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Law Enforcement and Corrections Standards and Testing Program

Guide for the Selection of Drug Detectors for Law Enforcement Applications

NIJ Guide 601–00

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The Law Enforcement and Corrections Standards and Testing Program is sponsored by the Office of Science and Technology of the National Institute of Justice (NIJ), U.S. Department of Justice. The program responds to the mandate of the Justice System Improvement Act of 1979, which directed NIJ to encourage research and development to improve the criminal justice system and to disseminate the results to Federal, State, and local agencies.

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FOREWORD

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

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

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

Technical comments and suggestions concerning this report are invited from all interested parties. They may be addressed to the Office of Law Enforcement Standards, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8102, Gaithersburg, MD 20899_8102.

Dr. David G. Boyd, Director
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COMMONLY USED SYMBOLS AND ABBREVIATIONS

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

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

PREFIXES

d	deci (10^{-1})	da	deka (10)
c	centi (10^{-2})	h	hecto (10^2)
m	milli (10^{-3})	k	kilo (10^3)
μ	micro (10^{-6})	M	mega (10^6)
n	nano (10^{-9})	G	giga (10^9)
p	pico (10^{-12})	T	tera (^{1012})

COMMON CONVERSIONS
(See ASTM E380)

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

Temperature: $T_{\_C} = (T_{\_F} - 32)\_5/9$
Temperature: $T_{\_F} = (T_{\_C} \_9/5)+32$

EXECUTIVE SUMMARY

This document surveys the field of contraband drug detection, with emphasis on different types of drug detection methods available and current commercial sources for detection equipment. The introduction includes background information on the problem of contraband drugs in the United States, the various applications of drug detection, and a discussion of considerations that are important in choosing a drug detection system. Key factors that should always be considered in selecting a drug detection system include (but are not necessarily limited to) the following: purchase cost; maintenance costs; throughput rate (related to screening speed); sensitivity of the system to different types of drugs; system portability; ease of use, including training and maintenance requirements; associated safety and environmental issues; and if the system is to be used to screen people, human factors that might interfere with use of the system, such as invasion of privacy concerns. Above all, it is important to bear in mind the specific applications for which the system will be used, such as whether it will be used primarily for checkpoint screening or for more wider-ranging searches or whether it will be used primarily for screening people, hand-carried articles, mail, vehicles, or some other type of item. Prior to making a purchase, it is highly recommended that buyers consult with product vendors and, if possible, with a neutral party that has expertise in the area of contraband drug detection.

The core of this document is made up of four chapters on four major types of drug detection: trace detection technologies (mechanical "sniffers"), canine detection, bulk detection technologies (e.g., x-ray and other imaging techniques), and manual search techniques. In the discussion of trace and bulk detection technologies, general background information is given to define terms and discuss problems. For individual technology-based detection techniques, there is, in most cases, a brief technical discussion of how the technique works. It is hoped that the discussion is not too technical, but those who find it too technical can skip the discussion. Those looking for more detailed information can consult the references listed in appendix 3. After the discussion of how the technique works, more practical information is given on the commercial availability of the technology along with issues such as cost, portability, and most suitable applications. Some information is compiled into tables. Web sites for a number of companies making both trace and bulk detection systems are listed in appendix 3.

In addition to appendix 3, there are two other appendices. Appendix 1 gives basic background information on common drugs of abuse, and appendix 2 provides a glossary of terms. The latter appendix should be useful to nontechnical readers who may not be familiar with the terminology used in discussing detection techniques.

GUIDE FOR THE SELECTION OF DRUG DETECTORS FOR LAW ENFORCEMENT APPLICATIONS*

1. INTRODUCTION

1.1 About This Document

This guide presents information about commercially available drug detection technologies and methods in a format that law enforcement agencies may find useful. The information can serve as a starting point for organizations wanting to become informed about the options they have when planning to procure equipment for the detection of illicit drugs. The emphasis is on what different technologies can do rather than on a detailed scientific explanation of how they work, and most of the material should be understandable to laypeople who have no experience in the field of drug detection. A limited amount of material is included that explains how different technologies work, but this information is presented primarily for background purposes. Readers who find it too technical can ignore it and still make use of the rest of the document. This document is not intended to be a reference guide for information about drugs, but some general introductory material is included in appendix 1.

This guide deals with the detection of contraband drug material and does not consider the detection of legal drugs of any type. It focuses on the most common and widely abused illicit drugs, such as cocaine, heroin, marijuana, methamphetamine, and LSD. The discussion is concerned primarily with the detection of macroscopic quantities of drugs in real-world settings, such as where they are bought and sold on the street or smuggled across border checkpoints. Detection of ingested drugs by techniques such as urinalysis is not considered in detail, since such techniques are of little practical value to the police officer on the street and are normally performed by medical or laboratory professionals.

There will inevitably be cases for which more information is desired. For this purpose, the guide includes a list of reference materials in appendix 3. Organizations desiring additional information are also encouraged to contact the authors of this document by phone or e-mail (see sec. 6.3).

1.2 The Problem of Contraband Drugs in the United States

Law enforcement agencies are fully aware that drug abuse and illegal trafficking in drugs are among the Nation's most serious problems. It is estimated that approximately 14 million Americans (or about 6 % of the population) currently use illegal drugs. It is sobering to consider some additional statistics associated with drugs and drug use in this country. The Web page of

* The products, vendors, and services listed in this document are those known to the authors as of June 1999. Inevitably, in a survey document of this type, some products and/or vendors may be overlooked. Listing of a product or vendor does not constitute an endorsement of that product or vendor either by Sandia National Laboratories nor by NIST, and no bias toward any product or vendor vis-a-vis any other product or vendor is intended.

the White House Office of National Drug Control Policy (ONDCP), Drug Policy Information Clearinghouse, provides the following information:

- A 1996 survey by the Substance Abuse and Mental Health Services Administration (SAMHSA) showed that 74 million Americans aged 12 and older had used an illicit drug at least once in their lifetime. This corresponds to nearly 35 % of the population. Furthermore, 10.8 % reported drug abuse during the last year, and 6.1 % reported use within the last month.
- For respondents in the 18– to 25–year-old range, 48.0 % reported illicit drug use at some point in their lives, while 53.1 % of the population aged 26 to 34 had used illicit drugs.
- A 1997 survey conducted by the National Institute on Drug Abuse (NIDA) concluded that 54.3 % of high school seniors nationwide had used an illicit drug at least once in their lives. Nearly half (49.6 %) reported use of marijuana, while 16.5 % had used stimulants, 13.6 % had used LSD, and 8.7 % had used cocaine.
- In 1996, the SAMHSA Drug Abuse Warning Network (DAWN) reported 487 600 drug-related episodes in hospital emergency rooms across the Nation. In 1995, 9 216 drug abuse deaths were reported by medical examiners in 41 metropolitan areas.
- A 1991 survey by the Bureau of Justice Statistics (BJS) reported that 49 % of State prison inmates committed their offenses while under the influence of drugs or alcohol, and 17 % committed their offenses to get money to buy drugs.
- In 1996, the Federal Bureau of Investigation (FBI) reported 1 506 200 State and local arrests for violations of drug laws in the United States. This compares with 937 400 arrests in 1987 and accounts for nearly 10 % of all arrests.
- In FY 1996, Federal agencies seized 1 535 kg of heroin, 15 008 kg of hashish, 115 541 kg of cocaine, and 649 965 kg of marijuana.
- The Administrative Office of the U.S. Courts reported that, of the 54 540 defendants convicted in Federal courts from July 1996 to June 1997, 19 360 (36 %) were convicted of Federal drug offenses. Of these, 17 718 were sentenced to imprisonment. The average sentence length was 80 months, and 228 defendants received life sentences.
- Drug offenders made up 23 % of the State prison population in 1995, up from only 6 % in 1980. In Federal correctional facilities, drug offenders made up 60 % of the population as of October 31, 1997 up from 25 % in 1980.
- Approximately 560 800 adults were on probation for drug offenses in 1995, accounting for 21.4 % of persons on probation.
- According to the U.S. Department of State's 1997 International Narcotics Control Strategy Report, the worldwide production of drugs in 1996 included 4 285 metric tons of opium, 303 600 metric tons of coca leaf, and 11 389 metric tons of marijuana.
- ONDCP reports that Federal spending on drug control programs amounted to $16 billion in 1998 and that State and local governments spent $15.9 billion on drug control activities in FY 1991. (More recent numbers are not available.)

These statistics give an indication of how serious and widespread the problem of illicit drugs has become. For this reason, it is imperative that law enforcement agencies be up-to-date concerning drug detection technologies that are available to them.

1.3 Applications of Drug Detection

Drug detection has a wide variety of applications, including the following:

(1) Screening suspects who have been apprehended. This may include searching their person, their vehicle, and packages or other belongings in their possession.
(2) Searching a room, building, car, airplane, boat, or other structure or vehicle that is suspected of storing drugs.
(3) Screening prisoners in or visitors to a correctional facility as they pass through designated checkpoints.
(4) Screening large numbers of people from the general public, for example, at a customs checkpoint, an airport, or at a border crossing.
(5) Screening hand-carried items at busy personnel checkpoints, for example, hand-carried luggage in an airport.
(6) Screening large numbers of vehicles at checkpoints such as border crossings and entrances to secure government facilities.
(7) Screening letters, packages, and other items that pass through a mailroom.

Prior to procurement of any drug detection system, it is vital to know how it will be used. The application(s) must determine the system selected and not vice versa. Each application is characterized by several factors, the most important of which are discussed in the next section.

1.4 Considerations in Choosing a Detection System

Many factors need to be considered when deciding whether to procure a particular drug detection system. These include, but are not necessarily limited to, the following:

(1) System purchase cost: This is obviously a limiting factor in many cases, especially when the purchasing organization is a small police department. Depending on the system chosen, the purchase cost could range from a few hundred dollars to $1M or more. Most technology-based systems cost in excess of $20K.
(2) System maintenance costs: These are important to consider, because a low purchase cost will not necessarily mean low maintenance costs and vice versa. For example, drug-sniffing dogs tend to have lower purchase costs than most technology-based trace detection systems, but they often have higher maintenance costs related to training. Maintenance costs can vary widely among the different technology-based detectors.
(3) Throughput rate: The number of items (people, vehicles, suitcases) that can be screened in a given period of time is referred to as throughput rate and is usually expressed in units such as people per hour and suitcases per minute. Throughput rate can be a crucial factor. It places limits on the amount of time that can be used to screen a single item and hence on system speed. If police are apprehending a suspect or searching a room, speed may not be an issue. In other applications, such as screening suitcases at an airport, speed is extremely important.
(4) Uniform (comprehensive) versus random screening: In settings where screening is being performed at a busy checkpoint, an option is to screen randomly selected fractions of the items (people, vehicles, baggage) passing through rather than all of the items. Although

this creates the possibility that an item with illicit drugs may pass through without screening, it allows more time to be spent on those items that are screened. In addition, a deterrent effect is accomplished because an entering person does not know if he or she is going to be screened. If random screening is an acceptable option, the range of detection systems that could be chosen is obviously large.

(5) Sensitivity to different types of illicit drugs: Depending on the geographic location, the types of people to be screened, and the application chosen, some illicit drugs may be more important to detect than others and outstanding sensitivity may or may not be considered important. Certain detection systems can detect some types of drugs better than others, and such capabilities should be reviewed in advance. The manufacturer should be one of the best sources of information in this regard, but information should also be sought from a neutral party.

(6) Items to be screened: Items to be screened with a drug detection system usually fall into one of four categories: people, hand-carried items, mailed or shipped items, and vehicles. It is important to know what items the system will be screening. Most technologies are well suited to some of these applications, but are not suited to all.

(7) System portability: Some systems are easily portable, while others are large and bulky and intended for dedicated use at a fixed checkpoint. Portability is important in some cases, for example, when it is desired that the system be moved quickly from place to place in a police car. If the system is to be used in applications where portability is necessary, it is important to learn details about such parameters as size, weight, and power requirements before making a purchase.

(8) Training and maintenance requirements: Some systems are simple to use and require very little maintenance, while others are much more complex and require frequent maintenance. Some also require more training than others. This is another area where consultation with the vendor can be very useful. If at all possible, training from the vendor should be provided as part of the purchase agreement.

(9) Safety and environmental issues: Some systems use small, sealed radioactive sources, and others use x-ray radiation. Although these systems can be operated safely, safety issues and concerns need to be understood and addressed prior to procurement. If people are being screened, use of x-rays or other ionizing radiation may lead to health concerns.

(10) Human factors such as invasion of privacy concerns: If one is screening people for drugs, concerns about invasion of privacy and Fourth Amendment rights need to be considered. Physical contact with test subjects to obtain samples for analysis might be considered too invasive in some situations. Personnel scanners using low-dose x-ray radiation produce an image of a person's body to look for contraband under clothing, and most people will consider this an invasion of privacy. It is important to consider how much people will tolerate, and this depends on where the system is deployed. For example, prisoners in a correctional facility can be subjected to more invasive searches than members of the general public traveling through an airport.

It is likely that some drug detection equipment will be purchased with several different applications in mind, and in such cases the purchaser needs to decide which screening applications and characteristics are most important. There is no such thing as a "one size fits all" drug detector, and compromises among the characteristics listed above will probably be necessary.

2. TRACE DETECTION TECHNOLOGIES

2.1 What is Trace Detection?

Trace detection of an illicit drug refers to detecting the drug by collection and analysis of microscopic amounts of the drug. These microscopic quantities can be in the form of vapor, particulate, or both.

Sampling the air adjacent to a solid mass of a drug allows drug vapor to be collected. All compounds, including illicit drugs, give off some vapor at all temperatures above absolute zero. However, the amount of vapor emitted by some key drugs is extremely small. For example, under equilibrium conditions at room temperature (25 °C or 77 °F) and atmospheric pressure (1 atmosphere or 760 mm Hg), the amount of heroin vapor present above a solid mass of heroin is only about one part per trillion (ppt). This means that only one molecule of heroin vapor will be present for every trillion molecules in the air. Although this sounds like a prohibitively small amount of vapor to make a detection, some trace detection technologies have or approach parts per trillion sensitivity. However, such low vapor pressures place a premium on both extremely sensitive detectors and highly efficient methods of collecting and concentrating the vapor sample and delivering it to the detector. The vapor pressures and equivalent vapor concentrations of several key drugs are listed in table 1.

Table 1. Vapor pressures of key drugs at room temperature

Drug	Vapor Pressure (Pa)	Vapor Concentration*	Reference
Cocaine	2.55×10^{-5}	0.25 ppb	E4
LSD	1.20×10^{-7}	1.2 ppt	E2
Heroin	1.01×10^{-7}	1.0 ppt	E4
Methamphetamine	21.7	214.0 ppm	E2

*ppm = parts per million; ppb = parts per billion; ppt = parts per trillion.

Table 1 shows that the vapor concentrations vary by more than eight orders of magnitude, from more than 200 ppm for methamphetamine to approximately 1 ppt for heroin. The vapor pressure is always a function of temperature and increases exponentially with increasing temperature. Figure 1 shows the temperature dependence of the vapor pressures of cocaine and heroin. In practice, a temperature increase of 5 °C (9 °F) approximately doubles the amount of vapor that is present at equilibrium above a solid compound near room temperature. This means that increasing the ambient temperature or heating an object that is suspected of containing illicit drugs is one way of increasing the amount of vapor present for detection.

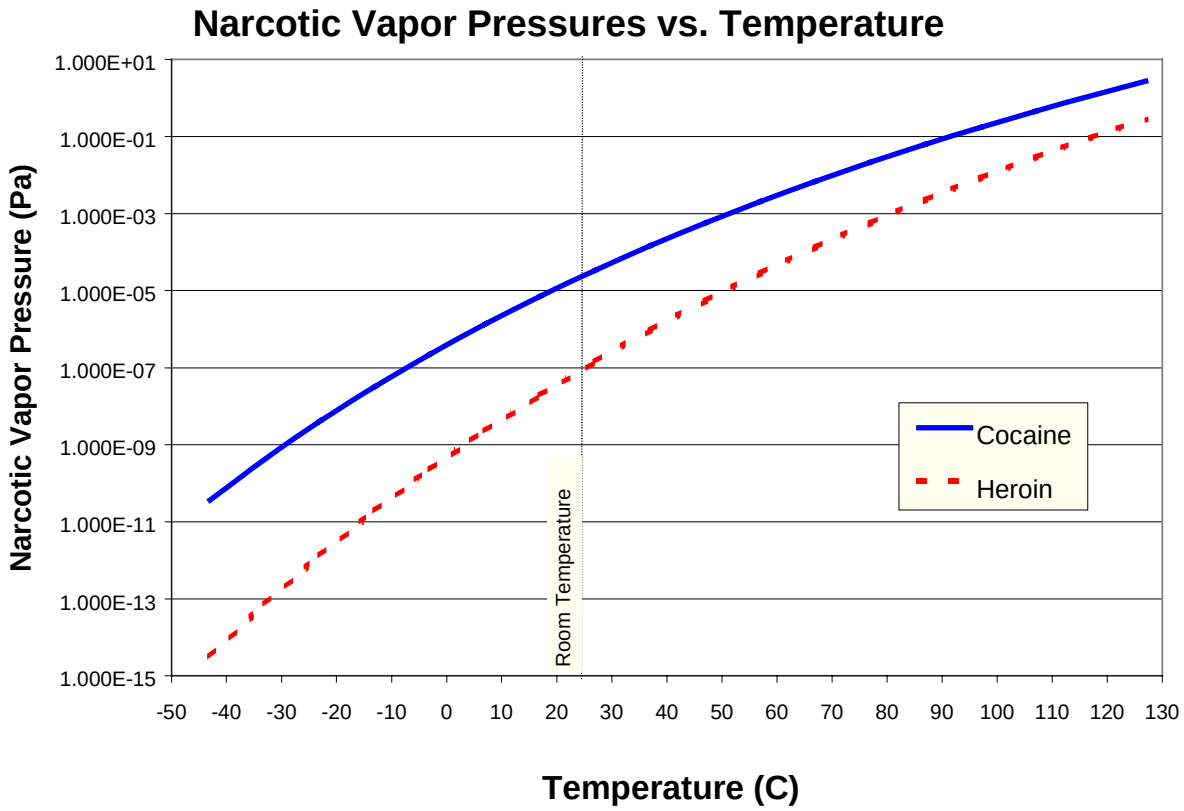


Figure 1. Temperature dependence of the vapor pressures of cocaine and heroin

Particulate refers to contamination in the form of microscopic solid particles. Such particles, typically with masses of a few micrograms or tens of micrograms, will be present on the hands of a person who has recently handled a solid mass of contraband drugs or any other chemical substance. Furthermore, particulate contamination is easily transferred from one surface to another, so a person who has handled cocaine will transfer cocaine particles to anything else he or she touches, including skin, clothing, door handles, furniture, and personal belongings. Completely removing particulate contamination from an object requires rigorous cleaning, and, in the case of bare hands, a single thorough washing may not be sufficient to remove all particles. The amount of particulate contamination resulting from contact with a material depends to some degree on both the nature of the material and the type of surface making contact. Powdery materials tend to transmit the most particulate contamination. Indeed, fine powdery materials may give rise to airborne particles when agitated, temporarily increasing the airborne concentration of the substance by orders of magnitude above its equilibrium vapor pressure. Particulate contamination is so tenacious and easily spread that a large fraction of the

$20 bills in the United States are contaminated with enough cocaine residue to yield positive detections with certain types of trace detectors.

There are two primary methods of collecting trace material for delivery to a trace chemical detector: vacuuming and swiping. Vacuuming is used to collect vapor and/or airborne particulate and is usually performed with a hand-held device similar to a Dustbuster→[**]. Air is pulled through a filter pad within this device, collecting vapor or particles of illicit drugs that are present in the air. The pad is then removed and presented to a sampling port on the trace detector for analysis. A few trace detectors are designed so that air can be sucked directly into an inlet port on the detector. Swipe collection, which is intended to collect particulate residue deposited on surfaces uses sampling pads that are wiped ("swiped") across a surface to be analyzed. These pads are usually supplied by the manufacturer of the detector used and can be applied to any surface, including clothing and skin. Once a swipe sample has been obtained, the pad is presented to a sampling port on the detector, usually in the same way as that of a vacuum sampling pad. Swiping is often more sensitive than vacuuming because it allows more particulate matter to be collected, and with low vapor pressure materials even one microscopic particle may contain a larger mass of material than would be present in a large volume of air saturated with vapor. However, swiping may sometimes be considered too invasive for purposes of personnel screening because it requires direct contact of the sampling pad with skin or clothing.

A final point about trace detection is that the amount of residual material that can be collected for analysis is not necessarily related to the amount of contraband material present. All else being equal, a large mass of heroin gives off more vapor than a small mass, but the amount of vapor present also depends on temperature, how the heroin is packaged, how long it has been packaged ("soak time"), and other factors. The amount of particulate contamination present is related even more loosely to the amount of contraband material present, as this depends more on how carefully the material has been handled than on the amount. Indeed, particulate contamination can be present from second-hand contact even if no contraband material is present. For this reason, trace detection cannot give a quantitative measure of the amount of contraband material associated with any level of contamination. Trace detection should, therefore, be used as a primary screening technique, a detection followed up by an alarm resolution procedure employing other methods.

The remainder of this chapter discusses several useful trace technologies for the detection of illicit drugs. A summary of companies selling trace detection equipment for drug detection is listed in table 2. Trained canines are also trace detectors because they detect drugs from residual vapor and particle contamination, but dogs are treated separately in chapter 3.

[**]The use of brand names in this standard does not constitute endorsement by the U.S. Department of Justice; National Institute of Justice; U.S. Department of Commerce; National Institute of Standards and Technology; Office of Law Enforcement Standards; or any other agency of the United States Federal Government, nor does it imply that the product is best suited for its intended applications.

Table 2. Trace drug detection systems

#	Trace Detector	Cost in K$	Detector Type	Advertised Sensitivity	Use	Size / Weight	Phone
1	Barringer Technologies, Inc. IONSCAN 400	50	IMS	50 pg to 200 pg	Personnel, package, and vehicle search	56 x 33 x 30 cm 27.5 Kg	(908) 665–8200
2	Electronic Sensor Technology EST Model 4100	25	GC/SAW	100 ppb	Personnel, package, and vehicle search	25 x 51 x 36 cm 16 Kg	(805) 480–1994
3	Gamma-Metrics PDA–200	55	Raman Spectroscopy	Unknown	Primarily identification of small but macro-scopic unknown samples	53 x 33 x 20 cm 13.5 Kg	(619) 450–9811
4	Intelligent Detection Systems NDS–2000	23	GC / Surface Ionization	Picograms to nanograms	Personnel, package, and vehicle search	51 x 13 x 14 cm 3 Kg	(613) 230–0609
5	Intelligent Detection Systems Northstar	Not yet available	GC/IMS	Picograms to nanograms	Personnel, package, and vehicle search	16 x 16 x 36 cm 3 Kg	(613) 230–0609
6	Intelligent Detection Systems Ariel	Not yet available	GC/IMS	Picograms to nanograms	Personnel, package, and vehicle search	102 x 51 x 76 cm 109 Kg	(613) 230–0609
7	Ion Track Instruments ITEMISER	44	IMS	100 pg to 300 pg	Personnel, package, and vehicle search	46 x 53 x 36 cm 19.5 Kg	(978) 658–3767
8	Ion Track Instruments ITMS Vapor Tracer	38	IMS	100 pg to 300 pg	Personnel, package, and vehicle search	33 x 13 x 13 cm 3 Kg	(978) 658–3767
9	JGW International, Ltd. Graseby Narcotec	40	IMS	Particulate drugs	Personnel, package, and vehicle search	46 x 38 x 18 cm 17 Kg	(703) 352–3400
10	Mine Safety Appliances Co. FIS	29	FIS	10 ppt to 1000 ppt	Personnel, package, and vehicle search	61 x 38 x 33 cm 9 Kg	(800) 672–4678
11	Mistral Field Test Kit Model M1004	0.5	Chemical	60 ng to 60 µg	Personnel, package, and vehicle search	3 aerosol cans 0.5 Kg	(602) 838–6420
12	Securetec Drugwipes	1	Chemical	10 ng to 50 ng	Personnel, package, and vehicle search	5 x 20 cm	(570) 327–6112
13	Viking Instruments Corp. Spectra Trak GC/MS	70	GC/MS	Low ppb by volume	Portable analytical lab instrument	61 x 41 x 53 cm 68 Kg	(703) 968–0101

2.2 Ion Mobility Spectrometry (IMS)

Ion mobility spectrometry (IMS) is one of the most widely used techniques for the trace detection of illicit drugs and other contraband materials. The principle of operation of an ion mobility spectrometer (also called an IMS) is shown in figure 2.

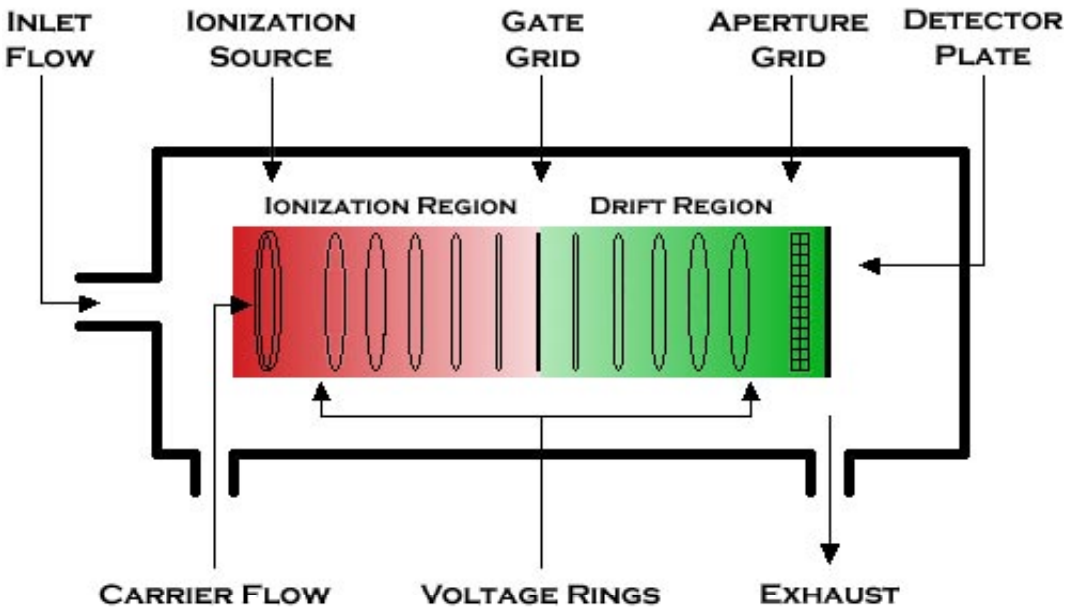


Figure 2. Schematic of an IMS detector

The spectrometer analyzes air for illicit drugs or other compounds of interest that may be present in the air in the form of vapor or airborne particulate material. It consists of two main sections: the ionization region and the drift region. In a typical IMS, ambient air is drawn into an inlet port at the rate of a few hundred cc/min. The air enters the ionization region where electrons interact with the incoming molecules to form positive or negative ions. In the case of illicit drugs, positive ions are formed. The source of the ionizing electrons is a small, sealed piece of metal that has been coated with a radioactive metal isotope, usually nickel 63. Once ions are formed, they are periodically admitted into the drift region through an electronically shuttered gate. The ions are drawn through the gate by a static electric field that pulls them toward a metal plate at the far end of the drift region. This "drift" of the ions from one end of the drift region to the other occurs at atmospheric pressure with many collisions between the ions and the various molecules present. The time that it takes the ions to travel the length of the drift region is called the "drift time," and for any given ion, this time is a complex function of the charge, mass, and size of the ions. Typical drift times are on the order of a few milliseconds. The current collected at the metal plate is measured as a function of time, and an IMS spectrum is a plot of ion current versus time, with different peaks representing different specific ions. A sample IMS spectrum is shown in figure 3. Sometimes an additional gas called the dopant or carrier gas is admitted into

the IMS to aid in the ionization process; ions of this gas normally form the largest peak in the IMS spectrum, which serves as a reference peak.

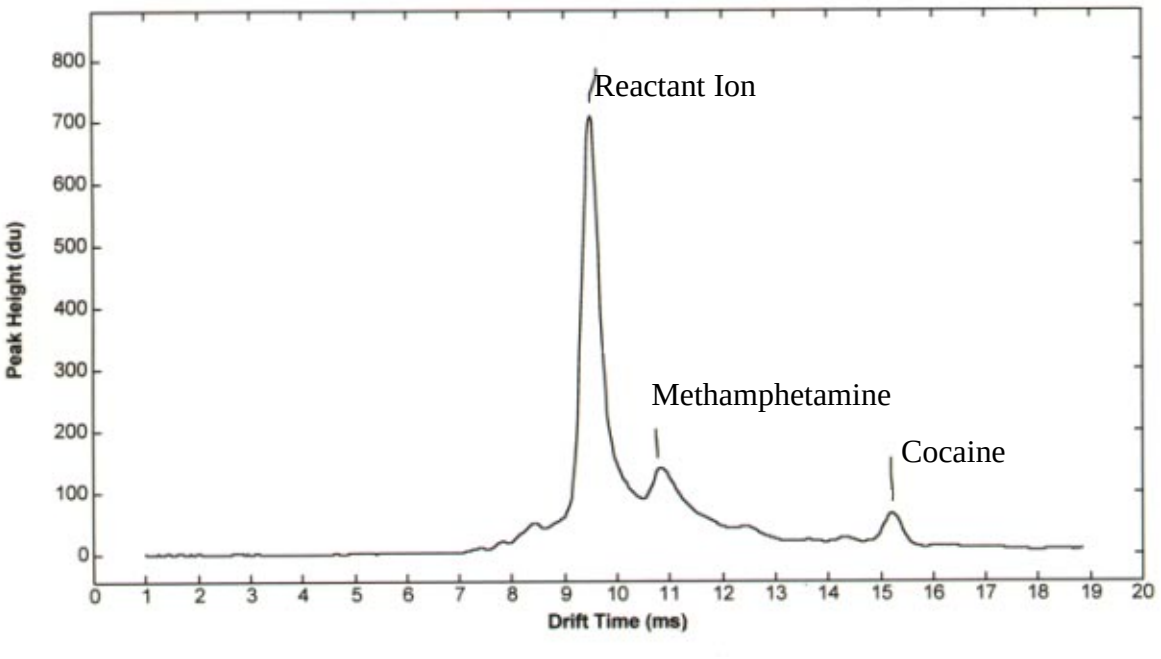


Figure 3. IMS spectrum indicating the presence of methamphetamine and cocaine

A number of features of IMS make it attractive for the detection of illicit drugs. The technique has probably been more widely developed than any other trace technology for drug detection, and a number of companies that sell IMS systems are listed in table 2. Compared with other technology-based drug detectors, IMS systems are moderately priced, with several systems in the $30K to $50K range. Maintenance costs vary from system to system, but are not large in most cases. Most of these systems are portable enough that they could be moved in the trunk of a police cruiser and can be operated by a person with only a few hours of training. These instruments have response times of only a few seconds, the proven ability to detect a number of key drugs, parts per trillion sensitivity in some cases, and audio and visual alarms that tell the user when a drug has been detected and the type of drug. The most effective means of collecting a sample for presentation to an IMS is surface swiping, but vacuum collection of samples is also possible for most systems. Figures 4 through 6 show photographs of some commercial IMS systems.

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

Figure 5. Commercial IMS drug detection system, Ion Track Instruments Vapor Tracer

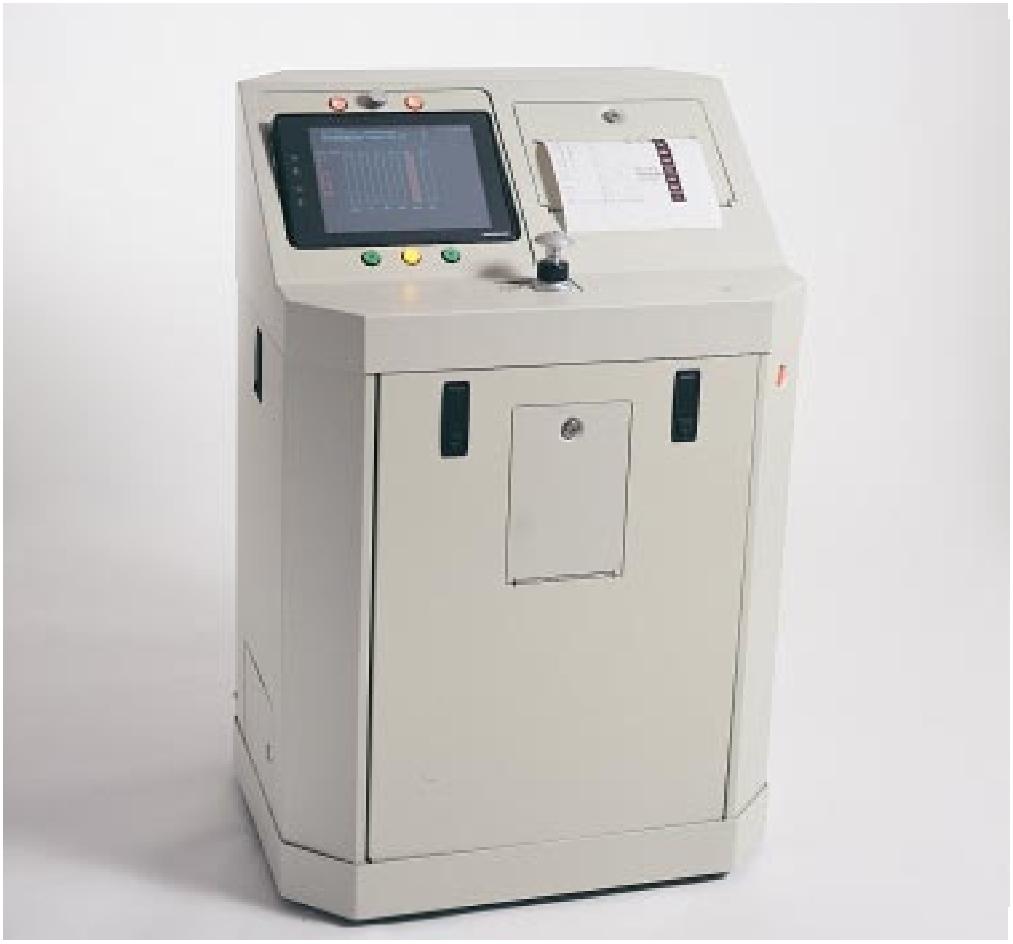


Figure 6. Commercial IMS drug detection system, Intelligent Detection Systems Ariel

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

Another possible drawback of IMS is that the compound discrimination is not outstanding, and two different ions of similar size and mass may appear to give one broad peak rather than two distinct peaks in the IMS spectrum. One method to attack this problem is to separate the molecules entering the IMS by first passing the incoming sample through a gas chromatograph (GC). A GC is essentially a hollow tube (or bundle of tubes), packed on the inside with beads coated with a special chemical substance (the "stationary phase"). This coating interacts differently with different molecules: if a mixture of different molecules is admitted simultaneously into the tube entrance, the different molecules will be sorted by type and each type will exit the far end of the tube at a different time, called the retention time. If two molecules have identical drift times in an IMS, they will almost certainly have different retention times in the GC, and their peaks can thus be resolved because they will enter the IMS at different times. A combined system of this type is referred to as GC/IMS, and such instruments are marketed by Intelligent Detection Systems (see table 2).

2.3 Field Ion Spectrometry (FIS)

Field ion spectrometry (FIS) is a relatively new trace detection technology (less than 10 years old) that is related to ion mobility spectrometry. It incorporates a unique ion filter using dual transverse fields that allow interferences to be eliminated electronically without the use of GC columns, membranes, or other physical separation methods. FIS is similar to IMS in that both involve separating and quantifying ions that are carried in a gas at atmospheric pressure. Furthermore, both systems use soft ionization methods that yield spectra where the species of interest produce the main features, that is, under the proper conditions there is little decomposition of the analyte.

In FIS, ions enter an analytical volume defined by a pair of parallel conducting plates where they execute two motions. The first is a longitudinal drift between the plates due to the bulk motion of a clean, dry carrier stream of air. The second is an oscillating motion transverse to the bulk flow velocity that occurs as the ions respond to an asymmetric, time-varying electric field between the two 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 compensate for the drift introduced by the primary field. The DC field strength needed to compensate for the AC field-induced drift depends on the mobility of the particular ion under investigation so that only specific ions can pass completely through the analytical volume and into the collection area for detection. In this manner, 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 known as an ionogram.

The sole manufacturer of FIS sensors is Mine Safety Appliances Company (MSA), and the system can be purchased for about $30K. The sensor has no moving parts except for a small recirculation fan and no consumables except a replaceable calibrator and gas purification filters. The system volume is approximately 0.02266 m^3 (0.8 ft^3), excluding the computer for control and display. Advertisements claim that the FIS system can detect drugs such as cocaine, heroin, and methamphetamine, and, in principle, it should be able to detect other drugs as well. Detection limits are not known, but advertised limits for other molecules of similar size are in the range of low parts per trillion to low parts per billion. No independent tests have been conducted

to verify these limits. A response time of 2 s for a single target molecule, plus another 5 s for each additional target molecule, has been reported. Like the IMS, the FIS uses a small radioactive source for ionization. Due to the newness of this technique, it may be better suited to laboratory research than field applications, but this could change in the future.

2.4 Surface Acoustic Wave (SAW) Sensors

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

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

SAW sensors are marketed by Electronic Sensor Technology (EST). The EST Model 4100, advertised as an "electronic nose," has received validation from the U.S. Environmental Protection Agency for environmental monitoring of volatile organic compounds in water and of polychlorinated benzenes (PCBs) in soil. It is also advertised as having been validated by ONDCP for drug interdiction efforts. The system costs approximately $25K. Total analysis time is typically 10 s to 15 s, including the time required for sample concentration in the cryogenic-trap. The system is advertised to have parts per trillion sensitivity for semivolatile compounds "such as drugs."

2.5 Mass Spectrometry

Mass spectrometry (MS) has long been one of the most powerful techniques available for the identification of chemical compounds in the laboratory. In a mass spectrometer, gas phase analyte molecules are first ionized, usually under a vacuum at a pressure of $\leq 1.33 \times 10^{-4}$ Pa. The ionized molecules then enter a region with an applied magnetic field where their paths are deflected because of their electric charge. The magnitude of the deflection is a function of the charge-to-mass ratio of the ions and, for a given magnetic field strength, only ions of a specific charge-to-mass ratio are deflected through an aperture to a collector where the resulting current is detected and amplified. By continuously varying the magnetic field strength, the types of ions reaching the collector can be continuously altered, resulting in a mass spectrum. The x-axis shows charge-to-mass ratio; however, because single-ionized particles are far more numerous and more long-lived than multiple-ionized particles, the x-axis can for most practical purposes be taken simply as a mass axis. The y-axis corresponds to signal intensity and is proportional to the

number of ions at a given mass. The ionization process in a mass spectrometer normally leads to some molecular decomposition, so one can observe both the ionized parent molecule and the ionized fragments (or "daughter peaks") of this molecule. The latter are referred to as cracking fragments, and a mass spectrum of a compound under a given set of conditions is sometimes called a cracking pattern. Even if two molecules have the same molecular weight, they will almost always have distinct cracking patterns and thus their mass spectra will be very different. For this reason, mass spectrometry has excellent specificity for identifying compounds, easily surpassing the capabilities of IMS and some other techniques in this regard. Furthermore, since identification is based upon charge-to-mass ratio and any molecule can be ionized, there are, in principle, no molecules that cannot be identified with this technique. Other advantages of MS include good sensitivity and lack of a radioactive ionization source. Disadvantages include the fact that mass spectrometers have traditionally been bulky and expensive. This is partly due to the need for high vacuum and the associated vacuum pumps. If high vacuum is not maintained, the ions formed in a spectrometer will undergo many gas phase collisions, resulting in further fragmentation and making data interpretation difficult or impossible.

In recent years, progress has been in miniaturizing mass spectrometers, resulting in some systems that are small enough to be transported in vehicles for field applications. One such system is the Viking Spectra Trak Gas Chromatograph/Mass Spectrometer (GC/MS), which weighs 68 kg and costs about $70K (fig. 7). This system is 61 cm x 41 cm x 53 cm and can be

Figure 7. Mass spectrometry-based detection system, Viking Instruments Spectra Trak GC/MS

easily transported in the back of a van. It is capable of analyzing solid, liquid, gas, and atmospheric samples, and has advertised sensitivity in the low parts per billion range for some analytes. Field operation from a cold start can be achieved within 20 min under most circumstances.

2.6 Raman Spectroscopy

When any type of molecule is irradiated with light, some of the incident light can interact with the molecules and be scattered by them. There are two basic types of scattering interactions: elastic scattering, in which the scattered light has the same energy as the incident light, and inelastic scattering, in which the scattered light has a different energy than the incident light. Inelastic scattering is of particular interest because the magnitude of the energy changes observed can be related to the structure of the molecule. These energy changes are related to changes in the electronic, vibrational, and rotational energies of the irradiated molecules. In Raman spectroscopy, a solid, liquid, or gas phase sample is irradiated with monochromatic light from a source such as a laser. Inelastically scattered light is then analyzed, focusing on energy losses in the range of approximately 500 cm^{-1} to 3500 cm^{-1}, corresponding to changes in the vibrational energy of the molecules involved. Because polyatomic molecules such as drugs have many different characteristic vibrations that can be excited, a Raman spectrum is a complex plot of energy change versus scattered light intensity. Raman spectroscopy is capable of detecting any type of drug, and, because a spectrum typically is composed of multiple peaks, this technique has excellent selectivity. It has traditionally been used primarily for laboratory analysis, but, as with many other techniques miniaturization and adaptation for field use are proceeding rapidly.

A portable Raman spectroscopy system for drug identification, the PDA–200, has recently been developed by Gamma-Metrics (fig. 8). The entire system weighs less than 13.5 kg, is 53 cm x 33 cm x 20 cm, and can be carried in a briefcase-like container. This system is intended more for analysis of small but macroscopic samples than for true trace analysis. Solid samples are placed in a small zip-lock bag and then inserted directly into a sample analysis port without further preparation. In principle, any type of drug can be detected or identified; those specifically mentioned as detectable include cocaine/crack, heroin, THC, marijuana, LSD, morphine, methamphetamine, amphetamine, and PCP. The system can run off batteries or line voltage. Advertised startup and analysis times are 5 min and 20 s, respectively.

Figure 8. Raman detection system, Gamma-Metrics PDA–200

2.7 Mistral Security Drug Detection and Field Identification Kit

A low-cost trace drug detection kit with potential applications in many areas of law enforcement is manufactured by Mistral Security, Inc. (fig. 9). This field kit comes with four types of aerosol sprays and three types of test papers. Used in various combinations, these sprays and test papers can be used to detect trace quantities of four important categories of drugs of abuse: cocaine, crack, and related substances; heroin and related substances; methamphetamine and other secondary amines; and marijuana, hashish, and other cannabinols. Operation is straightforward and does not require specialized training. The basic process involves two steps: wiping a surface or object suspected of having drug contamination (or a substance suspected of being a drug) with a piece of test paper followed by application of one or more of the aerosol sprays to that paper. If the drug class being checked for is present in sufficient quantity, the test paper changes color within a few seconds. Independent tests performed recently at Sandia National Laboratories indicate that this system works as advertised, though the lower limits of detection that were measured were in some cases poorer than those advertised by the manufacturer. These limits varied from 60 ng for tetrahydrocannabinol to 60 μg for cocaine. The Sandia test results indicate that this method of detection works well if there is direct contact of the test paper with a street sample of the drug or when swiping the hands of a person who has handled the drug. It is generally less effective when swiping a surface for fingerprints of a person who has handled drugs. Little work has been done to determine which chemicals, if any, might interfere with this kit's ability to detect drugs.

Figure 9. Mistral Security Drug Detection and Field Identification Kit

The entire Mistral Security drug detection kit can be purchased for about $500. The kit includes a sufficient amount of test papers and aerosol spray to conduct 80 to 100 tests for each class of drug. If one is interested only in one type of drug, the test papers and specific spray for that type can be purchased separately.

2.8 Securetec Drugwipes

The Drugwipe swipe pads made by Securetec represent another inexpensive, small, and highly portable means of drug detection that is relatively new. Drugwipe pads are used to look for particle residue from drugs via surface swiping. The four types of Drugwipes detect cocaine, heroin (opiates), marijuana, and amphetamines. A Drugwipe is swiped across the surface to be investigated and then the part of the wipe that made contact with the surface is folded over to come into contact with a chemically treated strip. This strip contains antibodies for the drug(s) in question. Finally, water is applied to the area where the wipe and strip have made contact. If the target drug is present, the drug and the antibody will interact to produce a color change within 1 min to 2 min. The color change will occur not only with the drug but also with certain drug metabolites, namely related compounds that are formed from drug decomposition or reaction in the human body if the drug has been ingested. For this reason, Drugwipes can be

used for urinalysis tests as well as trace analysis via surface swiping. A Drugwipe can only be used once.

Individually packaged Drugwipe units are sold for $8 to $10 each, depending upon the quantity ordered. Generally, they are purchased in quantities of 100, containing 25 drugwipes for each category of drug listed above. The individually packaged units are about 5 cm x 20 cm and come with a brochure describing how to use them. Sensitivity is reported to be in the range of 10 ng to 50 ng, depending on the type of drug. The Drugwipes are sensitive enough to screen money for recent contact with drugs (money that has had contact with drugs in the more distant past may not have enough contamination to yield a detection). Some test data are available from ONDCP, and in the future additional test data may be available from other agencies, including the FBI, the U.S. Customs Service, the Drug Enforcement Administration (DEA), and the U.S. Coast Guard. The combination of small size, low cost, lack of power requirements, and simplicity of use makes Drugwipes well suited for many field applications. A possible drawback is the 1 min to 2 min time required to observe a color change; this time limitation could make use of these wipes too slow for some large volume screening applications.

2.9 Gas Chromatography/Surface Ionization Detection

This proprietary technology forms the basis for certain trace detection systems formerly marketed by Scintrex and currently marketed by Intelligent Detection Systems (IDS, formerly CPAD). Because it is proprietary, little can be said about how this technology works. A brief discussion of this technology as it relates to explosives detection was given in previous documents on that topic (see Hannum and Parmeter, D4), where it is referred to as "thermo-redox" detection.

The IDS drug detection system based on this technology is the NDS–2000 (fig. 10). This handheld instrument is 51 cm x 13 cm x 14 cm and weighs only 3 kg (5 kg if run with an optional battery cartridge). Battery operation is one advantage of this system, which can also be run off a vehicle's cigarette lighter or a standard AC power outlet. Unlike IMS-based systems, it has no radioactive source and requires no carrier gas. The warmup time and analysis time are somewhat longer than for many systems: advertised as 45 min and 40 s, respectively. Information provided by IDS does give quantitative data on sensitivity, but simply states that the system can detect "minute traces" of drugs. The drugs detected include cocaine, opiates (heroin and morphine), cannabis (THC), and amphetamine-type stimulants (amphetamine, methamphetamine, and ecstasy). The system has both video and audio alarms. The vendor should be consulted for up-to-date cost information; comparable explosives detection system costs approximately $23K.

Figure 10. Intelligent Detection Systems NDS–2000

3. CANINE DETECTION

3.1 Introduction

Trained canines represent one of the most widely used and time-proven methods for the detection of illicit drugs. Like the technology-based systems discussed in chapter 2, dogs are trace detectors, but because they are unique in many ways they are treated separately in this chapter. In principle, dogs can be trained to detect any type of drug. This versatility, combined with a dog's superior mobility and its ability to follow a scent directly to the source, makes canine detection the method of choice for a variety of applications that have a significant search component. A number of government agencies train dogs to detect drugs, including law enforcement organizations, the U.S. Department of Defense (DOD), and the U.S. Customs Service. In general, a dog trains and operates as a partner with a person who is referred to as a handler or canine enforcement officer. The Customs Service currently has approximately 630 canine teams in the field, deployed at airports, seaports, and border checkpoints. Several types of dogs have been used for drug detection, of which the Labrador retriever is perhaps the most common. Other types used have included golden retrievers, German shepherds, Brittany spaniels, German short-hair pointers, and mixed breeds. Dogs have traditionally been obtained from animal shelters, but this is not ideal because of the very low success rates associated with training such dogs. Approximately one shelter dog out of 1 000 passes the basic tests that serve to admit a dog to a formal training program; of those that do pass, only a small fraction (perhaps 1 in 40–50) eventually pass a full training program and become certified search dogs. To develop a large pool of dogs that can yield a much higher percentage of certifiable detection canines, the Australian Customs Service has recently instituted a breeding program for Labrador retrievers that attempts to promote desirable genetic traits. This program has made excellent progress, with preliminary results showing an initial "graduation rate" of 28 % compared with the much lower success rates typical of shelter dogs.

3.2 Substances Detected

As stated above, dogs can, in principle, be trained to detect any type of drug or any type of chemical substance. However, a single dog cannot be trained to detect all drugs. There is always a tradeoff between the number of drugs or other substances the dog can detect and the proficiency with which the dog detects one particular substance. Dogs used by DOD are trained to detect nine different substances, and this number is fairly typical. Dogs have proven to be very effective at locating some of the most widely abused and economically important illicit drugs, including (but not limited to) marijuana, cocaine, heroin, hashish, and opium. It should be pointed out that the detection of a drug by a dog does not necessarily mean that the dog detects the active agent characterizing the detected substance. For example, several studies have indicated that when a dog smells street cocaine, it does not actually sense cocaine molecules but rather one or more other chemicals that are contaminants in the cocaine and that have considerably high vapor pressures. This means that a dog might not detect such a substance if it could be manufactured in ultrapure form. This, however, can also be an advantage of canine detection because, unlike a technology-based trace detector, a dog will not alarm on a minute amount of residue that has been present for a long time as the result of second- or third-hand contact. For example, dogs will not usually alarm on trace cocaine contamination on a $20 bill

because, unless the contamination is very recent, the impurities on which the dog bases its cocaine detection will have long since vaporized.

3.3 Strengths and Limitations

As with all detection techniques, canine detection has certain strengths and limitations. As mentioned above, the greatest strengths of canine detection are high mobility and the ability to track a scent to its source. The ability of a dog to rapidly screen a large area and to follow a scent gradient until it locates the object from which the scent is emanating greatly exceeds those of technology-based "sniffer" systems such as IMS. For this reason, dogs are ideally suited for drug detection applications that have a significant search component. These include searches of buildings and property; large and small vehicles including cars, trucks, ships, and aircraft; and large containers such as shipping crates. A dog can usually screen a large vehicle in about 5 min and a small vehicle in as little as 1 min. These times compare favorably with the screening times needed for other methods such as physical search by security guards or x-ray based vehicle portals. Dogs can also screen large amounts of luggage and mail, with reported screening rates of up to 2300 kg of mail in 30 min. Although technology-based "sniffer" systems are becoming easier to move around rapidly as miniaturization progresses, these systems are still a long way from competing with canines in this area. Furthermore, system response is usually a single discreet reading at a given point, and this reading does not vary instantaneously as the system is moved closer to or farther from the source. These facts make it extremely unlikely that canines will be rendered obsolete at any time in the near future.

The effectiveness of canine detection in real-world settings is exemplified by some statistics on seizures made as the result of detections by U.S. Customs canines from October 1996 through September 1997. During this period, 9 220 seizures of narcotics and other dangerous drugs were made. The seized materials were estimated to be valued at $3.1B. The seized substances included 189 892 kg of marijuana, 21 926 kg of cocaine, 402 kg of hashish, 148 kg of heroin, and 97 kg of opium.

Several limitations are also associated with the use of drug-detecting canines. The most significant of these is the short "duty cycle." A dog can typically work for only about 1 h before requiring a break. This is in contrast to many technology-based systems that, in principle, can operate 24 h a day. For this reason, dogs are usually not the detection method of choice for applications that involve extended periods of repetitive screening, such as the uniform screening of every person or vehicle passing through a customs checkpoint. However, dogs are still very useful in random screening situations, or for alarm resolution, provided that the dogs have an opportunity to rest periodically. Additional minor disadvantages of canines are that the dog cannot tell the handler what type of drug it has detected, and the dog's performance may vary somewhat due to health and weather conditions. Finally, dogs are not usually used to screen people because some people fear dogs and because a dog might bite someone. Table 3 compares some of the strengths and weaknesses of using canines and technology-based "sniffer" equipment. These two screening methods tend to have complementary strengths, so it is often advantageous to have both capabilities on hand and to use either or both depending upon the circumstances.

Table 3. Technology-based "sniffers" versus canine detection

	Sniffers	Canines
Work Period	24 h/day, in principle	1–2 h before rest
Mobility	Poor to good	Excellent
Follows Scent to Source	No	Yes
Molecule Detected	Drug of interest, or adduct or fragment	Uncertain in most cases
Purchase Cost	Moderate to high	Low
Maintenance Costs	Low to moderate	High (including training and handler)
Best Application	Checkpoint screening	Search

3.4 Costs, Training, and Additional Information

Compared with technology-based "sniffer" systems, drug-sniffing dogs have a low purchase cost but typically high maintenance costs. Procurement costs for a single dog are typically in the range of $3K to $10K depending upon the supplier and the dog's level of training. These costs compare favorably with technology-based "sniffer" systems, which typically cost in the range of $20K to $100K. Costs for feeding the dog and veterinary costs are also relatively minor: typical values are approximately $1K per year and $600 per year, respectively. The main costs associated with purchasing and maintaining a canine are the training costs, especially the salary and other costs associated with the handler/canine enforcement officer. In the DOD, the initial training after a dog has been acquired typically lasts 3 months, involves at least two people, and costs an additional $6K to $12K. Once initial training has been completed, the dog and handler continue to work and train together as a team, and a rigorous training schedule is maintained. Generally, some training is required on a monthly basis. The Federal Aviation Administration has estimated that the cost of maintaining one properly trained officer/canine team at a major U.S. airport is approximately $165K per year. Most of this cost is the salaries and overhead associated with the handlers. Although this figure is probably higher than the cost for a typical officer/canine team maintained by a local law enforcement agency, it demonstrates how maintenance costs associated with a canine can add up. In particular, the costs associated with the time, salary, and benefits of the handler(s) must be taken into account when estimating the cost of canine detection. Furthermore, there is clearly a human labor time investment; the hours an officer spends training and working with a dog are hours that could otherwise be spent doing other work.

Drug-sniffing dogs can be obtained from several sources, some of which also train dogs. A number of private canine-training facilities can be found on the Internet, and several are listed in the reference section (app. 3). As with the equipment listed in this document, listing of the Web sites of these private facilities is for informational purposes only and does not constitute an endorsement or a recommendation of these facilities over any others that may not be listed. State and local law enforcement agencies can also have canines trained at the Customs Canine Enforcement Training Center in Front Royal, Virginia, about 70 miles west of Washington, DC.

4. BULK DETECTION TECHNOLOGIES

4.1 What is Bulk Detection?

In bulk detection, a contraband substance is detected not from residual contamination but by the actual, macroscopic mass of the substance. Under this definition, the simplest form of bulk detection is manual search, that is, detection is based upon visual discovery by a human. Manual search is covered separately in chapter 5. In technology-based bulk detection methods, the item to be screened (e.g., a suitcase) is normally irradiated with some sort of incident radiation, and radiation that is transmitted, backscattered, or emitted from the contraband material is subsequently collected and analyzed. The most common type of technology-based bulk detection involves the use of x-rays. In x-ray systems, the object to be investigated is irradiated with x-rays, and x-rays that are either transmitted or backscattered from the object are collected. The collected x-rays are used to produce an image of the screened item that displays the contraband material, along with other contents. Other bulk detection technologies probe the screened item with neutrons or electromagnetic fields and then analyze emitted photons or changes in the applied (incident) field. Table 4 lists several technology-based bulk detection techniques, along with the incident and detected radiation for each technique. These technologies are discussed separately below.

Table 4. Bulk detection technologies

Technology (Acronym)	Incident Radiation	Detected Radiation
Transmission x-ray	X-ray	Transmitted x-rays
Backscatter gamma	Gamma ray	Backscattered x-rays
Backscatter x-ray	X-ray	Backscattered x-rays
Computed tomography (CT)	X-ray	Transmitted x-rays
Fluoroscopic imaging (FI)	X-ray	Transmitted x-rays
Thermal neutron activation (TNA)	Thermal neutrons	Photons (gamma rays)
Pulsed fast neutron analysis (PFNA)	Fast neutrons	Photons (gamma rays)
Nuclear magnetic resonance (NMR)	Magnetic field	RF energy
Quadrupole resonance (QR)	RF pulse	RF energy
Dielectric portals	Microwave field	Reflected microwave field
Millimeter wave portals (active)	mm-wave field	Reflected mm-wave field
Millimeter wave portals (passive)	None	mm-wave emissions

4.2 Transmission and Dual Energy X-ray Systems

There are three possible outcomes when an x-ray enters a material (fig. 11). The first is that the x-ray photon is absorbed. If the photon is not absorbed, then it may be backscattered, or it may simply pass through the material. Contraband detection systems that use x-rays can be based on both the transmission and the backscatter characteristics of materials. Backscatter technology is discussed in sections 4.3 and 4.4. In general, the use of simple transmission- imaging systems for bulk detection of drugs is limited to producing a black-and-white image that an operator must view to detect the presence of suspicious masses in a package. Because drugs consist mainly of

low-density, low-absorbing materials, it is often difficult for an operator to see the drugs in an image produced by a simple transmission system. To make the detection easier, in some cases automatic, more advanced techniques such as dual energy analysis are needed.

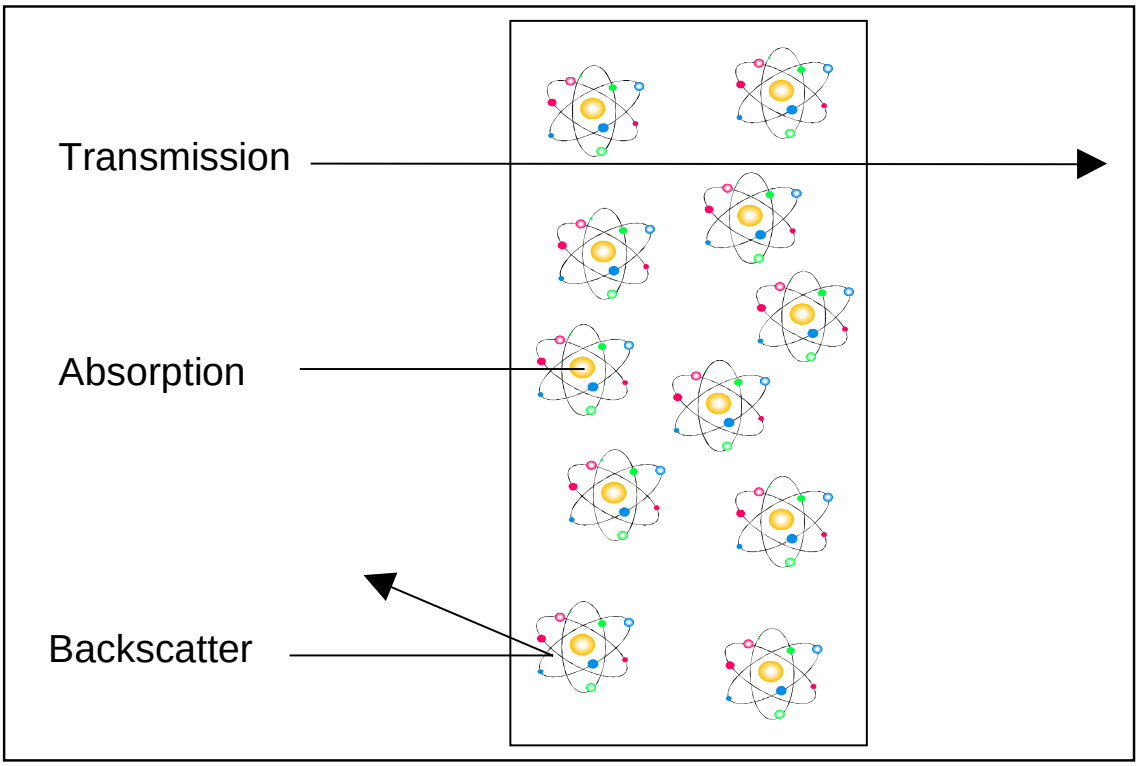


Figure 11. The three possible outcomes when x-rays encounter matter

The simplest transmission system is a fluoroscopic imaging (FI) system. This device produces an image directly when transmitted x-ray energy illuminates a fluoroscopic screen. The image can be viewed using a mirror, thus allowing an operator to view the screen without standing in the path of the x-ray beam. In this arrangement the object being viewed is exposed to a high dose of x-ray energy. Other devices use photographic film or temporary storage plates to capture the image. These devices reduce the x-ray dose the object receives, but the image is not immediately available in the case of the photographic film devices. There are also systems that use video cameras and video storage devices to capture the image. Despite the limitations, these simple systems are still in use for several reasons. The devices are often portable, and they are among the few bulk detection devices that can be transported to the field. They are also relatively inexpensive. Some tabletop systems are quite compact, and in some applications no other device can fit into the available space.

The next level of simple transmission system is the scanning black-and-white x-ray imager. Systems of this type screen carry-on baggage in airports. These systems use a fan or a sweeping beam of x-ray energy to scan a package as it is transported past the source and sensor. Figure 12 shows a typical transmission x-ray image. The sensor array is usually a linear arrangement of photodiodes. The output of the diodes is sent directly to an image processor that generates an image for display on a TV or computer monitor. The main advantages of these devices are moderate cost, a very low dose of exposure to the package (usually film safe), high speed, and ease of use. The disadvantages include larger size and higher cost than FI devices with little or no improvement in image quality or informational content.

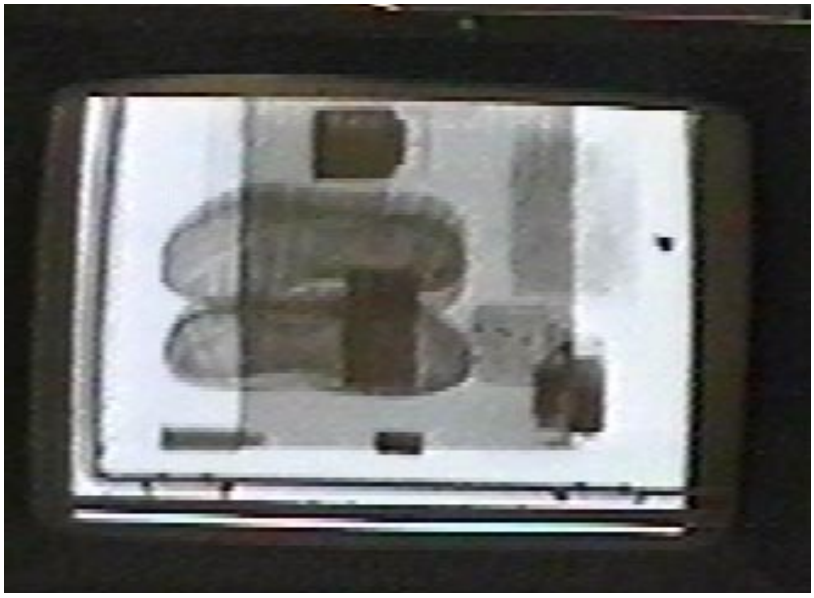


Figure 12. Transmission image of a typical carry-on bag containing a contraband simulant (contraband appears as the large shaded square.)

Dual energy is a technique that either exposes the package to two distinctly different energies of x-rays or exposes the package to a range of energies and analyzes the transmitted energy at different energy levels. By examining the interaction of x-rays of different energy, some discrimination among various types of materials can be made. For the purposes of x-ray analysis, solid materials can be divided into two broad categories: low atomic number or low-Z materials and high atomic number or high-Z materials. Low-Z materials, including organic materials such as drugs and explosives, are composed mainly of light elements such as oxygen, carbon, nitrogen, hydrogen, and chlorine. High-Z materials, including nearly all metals, are composed of heavier elements. Low-Z materials produce relatively large amounts of backscattered radiation, whereas high-Z materials produce little backscattering and are more efficient at absorbing radiation. Simple black-and-white transmission systems cannot easily distinguish between thick sections of organic low-Z materials and thin sections of high-Z materials. Dual energy systems can distinguish between these materials and highlight the difference using color. For example, in some systems low-Z material is displayed as orange whereas high-Z material is displayed as green. Note that some simple transmission systems

assign colors to various levels of transmitted energy. This is called pseudocolor and should not be confused with a dual energy system. The pseudocolor image contains no more information than a black-and-white transmission image. Some dual energy systems have enough specificity not only to distinguish between low-Z and high-Z materials, but also to distinguish among various low-Z materials. Figure 13 shows two displays from such systems. Many of these systems have been optimized for detection of explosives, and a few have been programmed to look for drugs. These systems also have the ability to analyze the image for automatic alarm upon the detection of drugs. The costs of these systems range from about $100K to $400K. The size of these systems is comparable to airport x-ray systems.

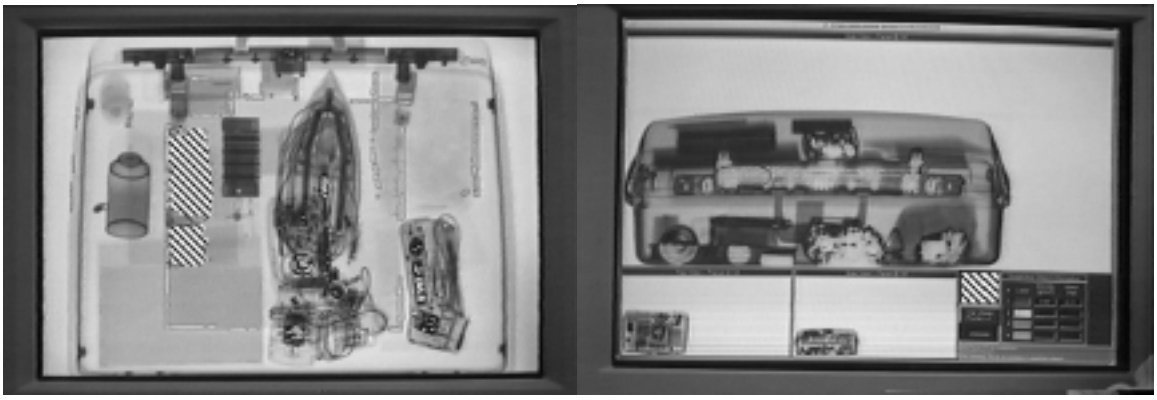


Figure 13. Dual energy system images rendered in black and white. The image on the left is from the vivid VDSI (stripes indicate the presence of contraband), and the image on the right is from the EG&G/Astrophysics Z-Scan (striped alarm square in the lower right hand corner indicates presence of contraband.)

4.3 Backscatter X-ray Systems

All materials backscatter x-ray energy to some degree, that is, reflect some incident x-ray radiation back toward the source. As discussed in section 4.2, low-Z materials are much more efficient at backscattering than high-Z materials. When backscatter energy is captured and used to produce an image, the low-Z materials will appear bright against a dark background as shown in figure 14. For this reason backscatter imaging can easily distinguish between low-Z and high-Z materials. A typical backscatter system has two monitors: one that displays the transmission image and one that displays the backscatter image.

Drawbacks of this technology include the inability to distinguish various low-Z materials from one another and the large size and high cost of most systems (which are comparable to dual energy transmission systems). In addition to low-Z imaging, advantages include speed and ease of use. Furthermore, these systems expose the screened package to the smallest radiation dose of all of the x-ray systems.

Figure 14. Backscatter x-ray image. Image is from the AS&E 101ZZ (contraband appears as the large whitish square). (Note this image is of the same baggage as that shown in figure 12.)

4.4 Low-Dose Backscatter X-ray Systems for Personnel Screening

Similar to the backscatter package search x-ray systems are the low-dose backscatter systems for inspecting personnel. These systems rely on very low-energy and low-intensity x-ray beams to scan a person to produce a backscatter image. Clothing, which has very low density, is in effect transparent to the system and any bulk object located under the clothing may be revealed. These systems are thus well suited to looking for contraband hidden under clothing. Because the human body is composed mainly of low-Z materials, the body is imaged as bright against a dark background. Objects such as guns and other metallic objects stand out in high contrast (dark) against the body's bright background. Low-Z materials are also bright in the backscatter image so they are shown in much lower contrast against the human body than metal objects. Nevertheless, low-Z contraband materials such as drugs can often be detected with this technology. Currently two systems of this type are marketed in the United States: the AS&E BodySearch and the Rapiscan Secure 1000. Cost is on the order of $100K per system. Two separate scans are normally taken, one of the front of the body and one of the back, with a total screening time on the order of 10 s to 15 s per person. Although proven to be effective in many circumstances, these systems suffer from two public relations drawbacks. The first is the perception that the radiation dose received may present a health hazard. In fact, the 3 μrem to 5 μrem received from a screening with one of these systems is far lower than the approximately 1 000 μrem received on a typical commercial flight (due to the extended time spent at high elevation). The second is the invasion of privacy issue where the images (fig. 15) produced by these systems show an image of a person's body (normally somewhat distorted) underneath his or her clothing. It is possible to make the images nonoffensive through editing with specially designed software, but this type of editing can remove information revealing hidden contraband.

Largely because of these drawbacks, the use of these systems, to date, has been confined primarily to correctional facilities where inmates and their visitors have little say about how they can be screened.

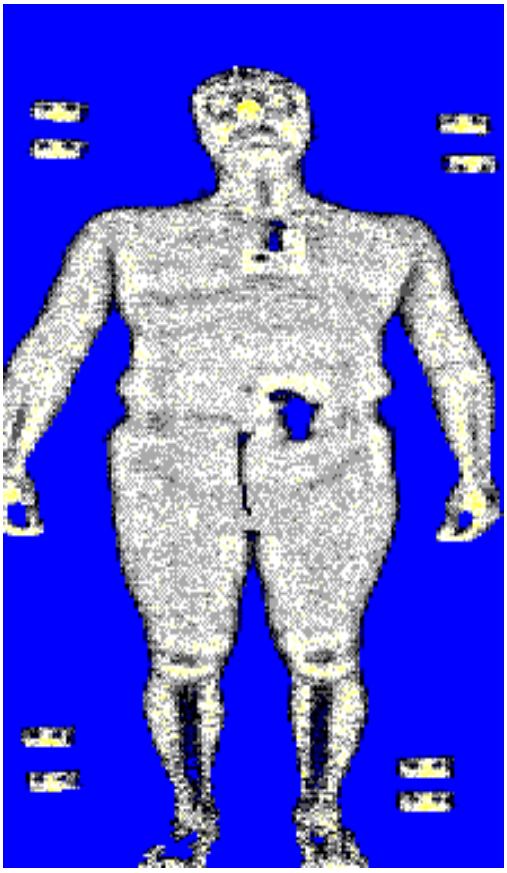


Figure 15. Low-dose backscatter x-ray image from the Rapiscan Secure 1000. Note the small handgun in the waistband. (The rectangles scattered around the image are radiation-measuring devices used during testing by Sandia National Laboratories.)

4.5 Computed Tomography (CT) X-ray Systems

Computed tomography (CT), sometimes referred to as computed axial tomography or CAT scan, scanning for the detection of contraband grew out of the medical industry. Early CT scanners were modified medical systems. Because the cost for these machines is very high (approximately $1M), their use for contraband detection has been limited to the detection of explosives in checked baggage in large international airports. However, if the price drops with further development there is no reason that these devices could not be used for the detection of drugs.

In these systems an x-ray source projects a fan of x-ray energy through a package being scanned onto a curved array of photodiodes. The source and diode array are mounted on a circular movable mount. The source and diode array take readings by rotating around the package. The

information from the scan is sent to a powerful computer and is converted into a two-dimensional slice. The package is moved forward slightly, and the process is repeated. When the slices are stacked, they form a three-dimensional picture of the package and its contents (fig. 16). The CT scanner can calculate the volume of any material inside the package, and the transmission properties of that material are in the scan information. Therefore, the scanner can determine with fair accuracy if the material has x-ray transmission characteristics (effective Z number) of explosives or drugs.

The disadvantages of CT scanners include very high price, large size, and that they are not film safe. The maximum size of a package that can be scanned by a CT is approximately the size of a large suitcase. Their main advantage is that they have the best probability of detection of all the x-ray systems.

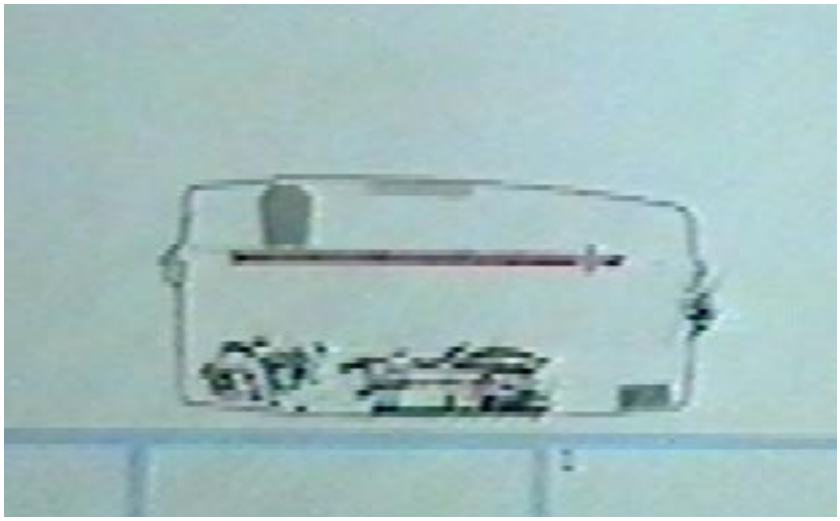


Figure 16. CT scan image from the InVision CTX 5000.
(The thin line is an edge view of a thin layer of contraband.)

4.6 Quadrupole Resonance (QR)

Quadrupole resonance (QR) is a relatively new technique in the detection of drugs. This method relies on the fact that an atomic nucleus with a distribution of electrical charge that is not spherical (this kind of nucleus is called a quadrupole nucleus) will become excited to a higher energy state when exposed to a pulsed radio frequency electric field. After the removal of the field, the nucleus will return to its normal relaxed state, and in the process it will emit a photon of characteristic frequency. Both the type of atom (for example, nitrogen or chlorine) and the crystalline structure of the compound it is part of (such as cocaine or heroin) determine the photon energy. Therefore, this signal is unique to specific types of drugs.

Some of the limitations of this technology are that it cannot detect certain types of drugs (if a specific drug, because of its composition or structure, does not have a quadrupole nucleus), it

cannot penetrate certain types of electromagnetic shielding, and it is currently limited primarily to searching smaller packages. Advantages of this technology include moderate cost, portability (some models), detection of explosives as well as drugs, and high specificity (it tells the operator the specific type of drug detected). Another advantage is that the energy is not harmful to people, magnetic media, or film. Finally, this technique is somewhat unique in that the shape of the contraband material is irrelevant: a spherical piece of material and a thin, flat sheet of the same mass are detected with equal proficiency. This is in contrast to most x-ray-based techniques that have difficulty detecting thin, flat sheets.

Detection systems based on QR are marketed by Quantum Magnetics (now owned by Invision Technologies). These systems vary in cost from about $60K to more than $300K, depending upon the size and specific application of the system selected.

4.7 Thermal Neutron Activation (TNA) and Pulsed Fast Neutron Analysis (PFNA)

Thermal neutron activation (TNA) relies on the interaction of thermal neutrons and certain atoms to detect contraband. Thermal neutrons are fast neutrons with energies from 6 to 14 million electron volts (MeV) that have been slowed to an energy of less than 1 eV. Originally developed to detect explosives, this technology has become useful for the detection of other materials. The basic operational principle is that, when a thermal neutron encounters a specific type of atom, the neutron is absorbed and the atom then emits a gamma ray. The energy of the gamma ray that is emitted is specific to that atom. In the case of the interaction with nitrogen (for explosives and some drugs) the gamma ray has an energy level of 10.8 MeV. Drugs contain much lower concentrations of nitrogen than explosives, and TNA systems do not usually rely on nitrogen content for drug detection. Chlorine that can be found in the hydrochloride forms of several drugs (e.g., cocaine hydrochloride and methamphetamine hydrochloride) emits gamma rays at between 5.7 MeV and 8.5 MeV, and TNA systems can use the presence of chlorine as an indication of the presence of these drugs. Many ordinary materials also contain nitrogen and chlorine, and TNA systems therefore rely on the fact that packages of contraband contain localized higher concentrations of these elements. The main advantage of TNA systems is that neutrons penetrate through large packages and through most shielding materials, making these systems suitable for searching large or metallically packaged objects such as the cargo inside a large truck. They also have the advantage, compared to x-ray systems, of identifying contraband based on elemental composition. Disadvantages include relatively high cost ($600K), health risks associated with human exposure to neutrons, and lack of complete specificity in distinguishing different types of contraband. In addition, not all drugs contain nitrogen and/or chlorine, and those that do not will not be detected by TNA (an example is THC, the active ingredient of marijuana).

Pulsed fast neutron analysis (PFNA) is a more recent technique that uses neutrons to analyze materials for contraband. PFNA has several advantages over TNA. First, more elements can be detected with fast neutrons (in the million electron volt energy range). In addition to hydrogen, nitrogen, and chlorine, carbon and oxygen can also be detected. This has the effect of making PFNA more specific and gives it the potential of detecting more types of contraband (for instance, those drugs with no nitrogen or chlorine content). PFNA also results in a three-dimensional image of the object being scanned with the suspect materials highlighted. The main

disadvantages are that current PFNA systems are designed to examine very large objects such as tractor-trailers, and these systems are very expensive (several million dollars). Ancore currently manufactures both TNA and PFNA systems.

4.8 Gamma Backscatter

Like x-rays, gamma rays interact with matter via absorption, transmission, and backscatter. Backscatter gamma detectors are small hand-held devices that use a radioactive source instead of an x-ray tube to produce penetrating radiation. Lightweight hand-held detectors based on gamma backscatter cost from $6K to $9K. Although these detectors cannot produce an image or specifically identify a contraband material, they are useful when inspecting a vehicle or package in the field where it would be difficult to use a different detector.

The device is held up to an area to be inspected and produces a signal. The magnitude of the signal is dependent upon the amount of energy that is being backscattered. An anomaly is detected when the signal level differs from the signal level that is expected. Determining a detection is the responsibility of the operator and, therefore, the operator must have a reasonable amount of experience using the device on similar objects. For instance, if the operator is inspecting tires on a vehicle, a detection is made when the signal is significantly different over a portion of a tire or if one of the tires produces a significantly different signal than the other tires on the vehicle. If all of the tires contain contraband, then the operator must determine that the tires are producing a signal that is unexpected based on his or her experience. Obviously more experienced operators are more successful than inexperienced operators.

Major strengths of gamma backscatter detectors are their size and portability, their cost, and their ease of use. Drawbacks include the production of ionizing radiation and that these systems only detect anomalies and not specific materials. Currently, Science Applications International Corporation (SAIC) and Campbell Security Equipment Company (CSECO) manufacture gamma backscatter systems.

4.9 Millimeter Wave and Microwave Imaging

Millimeter wave imaging is a new technology still under development that relies on the human body's emission of millimeter wavelength energy. In many ways the system is similar to the backscatter x-ray techniques for screening through clothing. However, because these devices use the body's own emissions to create images, this technology can be entirely passive, that is, no incident radiation is required. The concern of exposing humans to ionizing radiation (as is the case for backscatter x-ray) is thus eliminated. The one remaining concern in common with backscatter x-ray systems is the invasion of privacy. Since this technology is still in development, system costs and typical screening times are unknown. The final resolution of the image also is not fully known, but with the wavelength that is used, the resolution should, in principle, be fairly good.

Microwave imaging falls into two general categories. One type of system views a person at a distance by illuminating the body with low levels of microwaves and focusing the reflected image with a focusing antenna. This system is still under development, and final performance is

not known. One expected drawback is that the antenna is rather large and must be operated at a considerable distance. This could be a problem for installation in small spaces. The resolution of the system is not expected to be very good due to the wavelength of the energy (microwaves are on the order of centimeters in length). System price also cannot be ascertained at this time.

The second imager that uses microwaves is an imaging dielectrometer developed by Spatial Dynamics Applications, Inc. This device uses microwaves to measure the dielectric constant of materials on the surface of the human body. This device employs a vertical array of special antennas (probes) that sweep across the human body, examining the dielectric makeup of small regions immediately in front of the probes. The information is used to construct an image of the person's body surface. Objects under the clothing are revealed and are categorized by composition, metallic or dielectric (insulating), as in the cases of drugs and explosives. The resulting image does not include body details, so the invasion of privacy issue is of less concern. One possible drawback is that the person being screened must reach above his or her head to grasp handles located on a bar. The reason for this is to lift the arms away from the body to allow full viewing. Anyone with difficulty in lifting his or her hands over his or her head may find the screening process uncomfortable. This device is supposed to be available soon, but the cost is still unknown. Screening time is approximately 5 s.

4.10 Summary Table

Table 5 summarizes some key aspects of various bulk detection technologies.

Table 5. Comparison of bulk drug detection technologies

Technology	Specificity[1]	Film Safe	Cost	Portable Versions Available
Fluoroscopic Imaging (FI)	Poor	No	Low	Yes
Scanning Black and White X-ray Imager	Poor	Yes	Moderate	No
Dual Energy X-ray	Good	Yes	High	No
Backscatter X-ray	Moderate	Yes	High	No
Low-Dose Backscatter X-ray	Moderate	Yes	High	No
Computed Tomography (CT) X-ray	Good	No	Very high	No
Quadrupole Resonance (QR)	Excellent	Yes	Moderate	Yes
Thermal Neutron Activation (TNA)	N.A.[2]	Yes	High	No
Pulsed Fast Neutron Analysis (PFNA)	Good	Yes	Very high	No
Gamma Backscatter	Moderate	No	Low	Yes
Millimeter Wave Imaging	Moderate	Yes	Unknown	N.A.[3]
Microwave Imaging	Moderate	Yes	Unknown	N.A.[3]

[1]Poor - no discrimination between low-Z and high-Z materials. Moderate - can distinguish between low-Z and high-Z materials, but no discrimination between various low-Z materials. Good - can distinguish between various low-Z materials. Excellent – can identify specific drugs.

[2]Identifies nitrogen-bearing materials but does not attempt to identify low-Z and high-Z materials.

[3]Not yet commercially available.

5. MANUAL SEARCH TECHNIQUES

5.1 General Features

Manual search, also referred to as physical search, is a valuable contraband detection technique that can be used either alone or as a supplement to other detection methods. It is the cheapest form of contraband detection, with no costs other than the labor time of the personnel conducting the searches. It tends to be slow, invasive, and labor intensive compared with technology-based detection methods, but as in the case of canine detection it would be a mistake to dismiss it simply because it is "low tech." High throughput rates and noninvasive screening are not necessary in many law enforcement applications, and in such applications manual search may be the detection method of choice. The "low tech" nature of this type of screening may be an advantage in some situations, because it makes it relatively easy to train personnel in the methodology and there are no maintenance costs or downtime for maintenance.

Due to the relative slowness of manual search, the use of random screening may be appropriate in large volume, high throughput applications that use this technique. Recall that random screening means screening only a randomly selected small percentage of the people or items (personnel, hand-carried articles, vehicles) passing through a checkpoint. In instances such as searches of people and baggage at customs checkpoints in airports, random search is currently the rule. In some cases, the searches are not truly random but are based on answers to preliminary questions, suspicious behavior, or some form of profiling. In many cases, a technology-based detection method such as a trace system or an x-ray portal is used to screen personnel first, and manual search is used subsequently to resolve apparent alarms.

5.2 Manual Search of People

Manual search of people for drugs can occur in a variety of situations, ranging from suspect apprehension to screening at checkpoints. Searching for drugs in this manner is not intrinsically different from searching for weapons or any other type of contraband, and most law enforcement personnel are familiar with the appropriate procedures. In general, the persons being screened should be required to remove outer clothing such as coats, and then visually be inspected from head to foot, from front and back, and on both sides. If it is deemed necessary, and if it is permissible under the prevailing circumstances, the person can be frisked. It must be remembered that small amounts of an illegal drug can easily be concealed under someone's clothing, taped to the body, or stored in a body cavity. For this reason, visual inspection alone is never a foolproof technique. It is thus recommended that manual search of people be supplemented, at least occasionally, with other screening techniques such as trace detection systems or personnel x-ray scanners.

5.3 Manual Search of Hand-Carried Items

Hand-carried articles can include items such as luggage, briefcases, purses, backpacks, and packages. These are all common containers for surreptitiously smuggling illegal drugs through checkpoints, such as a customs checkpoint in an airport or a screening point for visitors to a prison. Such items may also need to be searched in a more choice setting, such as when a

suspect is being apprehended. All compartments of the article must be checked carefully, and it is often desirable to remove the contents to facilitate the search. Depending on the circumstances, the screener may open the various compartments or he or she may request that the individual being screened open them. The latter procedure is useful when there is any reason to suspect that the item might be booby trapped and is thus used frequently when searching for explosives. Supplementing the manual search with other screening techniques can be very helpful. At checkpoints with a high throughput rate, passing the items through an x-ray based baggage scanner can be especially useful, and this technique can screen a large number of items very rapidly. Other alternatives include swiping the outside of an item and analyzing the swipe with a trace detection instrument or having a trained canine sniff the item. If an individual refuses to submit an item for search at a checkpoint, both the individual and the item should not be allowed past the checkpoint.

5.4 Manual Search of Mailed or Shipped Items

Manual search of mailed or shipped items is, in principle, similar to manual search of hand-carried items, but with two important differences. The first deals with access to the article and the second with size. Mailed or shipped items normally cannot be opened by anyone except the addressee, so manual search of mailed items is often much less practical than that of hand-carried items. In a few cases, it may be possible to ask the addressee to open a mailed or shipped item in the presence of security personnel, and in some very special cases it may be possible to open the item in question without the addressee's permission. In many cases, however, manual search may be replaced by another technique, such as passing the item through an x-ray scanner, swiping its outside with a technology-based trace detection system, or having it sniffed by a canine. The last two methods may be impractical if one is screening large numbers of items with a large throughput rate. In this case an x-ray based system may be the best choice. The large size of some shipped items can also be an issue, both because it may make the use of certain x-ray scanners impossible and because it may mean a rather complex and time-consuming search for the item in question.

5.5 Manual Search of Vehicles

Manual search of vehicles is in general more difficult and complex than manual search of people, hand-carried items, and mailed or shipped items. Once again, there is no intrinsic difference between searching for drugs and searching for any other type of contraband material, such as concealed explosives or large amounts of currency. For this reason, a detailed set of procedures defined by the FBI's National Bomb Data Center to search vehicles for explosives may also be of interest to those wanting to search vehicles for drugs. Four different levels of searches have been defined, with a Level 1 Search being the least stringent and a Level 4 Search being the most stringent:

Level 1 Search: General examination of the vehicle's main compartments.
Level 2 Search: A thorough and deliberate search of all parts of the vehicle that are visually accessible and accessible by design.
Level 3 Search: A Level 2 Search plus nondestructive disassembly of the vehicle.

Level 4 Search: Levels 1–3 Search techniques plus destructive disassembly, which might include cutting upholstery, oil filters, tires, and so forth.

Searches of these types can be performed both at entry checkpoints where large numbers of vehicles pass through, and in isolated situations such as when a suspect is apprehended in a vehicle. If screening of large numbers of vehicles is desired, some form of random screening may be necessary, because screening every vehicle will almost certainly be excessively time consuming. It is often useful to supplement a manual search with other search techniques. Random screening using canines is particularly well suited to vehicle searches.

A Level 1 Search includes inspection of the following areas/compartments: the trunk, the passenger, the engine, the inside bumpers, the undercarriage and roof, and the wheel wells. A Level 2 Search is significantly more involved, with a somewhat different list of designated procedures for different types of vehicles. These types include (1) automobiles/pickups/station wagons, (2) trucks, (3) special equipment, and (4) rail cars. Hannum and Parmeter (D4) give more detailed information on both Level 1 and Level 2 Searches.

5.6 Manual Search of Buildings and Property

Manual search of buildings, rooms, or other areas for drugs is usually performed by law enforcement personnel after some cause for suspicion has been established and when a warrant has been properly obtained. Most law enforcement personnel are thus familiar with the appropriate procedures, and little needs to be said about the topic here. This is another application where trained canines probably represent the best detection technique, and if possible a manual search should be used as a supplement to canines rather than by itself.

6. SUMMARY

6.1 Use of This Document

This document is intended to be a useful starting point for law enforcement agencies that want to procure drug detection equipment. However, it must be remembered that a document of this type can only be a starting point and should never be the sole basis for a procurement decision. Once this document has been used to assess options and point a potential purchaser in the right direction, other steps should be taken. First, the vendors of the equipment of interest should be contacted to obtain the most detailed information available about the product in question. Keep in mind that the development of new systems in the field of contraband detection is proceeding quite rapidly, and discussions with vendors may reveal that some of the product information included in this guide is already outdated. In particular, discussions may reveal that new systems have been developed or that the price of an existing system has changed significantly.

Second, it is a good idea to ask the company for references, that is, customers who have used the product and can talk to a potential buyer about its strengths and weaknesses. Such parties will clearly be less biased toward a product than the vendor itself. Obviously, other law enforcement agencies that have used the product would be especially useful contacts.

Finally, it is often a good idea to consult with a neutral party that has established expertise in the area of contraband detection before making a decision to purchase drug detection equipment. The authors of this document are happy to answer any inquiries. Information also can be obtained from the National Institute of Justice and other State and Federal agencies.

6.2 Future Trends in Drug Detection Technology

This document has focused on the primary technologies and tools that are available for the detection of contraband drugs. Although new products enter the market regularly, we do not expect the principal drug detection technologies and methods to change markedly in the next few years. Recent years have seen refinements of various drug detection technologies and some weeding out of less useful technologies, but relatively few genuinely new technologies have been introduced. We anticipate that these general trends will continue. It often takes 3 to 5 years to get new technology to market, and it may take longer than that to develop a product that is affordable for most customers.

The potential market for drug detection equipment is large, but many of the potential customers are government agencies with limited funding for equipment acquisition. Because of this, there will undoubtedly be a trend toward miniaturization and cost reduction of existing equipment. In the area of trace detection, this trend is already in evidence. The proliferation of new systems does not necessarily mean that the number of systems on the market is constantly increasing, because some older systems will disappear due to market forces as it becomes clear that they no longer possess state-of-the-art capabilities. In fact, some of the system evaluations provided in appendix 3 (F1–F3) have already been taken off the market, and at least one recent survey concluded that the number of trace drug detection systems on the market *decreased* in the past 5 years.

Another likely future trend is the increased development of screening systems that use two or more technologies rather than a single technology. These multitechnology systems can, in principle, provide increased security at screening points, because technologies can be chosen that are complementary, that is, compensate for the other's weaknesses. An example of such a system might be a personnel portal, vehicle portal, or baggage scanner that combines a trace detection technology with one or more bulk detection technologies. Although such systems will no doubt be very useful once fully developed, it may be years before they are mature and economical enough for widespread use.

Finally, a warning is in order. New technologies do enter the market from time to time, and some actually represent improvements over existing technologies with regard to certain capabilities. However, buyers should have a skeptical attitude toward systems for which vendors seem to make completely unprecedented claims. Such claims might include sensitivity, that is, orders of magnitude beyond current technologies, the ability to detect drugs at extremely large distances, or the ability to perform as well as the best current technologies at a small fraction of the price. Such claims could prove to be true, but others may be erroneous or, in extreme cases, fraudulent. An old adage with considerable relevance is that if it sounds too good to be true, it probably is. When confronted with a new technology or system of this type, it is especially important for buyers to solicit advice from a disinterested third party before making a purchase. If possible, try to find out if a government organization or university has performed an independent evaluation of the system.

6.3 Additional Information

Any questions about this document, or the general issue of contraband drug detection, may be sent to the principal author: Dr. John E. Parmeter, Department 5848, Sandia National Laboratories, Albuquerque, NM 87185–0782; phone, 505–845–0894; fax 505–844–0011; e-mail: jeparme@sandia.gov. There may be additional useful information to convey, and all inquiries will be answered.

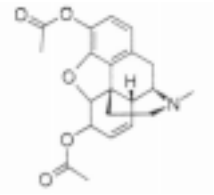
APPENDIX 1. BASIC INFORMATION ON COMMON DRUGS OF ABUSE

This section provides brief background information on several drugs that have been considered in this document. Readers desiring more detailed information should consult the references listed in appendix 3.

Heroin

Heroin, also known as diamorphine, diacetylmorphine, or acetomorphine, is a highly addictive drug derived from morphine. In its pure form, heroin is a white, odorless, crystalline compound, and "China White" has been used as a slang term for very pure Southeast Asian heroin. If exposed to air for a prolonged period of time, heroin tends to turn pinkish and sometimes emits an acetic acid odor. Heroin addicts normally dissolve the pure compound in solution and take the drug intravenously.

The chemical structure of heroin is shown below. The molecular formula is $C_{21}H_{23}NO_5$, giving the compound a molecular weight of 369.4. The density of the solid is 1.56 g per cubic centimeter. The melting point is 173 ºC, and the boiling point is about 273 ºC. The vapor concentration at room temperature and atmospheric pressure is approximately 1 ppt. This is the lowest value of all the drugs discussed in this appendix, making heroin an extremely difficult molecule to detect from its vapor. In virtually all applications, collection of particulate contamination is necessary to successfully utilize trace detection.



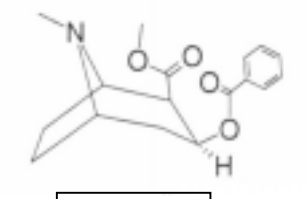
Heroin

Like morphine, which is used medically as a light anesthetic or sedative, heroin is derived primarily from the opium poppy. This poppy is grown principally in South Central Asia, from Pakistan and Afghanistan east to Burma, and to a lesser degree in Southeast Asia. Dried juice from unripe pods of this poppy is used to produce opium, a yellowish-brown drug that contains several chemicals including morphine. Worldwide production of opium was estimated to be 4285 metric tons in 1996, with more than half of the total coming from Burma and most of the rest from Afghanistan. Heroin is a common drug of abuse in the United States, though it lags well behind marijuana and cocaine in terms of overall usage. In FY 1996, 1535 kg of heroin were seized by various Federal agencies. A 1997 study by NIDA found that about 2.1 % of high school seniors had used heroin at least once in their lives. Heroin purchased on the street in the United States is typically only 50 % pure, and in 1997 purchase prices were in the range of $1K to $1.2K per pure gram.

Cocaine

Cocaine is another highly addictive drug that, in pure form, is a white crystalline substance. This crystalline or powder form is normally ingested nasally ("snorting"). Powder cocaine purchased in the United States is typically about 70 % pure, and costs approximately $100 per pure gram. Cocaine is also mixed with materials such as baking soda to form a grainy substance known as "crack," which is smoked and imparts an almost immediate "high" to users. Cocaine can be used medically in small quantities as a local anesthetic.

The molecular structure of cocaine is shown below. The molecular formula is $C_{17}H_{21}NO_4$, and the molecular weight is 303.4. The melting point is 98 ºC. The vapor concentration at room temperature and atmospheric pressure is about 0.25 ppb, or approximately 250 times higher than that of heroin (fig. 1). This vapor pressure means that vapor detection of cocaine is possible in some circumstances, but collection of particle contamination is still highly desirable to maximize the probability of detection.



Cocaine

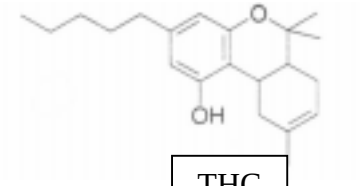
Cocaine is extracted from the coca leaf, which grows on a particular tree (*Erythroxylon coca*) indigenous to South America. Worldwide production of coca leaf in 1996 was approximately 303600 metric tons, with more than half coming from Peru and most of the remainder from Bolivia and Colombia. Cocaine is a very common drug of abuse in the United States, with more than 115000 kg having been seized by Federal agencies in FY 1996 alone. In fact, cocaine is so ubiquitous and paper currency is so often used as a substrate off of which to snort powder cocaine, that perhaps 50 % of the $20 bills in the United States have enough residual cocaine contamination to yield positive detections when analyzed with state-of-the-art trace detectors. The 1997 NIDA survey showed that about 8.7 % of high school seniors nationwide had used powder cocaine and that about 3.9 % had used crack.

Marijuana

Marijuana, also spelled marihuana, is a flaky greenish substance with a characteristic sweet odor formed from dried leaves and flower clusters of the hemp plant (*Cannabis sativa*). This dried plant material is smoked to induce a sense of euphoria. Marijuana is less addictive than cocaine and heroin, and it is the illegal drug most widely used in the United States. It can be purchased on the street for about $5 per gram. The purity of such marijuana is not known and varies widely.

The physiologically active agent in marijuana is a particular isomer of tetrahydrocannabinol, or THC, which is shown below. This molecule has the formula $C_{21}H_{30}O_2$, and a molecular weight of 314.5. The equilibrium vapor concentration of THC in air at room temperature and

atmospheric pressure is about 61 ppt, making this chemical about 60 times more vaporous than heroin but 4 times less vaporous than cocaine.

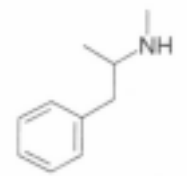


THC

Although the hemp plant is native to Asia, it has been cultivated nearly worldwide, and most marijuana is now produced in the Western Hemisphere. Of the approximately 11400 metric tons produced worldwide in 1996, nearly two-thirds were produced in Colombia and Mexico, and significant amounts are also produced domestically. More than 636000 kg of marijuana were seized by Federal agencies in FY 1996, more than all other illegal drugs combined. The 1997 NIDA survey found that nearly half (49.6 %) of all high school seniors in the United States had smoked marijuana at least once in their lives.

Methamphetamine

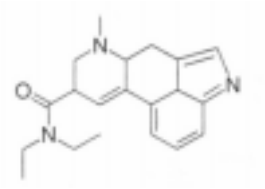
Methamphetamine is a central nervous system stimulant that can be synthesized from the reaction of benzyl methyl ketone and methylamine. Its structure is shown below. Its derivative, methamphetamine hydrochloride, is a commonly abused drug that is referred to variously as "speed," "meth," and "ice." This bitter tasting, crystalline substance has the molecular formula $C_{10}H_{15}N{\cdot}HCl$, a molecular weight of 185.7, and a melting point in the range of 170 ºC to 175 ºC. Another derivative that is a common substance of abuse is methoxydioxymethamphetamine or MDMA, also referred to as "ecstasy." The saturated vapor concentration of methamphetamine at room temperature and atmospheric pressure is approximately 214 ppm, making this by far the most vaporous of the illicit drugs considered in this study. In principle, this means that vapor detection of this drug should be relatively straightforward, but particle detection might be difficult due to the tendency of particles to evaporate rapidly. The 1997 NIDA survey showed that 16.5 % of high school seniors in the United States had used speed or similar stimulants at some point in their lives.



Methamphetamine

LSD

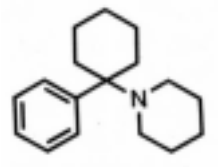
Lysergide, also referred to as D-lysergic acid diethylamide or LSD, is a hallucinogen that has been used experimentally to treat various psychiatric disorders. It is also a commonly abused drug. The 1997 NIDA survey estimated that 13.6 % of high school seniors nationwide had used it at some point. It can be formed microbially by *Claviceps paspali* over the hydroxyethylamide. It consists of prismatic crystals and has the molecular formula $C_{20}H_{25}N_3O$, a molecular weight of 323.4, and a melting point in the range of 80 ºC to 85 ºC. Its saturated vapor concentration at room temperature and atmospheric pressure is approximately 1.2 ppt. This extremely low value, similar to that of heroin, means that it is difficult or impossible to detect from its vapor in many circumstances and that trace detection needs to be focused on particle collection.



LSD

PCP

Phencyclidine, also known as angel dust or PCP, is a depressant that is a common drug of abuse in the United States. This compound, prepared by various synthetic routes, has molecular formula $C_{17}H_{25}N$ and a molecular weight of 243.4. It consists of colorless crystals, with a melting point of 46 ºC and a boiling point of approximately 136 ºC. Vapor pressure data are not available at present. The 1997 NIDA survey found that approximately 3.9 % of high school seniors nationwide had used PCP at some point in their lives.



PCP

APPENDIX 2. GLOSSARY OF TERMS

Alarm: a signal given by a detection system that indicates to the operator that a detection of a drug has been made. For a technological system such as an IMS the alarm might be either audio (e.g., a buzzer sound) 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.

Analyte: in analytical chemistry, the compound that one is attempting to study, analyze, or identify.

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 drugs) based on the images produced from reflected x-rays.

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

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

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

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

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

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

Dopant: see carrier gas.

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.

Fluoroscopic imaging (FI): 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.

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

Handler: the individual who works as a partner with a dog that is trained to sniff out drugs or explosives.

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

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

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

Mass spectrometer (MS): an instrument that performs mass spectrometry.

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

MeV: million electron volts.

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

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

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

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

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

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

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

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

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

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

Portal: a walk-through, booth-like structure that screens personnel for contraband. Examples include metal detection portals in airports and various types of explosives detection portals that are now on the market or in development. Drug detection portals may be developed in the near future.

Probability of detection: the probability that a certain system can detect a certain amount of a given type of drug under a particular set of conditions. If a positive detection is always made under these conditions, the probability of detection would be 100 %. If a detection is made only half the time, the probability of detection would be 50 %. In general, a large number of experimental trials must be conducted to accurately determine this parameter.

Pulsed Fast Neutron Analysis (PFNA): 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.

Quadrupole resonance (QR): a bulk detection technique in which the material under investigation is probed using radio frequency (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 drug detection on a randomly chosen selection of a large number of people or items. For example, a security checkpoint might screen every fourth person entering a secure facility. Random screening has the advantage of providing a deterrent against the illicit transport of drugs into a given area, while being less time consuming than uniform screening.

RF: radio frequency.

SAW: surface acoustic wave.

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.

Spotter: in canine detection, a secondary trainer who works with the canine and the primary trainer (i.e., handler).

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

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

Throughput rate: the rate at which a detection system 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.

Trace drug detection system: any drug detection system that detects drugs by collecting and identifying traces from the material. These traces may be in the form of either vapor or particulate.

Uniform screening: performing drug detection on all persons or items passing through a given security checkpoint and applying the same screening process to all of them. Uniform screening is contrast to random screening.

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

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

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

APPENDIX 3. REFERENCES

The following references are divided into subject categories. The list of Web sites for vendor companies contains all known Web sites of the companies whose products are listed in the tables in this report. The list of canine training facilities contains Web sites or other contact information on facilities that have come to our attention, but the list is not inclusive. In both cases, the lists are for informational purposes and do not constitute an endorsement of the products or training facilities.

(A) Web Sites/E-mail addresses of Vendor Companies

Trace Detection Technologies

(1) http://www.americansecurity.net (American Security and Control)
(2) http://www.barringer.com (Barringer Technologies Inc.)
(3) http://www.estcal.com (Electronic Sensor Technology)
(4) http://www.gammametrics.com (Gamma-Metrics)
(5) http://www.jgwgroup.com/graseby/grlcd.html (Graseby Dynamics)
(6) http://www.idsdetection.com (Intelligent Detection Systems)
(7) http://www.iontrack.com (Ion Track Instruments)
(8) http://www.msanet.com (Mine Safety Appliances Company)
(9) http://www.tdxinc.com (Thermedics Detection Inc.)
(10) http://www.vikinggcms.com (Viking Instruments Corporation)

Bulk Detection Technologies

(1) http://www.aracor.com (Advanced Research and Applications Corporation)
(2) http://www.as-e.com (American Science and Engineering)
(3) http://www.americansecurity.net (American Security and Control)
(4) http://www.ancore.com (Ancore Inc.)
(5) http://www.controlscreening.com (Control Screening LLC)
(6) http://www.egginc.com/egg/index.htm (EG&G Astrophysics)
(7) http://www.heimannsystems.com (Heimann Systems)
(8) http://www.invision-tech.com (InVision Technologies)
(9) http://www.lixi.com (LIXI, Inc.)
(10) http://www.rapiscan.com (Rapiscan Security Products)
(11) http://www.saic.com (Science Applications International Corporation)
(12) http://www.vidisco.co.il (Vidisco Ltd.)
(13) http://www.vividusa.com (Vivid Technologies)

(B) General References on Drugs and Drug Policy

(1) http://www.whitehousedrugpolicy.gov (Office of National Drug Control Policy home page).
(2) *Ten-Year Counterdrug Technology Plan and Development Roadmap,* Office of National Drug Control Policy, July 1998 (Official Use Only).
(3) *Counterdrug Research and Development Blueprint Update*, Office of National Drug Control Policy, January 1999.
(4) *NCJRS Catalog*, published bimonthly by the U.S. Department of Justice. See also the associated Web site, http://www.ncjrs.org.
(5) *What America's Users Spend on Illegal Drugs, 1988–1995*, Office of National Drug Control Policy, September 1997.

(C) Canine Training Facilities

(1) http://www.lik-9.com (Long Island K-9 Service, Long Island, New York).
(2) http://www.k9concepts.com (K-9 Concepts, Inc., Broussard, Louisiana).
(3) http://www.angelfire.com/biz/phillipscommanddogs (Phillips Command Dogs, Olean, New York).
(4) http://www.deltak9.com (Delta K9, Tallulah, Louisiana).
(5) http://www.k9-academy.com (Canine Academy, Leander, Texas).
(6) http://www.customs.treas.gov/top/k9.htm (U.S. Department of the Treasury, U.S. Customs Service, Canine Enforcement Training Center, Front Royal, Virginia).
(7) http://www.minn.net/uspca (United States Police Canine Association, Stafford, Virginia).
(8) http://www.txk9cop.com (Texas K9 Police Association, Dallas, Texas).
(9) http://www.policek9.com/canada.htm (Law Enforcement K9 Center, Richmond, British Columbia).
(10) http://www.pk9.com/ (Southwind Kennels Police K9 Homepage, Lenexa, Kansas).
(11) http://www.globalcorp.com/trainingacademy (Global Training Academy, Somerset, Texas).
(12) http://www.azalea.net/americanine (Ameri K-9 Training Kennels, Braggs, Oklahoma).
(13) http://www.pe.net/~narcdog (Drug Detection Dogs, Palm Springs, California).
(14) http://www.castlek9.com (Castle's K-9 Inc., Carlisle, Pennsylvania).
(15) http://www.llewellynsecurity.com (Llewellyn Security, Toronto, Ontario).

(D) References on Detection Techniques

(1) *Ion Mobility Spectrometry*. G. A. Eiceman and Z. Karpas, CRC Press (1994).
(2) *Vapor Detection with Surface Acoustic-Wave Microsensors*. H. Wohltjen, D. S. Ballantine Jr., N. L. Jarvis, R. W. Murray, and R. E. Dessy. American Chemical Society Symposium Series, Washington, DC, 403, p. 157 (1989).
(3) *The Application of an Integrated Multifunctional Field-Portable GC/MS System*. B. A. Eckenrode. Field Analytical Chemistry and Technology 2(1), p. 3 (1998).
(4) *Survey of Commercially Available Explosives Detection Technologies and Equipment*. D. W. Hannum and J. E. Parmeter. National Law Enforcement and Corrections Technology Center, Rockville, MD. (1998).

(E) Vapor Pressures and other Physical Properties of Drugs

(1) *The Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals*. Merck & Co., Rahway, New Jersey, 12th edition. (1996).
(2) *Handbook of Physical Properties of Organic Chemicals.* Edited by P. H. Howard, and W. M. Meylan and J. Funk. CRC Press, Boca Raton, FL. (1997).
(3) *Handbook of Data on Organic Compounds*. 3rd Edition, Volume III. Edited by D. R. Lide and G.W.A. Milne, CRC Press, Boca Raton, FL. (1993).
(4) *"Determination of Amphetamine, Cocaine, and Heroin Vapour Pressures Using a Dynamic Gas Blending System and Gas Chromatographic Analysis*. A. H. Lawrence, L. Elias, and M. Authier-Martin. Canadian Journal of Chemistry, 62, (1984).

(F) System Evaluations

(1) *Benchmark Evaluation Studies of the Illicit Substance Detector, Accupress, Sentor 5000, and Ionscan 350 Drug Detection Devices*. Prepared by the Narcotics Detection Technology Assessment Team, Office of National Drug Control Policy Counterdrug Technology Assessment Center, Washington, DC. November 1995.
(2) *Benchmark Evaluation Studies of the Barringer Ionscan 400, Graseby Narcotec, Viking SpectraTrak 672, Ion Track Instruments Itemiser, and CPAD Ariel/PID Drug Detection Devices*. Prepared by the Narcotics Detection Technology Assessment Team, Office of National Drug Control Policy Counterdrug Technology Assessment Center, Washington, DC. February 1996.
(3) *Benchmark Evaluation Studies of the Securetec Drugwipes, ITI Itemiser Contraband Detector, Graseby Narcotec, and Scintrex NDS–2000 Drug Detection Devices*. Prepared by the Narcotics Detection Technology Assessment Team, Office of National Drug Control Policy Counterdrug Technology Assessment Center, Washington, DC. November 1996.

NOTE: The three reports listed above are Law Enforcement Sensitive, for Official Government Use Only. Some of the systems evaluated are no longer on the market.

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