinder 152	Gas Chromatography/ Electron Capture	Personnel, package, and vehicle search	Ion Track Instruments, Inc. 978–658–3767
Model 85 Entry Scan Model 85 Dual Scan	Gas Chromatography/ Electron Capture	Personnel screening	Ion Track Instruments, Inc. 978–658–3767
EVD-3000	Thermo-Redox	Personnel, package, and vehicle search	Scintrex, Ltd. 905–669–2280
EVD-8000	Multi-column Gas Chromatography/ ECD	Personnel, package, and vehicle search	Scintrex, Ltd. 905–669–2280
EGIS® Model 3000	Gas Chromatography/ Chemiluminescence	Personnel, package, and vehicle search	Thermedics Detection, Inc. 978–251–2030
RAMPART	Gas Chromatography/ Chemiluminescence	Carry-on luggage, package and cargo search	Thermedics Detection, Inc. 978–251–2030
XID Model T-54	Chemical Adsorption/ GC/ Electron Capture	Personnel, package, and vehicle search	XID Corporation 973–773–9400
EST Model 4100	Gas Chromatography/ SAW	Personnel, package, and vehicle search	Electronic Sensor Technology, Inc. 805–480–1994
ORION ORION Plus	GC/IMS	Personnel, package, and vehicle search	IDS Intelligent Detection Systems, Inc. (formerly CPAD Technologies, Inc.) 613–230–0609

System	Technology	Use	Company
ORION Walk-Through	GC/IMS	Personnel portal	IDS Intelligent Detection Systems, Inc. (formerly CPAD Technologies, Inc.) 613–230–0609
ORION Mail Scanner	GC/IMS	Mail screening	IDS Intelligent Detection Systems, Inc. (formerly CPAD Technologies, Inc.) 613–230–0609
SIRIUS	GC/IMS	Simultaneous detection of narcotics and explosives	IDS Intelligent Detection Systems, Inc. (formerly CPAD Technologies, Inc.) 613–230–0609
V-bEDS	GC/IMS	Vehicle screening portal	IDS Intelligent Detection Systems, Inc. (formerly CPAD Technologies, Inc.) 613–230–0609
Graseby PLASTEC™	Ion Mobility Spectrometry	Personnel, package, and vehicle search	JGW International Ltd. 703–352–3400
Graseby GVD6™	Ion Mobility Spectrometry	Personnel, package, and vehicle search	JGW International Ltd. 703–352–3400
Graseby GVD4™	GC/ECD	Personnel, package, and vehicle search	JGW International Ltd. 703–352–3400
SpectraTrak™	Gas Chromatography/ Mass Spec	Portable analytical lab instrument	VIKING Instruments, Inc. 703–968–0101
FIS®	Field Ion Spectrometry	Personnel, package, and vehicle search	MSA Instrument Division 800–672–4678
PCP 100 PCP 110	Ion Mobility Spectrometry	Laboratory use, custom applications	PCP, Inc. 561–683–0507

Since the development of explosives trace detection systems is moving so rapidly, manufacturers should be contacted about the latest product specifications and pricing early in any decision-making process.

Several of the trace detection systems mentioned in this report have been evaluated at Sandia National Laboratories to determine various operational and performance capabilities through funding by the Department of Energy (DOE). Results of these tests are beyond the scope of this report but are available upon request. Please contact the authors of this report for more information.

Chapter 3. Canine Explosives Detection

History of Canine Detection and Organizations Using Canines

Trained dogs are an effective and time-proven tool for the detection of concealed explosives. Such dogs are used by a variety of State and Federal agencies, including the United States Secret Service, the Federal Aviation Administration, the Bureau of Alcohol, Tobacco and Firearms, and various law enforcement organizations. Probably the widest use of explosives-detecting canines has been in the military, where dogs have been used in other capacities since the World War I/ World War II era. Up through the period of the Vietnam War, dogs were used principally for sentry and patrol duties, but in more recent conflicts such as the Persian Gulf War (Operation Desert Storm) and Bosnia, explosives detection has been a key canine function. The remainder of this section will focus primarily upon the canine program in the Department of Defense (DoD). Most military bases/posts in the United States currently have their own canine training programs, typically involving several personnel and 6 to10 dogs. In all, DoD currently has about 1,300 operational dogs worldwide, with more than 500 of these being capable of explosives detection.

Substances Detected

The question, "What does a trained canine detect?" has been answered by one military expert this way: "WHATEVER the canine is trained to detect." Indeed, dogs can be trained to detect a wide variety of substances, including (but not limited to) explosives. At least in principle, there are no explosives that dogs cannot be trained to detect. As with an ion mobility spectrometer or most other types of technology-based trace detection equipment, there is some tradeoff between the number of compounds detected and the efficiency of detecting any one compound. As a general rule, sniffing dogs are trained to detect either explosives or narcotics, but not both classes of compounds. The dogs currently used in DoD are trained to detect a total of nine different types of explosive materials. Each dog is unique in that no two have precisely the same sensitivities to all nine materials, but each dog is required to reach some minimal level of proficiency with all of them.

Canine Training

The training of explosives-detecting canines is a complex process involving the dog, its handler, a trainer, and other individuals who observe testing and grant certification. DoD dogs undergo an initial certification process, an annual postcertification process, semiannual or annual validation testing, and regular monthly training. In all tests, each dog is required to maintain at least a 95-percent detection rate for the targets used. In addition, the canine cannot have a nonproductive response rate in excess of 5 percent. The initial certification involves 27 different targets or "training aids," which can be hidden up to 8 feet above ground level, or buried up to 3 feet below the ground. Certification/validation search times are typically 15 to 20 minutes. Initial certification normally occurs after the canine has had approximately 100 days of training. The installation commander/search granting official (magistrate) is the certifying official, responsible for seeing that the dog performs adequately and receives its certification if it does so. The validation testing is performed semiannually/annually and is overseen by an observer not associated with the training of the canine team. It normally utilizes 20 training aids. These targets may include not only bulk explosive samples, but also distracter agents (i.e. interferents). Distracter agents are used to reinforce the canine's ability to detect explosives material when such an agent may be present. The annual postcertification operational testing utilizes nine training aids, and is required to be reviewed by the installation commander/search magistrate. The monthly training also involves nine training odors in a variety of operational scenarios. The requirement here is for 4 hours of training per dog every duty cycle. Since the only time that counts toward this 4 hours is when the dog is actually searching for the explosives (i.e. the time taken to set up the search and clean up afterwards does not count), and since a given search might take only 20 minutes, this usually means that each dog undergoes some training every week. Failure to conduct retraining within a 30-day period requires recertification of the canine involved.

Strengths and Limitations of Using Canines

As with all explosives-detection techniques, the use of canines has some distinct advantages and also some limitations. The two most significant advantages associated with the use of canines are (1) mobility and (2) the ability to follow a scent to its source. The first of these is fairly obvious: a dog and a handler can move around a room, a building, or an outdoor area much faster than a person with an ion mobility spectrometer or some other technology-based trace detector. Because of this property of superior mobility, canines are the trace detection method of choice in situations where there is a significant search aspect, including building, aircraft, and vehicle screening. They are also useful in diagnostic applications where the target may be in a remote area, such as in mine detection or the investigation of a suspicious object found at the perimeter of a secure area. The mobility of the technology-based trace detection systems can be expected to improve with time as the technology is miniaturized, but almost all of the present systems are too large to be transported easily by a single person and cannot compete with canines in this respect.

The ability to follow a scent to its source, and thus locate the explosive object being sought, is probably even more important than mobility. Mechanical trace detection systems can determine whether explosive vapor or particulate matter is being detected at a certain point, but do not currently have the ability to determine the direction in which the signal increases. At best, trace samples could be collected from various points and analyzed by such a system to give some indication of where the scent is increasing, but this would be a slow and arduous process. The dog is an analog detector with near instantaneous response, so that once the scent is picked up the dog moves rapidly, directly to the source. Once again, this is a significant advantage in any application involving a search.

Other aspects of canine detection that can be considered strengths include good sensitivity, good selectivity versus interferents, speed of detection, and adaptability to tough environments. However, these are not always clearly advantages over mechanical trace detection systems, as are the two factors listed above, because most of the mechanical systems also perform well in these areas. It is particularly difficult to quantify sensitivity and selectivity and make a direct comparison between canines and the technology-based "sniffer" systems.

Among the limitations of canine detection, the short "duty cycle" is perhaps the most significant. Unlike a mechanical system, a dog is not capable of working 24 hours a day. In general, a given dog can search 40 to 60 minutes before requiring a break. This means that dogs are not ideally suited to applications that involve long periods of routine, repetitive screening, such as screening large numbers of people for explosives as they enter a government facility. Another disadvantage is that unlike a modern mechanical system, a dog cannot tell the operator what kind of explosive has been detected. When a dog indicates that it has made a detection, it may be advantageous to obtain some swipe samples in the area for subsequent analysis by a technology-based instrument, in order to determine the kind of explosive involved. The performance of dogs is also influenced by the handler. Dogs are generally not used for personnel screening, primarily because of the liability issues involved if a dog ever bites the person being screened; the fact that some people are afraid of dogs is also an issue. The performance of dogs can also be adversely affected by environmental conditions, with performance tending to be better on a cool, overcast day than on a very hot day. This probably results primarily from the fact that the dog will be more comfortable under the former weather conditions. In some cases, a dog may suffer from a temporary medical condition that reduces its detection efficiency, and this effect may not be obvious even to an experienced handler. Another important point involves postpurchase upkeep: since dogs need to undergo monthly training, there is often more "upkeep" involved with a dog than with a piece of mechanical "sniffer" equipment. Finally, canine detection is the least understood and the least scientifically studied of the explosives detection techniques. It is not clear, for example, whether a dog trained to sniff C-4 actually detects the RDX or some other chemical that is present in this material. Ongoing research efforts at Auburn University (Institute for Biological Detection Systems) should help shed some light on the issue of what a dog really detects under different circumstances.

Applications

The discussion above gives some idea of the detection applications most suitable to the use of canines. Some of the most popular uses include the search of vehicles, luggage, warehouses, aircraft, buildings and offices, and exterior areas such as the edges of buildings, parking lots, and property perimeters. These searches need to be performed bearing in mind that any given dog will require periodic breaks. As mentioned above, dogs are not usually used to search people because of liability issues and the fear of dogs that some people have. In many applications, a combined approach using both dogs and a mechanical system is very useful, with the mechanical system usually being used to confirm a detection made by the dog and identify the material involved.

Cost and Upkeep

DoD has its own centralized procurement system for the acquisition of explosives-detecting dogs and performs its own training as well. Law enforcement organizations can purchase dogs from civilian contractors. The purchase cost is usually in the range of $5,000 to $10,000. The initial training, which will typically involve two people and last up to 3 months, usually costs an additional $6,000 to $12,000. Once a dog has been procured, monthly training sessions are required. These are frequently conducted inhouse, so the main cost is the time of the personnel involved in the training. Training sessions can also be obtained from contractors or by participation in joint local police agency training. Feeding a dog will generally cost about $1,000 per year, and veterinary bills are typically approximately $600 per year.

Chapter 4. Automatic Bulk Explosives Detectors and Search Technologies

Bulk explosives detection devices measure some bulk characteristic of materials in an attempt to detect the possible presence of explosives. Some of the bulk characteristics that may be measured are the x-ray absorption coefficient; the x-ray backscatter coefficient; the dielectric constant; gamma or neutron interaction; and the microwave, millimeter wave, or infrared emissions. Further analysis of these parameters can result in calculated mass, density, nitrogen content, and effective Z (effective atomic number). While none of these characteristics are unique to explosives, they are sufficiently indicative to point to a high probability of the presence of explosives. Fortunately, many materials that share similar bulk characteristics with explosives are not common in everyday items. The false alarm rate for bulk detection devices can be low enough to allow for automatic detection of explosives and explosives-like materials.

It is important to note that most devices described in this section are not explosives detectors but are detectors of materials that have explosives-like characteristics. In addition, all have strengths and weaknesses. Perhaps a successful system based on bulk detection techniques could consist of two or more of these technologies working in concert. If enough information is gathered on a suspect material in this way, a real determination of the presence of explosives may be made. Most systems for the bulk detection of explosives involve either nuclear techniques or x-ray techniques. The following section will describe the x-ray techniques currently available for explosives detection applications.

X-Ray Techniques

In many cases x-ray technology bulk detectors are modified package-search x-ray scanners. These devices usually serve a dual purpose. The package being searched for guns or other contraband is simultaneously analyzed for the presence of materials that may be explosives. Simple single- energy transmission x-ray scanners do not provide enough information to make the explosives search automatic; a method to extract more information is needed. Dual-energy, dual-axis, and backscatter technologies allow the determination (or at least an approximation) of a material's mass absorption coefficient and effective Z number. Computer tomography scanners can extract enough information to calculate the material's density as well as its mass absorption coefficient. All of these technologies are beginning to provide lower cost alternatives to nuclear technologies.

When a photon of x-ray energy encounters matter there are three possible outcomes. The photon can simply pass through the material, the photon can be absorbed, or the photon can be deflected off of its original course (scattered). These three outcomes occur in distinct percentages determined by the energy of the x-ray and the bulk characteristics of the material (density, mass absorption coefficient, and effective Z number). Explosives have unique x-ray interaction characteristics as compared to everyday materials. The measurement of these interactions can be used to identify materials that have a relatively high probability of being explosives.

Transmission/Dual-Energy X-Ray

Dual-energy x-ray is simply a variation of the standard transmission x-ray, wherein the x-ray beam must penetrate the items under inspection to obtain an image. The transmission x-ray adds all objects and materials up in its beam path (line-of-sight) and makes one compound image out of the objects and materials. Single and multiple objects are seen as a single object. The more objects in the beam path, the more difficult it is to separate the image of one object from another. The inability of a transmission/dual-energy x-ray to separate objects from one another becomes particularly troublesome when the object under evaluation does not transmit or absorb x-rays well. Typically, these materials are low-Z/low-atomic-number materials or organics and include plastic explosives, drugs, and plastic weapons. Because organics do not absorb x-rays well, they leave poor x-ray signatures in a transmission x-ray. Transmission/dual-energy systems can detect organics if the background is uncluttered, but their strength lies in detecting metals or high-Z inorganic materials where penetration is important.

The advantage of dual-energy x-ray systems over single-energy systems is that material discrimination is achieved by comparing the attenuation ratio of low-energy x-rays to high-energy x-rays. There are two basic systems for achieving dual-energy interrogation for low-Z materials. First, the output of standard x-ray tubes is a fairly broad spectrum. Filters can cut the lower energy wavelengths in the beam, resulting in a beam with a higher average energy than the unfiltered beam. By exposing the package to the broad spectrum energy, then viewing the package with a linear array while also viewing the package with a second filtered linear array, dual-energy information can be obtained. The chief disadvantage to this method is that the energy separation is relatively small. The second method uses two x-ray tube operational voltages to provide the two energies. This way the energy separation can be as large as desired.

In a typical imaging system, dual energies around 75 kV and 150 kV are used to image low-density explosives and plastic weapons. X-ray transmission data are obtained essentially by standard methods at both energies and computer processed. The resulting image is displayed on a monitor for visual identification. The computer results characterize and identify the various materials by image shape, and artificial colors are assigned to various values of Z.

Specific identification of low-Z materials is dependent upon both Z and the thickness of the target material. Although dual energy is significantly better than single energy at determining Z, this method does not determine material thickness and, therefore, cannot completely and unambiguously determine the Z of a material. Another approach is to use dual axis/dual energy, which provides two images of the package at 90 degrees from each other. This two-view system can be thought of as a crude computed tomography scan. While two views do not provide enough information to compute a complete cross-sectional reconstruction, they do provide additional information for the system to make a determination for the presence of explosives-like material. Automated detection systems based on both dual-energy and dual-energy/dual-axis technology are currently manufactured by several companies.

Backscatter X-Ray

The only backscatter imager currently available provides both a standard transmission image of the package contents and a second, independent x-ray backscatter image, specifically of low-Z materials. The low-Z materials are distinguishable from the higher Z materials by their greater radiation scattering characteristics. Low-Z objects, such as plastic weapons, explosives, drugs, and organic materials that appear low contrast in conventional x-ray systems, are presented in bright white and are separately displayed on a second monitor. The visual comparison with the conventional image reduces the clutter, makes the low-Z items more visible, and aids the detection process for the low-Z items.

In a single-beam backscatter imager, another detector is positioned on the source side of the package to detect radiation backscattered by low-Z materials. These detector signals are then processed and displayed for comparison with the conventional transmission x-ray image. However, detection can be limited by an excessively dense article inside the package. In other words, low-Z objects behind the dense material may remain hidden, and it would be necessary to reexamine the package from the other side to complete the search.

A double-beam backscatter model avoids the above problem, but at almost twice the cost. This model is essentially two single-beam backscatter units positioned face-to-face that examine the package from both sides simultaneously. Thus, low-Z items are not obscured by a single, excessively dense object. Excessive amounts of low-Z material can be indicative of explosives, so automatic low-Z material detection is available as a threat alert option.

Computed Tomography (CT)

Computed tomography (CT) is an x-ray technique that produces two-dimensional images of cross-sectional slices of an object. A three-dimensional image can be obtained by appropriately combining a number of adjacent cross-sectional slices. (A direct cross-sectional view is obtained by computer processing of the x-ray transmission data from many different projections through the sample.) To obtain these measurements, the x-ray beam must penetrate the object to produce a sufficiently high signal level at the detector.

An important advantage of the CT technique is that x-ray transmission measurements and material absorption coefficients can be obtained directly from the material of interest, even if the specific target is obscured by surrounding materials. The CT technique provides maximum sensitivity and accuracy for material detection and identification. Most importantly, CT can be used to specifically identify explosives and discriminate them from most other innocuous, similar low-Z materials. This is possible because CT can determine the material thickness and because explosives generally have higher density values (~1.7 g/cm^3) but similar atomic numbers compared to similar innocuous materials. This method involves the simultaneous solution of equations for the measured absorption coefficients at each pixel. A knowledge of the material thickness allows an absolute solution for the absorption component and the automated specific identification of explosives.

The source and detector array both translate and rotate around a scan circle in which the object is centered. The x-ray beam penetrates the object and is detected on the opposite side. A set of projection data is obtained at a particular angle. The source and detector are then rotated at a small angle, and a new projection is obtained. Typically, 180 projections are taken at 1-degree intervals around the object. Each x-ray transmission measurement is converted into an electrical signal and computer processed. The reconstructed CT image is cross-sectional, and the computed attenuation coefficient at any point in the cross section is independent of overlying material.

Image reconstruction time for CT is usually less than 1 minute. These images have a more coarse spatial resolution than conventional x-ray images. A limiting resolution of 1 to 2 mm is typical for images of high-contrast materials. However, CT images do have improved density resolution compared to conventional x-ray images. For example, a 0.5-percent difference in the attenuation coefficient of a 1-cm object embedded in a 30-cm-thick section of material can be readily detected.

The disadvantages of present CT system designs are complexity, very high cost, higher package dose (current models are not film safe) compared to conventional x-ray scanners, and slower operation. These may be acceptable tradeoffs for increased performance in special applications.

Work is under way to produce a CT detection system of reduced complexity and cost for contraband detection purposes as well as a CT scanner that employs dual energies and helical scans.

Personnel Low-Dose X-Ray Scanning

A system is available that uses low energy x-rays at near-ambient levels to image materials on the bodies of persons being screened. The device can image guns and other contraband, including explosives hidden under the clothing of persons being scanned. This backscatter device exposes the subject to about 2.5 microrem per scan. While this energy level is very low and considered safe, many people find any exposure to x-rays objectionable. Invasion of privacy is also an important issue. Efforts are under way to lessen the degree of the intrusiveness of the images produced. This device is not in the truest sense a detector, because there is currently no automatic detection of explosive-like materials. Detection is performed by having the operator(s) visually inspect the images produced.

In any screening device to be used on people, safety is of prime importance. The radiation dose received while being scanned needs to be so low that it is virtually indistinguishable from background. Present scanners can scan only one side at a time. A person entering a scanner booth would have to be scanned two times, front and back, to ensure that no explosives are secreted on the person. For general use, the low-dose x-ray system should (1) be capable of processing approximately 10 people per minute, (2) have the demonstrated capability to discern the presence of an explosives mass on a person, and (3) demonstrate a radiation output of sufficiently low magnitude so that personnel will receive a radiation dose less than the permissible dose. Ideally, the radiation dose should be <5 microrem per scan.

Making an x-ray backscattering system fully automatic is not possible at the present time. The results of a scan are a computer-enhanced image on a display monitor showing the outline of the person and any concealed objects. Recognizing an object as being suspicious and requesting further verification to determine if it is or is not an explosive is the responsibility of the operator and/or security officer.

Other X-Ray Related Technologies

Several companies manufacture x-ray equipment or portable scanners for screening mail, small packages, and related incoming materials for the detection and recognition of explosive devices and related dangerous contraband. Systems based on fluoroscopic imaging include models that are handheld, weighing as little as 6 pounds; field portable units with photographic capabilities; and desktop systems with an integral viewing chamber for real-time, direct viewing of the suspect object. The item or package to be viewed is simply placed directly in front of the imaging scope or placed in the inspection chamber and within minutes the inspection is complete.

Other available imaging systems use portable radiographic x-ray generators with either dry or wet films, electroluminescent image panels, or dry, erasable phosphor screens to display the acquired images. Many of these systems are portable enough to be transported and set up by an individual.

Table 2. X-Ray Inspection Systems

System	Technology	Use	Company	Cost*
HI-SCAN 6040-A HI-SCAN 7555-A PS 5030	Dual-Energy X-ray	Hand carried luggage, packages	Heimann Systems 732–603–5914	Low/ Medium
HI-SCAN 5170-A CS 5070 HI-SCAN9075-TS	Dual-Energy X-ray	Check-in luggage, bulk items	Heimann Systems 732–603–5914	Medium
HI-SCAN 11080-TS HI-SCAN 85120-TS HI-SCAN 100170-TS	Dual-Energy X-ray	Large boxes, parcels, bulk items, and freight	Heimann Systems 732–603–5914	Medium / High
SCANTRAILER SCANVAN IV SCANMOBILE	Dual-Energy X-ray	Mobile screening systems	Heimann Systems 732–603–5914	High
HI-CO-SCAN	Dual-Energy X-ray	Vehicle and cargo search	Heimann Systems 732–603–5914	High
HI-SCAN 10065 EDS	Dual-Energy X-ray, auto-detect system	Checked baggage search	Heimann Systems 732–603–5914	High
CTX-5500-DS™	X-ray, Computed Tomography	Package and luggage search	InVision® Technologies, Inc. 510–739–2400	High
DYNAVISION® 910 DYNAVISION® 925 DYNAVISION® 400 A	X-ray Optional Dual Energy	Parcel, package, and luggage search	Control Screening, LLC 724–837–5411	Low/ Medium
MAILGUARD™ GUARDRAY	X-ray	Mail, small package search	Control Screening, LLC 724–837–5411	Low
MailSafex MailScope 500	X-ray Fluoroscope	Mail, small package search	XID Corporation 973–773–9400	Low
LIXI™	X-ray Fluoroscope	Mail, small package search, EOD	Lixi, Inc. 630–620–4646	Low
ISPS 80ST	X-ray Image Storage Panels	Portable viewing of suspicious packages	MINXRAY, Inc. 847–564–0323	Low
FSU6	Fluoroscopic X-ray	Field inspection system	MINXRAY, Inc. 847–564–0323	Low
RTR-3™	Portable X-ray	Portable viewing of suspicious packages	SAIC 800–962–1632	Low
Cabinet Postal Parcel Inspection System™	X-ray	Inspection of mail, hand-carried items	SAIC 800–962–1632	Low

System	Technology	Use	Company	Cost*
CDS-2002I™	Backscatter X-ray	Handheld contraband detector	SAIC 800–962–1632	Low
Rapiscan 119	Dual-Energy X-ray	Table top package search	Rapiscan Security Products 310–978–1457	Low
Rapiscan 300 Series Models 320, 322, 324, 326, 327, 328	Dual-Energy X-ray	Package search	Rapiscan Security Products 310–978–1457	Low/ Medium
Rapiscan 500 Series Models 520, 522, 524, 526, 527, 528,530, 532, X-ray Van	Dual-Energy X-ray Computer Enhanced	Package search	Rapiscan Security Products 310–978–1457	Medium/ High
Rapiscan Model 545	Dual-Energy X-ray Computer Enhanced	Cargo pallet search	Rapiscan Security Products 310–978–1457	Medium
Rapiscan “System 2000"	Dual-Energy X-ray	Large scale systems for border crossings, sea ports	Rapiscan Security Products 310–978–1457	High
Secure 1000	Backscatter X-ray	Personnel search	Rapiscan Security Products 310–978–1457	Medium
VIVID Models H-1™, APS™, VIS™, VIS-W™, and VDS™	Dual-Energy X-ray Computer Enhanced	Package and luggage search	Vivid Technologies, Inc. 781–938–7800	Medium/ High
AS&E® Models 66Z, 101GT, 101GTA	Z Backscatter® X-ray	Mail, packages, and baggage search	American Science and Engineering, Inc. 978–262–8700	Low
AS&E® Models 101Z, 101ZZ	Z Backscatter® X-ray	Large package and baggage inspection	American Science and Engineering, Inc. 978–262–8700	Medium
AS&E® Model 101XL PalletSearch™	Z Backscatter® X-ray	Large cartons and palletized cargo inspection	American Science and Engineering, Inc. 978–262–8700	Medium
AS&E® Model EXR-ZZ	Z Backscatter® X-ray	Package inspection, Real-time image analysis	American Science and Engineering, Inc. 978–262–8700	Medium

System	Technology	Use	Company	Cost*
AS&E® BodySearch™	Z Backscatter® X-ray	Personnel inspection	American Science and Engineering, Inc. 978–262–8700	Medium
AS&E® Models 101VAN, MOBILE 101-TRAILER, MobileSearch™, CargoSearch™, ContainerSearch™	Z Backscatter® X-ray	Mobilized, vehicle, and cargo Inspection	American Science and Engineering, Inc. 978–262–8700	High
TORREX II™ MINISCAN™	X-ray	Mail and small package inspection	EG&G Astrophysics 310–513–1411	Low
LINESCAN® Models 110™, 122™, 210™, 215™, and 222™	X-ray Dual-Energy X-ray	Mail, hand-carry, package Inspection	EG&G Astrophysics 310–513–1411	Low
LINESCAN® Models 107™, 111™, 112™, 226™, 231™, 232™, and 237™	X-ray Dual Energy	Large package, luggage inspection	EG&G Astrophysics 310–513–1411	Medium/ High
Mobile LINESCAN® LINESCAN® AutoVan™	X-ray Dual Energy	Mobilized package inspection	EG&G Astrophysics 310–513–1411	High
Z-SCAN™ Models 10, 12, 7	Dual-View/ Dual-Energy X-ray	Package inspection	EG&G Astrophysics 310–513–1411	Medium/ High
ÄoXray® μ-Ray 150 A-600	X-ray	Portable systems for small package, mail search EOD	Vidisco Ltd. 703–521–0300	Low
eXaminer MIC-80A	X-ray	Mail, handbags, parcels, briefcase inspection	Vidisco Ltd. 703–521–0300	Low
Varian Linatron®	X-ray	Vehicle and cargo screening 1 MeV to 10 MeV	Varian Industrial Products 415–424–4793	Medium/ High

** Low cost is defined as less than $70,000; medium cost is defined as $70,000 to $300,000; and high cost is defined as above $300,000.*

As shown in the table above, there are several x-ray systems available to inspect mail, small and large parcels, luggage, unknown devices, cargo, personnel, and vehicles of all sizes. These systems can range in cost from thousands of dollars to several hundreds of thousands of dollars depending on model, configuration, and options chosen. Several of the smaller, portable systems for field use or mail scanning cost approximately $25,000. Single-transmission x-ray systems can range in cost from $40,000 to $100,000, again depending on options and installation. Dual-energy systems average around $250,000 to $400,000 depending on options, and special systems for large cargo and vehicles and CT systems can easily be in the $1 million range. Before choosing a system, define all requirements for the application, work with a knowledgeable company salesperson or applications engineer, and solicit advice or information from a third party such as an independent testing laboratory or another government agency.

Several of the x-ray systems have been extensively tested for throughput and performance by the Federal Aviation Administration (FAA), and the test results should be available to other governmental agencies. Contact the authors of this survey if you require more information.

Chapter 5. Novel Trace and Bulk Detector Systems

This chapter covers a number of novel explosives detection technologies, most of which have not yet been fully developed commercially. They are included here for completeness, even though procurement of systems based on these techniques by law enforcement agencies is in most cases unlikely or even impossible at present. Company contacts are given where possible, so that interested parties can contact the companies directly to obtain the latest information.

Nuclear Detection Systems

Thermal Neutron Activation (TNA)

A number of nuclear techniques for detecting explosives have been suggested, some of which are under study and have been recently commercialized. The decision to use thermal, or low-energy, neutrons for the detection of explosive materials in packages is a natural one. Neutrons have excellent penetrating power and interact with nitrogen-rich materials, such as explosives, in a well-known and predictable way. The only technique that is commercially available and being used in several airports for scanning checked luggage is thermal neutron activation (TNA), developed by Science Applications International Corporation (SAIC). The difficulties with such technology at the present time include cost (approximately $900,000), size, and weight (more than 3,000 pounds).

Thermal neutrons are absorbed by many atoms. When a thermal neutron is absorbed there is an associated release of a gamma ray photon (much like a phosphor gives off visible photons when exposed to ultraviolet light). The wavelength (energy) of the emitted photon is very specific to the atom that absorbs the neutron. Because the wavelength of the photon is highly specific, the detection of photons of the wavelength emitted by nitrogen when absorbing a thermal neutron indicates the presence of nitrogen. The intensity (number) of the photons detected is an indication of the amount of nitrogen present. Explosives such as TNT, C-4, Semtex, and Detasheet® have a very high nitrogen content. Therefore, an area of high thermal neutron interaction with nitrogen indicates the probable presence of an explosive. Of course, the nitrogen in any other nitrogenous material, such as wool, nylon, orlon, silk, and leather, will interact with the neutrons and provide a nitrogen-dense area on the computer display. However, not many materials have the nitrogen density that the explosives possess.

Company: SAIC
(p): 800–962–1632

(f): 619–646–9718

Pulsed Fast Neutron Analysis (PFNA)

SAIC has invented and patented pulsed fast neutron analysis (PFNA), a technique that evolved from earlier work on investigating the use of fast neutrons to detect explosives concealed in luggage. A fully integrated PFNA system is now operational at SAIC's Santa Clara, California, facility. The system is being used to characterize cargoes and develop decision algorithms for the detection of drugs and especially explosives for various customers.

The PFNA technique measures the elemental composition of the contents inside the scanned object. A pulsed neutron created by a pulsed deuteron beam striking a deuteron target is shined on an object. The neutrons interact with the elemental constituents of the object and create gamma rays with energies characteristic of the elements. From the energy and time of arrival of the gamma rays in detectors, an elemental image of the object can be created. These measurements are used to generate a three-dimensional map of the contents inside the container. SAIC software determines the presence of specific combinations of elements and characterizes materials of interest. The contents of the scanned object can therefore be determined with a high degree of accuracy. The whole process is independent of operator interpretation since the detection of the material does not rely on either the shape or the material of packaging used.

PFNA stores the atomic fingerprint of every object it scans for later comparison, thereby making the system smarter over time. This is the only technology that can provide full material identification in containers ranging in size from luggage to full-sized shipping containers. It is similar to x-ray computer tomography and magnetic resonance imaging. However, these technologies are applicable only to smaller objects, and provide much less information than PFNA.

Preliminary testing has shown a high throughput of 600 to 1,000 per hour for luggage and parcels, and a detection accuracy of above 90 percent and a false alarm rate near zero. Further testing of the prototype system may involve an airport or a port facility in the near future.

Company: Science Applications International Corporation
(p): 408–727–0607
(f): 408–727–8748

Nuclear Magnetic Resonance (NMR) Explosives Detection

Nuclear magnetic resonance (NMR) detection is based on the fact that nuclei of many atoms possess weak magnetic moments. Hydrogen nuclei (protons) have properties suitable for the observation of NMR and are found in most materials. Some explosive materials and narcotics have almost unique responses to NMR and may be specifically identified in an automated search system. When a hydrogen nucleus is placed in a static magnetic field, the nuclear magnetic moment of the nucleus will align along the direction of the magnetic field lines. The alignment is imperfect and the nuclear magnetic moment processes at a specific frequency (Larmor frequency) for hydrogen. If an external radio frequency (RF) magnetic field is applied to the processing nuclei, some of the nuclei will realign against the static field, resulting in resonant absorption of energy from the RF field.

To observe NMR, the sample is placed in a strong static magnetic field and a short RF field pulse is applied at the Larmor frequency for the proper duration and intensity. The nuclei will absorb energy and come out of equilibrium. The characteristic time for the nuclei to return to equilibrium is controlled by a relaxation time T_1, the spin-lattice relaxation time. The spin-spin relaxation time constant, T_2, is a second time constant controlling the rate of decay of a transient magnetic resonance signal and is observed by a sample coil wound around the sample material. The resonant frequency, the signal amplitude, and the T_1 and T_2 characteristics of the signal form the basis for transient NMR analysis of composition, selective measurements of several constituents, and selective detection of contraband. Most explosives and narcotics exhibit long T_1, short T_2 behavior and can be distinguished from most other solid and liquid materials, which have shorter T_1 and longer T_2, respectively. Once a material is characterized, its unique signature can be recognized by this type of system.

The primary limitation of the NMR method is the inability to detect materials enclosed in a metal container or foil. Iron or large amounts of nonferrous metals in a package cause field distortion and reduce effectiveness. The strong static magnetic field can cause partial exposure of some magnetic tapes and can magnetize watches. Commercialized NMR systems are used in the medical field, whereas the quadrupole resonance technique (described below) is being commercialized for explosives detection.

Quadrupole Resonance (QR)

Quadrupole resonance (QR) technology is a promising new technology. This technology uses short pulses of radio frequency energy to excite spinning nuclei from their equilibrium positions. When the perturbed nuclei relax to their normal state, they emit photons of a characteristic frequency that are detected and analyzed. The operating principle is much like NMR, but QR uses no external magnetic field. The interaction of spinning nuclei (Nitrogen-14) with their local molecular environment causes the nuclei to align in preferred directions. This effect gives a unique signature for each nitrogen-containing material such as explosives or narcotics. One manufacturer of QR products has confirmed this uniqueness of signal by a database review covering 10,000 nitrogen-containing compounds. The resulting signal is very small, so the QR uses new superconducting sensors to detect this weak signal. Unlike TNA, which simply alarms on the presence of nitrogen rich materials, QR uniquely identifies the explosive because the device can distinguish explosives from explosives-like materials. Thus, QR is a true explosives detector.

A QR scanner is compact, noninvasive, does not subject the package to ionizing radiation, and will not erase magnetic media. One advantage of the QR technique over others is that it examines a volume without imaging. The configuration of the explosive, whether in bulk, sheet, distributed, etc., is irrelevant to detection by QR. There is no performance degradation when detecting thin sheet explosives typically only 2 to 3 millimeters thick.

Since this technology does not provide an image that can be interpreted by an operator, it should be used in conjunction with conventional x-ray imaging systems or manual search. In fact one manufacturer, Quantum Magnetics, has been working on a combined QR and dual-energy x-ray detector with EG&G Astrophysics. QR suffers from the same inability (as NMR) to detect contraband inside metal containers. Integrating this device with an x-ray machine does much to compensate for this shortcoming.

Table 3. Commercially Available QR Systems

System	Use	Company	Cost
QED™ 600	Examine mail, briefcases, small packages	Quantum Magnetics, Inc. 619–566–9200	$65k
QScan™-1000	Screen large packages, baggage, cargo	Quantum Magnetics, Inc. 619–566–9200	$365k
QScan™-500	Screen hand-carried items, baggage, boxes	Quantum Magnetics, Inc. 619–566-9200	$340k
QScan™-160	Screen hand-carried items, baggage, boxes	Quantum Magnetics, Inc. 619–566–9200	call for quote
LiquiScan™	Verification of liquid contents in glass, plastic containers	Quantum Magnetics, Inc. 619–566–9200	$230k
QDESK™	Hold baggage screening (customizable)	Quantum Magnetics, Inc. 619–566–9200	call for quote

Work in quadrupole resonance analysis in the immediate future will focus on two key areas. The first involves reducing the amount of indeterminate readings caused by magneto-acoustic ringing from metallic objects contained within baggage. The second goal is to expand the range of detectable substances beyond military explosives and narcotics.

Portable Isotopic Neutron-Spectroscopy (PINS) Chemical Assay System

The Portable Isotopic Neutron-Spectroscopy (PINS) Chemical Assay System was created in response to the growing worldwide need to determine *in situ* the specific nature of the contents of an assortment of containers of munitions and chemical weapons. PINS is a joint development of EG&G ORTEC and Idaho National Engineering and Environmental Laboratory (INEEL).

Such applications require portability, reliability, and ease of use. The performance of PINS has been verified in real-world use by the U.S. Army, which has successfully identified, in the field, hundreds of suspect munitions from burial sites and firing ranges. PINS readily and clearly distinguished between cylinders containing high explosives, ones that contain blister agents, and those filled with nerve gas. The system can identify:

- Chemical weapons, including nerve agents GA, GB (sarin), and VX.
- Blister agents HD, HN, HT (mustard gases), and Lewisite.

- High explosives such as composition B, RDX, and TNT.

Computer software acquires and analyzes the spectrum before reporting the constituents detected.

PINS is a novel application of a well-understood technique, using neutrons from a small moderated source, ^{252}Cf. The neutrons pass through the wall of the container and collide with the atomic nuclei of the contents. The ensuing nuclear reactions (neutron capture and inelastic scattering) produce gamma rays, which when appropriately detected and recorded, produce a gamma-ray spectrum. Typical sampling times are from 100 to 1,000 seconds. The gamma-ray spectrum peaks are found at energies associated with specific nuclear deexcitations characteristic of the chemical element concerned. The relative peak heights are related to the ratios of the elements inside the container.

These energies and ratios are in themselves uniquely characteristic of the contents of the container, whether it be high explosive, nerve gas, or other. In this way, with a library of known signatures, it is possible to determine unambiguously the contents of the container.

PINS is advertised as a portable system, which means that it can be transported for field use and can operate up to 8 hours on internal batteries. The system is shipped in five boxes with a total weight of 610 pounds Also, the high purity germanium detector must be refilled with liquid nitrogen every 18 hours for proper operation, and proper procedures must be followed when handling the neutron source.

System Model number: PINS-1
Company: EG&G ORTEC
(p): 423–482–4411

Other Nonnuclear Detection Techniques

EXPRAY Field Test Kit

EXPRAY is a unique, aerosol-based field test kit for the identification and detection of what the manufacturer refers to as Group A explosives (TNT, TNB [trinitrobenzene], 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. EXPRAY can be used as a preblast analysis tool, postblast investigative tool, and as a technical evaluation test on hazardous material sites.

The EXPRAY field kit is comprised of the following:

- 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, commercial and improvised explosives based on inorganic nitrates).
- Special test papers which prevent cross-contamination.

Initially, the suspected surface (a package, clothing, a person, etc.) is wiped with the special test paper. Then the paper is sprayed with EXPRAY-1. If a dark brown-violet color appears, this 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, spray the same test paper with EXPRAY-2. A pink reaction indicates the presence of Group-B explosives (most plastic types of high explosives belong to this group). If there is still no reaction, spray the same paper with EXPRAY-3. A pink reaction indicates the presence of nitrates that could be part of an improvised explosive. If EXPRAY-2 is applied after a positive result was obtained with EXPRAY-1, a change to pink color is an indication of a double-base or a triple-base explosive. Note that the order of spraying is critical for a successful detection, and all three sprays should be used in order to perform a complete test.

The EXPRAY system does have certain limitations. Not all explosives can be detected. Some nitrate-esters and the chlorate group give a negative result. These include the mixtures of potassium chlorate, sodium chlorate, and potassium nitrate with sugar, sulfur, and/or carbon. In addition, only the specific colors for the respective sprays should be judged positive. Other discoloration is possible, but should be judged negative. As with other detection systems, a negative result does not give absolute certainty of the absence of explosive substances.

The manufacturer claims EXPRAY can detect particles as small as 20 nanograms. Tests performed at Sandia National Laboratories show lowest detection levels for TNT at 10 to 20 times greater than those claimed by the manufacturer. The EXPRAY explosive detection kit is a low- cost, simple to use, and quick way of testing in the field for explosives residue.

EXPRAY Kit: Model M1553, Cost: $250
Company: Genesis Resource
(p): 602–838–6420

Dielectric Portal for Personnel

In 1992, Spatial Dynamics demonstrated that its patented dielectric sensor could discover all plastic items, metal items, and nonmetal items under clothing on human subjects. The dielectric sensor detection process is essentially automatic, with no operator interpretation and recognition required. There is also no problem with the privacy issue since high-resolution imaging is not required. The technology is safe, using microwave energy levels well below the government safety standards.

Dielectric Sensor

The dielectric sensor generates a low-energy microwave field. It then measures the dielectric and loss properties of the objects in the microwave field and compares them to known physiological values. Human physiology has a dielectric response that is uniquely identifiable. The human response is distinctly and measurably different from threat items such as metals, plastics, explosives, and incendiaries. If such an item is placed between a human and a dielectric sensor, the expected dielectric and loss measurements of the human will be altered and the threat item discovered.

The dielectric properties of a material alter the velocity of the microwave energy moving through the material. This change is the dielectric response of the material. A dielectric response has two parts. The first is the dielectric constant, which is a measure of how well the material acts as an insulator. The second is the dissipation factor, which relates to how well a material converts microwave energy into heat. The dielectric sensor looks for differences in these variables and uses them to differentiate between materials.

The dielectric sensor transmits a microwave field with a frequency of 5,500 MHZ. This frequency has been found to give the best tradeoff between penetration of clothing and target resolution. This frequency is critical since higher frequencies can be blocked by clothing that is heavy or damp and lower frequencies will produce too large a field, which reduces target resolution. The design of the sensor uses the patented antenna designs of Spatial Dynamics, which allow the establishment of a standing microwave field in such a way as to take repeatable dielectric measurements at a distance of up to 30 inches. The standard target size for these specific sensors is 2 inches by 2 inches.

Dielectric Portal

The dielectric portal consists of 32 dielectric sensors in a moveable array. A person enters the portal, places his or her hands on handle bars at face level, and then the sensors scan the person in a full 360-degree scan. Typical scan time is 4 seconds for a complete body search. The results are then automatically analyzed by computer.

Factory testing of the portal has been completed and results are similar to the results of the sensor testing in 1992. Plastic and metal weapons, explosives, incendiaries, and other contraband were detected successfully. Airport testing was scheduled for mid-1997. Contact the developer for cost information.

Dielectric Personnel Portal
Company: Spatial Dynamics Applications, Inc.
(p): 508–263–7704

Immunochemical Sensors for Explosives Detection

A brief section on immunochemical sensors and antibody-related explosives/chemical detection is included simply to outline some work being done in this area. To our knowledge, there are no commercially available explosives detection systems based on this technology.

An antibody-based biosensor has been developed at the Naval Research Laboratory, which is capable of detecting both drugs and explosives present at low levels in an aqueous sample. In the flow immunosensor, antibodies are immobilized onto a solid substrate, allowed to bind a fluorescently labeled signal molecule, placed in a small column, and attached to a buffer flow. Upon sample introduction, an amount of the fluorescent signal molecule is released that is proportional to the concentration of applied sample. The response time of the sensor is under a minute, and multiple samples can be analyzed without the need for additional reagents. Quantitative assays are being developed for a variety of compounds, including TNT, DNT, PETN, and cocaine. The laboratory prototype has been used to study how choice of fluorophore, antibody density, and flow rate affect the signal intensity and column lifetime. A self-contained commercial instrument that can analyze up to seven different compounds from a single sample is currently being engineered under a Cooperative Research and Development Agreement.
Westinghouse Electric is developing portable, handheld sensors capable of detecting numerous drugs of abuse (cocaine, heroin, amphetamines) and explosives (trinitrotoluene, pentaerythritol tetranitrate, nitroglycerin). The easy-to-use system consists of a reusable electronics module and

disposable probes. The sensor illuminates and detects light transmitted through optical cells of the probe during an antibody-based latex glutination reaction. Each probe contains all the necessary reagents to carry out a test in a single step. The probe has the ability to lift minute quantities of samples from a variety of surfaces and deliver the sample to a reaction region within the device. The sensor yields a qualitative answer in 30 to 45 seconds and is able to detect illicit substances at nanogram levels.

A sensor has been developed for detecting the presence of a particular chemical by determining the absolute frequency shift in the oscillating frequency of an antibody-coated oscillator. Specific antibodies deposited on a high-Q crystal oscillator detect the change in frequency as chemical particulates become trapped by the antibodies and change the effective mass of the crystal. In one system, two oscillating crystals are used, one that has been coated with the antibodies, and one that is uncoated. This permits detection of frequency differences between the oscillating frequencies of the two crystals, thus eliminating pressure, temperature, and humidity corrections that conventionally must be made. The sensor maintains a high specificity by using antibodies that are specifically related to the chemical to be detected, while achieving relatively good sensitivity by using high-Q oscillators, such as quartz or sapphire, and eliminating drift problems due to temperature, pressure, and humidity. In a second system, a single crystal is used having antibodies coated at specific nodal locations associated with harmonics of the fundamental frequency of oscillation of the crystal. Harmonic amplitudes are measured to determine the presence of the chemical of interest.

Millimeter Wave

In the search for ever higher resolution RADAR imaging systems, a new generation of electronics has emerged. Millimeter wave technology uses electromagnetic energy that lies between microwaves and long infrared. At millimeter wave frequencies this energy can be produced electronically as well as thermally. Because this energy can be thermally generated, there are natural millimeter wave emissions from the human body and any other object at or near room temperature. These natural emissions mean that an imaging system that employs millimeter wave technology can be either active (it illuminates the object or person being scanned with millimeter wave energy) or passive. Currently, the National Institute of Justice is funding development of millimeter wave personnel scanners with Lockheed/Martin Corporation, Chang Industries, and Thermotrex. Soon there may be a commercially available device that can image explosives, guns, and knives (even those that are made of plastics and ceramics) hidden underneath persons' clothing. These devices may be capable of imaging contraband at a distance without the risk of exposing the person to ionizing radiation. Possible applications of the personnel scanner include security at airports, courtrooms, correctional facilities, office buildings, schools, banks and other financial institutions, high-value manufacturing plants, and other buildings where metal detectors are in use today.

For applications where it may be difficult or impractical to deploy a fixed personnel scanner, a battery-operated, handheld unit is being developed. The scanning process takes only a few seconds, and the resulting image is displayed on a liquid crystal display (LCD) monitor on the backside of the scanner. Further millimeter wave imaging development is being done by Pacific Northwest Laboratory with the detection, placement, and identification of concealed weapons on a person.

Chapter 6. Metal Detection as an Accessory to Explosives Detection

When screening personnel or packages at entry points to secure areas or in public places such as airports, metal detectors serve as a very useful and sometimes essential supplement to explosives detection systems. While metal detectors do not detect explosives per se, they do serve as bomb detectors in cases where a bomb contains metal parts (e.g., most pipe bombs), and thus serve as an additional layer of security at screening points. Given that personnel portals for explosives detection are still in a state of evolution, this additional security is of considerable value.

For many checkpoints, it is illogical to deploy explosives detection without also deploying metal detection. Apart from the added detection probability for bombs containing metal parts, there are a number of advantageous features associated with this technology. First, there is always a need, often more pressing than the need to detect explosives, to detect firearms and other potential weapons entering a secured area. Commercial metal detection portals, when properly utilized, provide a reliable means of doing this. Second, the cost of such metal detectors is in general small compared to the cost of explosives detection systems. The cost of metal detection portals currently is in the range of $2,000 to $20,000—much less than the more than $80,000 cost associated with explosives detection portals that are either on the market or in development. Thus, if explosives detection is installed, installation of metal detectors should be possible at very little additional cost. Third, metal detectors represent a mature technology, in contrast to explosives detectors (particularly portals). This means that the performance of metal detectors is not likely to improve dramatically in the near future, and hence a metal detector that is purchased today will probably still be very nearly state-of-the-art 10 years from now. For all of these reasons, it seems prudent to deploy metal detection at all checkpoints where explosives detection is deployed, just as is already done, for example, in airports.

The principles of operation and performance parameters of metal detectors are beyond the scope of this survey, but interested persons can consult the literature of the manufacturer's listed below.

EG&G Astrophysics
4031 Via Oro Avenue
P.O. Box 22709
Long Beach, CA 90801–5709
(p): 310–513–1411

Federal Labs Systems
35 West Pittsburgh Street, Suite 203
Greensburg, PA 15601–2323
(p): 724–837–5411

Garrett Metal Detectors
1881 West State Street
Garland, TX 75042–6761
(p): 214–494–6151

Infinetics Inc.
201 Vandever Avenue
P.O. Box 2330
Wilmington, DE 19899
(p): 302–658–2421

Metorex, Inc.
860 Town Center Drive
Langhorn, PA 19047
(p): 215–741–4482

Rapiscan
12525 Chadron Avenue
Hawthorne, CA 90250
(p): 310–664–0437

Ranger Security Detectors Inc.
10001 Carnegie Street
El Paso, TX 79925
(p): 915–590–4441

Secure-Entry Industries
171 Marycraft Avenue
Woodbridge, Ontario, Canada
L4L 5Y3
(p): 416–850–0260

Chapter 7. Manual Search Techniques

Manual search, sometimes referred to as physical search, can be an important part of many explosives detection schemes. The items to be searched can be divided into several distinct categories: (1) people, (2) vehicles, (3) hand-carried articles, (4) shipped or mailed packages, and (5) buildings or property (bomb threats). Manual search will be used often at designated checkpoints where people or vehicles are entering a secured area. It is generally fairly slow, so if one is dealing with large throughput rates, manual search of all entering persons or vehicles may prove impractical. Under such circumstances, it is often necessary to apply manual searches on a random basis, by searching some randomly selected fraction of those passing through the checkpoint. One simple way to do this is to have a deck of plain white cards, some fraction of which are marked on the bottom with a red dot or some other distinguishing mark. Each pedestrian or vehicle driver entering a checkpoint can be asked to draw a card; if a marked card is drawn, the person or vehicle will be searched. This method provides a real deterrent because every person or vehicle has a realistic chance of being searched, but it saves time because only a fraction of them actually are searched. Alternatively, security guards at a checkpoint can limit searches to cases where the people involved appear to exhibit suspicious behavior. It must be remembered, however, that uniform searching of all entering items is desirable when it is feasible.

Another general point about manual search is that it is very often useful to combine it with other search techniques, including the use of canines, sniffer equipment, and x-ray-based detection systems. Because of this, there is necessarily some overlap between this chapter and some of the preceding ones.

Manual Search of People

Manual search of people for explosives can occur both at entry checkpoints and in more random situations, such as when a suspect is being apprehended. Searching for explosives in this manner is not intrinsically different from searching for narcotics or other contraband, and most law enforcement workers will be familiar with the appropriate procedures. Except in rare cases involving suicide bombers, booby-trapped bombs will not be an issue.

It is important to have the person being searched remove outer clothing such as coats, etc. The person then needs to be inspected visually from front to back, from head to foot, and on both sides. If deemed necessary, and if it is permissible under the prevailing circumstances, the person can be frisked. It is important to remember that, as with narcotics, small amounts of plastic high explosives can easily be concealed underneath clothing and taped to someone's body. For this reason, visual inspection alone will never be a foolproof technique. It is therefore highly recommended that manual search of people be supplemented, at least at times, with other detection techniques including metal detection, personnel x-ray scanners, and mechanical explosives trace detection systems.

Manual Search of Hand-Carried Articles

Hand-carried articles such as backpacks, purses, briefcases, and packages represent a common means of surreptitiously introducing a bomb or explosive material into a controlled area. It may also be necessary to search such items if they are in the possession of a person being arrested. In performing manual search of such articles, several rules need to be kept in mind. First, the officer performing the search should normally have the owner open the article in question, including all of the individual compartments if it is a backpack or something similar. This should prevent the officer from becoming the victim of a booby-trapped article. Second, all compartments of the article need to be carefully checked and, if necessary, all items inside it removed to facilitate the search. Finally, it is again recommended that the manual search be supplemented by other search techniques if time permits. Passing the article through an x-ray system or metal detector is especially useful and can be done rapidly for a large number of articles. Given slightly more time, the article can be swiped for contamination and the swipe examined with a trace explosives detection system. If available, canines can also be used to sniff the article. At checkpoints, refusal to submit an article for search should result in a denial of access to the area in question. In addition, security personnel should never agree to store an article that has not been searched.

Manual Search of Shipped or Mailed Items

Manual search of articles that have been shipped or mailed is in principle similar to search of hand-carried articles, but with two notable differences. The first has to do with access to the article, and the second with size. Shipped or mailed packages normally cannot be opened by anyone except the addressee, so manual search becomes much less practical. It can be utilized by asking the addressee to open packages that are deemed to be suspicious in the presence of security personnel, and possibly in emergency situations where examining the contents of the package without the addressee being present is deemed justifiable. More often, manual search can be replaced by putting the article through an x-ray scanner or metal detector, or by “sniffing” the article using either canines or a mechanical trace detection system. Note, however, that metal detection will be of no use if the shipped item contains metal parts to begin with, and x-ray examination may be impossible if the shipped article is too large for the x-ray scanners that are available. Canines and trace detection systems can be very useful if the number of items under investigation is limited, but if one is performing routine screening of large volumes of mail or packages, these methods may be impractical. The large size of certain shipped items is also an issue, not only because it may make the use of certain x-ray scanners impossible, but also because it will mean a more complex and time consuming search for the item in question.

Manual Search of Vehicles

One of the more complex topics to be covered in this chapter is the manual search of vehicles. The FBI's Bomb Data Center has defined different search levels for vehicles that are suspected of containing bombs or explosives. In general, the four levels are defined as follows, with Level 1 being the least stringent search and Level 4 the most stringent:

- Level 1 Search: General examination of a vehicle's main compartments.
- Level 2 Search: A thorough and deliberate search of all parts of a vehicle that are visually accessible and accessible by design.
- Level 3 Search: Includes the Level 2 search plus nondestructive disassembly of the vehicle.
- Level 4 Search: Includes the Level 1 through 3 techniques plus destructive disassembly, and might include cutting into upholstery, oil filters, tires, etc.

Needless to say, whenever a vehicle is expected of containing explosives, extreme caution should be exercised, and the vehicle should be held where it is pending the investigation by trained bomb search personnel. The searches listed above can be applied both at entry checkpoints and in cases where isolated vehicles are apprehended.

A Level 1 physical search, also referred to as a general access search because it may be performed routinely before granting vehicles access to a protected area, includes inspection of the following areas/compartments: the trunk compartment, the passenger compartment, the engine compartment, the inside bumpers, the undercarriage and roof, and the wheel wells. This information is covered in slightly greater detail in appendix II.

A Level 2 physical search is much more involved, with a slightly different list of procedures designated for different types of vehicles. These types include (1) automobiles/pickups/station wagons, (2) trucks, (3) special equipment, and (4) rail cars. Appendix II gives detailed information about the specific parts of a vehicle that should be investigated in a Level 2 search.

Manual Search of Buildings and Property (Bomb Threats)

Manual search of buildings or other property most often occurs after a bomb threat has been communicated, and is often the task of specially trained units. However, since a unit with the proper training may not always be available immediately, a brief introduction to this topic is useful.

It cannot be overemphasized that facilities such as police stations, courthouses, etc., need to have a plan of action *prepared in advance* in case a bomb threat is received. This will allow for a coherent response and will help minimize danger to personnel.

Many factors need to be considered in developing a bomb threat plan, including the physical size of the premises, the number of employees and other persons likely to be on the premises at any given time, the physical construction of the building(s), the number and type of exits from the building, and whether there are any materials on the premises that may pose a special hazard if a bomb were to be detonated (e.g., flammable or combustible materials). To have an effective bomb threat plan, input should be obtained from all interested parties, including management/ supervisory personnel, onsite employees, maintenance personnel, security personnel, and public safety officials.

Upon receiving a bomb threat, an effort has to be made to evaluate the credibility of the threat and to obtain as much information as possible. A standard list of procedures and questions to ask should be made available to all employees and posted near telephones. If a threat is received via telephone, the person receiving the call should keep the caller on the line as long as possible, and obtain as much information as possible about the nature of the device and its location. At the same time, he or she should try to have a coworker call 911 and alert building management, and then (if possible) the coworker should listen to the conversation on another line. In evaluating the credibility of the threat, it will be important to determine how much technical knowledge the caller has demonstrated, whether similar threats or attacks have been made recently, and whether recent events at the locale (e.g., a highly publicized trial at a courthouse) may lead to an increased likelihood of terrorist acts.

If a bomb threat is communicated, the first priority should always be the safety of those persons on the premises. Evacuation procedures must be in place and should be carefully followed if evacuation is deemed necessary.

The search of a building or grounds can be overt or covert in nature and may involve building security personnel or a special team. It may occur prior to evacuation in certain cases; for example, when an evacuation would be excessively time consuming or when the bomb is believed to be small enough that a complete evacuation is unnecessary. The search should be as thorough as possible over all areas where the bomb may be present and should be conducted or assisted by persons having intimate knowledge of the building. Explosives-sniffing canines should be used to supplement the physical search whenever possible, since dogs represent the detection technique best suited to finding a hidden bomb.

Additional Information

Those interested in additional details concerning manual search techniques can contact the authors of this document or Mark E. Christensen of Idaho National Engineering and Environmental Laboratory at 208–526–1240.

Chapter 8. Summary, Future Outlook, and Advice for Buyers

The explosives detection techniques discussed in this document are expected to remain the principal important techniques for use in law enforcement and other applications for at least the next several years. While new technologies will undoubtedly appear on the scene, there is usually a gap of 3 to 5 years between the appearance of a new technology and its commercialization for widespread use. Furthermore, new technologies are likely to supplement rather than replace existing technologies, which in many cases have had the benefit of years of research and development and have developed extensive user bases. The nontechnological techniques, such as canine detection and physical (manual) search, will also undoubtedly continue to be widely used, due to their broad applicability, distinct strengths, and cost effectiveness. We anticipate a trend toward somewhat greater specialization, but the techniques that are currently in wide use will not be displaced.

As far as the current trace detection techniques are concerned, we expect that the major trend will be toward the development of more easily portable miniaturized units, rather than toward greater sensitivity. The sensitivity of the current-generation state-of-the-art systems is already adequate for most applications where collection of samples by swiping is possible and, in some cases, borders on overkill. Miniaturization should combine with greater mass production to lead to significant cost reductions for some equipment. Portal technology can be expected to continue to improve as more effective methods for the noninvasive collection of explosives residue from people continue to be developed.

Similar trends will probably also take place in the continuing development of bulk detection equipment. In this case, the issues with personnel portals will include both noninvasiveness (i.e. respect of privacy) and the health effects (or perceived health effects) of the incident radiation. Computer tomography should continue to be developed for baggage screening and possibly other applications, with cheaper systems being produced than those currently available.

Another likely future trend is the development of portals and other devices that combine two or more detection technologies into a single system. Such systems can potentially enhance security significantly, because the detection technologies can be chosen such that one tends to counterbalance the weaknesses of the other. Several systems of this type are already proposed or in the early stages of development.

As stated above, the “low-tech” techniques of canine detection and physical search will continue to play important roles in explosives detection. While technological systems will improve, it is unlikely that anything will be developed in the next few years that matches the quickness and accuracy of a dog in going to the source of explosives vapor. Physical search will continue to be widely used in applications where screening time is not an overriding concern, if for no other reason than because it is cheap.

The first chapter of this document discussed issues that need to be borne in mind by purchasers of explosives detection equipment, but a few general points need to be stated or reemphasized here. Paying attention to these points should aid any law enforcement agency in procuring the types of detection systems that it really needs.

(1) Talk to the vendor of the product(s) you want to buy. The vendors are the most knowledgeable sources of information on the products that they sell, and can give excellent advice on applications. Vendors should also be able to refer you to similar customers who have purchased and used their product, and talking to these other customers can give you a less biased opinion from someone with hands-on experience with the vendor's product. Make sure that the customers you talk to have been using the equipment long enough to have a good grasp of the pros and cons. You should also ask the vendor who some of their competitor companies are and what the vendor company thinks makes its product unique or superior. Discussions with the competitors are usually also useful. Refusal of a vendor to give any information on who their competitors are *might* be a warning sign that the vendor is being less than totally candid.

(2) Always consider maintenance and other long-term costs in addition to purchase cost. Maintenance costs have not been emphasized in this document, both because they tend to be minor for many trace and bulk systems and because they are somewhat more variable and difficult to pin down than purchase cost. Nevertheless, these costs need to be considered when purchasing a system, and in some cases (e.g., canines) maintenance efforts can be substantial. The best source of information is the vendor company.

(3) Seek advice from a disinterested third party who has expertise in explosives detection. This advice could be sought by consulting a document such as this one, or through personal correspondence or phone conversations. Such advice is particularly important if discussions with vendors and other customers leave you with important questions still unanswered. Possible sources of information include the National Institute of Justice, the FBI, other law enforcement agencies, and the authors of this document. (The authors have recently been involved with the development of a walk-through explosives trace detection portal, and therefore, may not represent a totally disinterested third party.)

(4) Remember that the market for explosives detection equipment is evolving rapidly. This is especially true for trace and combined technology detection systems. Always determine your key needs and then choose a system that can meet these needs as well as possible for several years so that, no matter what new products are introduced during that time, you will still have something that is a real-life asset. Furthermore, it is a good idea to ask vendors what new products they are developing (if in fact they do not volunteer such information). It may be that by delaying a purchase for 6 months or a year, you can obtain a product that is better than anything currently available.

(5) Be wary of unknown companies selling radically new technologies that seem to make unprecedented claims about detection capabilities. Some such claims may prove to be correct, but other claims may be erroneous or, in extreme cases, fraudulent. In such cases, it is especially critical to obtain the advice of an outside expert before a purchase is made. Discussions with other customers may be less useful if the product is new and if those customers do not fully understand the technology. Try to find out if the equipment in question has been independently tested by a government laboratory or university, and discuss the matter with the people who have performed that testing.

Appendix I. Basic Information on Explosives

This appendix contains some basic information on the nature of explosives, explosive trains, initiators, various effects of explosions, and some applications of explosives.

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 who find themselves involved in the prevention and control of the illegal use of explosives.

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 5 miles per second. Temperatures generated by the conversion of a solid into a gas state may reach 3,000° to 4,000° 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 nucleus 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 20,000 tons (20 KT), or 40 million pounds, of TNT in explosive power, yet the amount of fissionable material required to produce this energy weighed approximately 2.2 pounds. 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 that 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 rapid 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 9,000 feet per second to more than 27,500 feet per second. As an illustration of detonation velocity, if a 5-mile (26,400 feet) length of garden hose were filled with RDX (detonation velocity 27,500 f.p.s.) and initiated at one end, the detonation would reach the other end of the 5-mile-long hose in less than 1 second.

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 that 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 microseconds). These gases exert pressures of about 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 7,000 miles per hour, 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 100 feet 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 200 feet 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 that 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 2 feet 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 that have occurred 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 that 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 (2,700 feet per second) 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 that 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 that 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 contain 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. Because 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 3,280 feet per second (f.p.s.). For example, black powder has a rate of approximately 1,312 f.p.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 3,280 feet per second. There is a wide range in the detonation velocities of high explosives, extending from some dynamites at 9,000 feet per second up to RDX at 27,500 feet per second.

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 (1,312 f.p.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 or she might place a TNT (23,000 f.p.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-degree angle from the surface of the explosive. Consequently, if the explosive is cut or shaped to provide 90-degree 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 was the primary user 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 firefighters 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 15-pound M2A3 shaped charge and the 40-pound 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 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 16,500 f.p.s. for mercury fulminate to 21,700 f.p.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 9,000 f.p.s. for some dynamites to 26,000 f.p.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 ½ inch 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 25-pound metal kegs. For commercial blasting, black powder is also pressed into cylinders measuring 2 inches by 1 1/4 inches. Some cylinders have a 3/8-inch 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 8 inches in length and packed in 25- and 50-pound 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 seconds per foot, while a less common type is designed to burn at the rate of 30 seconds per foot. 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 waterproofing materials and color markings. Commercial safety fuse is approximately 0.2 inches in diameter, about the size of a lead pencil, and comes in 50-foot, 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 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 ensure 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 25 pounds.

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 that 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 that 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 1 1/8-inch long, with an outside diameter of 1/4 inch. Number 8 blasting caps have the same diameter and are about 1 1/4-inch long. Electric blasting caps with leg or lead wires 24 feet 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 4 to 300 feet, are made of 22 gauge copper wires for lengths up to 24 feet 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 to 1.5 milliseconds 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 1 3/8 inches long and Number 8 are 1 1/2 inches long with outside diameters of approximately 1/4 inch. Some nonelectric caps may be larger. For example, the standard issue U.S. Army Corps of Engineers Special Number 8 blasting cap is 2.35 inches long and 0.241 inches 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, 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 grains of PETN per foot. Detonating cords up to 400 grains 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 grains 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 200 feet apart in a straight line would require a minimum of about 1,800 feet 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 21,000 feet or nearly 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 ounces up to a pound 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 24,500 f.p.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 4 ½ by 5/8-inch 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 that 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 is usually 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 1 1/8 to 1 1/2 inches in diameter and are about 8 inches long. In less common larger sizes, dynamite cartridges may be 4 to 6 inches in diameter and up to 38 inches 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 to 60 percent, with the more common ratings being 30, 40, 50, 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 1 1/4 by 8 inches for use in ditch blasting. The principal characteristic of ditching dynamite is its high detonation velocity of over 17,000 f.p.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. This produces a dynamite that is lower in cost and less sensitive to shock and friction than straight dynamite. Since it has less shattering effect, ammonia dynamite is more suitable for pushing or heaving 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 to 60 percent, with detonation velocities in the range of 7,000 to 9,000 f.p.s. However, special-purpose formulas producing velocities from 6,500 to 12,200 f.p.s. can be obtained.

When the wrapper is removed, ammonia dynamite appears light tan to light brown in color and has 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 nor desensitized by water. Since it is insoluble in water and tends to be waterproof and bind with 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 rock or ore.

Gelatin dynamites and semi-gelatin dynamites are manufactured in percentage strengths from 20 to 90 percent. It is an inherent property of gelatin dynamite to detonate at two velocities. Unconfined, it will usually detonate at about 7,000 f.p.s., but when confined, gelatin dynamites will detonate in the range of 13,000 to 22,000 f.p.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 to 90 percent with detonating velocities ranging from about 13,000 to 17,000 f.p.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 20,000 f.p.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 that 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 11,000 f.p.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, fairly safe to handle and transport.

One group of blasting agents is called nitro-carbo-nitrates or 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 that provide water resistance as long as the containers are not opened or damaged. Container sizes range from 4 to 11 inches in diameter, 16 to 24 inches in length, and weigh from 13.5 to 85 pounds. NCN is similar to 50- 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 is 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 approximately 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. When the bottle cap is pressed down, cutters automatically puncture the liquid-filled can. When the bottle is inverted and shaken, 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, Washington 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.

TNT (Trinitrotoluene). 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 1/4-pound, ½-pound, and 1-pound blocks. These blocks are normally packed in 50-pound 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 by the armed services as an alternative to TNT 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 24,000 f.p.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 that 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 24,000 f.p.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 that 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 flashbulbs 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 blast 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 that is not mixable with and about 1.6 times heavier than water. It may range from clear and colorless to amber in color and has even appeared 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 semi-frozen 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.

Appendix II. Vehicle Search Techniques

This appendix is a procedure outlining manual or physical search techniques as recommended by Mark Christensen of Idaho National Engineering and Environmental Laboratories (INEEL).

Vehicle Search Levels

Emergency Procedures for Searching Vehicles Suspected of Containing Explosives or Bombs (Bomb Search Procedures, the Bomb Data Center)

Level 1 Search. This includes general examination of a vehicle's main compartments (engine, truck, cargo, passenger cab, undercarriage, etc.) and may be supported with the use of a special nuclear material and/or explosive detector. Failure of the vehicle to pass this search could result in certain alternatives (access denial, arrest, Level 2, 3, or 4 searches, or impoundment as appropriate).

Level 2 Search. A thorough and deliberate search of all parts of a vehicle that are visually accessible and accessible by design (opening trunks, tire compartments, engine, trunk, cargo compartments, glove compartments, etc.). This search should be conducted with mirrors, flashlights, flex-scopes, etc., as required to assure coverage. This search may also be supported with the use of a special nuclear material detector and/or explosive detector.

Level 3 Search. This search level includes the Level 2 search plus nondestructive disassembly of the vehicle. There should be specific justification for the search to progress this far (for example, suspicious activities of the vehicle driver and/or passenger, or positive explosive detector indications). Disassembly might include removal of hubcaps, air cleaners, head and tail light lenses, panels, etc., which can be accomplished without damage to the vehicle. It is also possible that this may be carried out utilizing nondestructive x-ray techniques. Search could be authorized by the security supervisor.

Level 4 Search. This search level includes the previous Level 1 through 3 techniques plus destructive disassembly and might include cutting into upholstery, oil filters, tires. etc. If a Level 4 search is indicated, access of the vehicle into the area should be denied.

Note: If a vehicle is suspected of harboring any explosives, extreme caution should be exercised, and the vehicle should be denied access pending examination by trained bomb search personnel.

SEARCH PROCEDURE
Level I Physical/Hand Search—Automobile

1. Trunk Compartment (including behind seat, storage, etc.).
   a. Luggage, parcels, packages.
   b. Tool boxes.
   c. Around spare tire.
   d. All interior surfaces and voids.
   e. Fuel cans and air cylinders (off-load fuel cans and other incendiary materials).

2. Passenger Area.
   a. Luggage parcels, packages.
   b. Under dash.
   c. Under seats (visible areas).
   d. Glove compartment and contents.

3. Engine Compartment.
   a. Underside of hood.
   b. General fire wall, behind grill, and engine area (look for unnecessary components, type, etc.).

4. Inside bumpers (front and back).

5. General undercarriage and roof (check carefully around fuel tanks).

6. All (4) wheel wells.

Trucks (General)

SEARCH PROCEDURE
Level 1 Physical Search—Trucks

1. Cargo Area.
   a. Parcel, package, and equipment, etc.
   b. Ceiling, walls, and floor (walk-through).
   c. Noncargo containers, tool boxes, etc. (off-load fuel cans).

2. Passenger Area.
   a. Parcels and packages.
   b. Luggage.
   c. Under seat and behind seat (fold up/down seats).
   d. Sleeper area.

3. Glove compartment and cab storage areas.

4. Engine.
   a. Open hood or cab cover. Search readily accessible areas.

5. General framework, undercarriage and wheel assemblies, tool boxes, wheel wells, etc. (Check around fuel tanks very carefully.)

6. Bumpers, steps, and running boards.

7. Roof of cab and cargo box/trailer.

8. Check external trailer compartment length, depth, etc., to assure that false panels capable of concealing personnel are not built in.

The search areas noted below are in addition to those specified for trucks (general):

Tank Trucks

1. Check hose compartments.
2. Check pump compartments.
3. Check filler cap area.

Gas Cylinder Delivery Truck

4. Inspect generally between cylinders (assure that only cylinders are present and that they appear normal).

Multicompartment Service Truck

5. Check each compartment and contents.

Emergency Vehicles

6. Check compartments and/or treatment area.
7. Check hose storage area.

Cask Shipping Trailers

8. Inspect around cask-holding mechanism and special cask trailer apparatus.
9. Assure casks are sealed.

Safe, Secure, Transport (SST) Shipments (no authority to search)

10. Check or have courier verify that seals are intact.
11. Inspect SST tractor-trailer and escort vehicles for any abnormalities.

SEARCH PROCEDURE

Level 1 Physical Search—Rail Cars

Couriered coaches, locomotives, cabooses, and special nuclear-material cars do not require searches.

Couriered Rail Shipments

1. Seals on cask or fuel assemblies, etc., that are under escort by courier should be checked prior to release or acceptance.

2. All couriered rail cars and locomotives that enter the protected area should be inspected for abnormalities during pickup and delivery. Shipping car inspection as below when not in custody of couriers (once released or before assumption).

Noncouriered Rail Shipments (cars picked up or delivered)

1. Check seals on casks, fuel assemblies, or special nuclear material container.

2. Inspect wheels (inside and outside).

3. Inspect behind trucks.

4. Inspect undercarriage of bed. Search channel and "I" beams, side sills, floor supports, and coupling shank.

5. Check around containers, dunnage, equipment, materials, etc.

Box Car (in addition to Noncouriered Rail Shipment Search)

6. Inspect interior walls, floor, ceiling, door.
7. Inspect roof and walkway.
8. Inspect exterior surface. Check any voids and access panels.

Tank-Type Car (inspect carefully and closely in addition to Noncouriered Rail Shipment Search)

9. Inspect hose lockers or pump mechanism panels.
10. Inspect fill, port area, and walkway.
11. Inspect surface of tank for unusual attachments.
12. Inspect channels and voids created where tank joins carriage or bed.

SEARCH PROCEDURE
Level I Physical Search—Special Equipment

1. Check engine compartments.
2. Check air storage and tool compartments.
3. Check undercarriage (all the way around).
4. Inspect under seats and cushions.
5. Check behind track mechanisms.
6. Inspect battery compartments.
7. Check all booms and masts.
8. Inspect behind wheels.
9. Inspect fender wells.
10. Check all roofs.

SEARCH PROCEDURE
Level 2 Physical Search—Automobile/Pickup/Station Wagon

A. Front Section:

   1. Front license plate: Examine area behind license plate.

   2. Front directional lights (two locations): Examine cover. Be alert for indication of recent installation.

3. Front bumper: Examine inside surface. If bumper is close to auto structure, use an inspection mirror.

4. Grill work: Examine between and inside of the grill work.

5. Headlights (two locations): Be alert for indications of recent installation.

B. Side Section (both sides—repeat the following on other side of car):

6. Front side lights: Examine lamp cover. Be alert for indications of recent installation.

7. Front hubcaps: Remove and examine cap and wheel and/or inspect for recent removal.

8. Front wheel wells: With the aid of a flashlight and inspection mirror, examine inside of wheel well. Contraband has been found attached by magnets to the inside surfaces of wheel wells.

9. Door handles: Examine underneath.

10. Rear hubcaps: Remove and examine cap and wheel and/or inspect for recent damage.

11. Rear wheel wells: Same as search point #8.

12. Rear side lights: Same as search point #6.

13. Window cutouts: Roll windows down and look down into the interior of the door where possible.

14. Surface of doors: Open door and examine underside for possible cutouts.

15. Front side of doors: Open door and examine front side of door and adjacent structure of auto for possible cut-outs.

16. Rear side of doors: Open door and examine rear side of door and adjacent structure of auto for possible cut-outs.

C. Rear Section:

17. Rear license plate: Examine area behind license plate.

18. Rear bumper: Examine inside surface of bumper. If bumper is close to auto structure, use an inspection mirror.

19. Tail lights and back-up lights (right and left): Examine inside of lamp covers. Be alert for indications of recent installation.

20. Fuel filler neck: Remove cap and examine inside for possible suspension of contraband into the neck. Be cautious of volatile fuel fumes. Confirm presence of gasoline or diesel fuel. Assure no smoking in area while this is done.

D. Engine Compartment:

21.Battery: Examine area under and around battery.

22.Voltage regulator: Examine cover for signs of recent installation.

23. Air filter: Examine for indications of recent installation. Examine the “thumb” type hold-down nut and area immediately adjacent for signs of tampering. The air filter is not a vital engine part, and the inside filtering element can be easily removed and replaced with contraband material.

24. Oil filter: Examine for indication of recent installation or modification. The oil filter is not a vital engine part, and it is possible to internally modify an oil filter so as to bypass the engine oil and leave the interior of the filter hollow for the concealment of contraband.

25. Windshield washer liquid container: Examine the interior with the aid of a flashlight.

26. Radiator filler neck: Examine inside for possible suspension of contraband packages. Be extremely careful when removing cap. Wrap your hand in a large towel or use an insulated rubber glove and stand back. This is a hazardous operation.

27. Grill work: Search area around and inside the grill.

28. Hood cover and entire engine compartment structural work: Examine around and under all structural members and engine components for possible attachment of contraband packages. Examine inside of "weight reduction" holes in stiffener members attached to under surface of hood.

E. Passenger Compartment:

29. Glove compartment: Examine interior and contents.

30. Entire dash panel: With the aid of an inspection mirror and flashlight, examine the entire space behind the dash panel.

31. Ventilation and heating ducts: With the aid of a flashlight, inspection mirror, and/or the fiber scope, examine the inside of the outlet housing and ducts. Be alert to signs of recent installation. This is a prime search point.

32. Floor mats and back side of control pedals: Examine the underside of all floor mats. Examine back side of control pedals for attachment of contraband packages.

33. Front seats: Examine underneath. With the aid of a flashlight and inspection mirror, look up into cushion springs from the bottom.

34. Bucket seat backs: On most bucket type seats, the inside back panels snap off to expose an area of considerable size.

35. Ashtrays: Remove inside containers and examine contents and space inside of holding structure.

36. Back seat: Remove back seat. Examine cushions and springs area. Most back seats easily snap out by pulling up on forward edge.

37. Rear seat back: With back seat removed, look up into area behind seat back and auto structure. Also check under fold-down seats.

38. Top of passenger compartment (sun visors, mirror, dome light, and header): Examine sun visors and behind the same; behind rear view mirror; and dome light assembly for signs of

recent installation. Examine header for slits and bulges.

F. Trunk Compartment (and related storage compartments):

39. Trunk roof: Examine trunk roof forward and under rear window deck.

40. Spare tire: Loosen spare tire and examine area under tire. Be alert to signs of recent work on tire and rim. Check for air pressure.

41. Trunk bottom covering: Examine underneath.

42. Recessed space behind rear wheel well: Some automobiles have a recess in the area behind the rear wheel well. This recess is usually covered with a cardboard panel and the trunk bottom covering and gives the trunk a continuous flat appearance.

43. Tail light assembly covers: The lamp assemblies of most tail lights are accessible by removing the back cover, which is located in the trunk. Be alert to signs of recent installation.

44. Bottom surface of trunk lid: Examine inside of "lightening" holes in stiffener members attached to underside of trunk lid.

G. Under Structure:

45. Front gravel panel: Examine inside.

46. Bottom of radiator: Examine for signs of modification work. The appearance of unusual welds, brazing, soldering, and painting could be an indication of possible installation of false bottoms or compartments. This is a prime search point.

47. Wheel wells (four locations): Examine inside surfaces from the bottom.

48. Engine oil pan: Be alert to signs of recent installation; search same details as #46.

49. Muffler: Also be alert to signs of recent installation. Search same details as #46.

50. Fuel tank: Also be alert to signs of recent installations. Search very closely for attached small charges, wires, etc. Search same details as #46.

51. Rear gravel panel: Examine inside.

52. Right rocker panel: Examine for cut-outs and signs of modification.

53. Left rocker panel: same as Search Point #52.

54. Entire framework: With the aid of an inspection mirror and portable lighting, examine the entire under-framework for the attachment of contraband packages by the utilization of tape, wire, or magnets.

SEARCH PROCEDURE
Level 2 Physical Search—Truck—General

1. Bumper and Grill Work.
   a. Attachment of packages to grill work and bumper.
   b. Back of license plate.
   c. Inside of vent openings.

2. Engine Area.
   a. Check for recently worked screw, nut, and bolt fasteners on engine accessory and hose assemblies.

   b. Check for attachment of packages to underside of hood. Check engine block, steering column, etc. Check radiator only if suspicion demands (open cap with caution).

   c. Inside of cowling surrounding fan blades.

   d. Air filter housing

3. Tire and Wheel Assemblies: Check all tire and wheel assemblies for evidence of recent removal. Inspect between dual wheels.

4. Cab Area.
   a. Seat cushions.
   b. Under seats.
   c. Under and behind instrument panel.

d. Inside of glove compartment.
e. Behind stereo-deck assembly. Check tapes, speaker housing.
f. All suitcases and packages.
g. Ash trays.
h. Headliner.
i. Under or behind all foot pedals.
j. Area on top of deck next to front window or windshield.
k. Behind sun visors.
l. Under floor mats.
m. In door panels (roll windows down, shine light into opening).
n. Inside of vent hoses and outlets.
o. Behind seats.

5. Baggage Compartment.
   a. Examine all suitcases and packages.
   b. Check for packages attached to top of compartment.
   c. Behind insulation and padding on compartment.

6. Cab Sleeping Area.
   a. Under mattress.
   b. In pillows.
   c. Between blanket covers.
   d. In ventilation outlets.
   e. In headliner area.

7. Battery Boxes.
   a. In cell compartments. Be careful of acid when removing and replacing caps.
   b. Between battery body and wall of box.

8. Fifth Wheel Area: (Under and around).

9. Trailer Refrigeration Unit (not on all trailers): Examine all compartments.

10. Ice Bunker Compartment (not on all trailers): Access gained by two doors, one on each side, front of trailer. This is a prime spot.

11. Roof—both Tractor and Trailer: Packages attached to roof top. Check entire length. Use ladder or mirror on pole.

12. Under Entire Tractor-Trailer: Check for packages attached to structural framework under entire length of tractor and trailer. Note: Information received from various truck drivers suggests that the attachment of contraband packages to the under-frame of tractors and trailers is a favorite method employed for smuggling activities. Check fuel tanks very closely.

13. Spare Part and Tire Chain Compartment (not found on all trailers): Outside and inside of compartments.

14. Interior of Trailer:
    a. Between side walls, ceiling, and bumper panel (usually plywood).
    b. Check for recently installed screws.
    c. Examine floor for loose flooring and hidden compartments.
    d. Ceiling (for attached packages).

15. Wheel Axles: Check for attached packages.

16. Company Sign Panels (found on most trailers): Check for contraband concealed in spaces between sign and trailer body.

17. Canvas or Plastic Document Pouches: Examine inside and behind.

18. Bumper on Rear of Trailer: Examine the inside of the hollow channels.

19. Trailer—Upward Sliding Door (not on all trailers): Examine portion of inside ceiling that is covered by sliding door when door is in open position. Step into trailer and close door; examine ceiling and door track with the aid of a flashlight.

20. Light Lenses and Reflectors: Located throughout trailer and tractor. Examine visually with the aid of a light source to determine possible inclusion of contraband in space between face glass and bulb. Also check for recently removed hold-down screws.

21. Externally Mounted Air Filter (on some tractor models): Check for recent installation.

22. External Tractor Air Inlets: Examine inside for contraband.

23. Inspect all panels that could conceal personnel, etc. Check thickness of panels. Measure internal depth/length of trailers vs. external depth/length. Differences greater than 8 inches are suspect.

SEARCH PROCEDURE
Level 2 Physical Search—Special Trucks

The search areas noted are in addition to those specified for trucks (general).

Tank Trucks (Note: Tank trucks, particularly those containing flammables, are extremely high-risk sabotage items even without driver involvement.)

1. Inspect hose compartments. Remove hoses if necessary. Use flashlight for long cylindrical hoses and compartments.

2. Check pump and storage compartment (top, bottom, sides, doors, and contents).

3. Check filler cap areas.

4. Check areas between tank and frame.

5. Assure no unusual attachments to tanks.

Gas Cylinder Delivery Truck (Gas cylinders are almost impossible to search in large quantities. Search carefully.)

6. Check between all cylinders.
7. Check cylinders for wiring or attachments. Check all frame platform voids.

Multicompartment

8. Check each compartment and contents.
9. Check any voids behind compartments.

Emergency Vehicles

10. Check all compartments and contents.
11. Check hose storage areas (draft tubes and fire hoses).
12. Check around special apparatus (mattresses in ambulances, rescue equipment).

Cask Shipping Trailers

13. Inspect around and under each cask to assure no attachments, unusual wire, etc.
14. Inspect cask-holding fixtures and stabilizers, and check inside any voids or hollow areas.
15. Inspect each cask seal.
16. Check all "I" beam and channel structures from both outside and inside.

SST Tractor-Trailers

17. Inspect SST tractor seal or have courier verify that it is intact.
18. Observe SST trailer and trailer escort vehicles for any abnormalities.

SEARCH PROCEDURE.
Level 2 Physical Search—Special Equipment

1. Engine Area.
   a. Check air and oil filters for authenticity and recent access.
   b. Check fire walls and cowling for attachments.
   c. Check battery box area.
   d. Check radiator content (extremely hazardous check if equipment has been running, so perform only if suspicious or engine is cold).
   e. Check any tool or spares compartment.
   f. Check heater hoses and ducting.
   g. Assure no attachments to engine or housing.
   h. Check hydraulic tank content. Remove cap and verify that no wires or string are hanging in the tank.

2. Cab or Operating Area.
   a. Inspect seat cushions.
   b. Under or behind seats.
   c. Tool and storage areas.
   d. Behind visors.
   e. Under floor mats.
   f. Inside and around vent hoses and ducts.
   g. Behind dash and instrument panels.
   h. Parcels and packages (lunch kits, thermos bottles, canned and bottled drinks).
   i. Check fuel tank (no smoking). Open and assure gasoline or diesel presence, and that there are no wires hanging in tank.

3. Undercarriage.
    a. Check undercarriage framework voids, access panels, channels, and shelf-like areas.

4. Track Mechanisms and Wheels.
    a. Inspect backside of wheels.
    b. Between double wheels.
    c. Inspect behind track mechanisms and drive wheels.

5. Booms, Masts, and Buckets, etc.
    a. Have booms lowered to check access holes, voids, channels, etc., for items and attachments.
    b. Check blades, buckets, blocks, etc., for attachments.
    c. Check around mast, top of masts, etc.

6. Inspect Battery Compartment (battery powered vehicles).
    a. Open battery compartment, check around batteries, open cells if appropriate.
    b. Check access doors. Check top, bottom, and sides of compartment.

7. Roofs.
    a. Check top of roofs, roll bars, roll cages, etc.

8. Fender Wells.
    a. Check fender wells with mirror or flashlight as required.

9. Special Apparatus.
    a. Check any ballast boxes, compartments, liquid containers, attachment area.
    b. Check footpads/stabilizers.
    c. Check other special apparatus.
    d. Check general hydraulic system, pipes, pumps, valves, reservoirs, etc.

10. Lights.
    a. Inspect around lights for recent installation.
    b. Assure lights are functional type (not false).

SEARCH PROCEDURE
Level 2 Physical Search—Rail Cars

(Courier coaches, locomotives, cabooses, and special nuclear-material cars do not require search.)

Couriered Rail Shipments

1. Seals on cask or fuel assemblies, etc. that are under escort should be checked prior to release or acceptance of the rail car.

2. All couriered cars, switch engines, etc., that enter a protected area should be observed for abnormalities.

Noncouriered Rail Shipments (cars picked up or delivered) and All Rail Cars Not in Custody of Couriers

1. Check seals on casks, fuel assemblies, special nuclear-material containers, etc. Assure they have not been subject to tampering.

2. Inspect all wheels (inside and out). Use mirror or look through the opposite side.

3. Inspect trucks and journal bearing inspection access areas (journal holes). Inspect inside of trucks and any voids of shelf area carefully.

4. Check coupler top, sides, and bottom. Inspect shelf areas or voids.

5. Check all undercarriage beams and supports. Accomplish this with a mirror; view from ends, view from opposite sides and/or crouching under the car. Inspect all access holes and voids in the undercarriage. Look at all shelf areas.

6. Inspect brake cylinders, air storage tanks, etc., in the undercarriage area. Assure that they appear authentic and do not have wires or attachments.

7. Inspect the top of the rail car bed. Check any tool boxes or equipment containers.

8. Inspect around dunnage and rail car cargo.

9. Inspect around casks or special nuclear-material containers and support mechanism. Check all voids, behind braces, within channel, “I” beam, and tubular supports.

10. Check any cooling control instrumentation panels and mechanisms. Assure that coolant storage tanks appear authentic without attachments.

11. Remove or inspect under tarps and dunnage.

12. If equipment or materials are being shipped on the rail car, inspect them thoroughly (access panels, structure, boxes, etc.).

13. If a box car is utilized, check interior walls and ceiling. Inspect between exterior and interior walls. With mirror and light inspect all voids and access areas.

14. Also inspect roof of car.

15. Inspect behind sign panels and doors.

Tank-Type Cars

Note: If a tank car (fuel oil, LPG, or any other chemicals or gas) is to be inspected, check these with extreme care both from a personal safety standpoint and from the fact that they contain tremendous potential energy and could be prime targets for sabotage.

16. Inspect any hose lockers or pump panels.

17. Inspect fill port area and walkways.

18. Inspect the overall surface of the tank for attachments of explosives devices. Check for unnecessary wires, etc.

19. Inspect any channels or voids where tank joins carriage or bed.

SEARCH PROCEDURE (Animal-Assisted)

Typical procedures using search dogs are as follows:

1. Allow dog to run and exercise briefly to become familiar with its surroundings. Attach leash/collar.

2. Have all vehicle doors, hood, trunk, compartments, and any covered openings opened. This assumes that the vehicle has been occupied recently. If not, caution is to be exercised, since opening doors during an actual search can be hazardous (rigged to trigger explosion) if the vehicle is abandoned or unattended.

3. Proceed directly to the downwind side of the vehicle.

4. Start search at a specific point and search in a counter-clockwise manner, paying particular attention to fenders, wheels, wheel wells, hubcaps, bumpers, and door/passenger area.

5. If the dog shows interest in the inside of the vehicle, let the animal go in and complete a search of seats, floorboards, and dashboards. (Reference Step 2 above.)

6. The dog should be directed into and allowed to search the cargo areas.

7. The undercarriage should receive attention. This is difficult on automobiles but readily accessible on larger trucks and railcars.

8. If contraband is suspected, follow specific plan for security incident notification and action.

Note: Follow the specific procedure under which the search animal has been trained. The animal handler/trainer is best qualified in this respect.

Appendix III. Glossary of Terms

Appendix III is a glossary of commonly used terms relating to explosives and explosives detection technologies and equipment.

alarm: a signal given by an explosives detection system (EDS) that indicates to the operator that a detection of explosive material has been made. For a technological system such as an ion mobility spectrometer (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 that 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 explosives detection system (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 one is attempting to study, analyze, or identify.

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.

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.

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 nitro-carbo-nitrates (NCN) mixtures in a gel-like consistency.

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

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.

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

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 that 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 (see definition below), 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 ion mobility spectrometry (IMS) technology, the carrier gas (also called dopant) is a gas that is added to the inlet airflow 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: *see* shaped charge.

certification: a process through which an explosives detection section (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 commercial explosives detection system (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.

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

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

Cordeau Detonant: a brand name for detonating cord (see detonating cord).

CT: *see* 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 (see 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 (see above).

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 17,000 fps.

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: *see* 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 viewed 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: *see* 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 form the basis of most current portal metal detectors.

EDS: *see* explosives detection system.

effective atomic number: for a substance made up of more than one element, the apparent atomic number that results if one treats the substance 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.

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

explosives: compounds or mixtures of compounds that, 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 on the microseconds time frame.

explosives detection system: any device, person, or animal that 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.

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 that 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.

fps, f.p.s.: feet per second, the standard unit for detonation velocities.

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 nitro-carbo-nitrates (NCN) in small pellet or granular form.

gamma rays: high-energy electromagnetic radiation emitted by certain atoms when they are properly stimulated, as in the technique of thermal neutron activation (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: see nitrocellulose.

handler: the individual who works as a team with a dog that is trained to sniff out explosives or narcotics.

HE: *see* 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 that 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 that do not detonate, but rather explode via the process of deflagration.

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

lower limit of detection (LLOD): the smallest amount of explosive of a particular type that a given EDS can detect. It is usually expressed in mass units, such as 10 grams, 5 micrograms, etc.

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 nonzero nuclear spin. These atoms are affected by the application of an external magnetic field and can give rise to a nuclear magnetic resonance (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 ion mobility spectrometry (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 one second, usually written as μsec.

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: *see* 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 (see definition below). Neutrons are neutral (i.e., they have no electrostatic charge).

NG: *see* 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: *see* 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 thermal neutron activation (TNA), nuclear magnetic resonance (NMR), and quadrupole resonance (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 nitroglycerin (NG) on a heart patient who has 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: *see* pulsed fast neutron analysis.

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

picogram: one trillionth of one gram, usually written as pg.

PINS: *see* portable isotopic neutron spectroscopy.

pipe bomb: a homemade bomb in which explosive material is packed into a section of pipe (usually metal). 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 Californium (Cf) source.

portal: a walk-through, booth-like structure that 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.

postblast 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 ready-made ANFO explosive is also marketed under the name “Prills.”

Primacord®: a brand name for detonating cord (see definition above).

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 (see definition above).

probability of detection: the probability that a certain explosives detection system (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 that 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: *see* 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: *see* 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 that 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 that 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 explosives detection system (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: *see* 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 (see definition above).

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 (see definition above).

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 explosives detection system (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 to 100 angstroms (one angstrom = 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 (see definition above).

Appendix IV. References and Reading List

Appendix IV is a list of books, journals, and manuals, some of which were used in the preparation of this document. Listed are several sources of information on explosives and explosives detection for readers who might desire additional information.

General Explosives and Pyrotechnics

Blaster's Handbook. E.I. du Pont de Nemours and Co., 1980.

Bowden, F.P. and Yoffe, A.D. *Fast Reactions in Solids*. Butterworths Scientific Publishing, 1958.

Bowden, F.P. and Yoffe, A.D. *Initiation and Growth of Explosion in Liquids and Solids*. Cambridge University Press, 1952.

Brauer, K. *Handbook of Pyrotechnics*. Chem. Publishing Co., 1974.

Chase, W.G. and Moore, H.K. *Exploding Wires*. New York: Plenum Press, 1959.

Cook, M.A. *The Science of High Explosives*. Reinhold Publications, 1958.

Cooper, Paul W., Kurowski, Stanley R. *Introduction to the Technology of Explosives*. VCH Publishers, Inc., 1996.

Ellern, H. *Military and Civilian Pyrotechnics*. Chem. Publishing Co., 1968.

Encyclopedia of Explosives and Related Items. PATR-2700, Picatinny Arsenal.

Explosive Trains. Army Materiel Command Pamphlet 706-179, March 1965.

Explosives and Rock Blasting. Atlas Powder Co., 1987.

Fickett, W. *Introduction to Detonation Theory*. University of California Press, 1985.

Fickett, W. and Davis, W.C. *Detonation*. University of California Press, 1979.

General Information Bulletin 97-1. FBI Explosives Unit-Bomb Data Center.

Journal of Energetic Materials. Wharton, New Jersey: Dowden, Brodman, and Devine Publishing.

Journal of Propellants, Explosives, Pyrotechnics (official journal of the International Pyrotechnics Society). VCH Publishing, Weinheim, FRG.

Journal of the Society of Explosives Engineers.

Kohler, J., Meyer, R. *Explosives*. VCH - Verlagsges. Weinheim, FRG, 1993.

McLain, J. *Pyrotechnics*. Franklin Institute Press, 1980.

Military Explosives. TM 9-1300-214/TO 11A-1-34. Departments of the U.S. Army and the U.S. Air Force, (Rev. December 1970).

Principles of Explosive Behavior. Army Materiel Command Pamphlet 706-180, April 1972.

Walters, W.P. and Zukas, J.A. *Fundamentals of Shaped Charges*. John Wiley and Sons, Inc., 1989.

Yinon, J., Zitrin, S. *The Analysis of Explosives*. Pergamon Press, 1984.

Explosives Detection

American Science and Engineering, Inc. Product Sales Literature. Internet: http://www.as-e.com.

Barringer Instruments, Inc. Product Sales Literature.

Control Screening. Product Sales Literature. E-mail: csllc@trib.infi.net.

CPAD Technologies, Inc. Product Sales Literature. Internet: http://www.cpadtech.com.

EG and G Astrophysics. Product Sales Literature. Internet: http://egginc.com.

Eiceman, G.A. and Karpas, Z. *Ion Mobility Spectrometry*. CRC Press, Inc., 1994.

Elias, L. and Newdorfl, P. *Laboratory Evaluation of Portable and Walk-Through Explosive Vapor Detectors*. Proceedings from the 3rd Symposium on the Analysis and Detection of Explosives.

Mannheim-Nenostheim, FRG, 1989.

Entry-Control Systems Technology Transfer Manual. Sandia National Laboratories, 1989.

Fishbein, R.H. “Pulsed Fast Neutron Analysis.” *National DEFENSE* (May/June 1997).

Graseby Security. Product Sales Literature. E-mail: arhodes@ds5200.gradyn.uk.

Hannum, D.W. *Performance Evaluations of Commercial Explosive Vapor Detectors*. Sandia National Laboratories, SAND96-0207, 1996.

Hannum, D.W. *Performance Evaluations of Commercial Explosives Vapor/Particulate Detectors.* Sandia National Laboratories, 1996.

Hannum, D.W. *Performance Evaluation of Ion Track Instrument's Vapor Intensifier for Plastic Explosive Recognition (VIPER)*. Sandia National Laboratories, SAND93-1058, 1994.

Heimann Systems, a Division of Siemans Components, Inc. Product Sales Literature.

InVision® Technologies, Inc. Product Sales Literature. Internet: http://www.invision-tech.com.

Ion Track Instruments, Inc. Product Sales Literature.

Lixi Inc. Internet: http://www.lixi.com.

McLuckey, S.A., Goeringer, D.E., Asano, K.G., *Atmospheric Sampling Glow Discharge Ionization and Triple Quadrupole Tandem Mass Spectrometry for Explosives Vapor Detection*. Oak Ridge National Laboratory, 1993.

MinXray, Inc. Product Sales Literature.

Nicolet Imaging Systems. Product Sales Literature. Internet: http://www.nicing.com/s1000.html.

Physical Protection Systems Design Methodology. Sandia National Laboratories, 1996.

Proceedings from the First International Symposium on Explosives Detection Technology. Sponsored by the FAA, November 1991.

Proceedings from INMM Annual Meetings, 1996, 1997.

Proceedings from Sandia National Laboratories Explosives Detection Workshop. Sponsored by the DOE, March 1997.

Proceedings from the Second Explosives Detection Technology Symposium and Aviation Security Technology Conference. Sponsored by the FAA, November 1996.

Proceedings from The Third Workshop of the International Civil Aviation Organization (ICAO) Ad Hoc Group of Specialists on the Detection of Explosives. Sponsored by the FAA, October 1995.

Rapiscan Security Products, Inc. Product Sales Literature. Internet: http://www.rapiscan.com.

Science Applications International Corporation. Product Sales Literature. Technical Briefs. Internet: http://www.saic.com.

Scintrex, Ltd. Product Sales Literature. Internet: http://www.scintrexltd.com.

Thermedics Detection, Inc. Product Sales Literature. Internet: http://thermedics.com.
E-mail: sales@thermedics.com.

Vidisco, Ltd. Product Sales Literature.

Vivid Technologies Inc. Product Sales Literature.

XID Corporation. Product Sales Literature.