Disruptive Technologies

1. INTRODUCTION

The increasing growth in the use and trafficking of narcotics has become a worldwide social problem. Inspecting people and property plays a key role in the eradication of illicit drugs from society and it has stimulated the development of a variety of detection technologies to aid in these activities. This document surveys the field of illicit drug detection with emphasis on the different types of drug detection methods available.

Of the four major types of drug detection, trace detection (mechanical “sniffers”) and bulk detection (*e.g.*, x-ray and other imaging techniques) are relatively new technologies. Canine detection and manual search techniques are the methods that have been used traditionally. Trained canines excel at both trace and bulk detection and the capabilities of detection dogs are discussed separately in Appendix 1.

Key factors for consideration when selecting a drug detection system include (but are not necessarily limited to) the following:

- Cost – purchase and maintenance,
- Speed – throughput rate,
- Sensitivity – to different drug types,
- System portability,
- Ease of use – including training and maintenance requirements,
- Safety of use – including environmental issues, and
- Privacy concerns – if people are to be screened.

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 and whether this involves the screening of people, property, buildings or vehicles.

This discussion is concerned primarily with the detection of drugs in real-world settings, such as where they are used, bought and sold on the street. Detection of ingested drugs by techniques such as urinalysis is not considered since such techniques are normally performed by medical or laboratory professionals.

Drug detection equipment can be used in several different applications, and the user 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

Trace detection of an illicit drug refers to the detection of drugs by collecting and analysing microscopic amounts of the sample. These microscopic quantities can be in the form of vapour, particulate, or both.

There are two primary methods of analysing volatile or particulate samples, Electronic sniffers and colourimetric reaction. Both these techniques consist of three main parts: a sampling system, a detection system, a data acquisition and processing system.

2.1. The Electronic Sniffers

The Electronic Sniffer instruments analyse odours in a way similar to human nose, by sampling and analysing the headspace generated by liquid, gaseous or solid samples. All compounds, including illicit drugs, give off vapour, the amount being proportional to their vapour concentrations. The vapour concentrations of several key drugs are listed in Table 1. Heroin, for example, has a low vapour concentration and the headspace above a solid sample will contain only one part per trillion (ppt) of heroin vapour. Although some of the vapour concentrations are extremely low, trace detection technologies are now approaching parts per trillion sensitivity; this sensitivity is comparable to that of the canine olfactory system.[1]

Table 1. Physical properties of key drugs at room temperature

Drug	Molecular Weight	Formula	Equilibrium vapour concentration*	Equilibrium vapour concentration (PPM)[2,3,4]
Methamphetamine	185.7	$C_{10}H_{15}N.HCl$	214 ppm	214
Cocaine	303.4	$C_{17}H_{21}NO_4$	0.25 ppb	0.00025
Tetrahydrocannabinol	314.5	$C_{21}H_{30}O_2$	61 ppt	0.000061
LSD	323.4	$C_{20}H_{25}N_3O$	1.2 ppt	0.0000012
Heroin	369.4	$C_{21}H_{23}NO_5$	1.0 ppt	0.0000010

* In air at room temperature and atmospheric pressure, *ppm = parts per million; ppb = parts per billion; ppt = parts per trillion.

Collection of the sample by vacuuming concentrates vapours onto a membrane or filter pad which is presented to a sampling port on the sniffer for analysis. Alternatively, instruments with highly sensitive detectors are designed so that air can be sampled directly into an inlet port.

A variety of different detection technologies are available for vapour sensing and analysis. These include, Conductivity Sensors (using metal oxide sensors), Ultra-Fast Gas Chromatography, Fingerprint Mass Spectrometry, and Soft Ionized Mass Spectrometry. The Electronic Sniffer is designed as a monitor to provide rapid and early identification of changes in the atmosphere caused by the presence of particular chemical species to which it has been trained. Each detector type / system has advantages and disadvantages, some of which are detailed in the National Institute of Justice review, Guide for the Selection of Drug Detectors for Law Enforcement Applications.[5]

A new development in this field is array-based sensing. Array sensing employs non-specific chemical conductometric sensors, each with a different sensing metal oxide medium that change resistance when exposed to vapours. The sensors are not specific to any one vapour but identification is made from the pattern of response in the whole array. Array-based sensors are based on a biological model of “sniffing” and can be trained, using a software analysis program such as pattern recognition, to detect new patterns.

2.2. Colourimetric Detection

Particulate refers to contamination in the form of microscopic solid particles. Such particles, typically with masses of a few micrograms, will be present on the hands of a person who has recently handled a solid mass of drugs or any other chemical substance. Particulate contamination is easily transferred from one surface to another, so a person who has handled drugs will transfer particles to anything else they come in contact with, including skin, clothing, door handles, furniture, and personal belongings. This is known as cross-contamination.

Swipe collection, which is intended to collect particulate residue, uses sampling pads that are wiped (“swiped”) across a surface to be analysed. Swiping is often more sensitive than vacuuming because it allows more particulate matter to be collected, 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.

Particulate residues arising from illicit drugs can be analysed using a variety of colourimetric kits. Typically these are based on chemical or antibody reactions to the drugs analysed.

2.2.1. Chemical Analysis

Identification of narcotics or other controlled substances can be a difficult task. There are many potential methods and formulae, that all require knowledge of chemistry and laboratory techniques. The sequence of chemical tests used to completely identify a particular narcotic is shown in Figure 1.

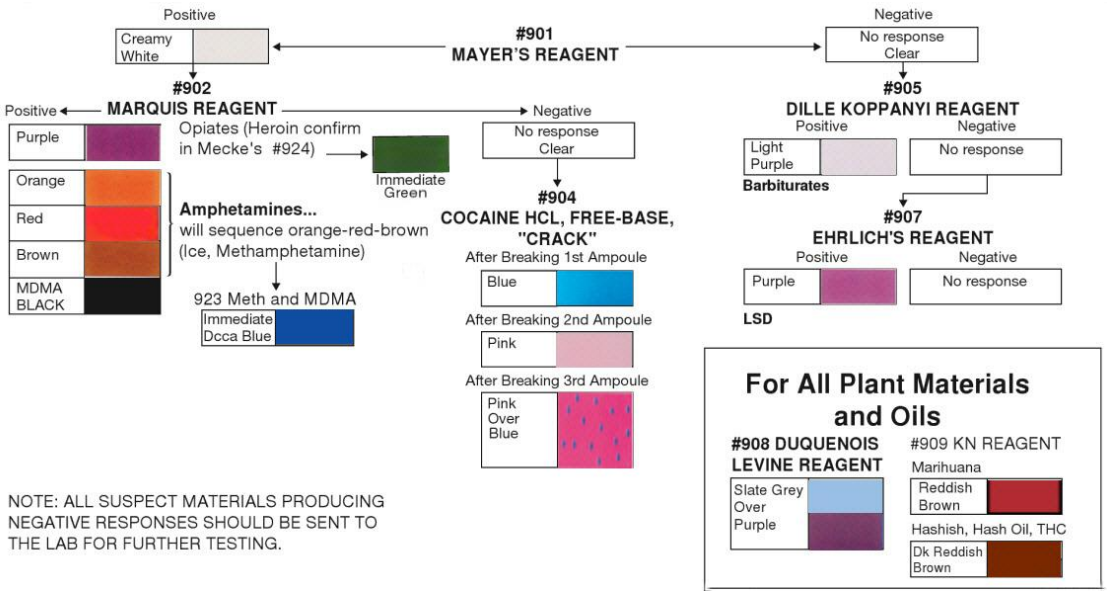

Figure 1. Colour coded results for narcotic tests

Presumptive test kits for Cocaine, Opium Alkaloids, and Methamphetamine & MDMA

For quick presumptive testing, colour spot tests for identification purposes are typically used, and these are generally completed outside of a laboratory. The kits are designed so that there is no need for measurement of chemicals or special equipment. In each plastic tube are crushable glass ampoules with the chemical reagents required to produce a colour upon reaction with a specific narcotic. If a predictable colour or series of colours occur, a positive confirmation may be presumed. A forensic laboratory is then required to qualitatively identify a substance.

2.2.2. Immunoassay

Immunoassays can also provide real-time field analysis of a variety of drugs as a preliminary evaluation. Immunoassays use antibodies, proteins that chemically bind with specific substances called antigens (*i.e.*, in this case, the drug), to detect the presence of a specific drug. In immunoassay tests, a known amount of an antibody is added to the specimen and

this is followed by the addition of a known amount of labelled drug. Any drug present in the specimen will compete with the labelled drug to bind with the antibodies forming drug-antibody complexes. The amount of labelled drug that is able to bind with an antibody is a function of the amount of drug. Chemical spectrophotometric endpoints of these reactions are used to semi-quantitatively identify drugs in the specimen.

The demand for ready-to-use versions of these immunoassays, usable in simple laboratories, at home or in the field, has resulted in the development of "dipstick" versions of this assay. Practically, this device consists of up to four individual cellulose test strips each precoated at one end with a specific, coloured antibody - immobilised drug conjugate. During testing, an aqueous test sample is allowed to move across the strip and any drug present competes with the immobilised drug conjugate for the coloured antibody. If a sufficient amount of drug is present, the coloured antibody moves along the strip. The absence of a coloured line in the test region indicates a positive result for that particular test. If there is no drug present, the coloured antibody remains bound to the immobilised drug to form a visible line at the test region.

A new development in this field is the antibody array chip for label-free optical detection of low molecular weight compounds. As a proof of principle, the chip is proven capable of rapidly (approximately 1 min) determining hits from aqueous cocktails composed of four common narcotics, cocaine, ecstasy, heroin, and amphetamine, using imaging surface plasmon resonance (SPR) as the detection principle.

2.3. Summary

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. Furthermore, when performed in the workplace, these tests are non-specific and may only detect the presence of a particular drug group and the results can only be reported as presumptive. Trace detection should, therefore, be used as a primary screening technique, a detection followed up by an alarm resolution procedure employing other methods.

A summary of the drug detection techniques currently available is listed in Table 2. Trained canines are also trace detectors because they detect drugs from residual vapour and particle contamination and are discussed in full in Appendix 1.

Table 2. Comparison of Technology-based Trace Devices and Canines for the detection of  Illicit Drugs

Feature	Electronic Sniffers	Colourimetric Kits	Canines
Detection Principle	Sample ionisation, Conductivity, Mass Spectrometry	Chemical or Antibody colourimetric reaction	Canine olfactory system
Sensitivity	pg –ng, ppb – ppt	ng, <5 ppm	ppb – ppt
Accuracy	Estimated at 72 - 90%[6]	98.9%[7]	Excellent ratio of detection to false positives
Molecule Detected	Drug of interest, adduct or fragment	Drug of interest, adduct or fragment	Uncertain in most cases
Multiple drugs	Up to 12 scent profiles	Detects wide range of drug types	Optimally 9 scent profiles
Scent Layering (contaminating scents)	No – Detects selected and most prevalent scents only	No	Yes – dogs are able to ignore extraneous or masking scents to identify a scent profiles
Range	Must work in close proximity to the sample	0 m – needs contact with particulate residue	Up to 20 m depending on conditions
Source Identification	No	No	Immediate & Automatic, Self-directing
Confirmation Required	Yes - won't find source	Yes – detects only residue	Yes - to determine which drug
Simplicity	Requires setting up and calibration for every session. Operated by a trained technician	Easy to operate Slow to develop colour	Requires trained dog handler Swift High throughput
Reliability	Too new to say	Yes	Good – but Illness dependant
Work Period	24 h/day, in principle	24 h/day, in principle	1–2 h before rest
Mobility	Poor to good	Good	Excellent
Weight	3 - 110 Kg	<1 Kg	30 Kg (self-propelled)
Cost	$23,000 – $70,000	$20 – 1000 set up	$5000 plus upkeep
Purchase Cost	Moderate to high		Low
Maintenance Costs	Low to moderate	None	High (including training and handler)
Cost per Test		~$20 per test	~$200 per hour
Use	Particulate and volatile drugs Used in personnel, package and vehicle search	Particulate drugs Discrete and unobtrusive testing of property, packages and vehicles. Not suitable for large sample screening of screening of people.	Particulate or volatile drugs. Buildings, area and checkpoint search, personnel, package and vehicle search. Provides a Deterrent effect High mobility, flexibility, security and cost efficiency
Best Application	Checkpoint screening	Confirmatory	All search types

3. BULK DETECTION TECHNOLOGIES

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 based upon visual discovery by a human. A range of devices, based on radiation technologies, are also currently available which may speed up screening and detect contraband in areas in accessible to humans.

3.1. Technology-based bulk detection methods

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 analysed. Other bulk detection technologies probe the screened item with neutrons or electromagnetic fields and then analyse emitted photons or changes in the applied (incident) field. Table 3 lists several technology-based bulk detection techniques currently available.

Table 3. Comparison of bulk drug detection technologies

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

The utility of these Technology based search devices centres on their speed, application in hazardous areas, and in situations where privacy may be an issue. These machines may be costly to purchase and maintain and require specialist training in use and interpretation of the results.

3.2. Manual Search Techniques

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 labour time of the

personnel conducting the searches. It tends to be slow, invasive, and labour 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 non-invasive 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. 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.

3.2.1. Manual Search of People

Manual search of people for drugs can occur in a variety of situations *e.g.*, screening at checkpoints. Searching for drugs in this manner is not intrinsically different from searching for weapons or any other type of contraband. 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 fool proof 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.

3.2.2. 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. 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 analysing the swipe with a trace detection instrument or having a trained canine sniff the item.

3.2.3. 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 many cases however, manual search may be replaced by another technique, such as passing the item through an x-ray scanner, having it sniffed by a

canine, or swiping its outside with a technology-based trace detection system. The latter method 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, in this case using a canine would be the best option.

3.2.4. 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 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 non-destructive 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.

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.

3.2.5. Manual Search of Buildings and Property

Manual search of buildings, rooms, or other areas for drugs is usually performed after some cause for suspicion has been established. 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.

4. SUMMARY

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, the principal drug detection technologies and methods will not 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.

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.

Drug detection equipment can be used in several different applications, and the user 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.

Although some of the methods discussed are ideal for specific applications, all round the most efficient and cost effective drug detection method is still the use of the canine olfactory system.

5. GLOSSARY OF TERMS

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.

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.

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.

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 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.

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.

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.

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.

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 vapour 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.

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

6. REFERENCES

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