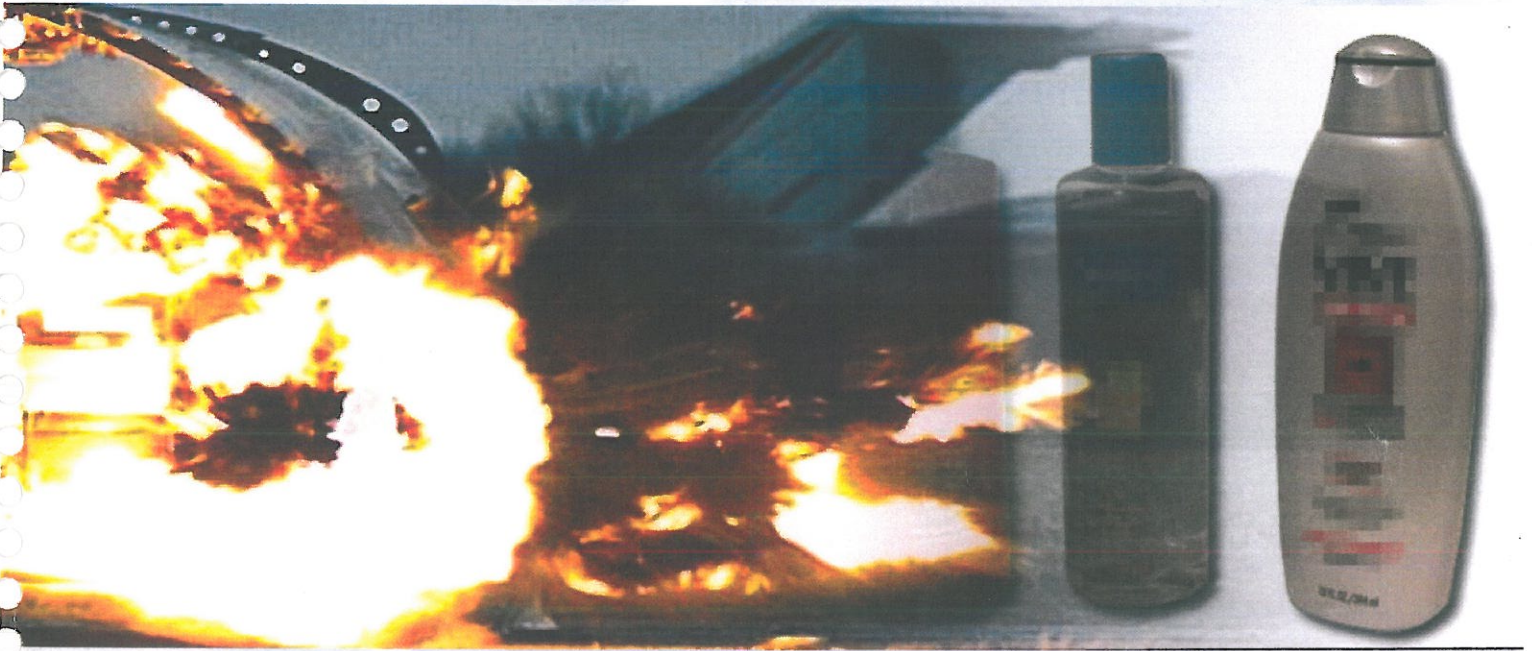


Study of Different Liquid Explosives Detection Technologies & Commercially Available Detectors



**A Project by
Center for Police Research
Pashan, Pune**



**Presented By
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Preface

Terrorism is reaching new heights each day. We all are well aware of the growing terrorist activities and the latest innovative techniques they are using in each and every blast. They are no more illiterate but are skilled and tech savvy.

Internet is the most readily available mode to gain knowledge in any related field. Terrorists are using these methods to acquire techniques / knowledge about substances / chemicals which are available in day-to-day articles for preparing bombs. They are disguised to by-pass the security systems established by security forces.

One of the most dangerous categories is 'Liquid Explosives'. Liquid Explosives are (1) those chemicals which are designated as explosives or dangerous liquids and (2) preparation of liquid explosive composition from two chemicals which are ingredients of two non-explosive liquid or one of them is solid day-today used substances. It is certainly a big challenge for the security forces to secure the place and prevent them from any terrorist attack. They also have to ensure that the industry and society do not suffer due to security measures implemented. To achieve this, they need information on the available and reliable technologies and gadgetry in the market which are user friendly reliable, easy to use and carry and with less training. Hence, CPR Pune has decided to conduct a research project on **"To test various explosive detectors and different technologies for explosive detection"** with special reference to Liquid Explosives.

The main aim of this project is to test explosive detectors with liquid explosives samples especially those explosive detectors which Maharashtra Police Department is using and also to suggest which one gadget / technology is best suited in the real time situation.

I commenced this project with great honor and I am indeed very thankful to Mr. S.P.S. Yadav Add. DG CID and Exec Director, CPR, Pune and Mrs. Borwankar, Spl IGP, SCRB, CID and Member Secretary CPR, Pune who have suggested my name for such an important research work. I would also like to mention, Shri Shivanandan – Commissioner State Intelligence and Shri P. K. Jain IG Security who not only supported me but also gave me an opportunity as well as exposure to acquire good knowledge for this project. Their support and kind approach kept me alert for the completion of this project. I am also very thankful to Mr. Sanjeev Dayal Add DG L&O MS Mumbai for guiding me to keep my project on right track.

This project report is intended solely for research purpose for Centre for Police Research, Pashan Pune. Commercial use whatsoever is strictly prohibited. The project involves compilations of data from various sources such as internet, magazines, scientific reports etc. Practical testing has been carried out only at HEMRL, CPR and SSTS.

Acknowledgements

Since this was a very new subject for me and also a technical one, I discussed this subject with Mrs. Borwankar and Mr. S.P.S. Yadav Sir, which helped me to chalk out a plan. The first task was to learn about what are liquid explosives and for that I took help of my best friend in C-DAC, Mr. Goldi Misra and Mr. Prashant Dinde. We browsed the internet and collected a lot of information about liquid explosives and explosive detectors. But still, we were not satisfied with the data, we acquired.

Then I visited Delhi and met many marketing and selling agents, to name a few, Mr. Pravin Surana, Mr. Chakroborti, Mr. Col. Kanwar and Mr. Harish Kapoor all of them dealing in different products on explosive detectors. Meeting them was fruitful as I collected technical, operational and financial information about their products. Later I visited Major Jose and Col. Ahooja at NSG Manesar – Haryana and collected valuable inputs about testing of explosive detectors. Further, I visited NSG Bomb Disposal Unit of Manesar and collected information regarding the testing parameters of the Explosive Detectors from Col. P.P. Singh. Subsequently, I met Shri T.V. Narayanan (Ex. Dy. Commissioner BCAS) who has authored many books. He was so genuine, supportive and caring. I just cannot forget his hospitality and helping nature. He cleared my ideas about liquid explosives and their properties. Then, I approached NICFS, Prof. Rajvanshi offered me selective valuable papers about Liquid Explosive. My Delhi visit was very fruitful and I gained immense knowledge. Also it increased my level of confidence.

On returning to Pune, I visited HEMRL which is an Apex body in High Energy and a Unit of DRDO. Dr. Asthana at HEMRL, is a very knowledgeable and pleasant personality was kind enough to extend all kind of guidance and help. He nominated a great knowledgeable, dedicated and hardworking scientist Mr. Rajesh Pawar. This person has amazing qualities which left me spell bound. He has tremendous knowledge, data and literature on the subject. His modesty touched me. You just cannot stop yourself from loving him. The same stands true with his associate Miss Sanchita. Both of them have guided and participated in my actual testing of explosive detectors of different sensitive and dangerous Liquid Explosives. They have prepared samples of liquid explosives.

The BDDS Unit PIs. from Mumbai, Thane, Pune, Nanded have whole heartedly provided the explosive detectors along with the trained manpower for testing the Explosive Detectors at HEMRL. Many times, great difficulties arose during the testing and Mr. Pandey of HEMRL has provided logistic support without any hesitation. The testing was conducted in the campus of CPR, HEMRL and in SSTS. I must mention the names of my colleagues Mr. Khedekar and other SSTS staff who have helped me readily. It is true with my drivers Mr. Nagargoje and Mr. Ghorpade whose continued assistance is invaluable.

After concluding the first test, I met another knowledgeable personality Mr. Roomy Tarapore and after few discussions I gained a greater insight from him about liquid Explosives and detectors.

Later on, I collected all the samples which are commonly used by civilians and passengers. These included explosive ingredients and non explosives also.

During first Testing at HEMRL, we had taken into consideration the different weather conditions, temperature difference and interference as well as dusty and windy conditions. Also by blowing several coolers in a closed room we created a humid atmosphere and tested the sample. Dr. Rajesh Pawar guided me to understand different technologies and operation details of Liquid Explosive detectors. He informed me about nature and properties of liquid explosives, types of liquid explosive and what other brands existed and technological advances across the globe and the present situation of those technologies. He also taught me how to handle the samples of sensitive and dangerous liquid explosives. I am greatly obliged and grateful to him for imparting knowledge, sharing database and guiding me willingly without any hesitation. He is the person who never says "NO" to any help and his hospitality was remarkable.

Coln. Lalit Kapoor of CME-Pune and former Dy. Director Bomb disposal unit NSG is a very intelligent & knowledgeable person in the field of Bomb, IED & explosive detectors. I must appreciate his helping nature & exchanging views on this subject. He arranged my participation in the International seminar on latest trends Bomb Detection techniques & explosive detectors held in NSG and also boosted up my knowledge & moral for completion of the project meaning fully.

Then I have visited the International exhibition on security gadgets held at Pragati Maidan New Delhi. Visit to this seminar proved to be informative and fruitful that gave me an opportunity to analyse different practical aspects of various explosive detectors.

The great difficulty I personally faced is to write, get it typed and printed. I must mention that without precious help by Mr. Rajesh Pawar, Mrs. Nina Dinkar, Mrs. Snehal Deshpande and Mr. Amit Rajput at C-DAC in typing and formatting this document would never come into existence in such a nice way.

Last but not the least, I would like to convey my gratitude to the scientists and reporters for having shared their valuable knowledge on the internet.

Let me confess that without pursuance and moral boosting discussions with Mrs. Borwankar, this project would not have been completed. I must appreciate her motherly behavior and approach which forced me to take this task more than a police work. I also would like to thank all the staff of CPR, who have continuously supported my research work.

I thank all of them whom I have mentioned and those whom I have not, as they are the real participants in this successful completion of the project.



Synopsis



SYNOPSIS

Name of the project:

Study of different 'Liquid Explosives Detection' technologies and commercially available detectors.

Document Scope and Purpose

There is an exponential increase in the menace of terrorism that leads to loss of precious human life and loss of property and infrastructure. Recent incidents of use of liquid explosives by terrorists have raised alarm all over the globe since there are no fool proof detectors to detect the components used to make these explosives. The purpose of this document is to give consolidated information on:

1. History and Threats due to liquid explosives
2. Types of liquid explosives
3. Detection technologies

This document provides information along with principle of operations of the individual technologies and related detection devices. Along with that Testing the competence of explosive detectors presently available with Police Department to detect Liquid Explosives are also touched upon.

Finally conclusion is drawn as to which detectors can be potential candidates for detection of liquid explosives and based on them will form guidelines for law enforcement agencies for selection of such detectors.

Ultimate End Goal:

To equip law enforcement agencies with adequate knowledge of latest liquid explosive detection technologies and techniques to facilitate suitable selection.

History and Threats due to liquid explosives

Foiled London Bombing Case - Recent Case of suspected UK Plot:

On August 10, 2006 British officials appears to have revealed and foiled a terror plot to blow up many planes leaving UK airports and flying to locations across the US. Security experts believe that potentially extremely effective liquid explosives would have been used, taken on board in hand luggage, possibly disguised in fizzy drink bottles. Detonators were to be disguised as electronic equipment. It is thought there could have been three waves of attacks targeting three aircraft each time on different days, with the perpetrators hoping the destruction of the planes would have destroyed evidence of how they carried out the attack allowing them to attack again after a pause. This prompted the Joint Terrorism Analysis Centre (JTAC) to upgrade the security level to critical, which imposed ban on taking hand luggage on to flights till security threat level was lowered.

Philippines Plane Explosion Case:

On December 11, 1994 explosion on board PAL Flight 434 killed one passenger. The flight was on its second leg from Cebu to Tokyo when a bomb exploded, killing one passenger. Authorities later discovered that a passenger on the aircraft's preceding leg was Ramzi Yousef, who United States authorities have branded a master Al-Qaida bomber and terrorist. He was later convicted of the first World Trade Center bombing, for which he was sentenced to death by lethal injection. Yousef boarded the flight under an assumed name.

Korean Plane Explosion Case:

In 1987, KAL Flight 858 was destroyed using the explosives C-4 and PLX, the latter of which is a liquid. PLX, or Picatinny Liquid Explosive, is a liquid binary explosive, a mixture of 95% nitromethane and 5% ethylene diamine. It is a slightly yellowish liquid. It was developed at Picatinny Arsenal during World War II for cleaning of minefields. It was to be mixed just before use. PLX was one of the explosives used to down Korean Air Flight 858.

Operation Bojinka US:

On Flight 434, Yousef used one tenth of the explosive power he planned to use on eleven U.S. airliners in January of 1995. The bomb was designed to slip through airport security checks undetected. The explosive used was liquid nitroglycerin, which was disguised as a bottle of contact lens fluid. The wires he used were hidden in the heel of his shoe. At that time, metal detectors used in airports did not go down far enough to detect anything there.

Starting on January 21, 1995 and ending on January 22, 1995, they would set the bombs on 11 United States-bound airliners that had stopovers all around East Asia and Southeast Asia... The bombs would have been timed before the operatives stepped off the planes. The aircraft would have blown up over the Pacific Ocean and the South China Sea almost simultaneously. If this plan worked, several thousand would have perished, and air travel would have been shut down worldwide for days, if not weeks. The U.S. government estimated the prospective death toll to be about 4,000 if the plot had been executed. 'Operation Bojinka' was very similar to the plot that the British claim to have uncovered in August 2006.

Why liquid explosives are favorite of terrorists?

1. Easily available in day-to day used products and at cheaper price
2. Very difficult to detect
3. On board preparation is possible
4. Easily disguisable to by present security/detection techniques
5. Easy to carry
6. Powerful explosion
7. Highly sensitive nature hence easily detonable
8. Since day-to-day products are being used for the preparation of bombs, one explosion creating terror in the mind of common man and also embarrass government to find out protective measures and equipments.

Liquid Explosives

Most explosives work in basically the same way. They burn or decompose very quickly, producing lots of heat and gas, which rapidly expands and can tear things apart. Usually, an explosive material requires some kind of stimulus, like heat or shock energy, to get the process started.

There are several types of liquid and gel explosives some of which are very volatile and sensitive. Liquid explosives can be prepared

- a) All components are in liquid form but neither of them is of explosive nature and produce liquid explosive
- b) All components are in liquid form but at least one of them is of explosive nature and produce liquid explosive
- c) All components are in solid form and produce liquid explosive using solvent medium
- d) Components may be solid or liquid but produce liquid explosives
- e) All components or one of them are in liquid form and produce solid explosive

Following are the various types of liquid explosives

- Slurry and Water gel explosives
- Emulsion explosives
- Nitroglycerin
- Incendiary or flame producing chemicals
- Peroxide explosives
- Nitromethane
- Ammonium nitrate fuel oil (ANFO)
- Astrolite G and Astrolite A-1-5
- Two component Kinepak
- Binex
- Nitroparaffin

Properties of liquid explosives:

- 1) **Sensitivity to impact, friction and shock:** The liquid explosives that are more sensitive to these stimuli can be initiated by simple initiation mechanisms and that is why they should be handled with extreme care. TATP and HMTD are extremely sensitive to shock and therefore difficult to transport. This is the reason why terrorists carry the ingredients required for preparing them to the site of event.

- 2) **Thermal sensitivity:** Explosives like TATP and HMTD are extremely sensitive towards thermal energy and can be detonated with the help of burning match stick or cigarette.
- 3) **Flammability:** Some of liquids like kerosene, petrol, fuel oil, alcohols, acetone, etc are highly flammable. They form gaseous cloud in surrounding atmosphere which can take up energy from any kind heat source (like electrical spark, burning wood, etc) and ignite the whole liquid at once. If large quantities of flammable liquid is stored in confined space such thermal stimulus can lead to rapid build up of pressure due to gaseous products formed due to burning of the liquids and hence lead to large scale destruction due to explosion.
- 4) **Flash point:** This is the minimum temperature at which the vapor above a liquid fuel will first support a combustion transient or "flash". The flash point is measured by a standardized test (ASTM D56) using a small quantity (50 cc) of liquid that is slowly heated (about 1° C/minute) until a flash is observed when an open flame is dipped down into a covered vapor space. The legal description of *flammable* is used for all liquids with a flash point less than 100° C, and the term *combustible* is used for liquids with a flash point in excess of 100° C.
- 5) **Volatility and Vapour pressure:** Volatile liquids have high vapour pressures meaning that the concentration of its molecules in gas phase is high.

Technologies available

Ion Mobility Spectrometry (IMS):

Ion mobility spectrometry (IMS) was created between 1965 and 1970 from studies on ion - molecule chemistry at atmospheric or elevated pressure with mass spectrometers and from ionization detectors for airborne vapor monitoring.

Principle: IMS detection is based on how fast ions move and reach the detector. The mobility of ions is dependent on the shape, size and mass of explosive molecules. The sampling is done either by drawing in air near the suspected object or by swiping a surface to collect particles with swipe strip. The sample then enters the ionization region of the IMS detector, where electrons interact with the incoming explosive molecules to form negative ions. The negative ions are allowed to move into the drift region of the IMS by opening of shutter grid. The time required for the ions to reach the ion collector like Faraday cup is called the drift time. A plot of current versus drift time yields ion mobility spectrum. The drift time is used to identify a material as a potential explosive. Typical drift times are on the order of a few milliseconds (1 millisecond = 0.001 second.)

Electron Capture Detector (ECD):

Principle: ECD comprises of an ionization chamber in which electrons produced from a radioactive cathode, usually tritium or Nickel-63 are injected into a stream of inert carrier gas (helium or argon), where they lose their energy by inelastic collisions with the carrier gas molecules and become thermalized. These thermal electrons are collected by an anode that produces a constant (standing) current. When an electron-capturing compound (such as an explosive) is introduced into the carrier gas, the standing current is reduced and the detector responds to the change.

In order to make the electron-capture detector more specific, some explosive detectors combine ECD with gas chromatography, which separates the volatile components in the sampled air in a column containing a stationary phase. The components emerge from the column at different retention times. The detection system assesses these retention times in conjunction with the ECD output and determines whether an explosive is present or not.

Chemiluminescence (CL):

Principle: The chemiluminescence principle is based on the detection of infrared light emitted from electronically excited NO_2^* . Most common explosives contain nitrogen (N) in the form of either nitro (NO_2) or nitrate (NO_3) functional groups. Also taggants used in plastic explosives contain NO_2 groups. The intensity of emitted IR light is directly proportional to the amount of NO present, which is related to the amount of the original nitrogen-containing explosive material.

Thermo-Redox (TR):

Principle: It is an electrochemical technique based on the thermal decomposition of explosive molecules and the subsequent reduction of NO₂ groups. A sample is drawn into the system and is allowed to pass through a concentrator tube, which selectively traps explosives. On rapid heating NO₂ molecules are released which are detected using proprietary technology.

Surface Acoustic Wave (SAW):

Principle: Surface acoustic wave (SAW) detection of explosives is based on shift in resonance frequency that occurs when these materials get deposited on the SAW crystal surface (detector surface). The frequency shift also depends upon the properties of the material being deposited, the surface temperature, and the chemical nature of the crystal surface.

Field Ion Spectrometry (FIS):

Field ion spectrometry (FIS) is a relatively a new trace detection technology introduced in mid 90's, and offers improvement over IMS wherein separation and detection of explosives is achieved by a single setup (use of GC is not essential).

Principle: The separation of explosive molecules in sample is achieved by application of high field gradients as compared to that in IMS. The detection of ions of explosive molecules formed is detected in manner similar to that of IMS. The mobility of the ions is non-linearly dependent on the field gradient hence it is also referred to as non-linear IMS.

Mass spectrometry

Principle: Mass spectrometry (MS) uses an explosive material's molecular weight and fragmentation patterns for identification. While there are different types of mass spectrometers, it is basically a mass filtering technique. Molecules are ionized and passed through a filter (e.g., magnetic, ion trap, time-of-flight), which allows ions to be identified based on their charge-to-mass ratio.

Quartz crystal microbalance

The "biosensor" program initiated in 1995 by the Swedish Biosensor Applications AB is among one of the very few in Europe targeted specifically at humanitarian demining applications. Biosensors can be easily adopted for portable vapor detection systems, often referred as "artificial dog nose".

Principle: A piezoelectric crystal (i.e., a Quartz Crystal Microbalance, QCM), whose surface is covered by an adsorbent polymer/antibody reacting with explosive molecules. The antibodies detach themselves from the sensor, and the resulting variation in oscillating frequency of the crystal is measured.

Detector based on diamagnetism:

Principle: Diamagnetism is a universal property. The diamagnetic substances do not allow magnetic field to pass through it. The diamagnetic material in earth's magnetic field results into magnetic polarity, which can be detected by the explosive detector while cutting field lines at particular angles and at tangent, thus offering a directional detection device.

Raman spectroscopy

Principle: Raman spectroscopy involves an inelastic light scattering process that shifts the frequency of the incident photons to low energy (Stokes Raman) or high energy (Anti-Stokes Raman). The interaction of light photon with molecule, liquid or crystal of explosives their energy in vibrational and rotational states may be exchanged. Like infrared absorption spectroscopy Raman scattering spectroscopy provides unique set of vibrational modes of explosive molecule. The technique is capable of remote non-destructive detection of explosives with high sensitivity. Though Raman spectra under visible excitation are available for most explosives only recently this method has become promising tool for trace level detection at standoff distance. It can also be used as screening method for explosives at airports and other transport centers.

Chemical reagent based (Color Change)

Principle: The addition of chemical reagents to an explosive sample results in color change characteristic of the explosive present. The chemical reagent based kit is useful for detection and identification of explosive in field and is useful for post explosion analysis or analysis of seized explosives.

Visible or Ultraviolet (UV) Fluorescence

Principle: When UV light is used to illuminate the samples containing explosive material the explosives materials fluoresce even when present in trace amounts. Amplifying fluorescent polymers fluoresce in visible range of electromagnetic radiation which gets quenched on interaction with aromatic explosives.

Quasistatic Electrical Tomography

The detector detects hazardous liquids by measuring permittivity or dielectric constant of the material. The technique employed is called as quasistatic electrical tomography. The device is electronic and does not use ionizing or microwave radiation source. Sensing part is a linear array of electrodes of which one set of electrodes creates alternating electric field in the space while the other set of electrodes measure this field perturbed by the object under investigation. It can be employed at the airports, check-points, places where there is heavy traffic of people (for example stadiums, malls and discos), etc. It is possible to distinguish substances as gasoline, incendiary mixtures, acetone, nitroglycerine, various spirits, ethers and other dangerous liquids from water, nonalcoholic and alcoholic drinks (including strong), dairy products, etc. without violation of the container sealing. When a dangerous liquid is sensed the LED glows red which is otherwise red

Canine Detection of Explosives

The olfactory system of the dogs being sensitive can be trained for the search of area for any explosive device. Although daily working hours of dog are relatively short, dogs can easily cover several thousand square meters per day. They generally sense the explosive vapours. However, as described in the previous paragraph vapor pressure (table below – data at 20°C) of most of the explosives being low, results in their low vapour concentration.

Bulk explosive detection

The X-ray systems and nuclear techniques that are finding application in bulk explosive detection are discussed in this chapter. Most of them belong to fixed type whereas some of them are available in vehicle mounted version. They are commonly used at airport, seaport as well as to monitor sensitive entry points.

X-ray Techniques:

In x-ray systems, the absorption occurs basically due to x-ray interaction with the electrons of an atom via photoelectric effect. Thus, x-ray is absorbed and knocks out one of the atom's internal electron. The mass attenuation coefficient (μ) depends on the energy of the x-rays and effective atomic number (Z_{eff}), which is related to the weighted average of the atomic numbers (Z_i) of the constituent elements of a substance. Compton scattering is another phenomenon in which x-ray photon hits an electron and transfers part of its energy to it while retaining reduced energy.

- I. Transmission
- II. Dual energy x-ray
- III. Back scatter X-ray
- IV. Computed tomography

I. Transmission X-ray :

The photons of x-ray can simply pass through the material or can be absorbed or deflected. Dual energy, dual axes and backscatter technologies allow a fairly approximate determination of mass attenuation coefficient and effective Z-number. Computed tomography can extract information to calculate the density of material as well as its mass attenuation coefficient. These technologies provide low cost alternative to nuclear technologies.

II. Dual Energy X-ray:

It is a variation of standard single energy transmission x-ray. Although dual energy system is superior to single energy system, it cannot determine the material thickness. Low atomic number materials like plastic explosives cannot be detected. They are more suitable for metal detection.

The use of dual axes / dual energy system provides two images of the package at 90° and can be considered a run down version of computed tomography. Although it does not provide complete cross section reconstruction, it provides additional information for detecting explosive like materials.

III. Backscatter X-ray:

The backscatter imager distinguishes low Z materials from high Z-materials by their greater radiation scattering characteristics. Low Z-objects like explosives and drugs, which appear in low contrast in conventional x-ray system, appear as bright white material in back scatter and are separately displayed on a second monitor. A comparison with conventional image reduces the scatter and makes the low Z item more visible. In a single beam scatter imager, another detector is positioned on the source side to detect radiation backscatter by low Z-material. However, low Z-objects behind the dense material may remain hidden. A double beam backscatter detector positioned face to face examines the package from both the sides simultaneously. It can indicate the excessive amount of low Z-material, and thereby can be indicative of explosives or drugs.

A combination of backscatter x-rays together with the standard transmission system provides information that helps in separating the effects of density and effective atomic number (Z_{eff}), thus providing means of identifying high density, low Z_{eff} materials like explosives and narcotics.

IV. Computed Tomography :

CT is a x-ray technique producing two-dimensional images of cross sectional slices of an object. By combining the adjacent cross sectional slices, a three dimensional image can be obtained. These images have relatively improved density resolution as compared to transmission x-ray system. It can specifically identify explosives and discriminate them from most of the innocuous materials of low Z-number as it determines the material thickness, and because explosives generally have higher densities than other innocuous materials of near Z-number. The knowledge of material thickness allows specific identification of materials like explosives.

The disadvantages of current CT scan system design are complexity, high cost, higher package dose and slower operation. The work is on for optimizing the technique and the use of dual energy as well as helical scan is being explored.

Nuclear Techniques:

Nuclear techniques are receiving great interest for such applications. Major advantage of nuclear techniques over X-ray technology is that they do not depend on human interpretation. The detection of suspicious object is automatic, and it need not be to be identified by the operator viewing the images. The systems can operate year round as there is no human interface.

- I. Thermal Neutron Activation (TNA)
- II. Pulsed Fast Neutron Activation (PFNA)
- III. Nuclear Quadrupole Resonance (NQR)

I. Thermal Neutron Activation (TNA):

Neutrons have excellent penetrating power and interact with nitrogen rich materials like explosives. On absorption of thermal neutron, an associate release of 10.8 MeV γ -ray photon occurs from nitrogen nuclei.

The intensity of the photons is an indication of the amount of nitrogen present, and thereby nitrogen rich explosives can be readily detected by TNA actuating an alarm.

The technique developed by Science Application International Corporation (SAIC) is commercially available and used at some of the airports. The present reported cost of the system is about US \$ 9 lakh. The method is effective in detecting the explosives. However, it has limitation for universal application, as it is not capable of detecting carbon and oxygen.

II. PFNA:

The Pulsed fast neutron activation (PFNA) analysis employing pulsed neutron generator producing 8 MeV neutrons overcomes the drawback of TNA. It provides a three-dimensional image of the objects as well as location of the detected material. Owing to such capability, it provides means to detection of explosives.

PFNA stores the atomic fingerprints of every object it scans for comparison, thereby making the system smarter. It can provide material identification for objects ranging from luggage to full size shipping containers. The preliminary testing has established throughput of 600-1000 /hour for luggage and parcels. It gives the detection accuracy greater than 90% and false alarm rate near zero.

The drawbacks of neutron-based systems are the system complexity and cost, radiation hazard, system weight (especially due to heavy shielding) and power requirements.

III. Nuclear Quadrupole Resonance (NQR):

Quadrupole resonance is emerging as a viable technique not only for detecting crystalline materials hidden in cargo and airline baggage but also filled in landmines. When a low-intensity RF signal of the correct frequency is applied to the explosive, usually in the range 0.5 to 6 MHz, the energy state of some of the ^{14}N nuclei can be altered. After the RF stimulation is removed, the nuclei can return to their original state, releasing energy and producing a characteristic radio signal. The signal can be detected utilizing a special radio receiver and be measured for analysis of the compounds present. Detecting the presence of explosives becomes similar to tuning a radio to a particular station and detecting the signal, and the uniqueness of a molecule's electric field renders NQR technology to be highly compound specific.

Explosive detectors available with Maharashtra Police Department

SRTVD-8 TVIN

Introduction: SRTVD-8 TVIN is handheld explosive detector. This is the basic model from which MO2M and MO8 have evolved.

SRTVD is designed for the inspection of: Hand luggage, Luggage and loads transported by all means, Letters and parcels, Clothes, Buildings, offices and public areas, Furniture, Vehicles.

Principle: The detector works on the principle of modified version of ion mobility spectrometry. This is the trace detection method operating on non linear differential mobility technology for detecting traces and vapours of explosive samples.

MO-2M

Introduction: This is the upgraded version of SRTVD-8 TVIN.

Principle: Same as SRTVD-8 TVIN with improved electronics and miniaturized non linear differential mobility spectrometer.

MO8

Introduction: This is the upgraded version of MO-2M. The MO-8 - TVIN is a portable explosive detector designed for inspection of persons, baggage, vehicles, trains, aircraft and large areas as offices and apartments, etc., by sampling and analyzing of ambient air and residual particulates from suspect surface. The MO-8 - TVIN is capable of detecting military and industrial explosives such as TNT, NG, PETN, RDX, C4 and their mixtures.

Principle: Same as SRTVD-8 TVIN with improved electronics and miniaturized non linear differential mobility spectrometer.

Model HS 97

Principle: The detector detects explosives using gas chromatography coupled with electron capture detector (ECD).

Quantum Sniffer QSH-150

Principle: IMS detection is based on how fast ions move and reach the detector. The mobility of ions is dependent on the shape, size and mass of explosive molecules.

First Defender

Principle: Detection is based Raman spectroscopy technique.

Considerations of Testing:

The idea behind the project was to evaluate the detectors available commercially keeping in mind the practical usage. The performance of the detectors was evaluated under different environmental conditions like cold, hot, humid, dusty etc. The detectors were evaluated in both open and closed bottled conditions. Detection capability was also evaluated in presence of interferents. By simulating the field conditions we could actually predict the performance of the detectors in practical scenarios. The focus was kept on liquids commonly used by passengers/ civilians ranging from shampoo, hair dye, and deodorant to solvents and explosives. Most of the above mentioned substances include the compounds used in explosive compositions specifically liquid explosives. Most of the liquid explosives used by anti- national elements are prepared as follows:

1. Liquid + Liquid = Liquid e.g. EGDN
2. Liquid + Solid = Liquid e.g.
3. Liquid + Liquid = Solid e.g. TATP
4. Liquid + Solid = Solid e.g.

These compositions are individually available in any of the commercially available products like hair dye, nail polish etc. When combined in correct proportions these might result in explosive compositions (like TATP, HMTD, EGDN etc.). Therefore, the emphasis was to detect the presence of individual components used to prepare the liquid explosives beforehand in order to avert any possible attempt by terrorists.

In addition to detection of explosive compositions, the ability of the detectors to detect non-hazardous substances like plain water, oil, drinks etc was also tested.

So also the performance of the liquid explosive detectors on battery back-up, ease of use, selectivity, false positive /negative alarm rate, warm- up time, analysis time, versatility, portability and availability of carrier gases was tested.

The evaluation of the detectors was carried out using approximately 30 odd substances.

Conclusion:

None of the evaluated detector showed consistency in the result. Hence the reliability of the detectors is in question. In most of the cases it was observed that though the detectors gave alarms but the identification of the explosive was wrong. Another issue is the warm up time. The warm up time for detectors like Model HS 97, First Defender are high. Also the battery back-up is less. In field conditions where the personnel would be working for hours, the battery back- up should be more. Most of the detectors failed in presence of interferents except for the Mininose and First Defender where the principle of operation is different (i.e. particulate & contact mode). SDT Mininose detector operates in particulate mode corrosive conditions does not affect the result. The same is true with hot and windy conditions. SDT Mininose requires very little training since the results are displayed on the screen. The best known detectors available with Maharashtra police department for detection of explosives were tested under the project for their performance against liquid explosive and hazardous liquid samples. Their ability to distinguish between explosive & non- explosive material, the analysis time required was tested in closed, open, cold, warm, windy, humid and corrosive atmosphere. SDT mininose is based on swipe/sampling method. The liquid in liquid explosives cause damage to the sampling film thereby rendering it least useful for detection of liquid explosives.

Model HS-97 was not able to detect liquid explosives except NG, EGDN, ANFO, RDX/ANFO. It gives false alarm both false positive as well as false negative alarm. Further its use involves recurring expenditure in terms of organization. Above all the detector is based on old technology and currently out of production. Thus it is concluded that model HS-97 is not useful for detection of liquid explosives.

MO8 is the upgrade version of MO2M, However drawback of MO2M still exists in MO8. The false alarm rate is high and is not in acceptable range. It also gives false indication of type of material detectors and its capability to detection of liquid explosive is poor.

First defender requires proper alignment and intimate contact with surface of the liquid explosive device. If the alignment is inappropriate no signal is obtained. When liquid samples are enclosed in opaque plastic or glass container and in case of metallic container the detection becomes impossible.

In open condition, the sample can be analyzed in vial; however this requires handling of explosive device which is dangerous.

DLD is a handy detector and is able to distinguish between hazardous and non hazardous material. However, DLD required that liquid sample should be present to level sufficient to cover the entire sensing area. If the liquid explosive is enclosed in metallic container DLD cannot detect it. It does not give any details of material detected. DLD is easy to use and does real time analysis. It does not require special training and can be used at entry ports like airport, railway stations, and malls etc. where huge number of samples needs to be scanned.

Summary

The complied results of this project indicate that the detectors available with Maharashtra police department are not capable to detect liquid explosives. Since DLD is user friendly and easy to use in the field it may be considered for scanning of large number of samples in real time. As DLD does not give details of samples detected, in second phase of scanning first defender or equivalent detector may be appropriate for detailed analysis of sample.



Part I

Liquid Explosives Detection



Name of the project:

Study of different 'Liquid Explosives Detection' technologies and commercially available detectors.

Document purpose:

There is an exponential increase in the menace of terrorism that leads to loss of precious human life and loss of property and infrastructure. Recent incidents of use of liquid explosives by terrorists have raised alarm all over the globe since there are no fool proof detectors to detect the components used to make these explosives. The purpose of this document is to give consolidated information on:

1. History and Threats due to liquid explosives
2. Types of liquid explosives
3. Commercially available detection technologies – principle of operation, advantages, disadvantages of these detectors and their utility in detection of liquid explosives

Finally conclusion is drawn as to which detectors can be potential candidates for detection of liquid explosives and based on them will form guidelines for law enforcement agencies for selection of such detectors.

Ultimate End Goal:

To equip law enforcement agencies with adequate knowledge of latest liquid explosive detection technologies and techniques to facilitate suitable selection.

Document Scope:

- 1) To provide information about different technologies for liquid explosive detection.
- 2) To aid security forces in selection of liquid explosive detection equipment for various different applications.
- 3) This document provides basic and practical information along with technical information description of principle of operations of the individual technologies and related detection devices.
- 4) Comparison of performance of different commercially available detection equipments.
- 5) To test the competence of explosive detectors presently available with Police Department to detect Liquid Explosives.

Introduction

This compilation is based on the data published in literature and that available on internet.

The use of liquid explosives by terrorists has raised the attention to the use of hazardous liquids as threats to people, buildings and transportation systems. Hazardous liquids such as explosive mixtures, flammables or even chemical warfare agents (CWA) can be concealed in common containers and pass security checks undetected. This work presents three non invasive, non destructive detection approaches that can be used to characterize the content of common liquid containers and detect if the liquid is the intended or a concealed hazardous liquid. Fiber optic coupled Raman spectroscopy and Stand off Raman spectroscopy were used to inspect the content of glass and plastic bottles and thermal conductivity was used to asses the liquid inside aluminum cans. Raman spectroscopy experiments were performed at 532 nm, 488 nm and 785 nm excitation wavelengths. The hazardous liquids under consideration included CWA simulant DMMP, hydrogen peroxide, acetone, cyclohexane, ethanol and nitric acid. These techniques have potential use as a detector for hazardous liquids at a check point or to inspect suspicious bottles from a distance.

History and threats due to liquid explosives

It has been extensively used by Middle Eastern terrorists. It is also suspected to have been used during the 7th July 2005, London' bombings. It is stated that just 24 ounces of TATP could blow a hole in the hull of a heavy ship, let alone the skin of an airliner. The Algerian terrorist arrested upon entry to the US from Canada prior to the millennium celebration was found to possess HMTD in addition to conventional explosives.

There have also been at least two prior terrorist attacks on planes using liquid explosives, on Korean and Philippines aircraft.

Korean Plane Explosion Case:

In 1987, [KAL Flight 858](#) was destroyed using the explosives C-4 and PLX, the latter of which is a liquid. PLX, or Picatinny Liquid Explosive, is a liquid binary explosive, a mixture of 95% nitromethane and 5% ethylene diamine. It is a slightly yellowish liquid. It was developed at Picatinny Arsenal during World War II for cleaning of minefields. It was to be mixed just before use. PLX was one of the explosives used to down Korean Air Flight 858.

Philippines Plane Explosion Case:

On December 11, 1994 explosion on board PAL Flight 434 killed one passenger. The flight was on its second leg from Cebu to Tokyo when a bomb exploded, killing one passenger. Authorities later discovered that a passenger on the aircraft's preceding leg was Ramzi Yousef, who United States authorities have branded a master Al-Qaida bomber and terrorist. He was later convicted of the first World Trade Center bombing, for

which he was sentenced to death by lethal injection. Yousef boarded the flight under an assumed name.

Operation Bojinka US:

US prosecutors said the device was a "Mark II" "microbomb" constructed using Casio digital watches as described in Phase I of Operation Bojinka of which this was a test. On Flight 434, Yousef used one tenth of the explosive power he planned to use on eleven U.S. airliners in January of 1995. The bomb was designed to slip through airport security checks undetected. The explosive used was liquid nitroglycerin, which was disguised as a bottle of contact lens fluid. The wires he used were hidden in the heel of his shoe. At that time, metal detectors used in airports did not go down far enough to detect anything there.

Starting on January 21, 1995 and ending on January 22, 1995, they would set the bombs on 11 United States-bound airliners that had stopovers all around East Asia and Southeast Asia... The bombs would have been timed before the operatives stepped off the planes. The aircraft would have blown up over the Pacific Ocean and the South China Sea almost simultaneously. If this plan worked, several thousand would have perished, and air travel would have been shut down worldwide for days, if not weeks. The U.S. government estimated the prospective death toll to be about 4,000 if the plot had been executed. 'Operation Bojinka' was very similar to the plot that the British claim to have uncovered in August 2006.

Foiled London Bombing Case - Recent Case of suspected UK Plot:

On August 10, 2006 British officials appears to have revealed and foiled a terror plot to blow up many planes leaving UK airports and flying to locations across the US. Security experts believe that potentially extremely effective liquid explosives would have been used, taken on board in hand luggage, possibly disguised in fizzy drink bottles. Detonators were to be disguised as electronic equipment. It is thought there could have been three waves of attacks targeting three aircraft each time on different days, with the perpetrators hoping the destruction of the planes would have destroyed evidence of how they carried out the attack allowing them to attack again after a pause. This prompted the Joint Terrorism Analysis Centre (JTAC) to upgrade the security level to critical, which imposed ban on taking hand luggage on to flights till security threat level was lowered. US homeland security chief Michael Chertoff, who said the plot was "suggestive" of al-Qaeda, claimed the planning was in its "final stages".

The answer, say security experts, highlights the need for a security system based on sophisticated profiling: It may be more important for the security system to be geared towards detecting passengers with intent to do harm rather than relying on detecting the specific means they've chosen. Boston's Logan Airport is currently testing a version of profiling called the SPOT program, but it avoids the ethnic profiling that many security experts say, despite its objectionable political connotations, would have to be the focus of an effective system.

Authorities in both the United States and Great Britain warned all passengers that liquids would not be allowed in carry-on luggage until the crisis passed during August 2006. They imposed ban on liquids included hair spray, shampoo and beverages, items people travel with all the time.

A passenger at airport, described passengers crowding around the trashcans dumping anything that could be considered liquid, even toothpaste. But he passed unchecked through security with toothpaste and lotion in his hand luggage, showing the difficulties of enforcing tighter measures in a country with 700 million passengers a year.

Why liquid explosives are favorite of terrorists?

- 1 Easily available in day-to day used products and at cheaper price: Most of the ingredients required to prepare a bomb come from day-to-day articles like acetone from nail polish remover, hydrogen peroxide in hair dye which creates a highly sensitive liquid explosive called TATP.
- 2 Very difficult to detect: Present explosive detection systems are tuned for detection of military and civil explosives and not the hazardous liquids that can be used in IEDs. Also several products used in day-to-day life contain these chemicals, which may lead to false alarms.
- 3 On board preparation is possible: Taking two different items, which are independently not recognized as explosives, onboard and mixing them for the preparation of bomb is possible.
- 4 Easily disguisable to by present security/detection techniques: NG is used in the medicine used for heart disease. The terrorist may by-pass the security system by carrying NG in medicinal pill forms. They can be easily hidden inside innocent looking bottles or cans like Gin, Whisky, Cold drinks, baby bottles, perfumes and deodarants. Liquid explosives would not necessarily be picked up by sniffer type security scanner if place carefully in sealed and cleaned containers.
- 5 Easy to carry: Number of products in day-to-day use can be easily transported to the destination without any suspicion.
- 6 Powerful explosion: NG can be viscous liquid below 56 F and its detonation generates gases that would occupy more than 1200 times its original volume at room temperature. The clear liquid Astrolite G has velocity of detonation as twice as that of TNT.
- 7 Highly sensitive nature hence easily detonable: TATP and HMTD can be initiated with slightest shock or spark while NG can detonate on slightest movement.
- 8 Since day-to-day products are being used for the preparation of bombs, one explosion creating terror in the mind of common man and also embarrass government to find out protective measures and equipments.

Liquid Explosives

Most explosives work in basically the same way. They burn or decompose very quickly, producing lots of heat and gas, which rapidly expands and can tear things apart. Usually, an explosive material requires some kind of stimulus, like heat or shock energy, to get the process started.

Conventional explosives

- (a) Trinitro Toluence (TNT)
- (b) Research Development Explosive (RDX)
- (c) Her Majesty's Explosive (HMX)
- (d) Penta Erythritol Tetra Nitrate (PETN)
- (e) Tetryl
- (f) Nitro Glycerine
- (g) Nitro Cellulose
- (h) Tagants like Ethylene Glycol Di Nitrate (EGDN) and Di Methyl Nitro Butane (DMNB)
- (i) Ammonium Nitrate (AN)
- (j) C-4
- (k) SEMTEX (PETN+RDX)
- (l) Ammonium Nitrate Fuel Oil (ANFO)
- (m) Plastic bonded explosive including plastic explosive (PE) and low temperature plastic explosive (LTPE).
- (n) Tri Acetone Tri peroxide (TATP)
- (o) Hexa Methylene Triamino Di Peroxide (HMTD)
- (p) Dinitro Toluene (DNT)
- (q) Prima Cord
- (r) Data sheet (Sheet explosive)

Conventional explosive compositions

| | |
|-------------|--|
| SEMTEX | RDX + styrene butadiene + oil + orange colour + antioxidant |
| SEMTEX-H | RDX + PETN + styrene butadiene + motor oil + additives |
| C-2 | RDX + TNT + DNT + NC + MNT (mononitrotoluene) |
| C-3 | RDX + TNT + DNT + Tetryl + NC |
| C-4 | RDX + polyisobutylene + fuel oil |
| Cyclotol | RDX + TNT |
| Pentolite | PETN + TNT |
| Tetryol | TNT + Tetryl |
| Detasheet | PETN + plasticizer |
| Dynamite | NG + NC + SN (sodium nitrate) |
| Red diamond | AN + SN + NG + EGDN + chalk + sodium chloride + pulp (wood, grain, etc.) |
| ANFO | AN + fuel oil |
| Prillex | AN + diesel oil |

(AN: Ammonium nitrate; SN: sodium nitrate; NG: nitroglycerin)

Home made explosives

Powder from shotgun shells or small arms ammunition, match heads, firecracker, and ammonium nitrate fertilizers can also be accumulated in sufficient volume to create a devastating main charge explosive. Following combinations of commonly available materials are used by terrorists to fabricate an IED.

- Match head composition
- Ammonium nitrate & aluminium mixtures
- Nitric acid and cellulose material mixtures
- Mixtures of potassium chlorate or potassium chromate with sugar or wax
- Mixtures of potassium chlorate, charcoal and sulphur
- Mixtures of ammonium nitrate, aluminum and stearic acid
- Magnesium and powdered aluminum mixed with iron oxide
- Ammonium nitrate/sodium Perchlorate with fuel nitromethane/ Al

Starch, flour, sugar, or cellulose materials can also be treated with chemical reagents to obtain effective explosives.

Liquid Explosives

There are several types of liquid and gel explosives some of which are very volatile and sensitive. Liquid explosives can be prepared

- a) All components are in liquid form but neither of them is of explosive nature and produce liquid explosive
- b) All components are in liquid form but at least one of them is of explosive nature and produce liquid explosive
- c) All components are in solid form and produce liquid explosive using solvent medium
- d) Components may be solid or liquid but produce liquid explosives
- e) All components or one of them are in liquid form and produce solid explosive

Following are the various types of liquid explosives

- 1. Slurry and Water gel explosives:** Developed as replacement for dynamite. They are packaged in plastic and look like very large sausages. They require a detonator and are not subject to heat, friction or electrical detonation.

| | |
|------------------|--|
| Sigmagel Titagel | Ammonium nitrate + sodium nitrate + calcium nitrate |
| Tovex | Ammonium nitrate + monomethyl ammonium nitrate + additives |

- 2. Emulsion explosives**

| | |
|----------|------------------------------------|
| Petrogel | NG + EGDN + NC + SN + additives |
| Nipak | AN + SN + additives + polyurethane |

- 3. Nitroglycerin:** Nitroglycerine is a colorless to pale-yellow, viscous liquid or solid (below 56°F) used since 1867. It is the most instable of explosives but extremely powerful and may detonate with the slightest movement. It is made out of reaction of cellulose with the combination of sulphuric and nitric acids. It can be stabilized by a

combination of freezing or reconstitution (cotton balls soaked and then dried) or the addition of compounds that can then be removed. The liquid looks clear but with aging becomes brown. It is an explosive ingredient in dynamite (20-40%) with ethylene glycol dinitrate (80-60%). It has a high nitrogen content (18.5%) and contains more than enough oxygen atoms to oxidize the carbon and hydrogen atoms while nitrogen is being liberated, so it is one of the most powerful explosives known. Its detonation generates gases that would occupy more than 1,200 times the original volume at room temperature.

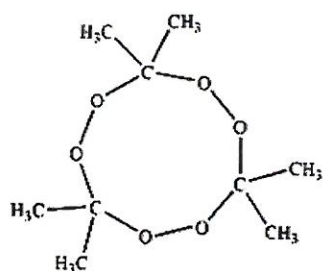
4. Incendiary or flame producing chemicals:

These type of explosives have been widely used and when packed in a suitable container may cause large scale damage. Eg. Gasoline, Gelled Gasoline, chlorate sugar and thermite.

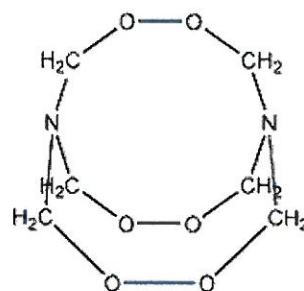
5. Peroxide explosives

During recent time, non-nitrogen explosives like triacetone triperoxide (TATP) are finding application. Lack of solid detonation by-products pose difficulty in identifying it in post explosion analysis. TATP (density: 1.2 g/cm^3 m.p. $94-95^\circ\text{C}$) is high explosive having high volatility and high sensitivity. It is reported that highly pure TATP is slightly more sensitive than PETN. TATP is synthesized from equal amounts of acetone (solvent and nail polish remover) and concentrate hydrogen peroxide (hair bleach) in presence of hydrochloric acid or sulphuric acid (common in auto batteries) or phosphoric acid. Israel has seen an increase in its use in terrorist bombings. Although it is manufactured from liquids, it is white crystalline powder and not a liquid. It has been extensively used by Middle Eastern terrorists. It is also suspected to have been used during the 7th July 2005, London bombings. It is stated that just 24 ounces of TATP could blow a hole in the hull of a heavy ship, let alone the skin of an airliner. Besides their explosive power, there is another risk to explosives like TATP and TCAP (both are also known as acetone peroxide). These explosives are highly unstable, extremely impact and friction sensitive and can cause accidental explosion.

Hexamethylene triperoxydiamine (HMTD) is another sensitive high explosive of choice for terrorist groups. The Algerian terrorist arrested upon entry to the US from Canada prior to the millennium celebration was found to possess HMTD in addition to conventional explosives. It is sensitive to shock, friction, heat and flame. HMTD can be made from hydrogen peroxide and hexamine fuel tablets available in camping stores mixed with Sulphuric or citric acid as catalyst. It is not a liquid though, made from liquids. It is also suspected to have been used during the 7th July 2007 London bombings. Normally all the above liquid explosives need detonator to initiate explosion.



TATP



HMTD

6. **Nitromethane:** Nitromethane was first synthesized by Kolbe in 1872. Pure nitromethane will not usually detonate unless it is subjected to extreme shock and/or confinement at elevated temperatures. It is so insensitive that it was not until 1938 that its detonation property was revealed by McKittrick. Once this detonation property was discovered, research was initiated to find sensitizers to increase its ease of detonation. World War II research produced sensitizers: primarily amines or polyamines such as diethylamine, triethylamine, ethanolamine, ethylenediamine and morpholine. The sensitizers nitromethane detonatable with a blasting cap. Sensitization of nitromethane can also be achieved by addition of non-chemical, air entrapping structures, such as resin micro balloons and polymeric foam as well as pyridine. The air bubbles, while having the desired result of sensitization, have the undesired result of decreasing the density, and thereby lowering the velocity.

In 1945, Ericksen and Rowen listed over one dozen nitromethane - amine mixtures along with their explosive ability.

Liquid nitromethane based explosive compositions can also be converted into a semi-solid or gelled state by the addition of a gelling agent leading to increase in density and, therefore, the detonation pressure of the semi-solid or gelled compositions.

Nitromethane is employed to reduce the sensitivity of nitroglycerine.

Trinitrotoluene was found to be soluble in nitromethane, thus making it possible to formulate more powerful compositions involving the two components.

A foamable nitromethane composition can be made by the addition of stabilizers, thickeners, sensitizing and foaming agents. It also teaches the addition of metals, including aluminum, to enhance the total energy of the system. The idea is that the foam would be applied to a mine field and then detonated. Two problems with this method is the very low density of the foam, thus low velocity. Another problem is the useable life of the foam after its application. This would greatly vary depending on conditions such as temperature, wind, sunlight, etc.

Mixtures of nitromethane and nitroethane are used as an oxidizing liquid and aluminum fuel granules having an average particle size within the range of 1/64 to 1/4 inch and an average bulk density within the range of 0.2 to 1.0 grams/cc. The resultant explosive is a blasting agent requiring a one pound booster for initiation, not a cap sensitive, small diameter mixture.

There are fewer restrictions on obtaining and transporting these chemicals.

7. **Ammonium nitrate fuel oil (ANFO):** ANFO is composed of approximately 94.3% AN and 5.7% FO by weight. The normal ratio recommended is 80 ml of fuel oil per kg of AN. In practice, a slight excess of fuel oil is added. As underdosing results in reduced performance while overdosing merely results in more post-blast fumes. The basic chemistry of ANFO detonation is the reaction of ammonium nitrate (NH_4NO_3) with a long chain hydrocarbon ($\text{C}_n\text{H}_{2n+2}$) to form nitrogen, carbon dioxide and water. ANFO is considered as a high explosive which decomposes through detonation rather than deflagration with a high velocity of detonation. It is a tertiary explosive consisting of distinct fuel and oxidizer phases and requires confinement for efficient detonation and brisance. Its sensitivity is relatively low; it generally requires a booster (e.g., one or two sticks of dynamite or Tovex) to ensure reliable detonation. The explosive efficiency associated with ANFO is approximately 80% of TNT, ie 0.8 TNT equivalency. The most efficiently mixed ANFO mixtures can exceed 1.6 TNT equivalency.
1. **Astrolite G and Astrolite A-1-5:** Astrolite explosives were discovered in the 1960's. These are colourless liquids and do not detonate unless sensitizer material is added. These can be initiated by mechanical or electrical detonation. Astrolite explosives are formed when ammonium nitrate is mixed with anhydrous hydrazine. This produces a clear liquid explosive called Astrolite G. When aluminum powder (100 mesh or finer) is added to the Hydrazinium Nitrate slurry, it forms Astrolite A-1-5. Astrolite G is a clear liquid explosive that produces a very high detonation velocity, almost twice as powerful as TNT.
2. **Two component Kinepak:** Kinepak is civil explosive and available commercially. It is a syrupy red liquid which can be detonated after addition of sensitizer. Two individual, nonexplosive components are combined by the user to form a cap sensitive explosive. The first component which is liquid is predominantly nitromethane (NM) while the other component which is solid is primarily finely divided ammonium nitrate (AN). The commercial product Kinepak is packaged in several different sizes and shapes of plastic bottles as well as foil pouches (bags) which are intended for various applications. In each case, the solid component container is supplied with an appropriate amount of premeasured liquid in another individual container. In order to use Kinepak, the liquid component is simply poured into the solid component. Within about five to fifteen minutes, the liquid (which is usually colored red) will soak down to the bottom of the container, as evidenced by the pink color. At this point, it has the consistency of moist powder and is a cap sensitive, high explosive. It can be used in most situations where it would be suitable

to use cartridge explosives such as dynamite, water gels and small diameter emulsions.

- 3.. **Binex:** Binex is a two component system of an aqueous solution of sodium perchlorate and aluminum powder. When these two components are combined, a liquid explosive is formed that is cap sensitive. It is believed that this composition would not be a viable product as a replacement for cartridge explosives because of the high cost and the environmental concerns with the sodium perchlorate solution. However, there is a current military application where this product is used to blast fox holes in conjunction with an entrenchment kit for soldiers. It is known that this explosive has detonation velocity that is much lower than Kinepak.
4. **Nitroparaffin:** There are other binary systems based on nitroparaffins such as nitromethane, nitroethane, nitropropanes, etc. Under the right circumstances, they can act as a fuel (as when combined with ammonium nitrate) an oxidizer or a stand alone explosive, especially nitromethane. However, they are too insensitive to be used as explosives. As in case of nitromethane these nitroparaffins need to be sensitized by resin balloons and amines (like ethylenediamine) so that they will detonate with a blasting cap. However since the balloons will float to the surface of pure nitromethane, a thickening (gelling) agent must be added to prevent this. These mixtures become unstable and decompose after a few days. Most of these sensitizing agents are very toxic and difficult to work with safely.

Properties of liquid explosives:

- 1) Sensitivity to impact, friction and shock: The liquid explosives that are more sensitive to these stimuli can be initiated by simple initiation mechanisms and that is why they should be handled with extreme care. The insensitive liquids can be made sensitive to these stimuli by addition of sensitizers, for eg primary amines are added to nitromethane as sensitizers. Also liquids having very high sensitivity can be made less sensitive by addition of resins. Example of reduction in sensitivity is the addition of nitromethane to nitroglycerin. TATP and HMTD are extremely sensitive to shock and therefore difficult to transport. This is the reason why terrorists carry the ingredients required for preparing them to the site of event.
- 2) Thermal sensitivity: Explosives like TATP and HMTD are extremely sensitive towards thermal energy and can be detonated with the help of burning match stick or cigarette.
- 3) Flammability: Some of liquids like kerosene, petrol, fuel oil, alcohols, acetone, etc are highly flammable. They form gaseous cloud in surrounding atmosphere which can take up energy from any kind of heat source (like electrical spark, burning wood, etc) and ignite the whole liquid at once. If large quantities of flammable liquid is stored in confined space such thermal stimulus can lead to rapid build up of pressure due to gaseous products formed due to burning of the liquids and hence lead to large scale destruction due to explosion.

- 4) Flash point: This is the minimum temperature at which the vapor above a liquid fuel will first support a combustion transient or "flash". The flash point is measured by a standardized test (ASTM D56) using a small quantity (50 cc) of liquid that is slowly heated (about 10 C/minute) until a flash is observed when an open flame is dipped down into a covered vapor space. The legal description of flammable is used for all liquids with a flash point less than 1000 C, and the term combustible is used for liquids with a flash point in excess of 1000 C.
- 5) Volatility and Vapour pressure: Volatile liquids have high vapour pressures meaning that the concentration of its molecules in gas phase is high.

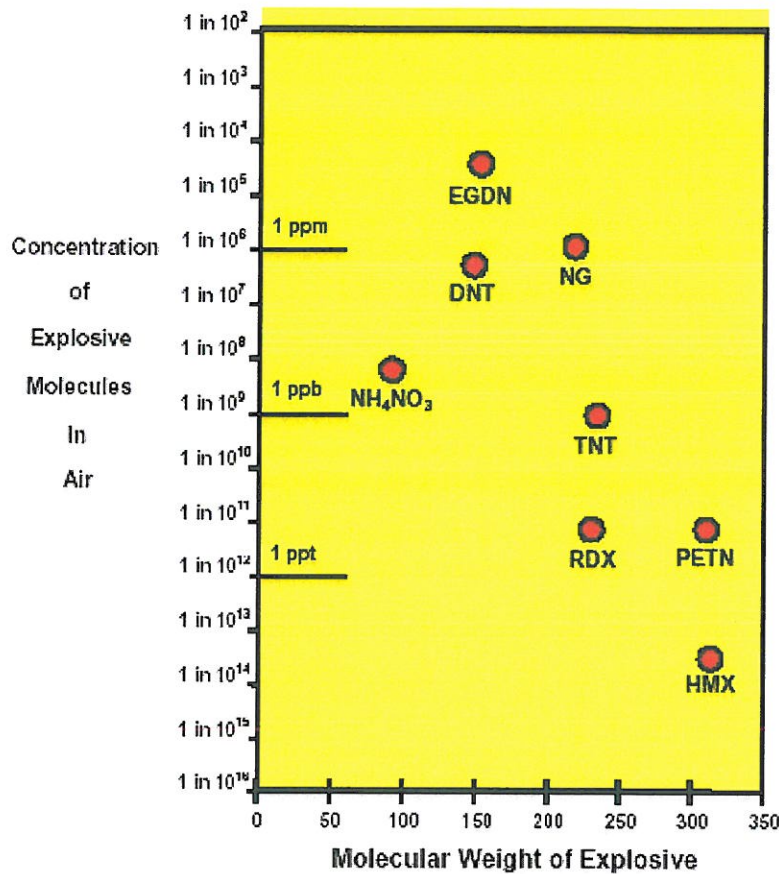
High vapour pressure explosives include ethyleneglycol dinitrate (EGDN), NG, 2,4-dinitrotoluene (DNT). The medium vapour pressure group includes TNT and ammonium nitrate whereas low pressure group includes HMX (octogen), RDX (hexogen or cyclonite) and PETN (penta erythritol tetranitrate). Vapour pressure for mixtures containing these explosives may be even lower. The vapour pressures of common explosives at 25° C as determined under ideal equilibrium conditions, i.e. in airtight containers are listed below:

| Explosive | Vapour pressure (mm of Hg at 25° C) |
|-----------|--|
| NG | 4.3×10^{-4} |
| TNT | 7.0×10^{-6} |
| RDX | 8.0×10^{-8} |
| PETN | 7.0×10^{-9} |

The actual vapour pressures in air are much lower than these values. The factors like air currents and temperature play a significant role in influencing the amount of explosive in vapour state in air. Further, the polymeric binders, plasticizers and other additives used to prepare certain explosive compositions [like fuel oil is added to ammonium nitrate to make ANFO] lead to further reduction in the concentration of explosives in vapour state. If explosive compositions are filled in either metallic or plastic containers (hermetically sealed), which may be buried under earth/water, or hidden in buildings or vehicles, further reduction occurs in the concentration of explosives vapours available for detection. It has been reported that the effective vapour pressure can be reduced by a factor of 1000 by sealing explosives in plastics. The very low pressure of some explosive materials is a challenge for the explosive detector which uses vapour sample. Low vapour pressure explosives are better detected with swipe collection, however, this is extremely dangerous to deal with liquid explosives having extreme sensitivity for friction and shock. Therefore vapour sampling is more preferable over swipe method.

As per recommendations of International Civil Aviation Organization (ICAO) taggants like EGDN (ethyleneglycol dinitrate), o-MNT (ortho-mononitrotoluene), p-MNT (para-mononitrotoluene) and DMNB (dimethyl nitrobutane) having vapour pressure orders of magnitude higher than common explosives are added to the explosives

manufactured under Government license in several countries so that the explosive detection becomes easier. However, illegally acquired explosives and home made explosives cannot be expected to contain these taggants.



Vapour concentrations of neat high explosives in saturated air at 25°C.²

6) Lower and upper explosion limits:

The explosive range is between the lowest explosive limit (LEL) and the upper explosive limit (UEL). The LEL is the lowest concentration of vapour in air, which will burn or explode upon contact with a source of ignition. Below the LEL, the mixture is too lean (i.e. there is insufficient fuel). The UEL is the highest concentration of vapour in air, which will burn or explode upon contact with a source of ignition. Above the UEL, the mixture is too rich to burn (i.e. there is insufficient oxygen). The LEL and UEL are usually indicated by the percentage by volume of vapour in air. For example diethyl ether, the LEL is 1.9% and the UEL is 36% by volume of air. This range becomes wider with increasing temperature and in oxygen-rich atmospheres.

- 7) Velocity of detonation: The **velocity of detonation** of an explosion is the rate at which the detonation/combustion wave travels through the explosive. It is usually measured in metres per second ($\text{m}\cdot\text{s}^{-1}$). VoD of NG is 7700 ms^{-1} .

Table of Explosive Detonation Velocities

| Explosive Name | Abbreviation | Detonation Velocity (m/s) | Density (g/cm^3) |
|------------------------------------|--------------|---------------------------|------------------------------------|
| <i>Aromatic explosives</i> | | | |
| Trinitrotoluene | TNT | 6,900 | 1.6 |
| Picric Acid | TNP | 7,350 | 1.7 |
| <i>Aliphatic explosives</i> | | | |
| Methyl nitrate | | 8,000 | 1.21 |
| Nitroglycol | | 8,000 | 1.48 |
| Nitroglycerine | NG | 7,700 | 1.59 |
| Pentaerythritol Tetranitrate | PETN | 8,400 | 1.7 |
| Nitroguanidine | NQ | 8,200 | 1.7 |
| Cyclotrimethylenetrinitramine | RDX | 8,750 | 1.76 |
| Cyclotetramethylene Tetranitramine | HMX | 9,100 | 1.91 |
| <i>Organic Explosives</i> | | | |
| Acetone Peroxide | AP | 5,300 | 1.18 |
| Ammonium Nitrate | AN | 5,270 | 1.3 |

Ref: http://en.wikipedia.org/wiki/Table_of_explosive_detonation_velocities referred on 23rd Dec 2008.

- 8) Melting and boiling points: The melting and boiling points of liquid explosives and hazardous liquids are compiled in table It may be noted that some of these explosives either decompose or explode before their boiling point.



Detonation Techniques of Liquid Explosives

Detonation Techniques of Liquid Explosives

Most explosives work in basically the same way. They burn or decompose very quickly, producing lots of heat and gas, which rapidly expands and can tear things apart. Usually, an explosive material requires some kind of stimulus, like heat or shock energy, to get the process started.

Many people don't think of explosives as liquids, though. Most of us imagine them as solids, like gunpowder or C-4. But one has probably heard of one liquid explosive already -- nitroglycerin. Nitroglycerin is made of carbon, nitrogen, hydrogen and oxygen. A physical shock can start a chain reaction that breaks its molecules down into carbon dioxide, water and oxygen. The breaking of the bonds between the atoms releases an enormous amount of energy in a very short amount of time.

Nitroglycerin is a component in some relatively stable solid explosives, like dynamite. But as a liquid, it's extremely dangerous and volatile. You typically have to use a blasting cap to detonate a stick of dynamite, but you can accidentally trigger a nitroglycerin explosion with a physical shock. It doesn't blow up at the slightest movement as depicted in some movies and TV shows, but you can detonate it by hitting it.

Nitroglycerin is oily and clear, so if you poured some into an opaque lotion bottle, no one but you would know what was really inside. However, nitroglycerin's inherent instability would make this bottle very dangerous for you to carry around.

The attackers most likely did not plan to use nitroglycerin, but the liquid explosives they chose probably had similar chemical properties. Like nitroglycerin, most liquid explosives are made of unstable molecules. These complex molecules break down into ordinary, stable molecules when exposed to the right stimulus. Even a very minor shock can start the process, and since it involves the breaking of atomic bonds, it releases enormous amounts of energy.

The terrorists most likely intended to remove the explosives from their carry-on luggage and detonate them while the planes were over the Atlantic Ocean. They may have planned to use explosives that require the mixing of two different liquids in order to start the reaction. Unnamed sources have stated that the attackers planned to mix a liquid dyed to resemble a sports drink with a peroxide gel to create an explosive substance.

According to other sources, the attackers intended to use triacetone triperoxide, which can be made from readily available substances like hydrogen peroxide, acetone and acid. Like nitroglycerin, triacetone triperoxide molecules are made of hydrogen, oxygen and carbon. When it explodes, it breaks down into large amounts of ozone and acetone.

Regardless of which exact substance the attackers planned to use, the liquid nature of the explosives would have been central to the plot for two reasons:

- Liquid explosives are very volatile, so the attackers would not necessarily need elaborate or powerful detonators to start the explosion. Without as much material to smuggle on board, the attackers would be less likely to attract the attention of airport security. In the case of the August 2006 plot, unnamed

officials speculated that the attackers planned to use cell phones or MP3 players as detonators.

Smuggling a liquid onto an airplane would not be very difficult. The attackers may have planned to use ordinary bottles made for hair gel, shampoo, lotion or other liquids and gels. Under typical circumstances, airport security probably would not question items like these.



**Explosive Detectors Available
with Maharashtra Police**

Explosive detectors available with Maharashtra Police Department

- 1 SRTVD
- 2 MO-2M
- 3 MO8
- 4 Model HS 97
- 5 EVD – 3000

The details of the above mentioned explosive detectors are compiled below from the brochures and literature reported data.

SRTVD-8 TVIN

Introduction: SRTVD-8 TVIN is handheld explosive detector manufactured by Sibel Ltd, Russia and marketed in India by Precision Operating Systems (India) Pvt Ltd, Thane. This is the basic model from which MO2M and MO8 have evolved.

SRTVD is designed for the inspection of

- 1 Hand luggage
- 2 Luggage and loads transported by all means
- 3 Letters and parcels
- 4 Clothes
- 5 Buildings, offices and public areas
- 6 Furniture
- 7 Vehicles

When fitted with the TVIN accessory (included in the set), it also operates as explosive trace detector.

Principle: The detector works on the principle of modified version of ion mobility spectrometry. This is the trace detection method operating on non linear differential mobility technology for detecting traces and vapours of explosive samples.

Operational details: Detects trace amount of explosive vapours by sampling and analyzing air samples taken from surface or non-sealed objects. The sample is drawn from air using air pump and then subjected to ionization using radioactive source like tritium. The ionized explosive molecules are accelerated to high electric field where in the mobility of the ions is non-linearly dependent on the field strength. This is the modified version of ion mobility spectrometry. The ions are separated using asymmetric field applied alongwith the accelerating field and the signal is generated when the ions are detected by ion detector like Faraday cup/plate.

Thermal Vapours Intensifier TVIN: TVIN is very useful for detecting explosive residues in gaseous (vapours), solid (particles) and liquid (solutions) phases. It increases significantly the sensitivity of the detector to substances having low vapours pressure (poor volatility), such as PETN, RDX, plastic explosives, etc. This becomes possible due

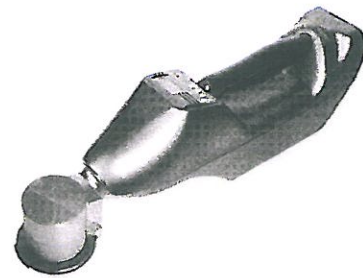
to the heating in TVIN and pre-concentration by the sampling device. The operator can perform several sampling procedures simultaneously using the sampling device and/or sampling cards with subsequent analysis.

Advantages:

- Sensitivity increases significantly to substances having low vapour pressures such as RDX, PETN and plastic explosives
- Detect explosive residues in gaseous, solid and liquid phases hence useful for post-blast investigations
- Detection procedure is completely automatic and real time with response time of 15s
- Specially designed easy to use software
- No gas required, no filters, no additional products like calibration accessories
- No special training required
- No cold start time
- Portable, light weight and easy to use
- PC compatible

Disadvantages:

- High rate of false alarm
- Radioactive source is used
- Not useful to detect liquid explosives
- Frequent recalibration required
- Not useful for sampling in windy and dusty conditions



MO-2M

Introduction: This is the upgraded version of SRTVD-8 TVIN.

Principle: Same as SRTVD-8 TVIN with improved electronics and miniaturized non linear differential mobility spectrometer.

Operational details: The sample from atmosphere is drawn in with the help of air pump and subjected to ionization using radioactive source like tritium. The ionized explosive molecules are accelerated to high electric field where in the mobility of the ions is non-linearly dependent on the field strength. This is the modified version of ion mobility spectrometry. The ions are separated using asymmetric field applied alongwith the accelerating field and the signal is generated when the ions are detected by ion detector like Faraday cup/plate.

Thermal Vapours Intensifier TVIN: TVIN is very useful for detecting explosive residues in gaseous (vapours), solid (particles) and liquid (solutions) phases. It increases significantly the sensitivity of the detector to substances having low vapours pressure (poor volatility), such as PETN, RDX, plastic explosives, etc. This becomes possible due to the heating in TVIN and pre-concentration by the sampling device. The operator can perform several sampling procedures simultaneously using the sampling device and/or sampling cards with subsequent analysis.

Advantages:

- Fully automatic real time hand held detector,
- Ready to operate in less than 10 seconds after automatic calibration,
- Constant adjustment of operating conditions in line with the changes in the atmosphere,
- Connection to a desktop or notebook PC (blue tooth),
- Specially designed easy to use software,
- No gas required, no filters, no additional products
- No special training required
- No cold start time
- Portable, light weight and easy to use

Disadvantages:

- High rate of false alarm
- Radioactive source is used
- Not useful to detect liquid explosives
- Frequent recalibration required
- Not useful for sampling in windy and dusty conditions

Substances detected:

TNT, NG, PETN, RDX, TATP and compositions such as C4, Semtex, Dynamite, EGDN, DMNB

Sensitivity: in vapor mode : 10^{-13} g/cm³ for TNT (0.01 ppb) in traces mode : 50 pg.



MO8

Introduction: This is the upgraded version of MO-2M. The MO-8 - TVIN is a portable explosive detector designed for inspection of persons, baggage, vehicles, trains, aircraft and large areas as offices and apartments, etc., by sampling and analyzing of ambient air and residual particulates from suspect surface. The MO-8 - TVIN is capable of detecting military and industrial explosives such as TNT, NG, PETN, RDX, C4 and their mixtures.

Principle: Same as SRTVD-8 TVIN with improved electronics and miniaturized non linear differential mobility spectrometer.

Operational details: Sampling system (front part) includes a sampling nose, gas tract consisting of analytical and reference channels and a built-in vortex generator. Vortex generator produces the spinning airflow to the reverse air inlet and creates a low pressure air space resulting in actual air sampling in sniffing motion and ensuring almost nil false alarm rate.

The sample from atmosphere is drawn in with the help of air pump and subjected to ionization using radioactive source like tritium. The ionized explosive molecules are accelerated to high electric field where in the mobility of the ions is non-linearly dependent on the field strength. This is the modified version of ion mobility spectrometry. The ions are separated using asymmetric field applied alongwith the accelerating field and the signal is generated when the ions are detected by ion detector like Faraday cup/plate.

Thermal Vapours Intensifier TVIN: TVIN is very useful for detecting explosive residues in gaseous (vapours), solid (particles) and liquid (solutions) phases. It increases significantly the sensitivity of the detector to substances having low vapours pressure (poor volatility), such as PETN, RDX, plastic explosives, etc. This becomes possible due to the heating in TVIN and pre-concentration by the sampling device. The operator can perform several sampling procedures simultaneously using the sampling device and/or sampling cards with subsequent analysis.

Advantages:

- Inbuilt lithium ion rechargeable battery
- In addition to the visual indication of the type of explosive and its concentration, the ionogram is also displayed on the LCD.
- Storage of ionogram in memory
- Blue tooth capability
- Specially designed "Io Scan 2.0" software with programmable windows.
- The program can be updated to include detection of new explosives as they become known.
- High sensitivity and selectivity, false alarm rate less than 1%.
- Fully automatic real time hand held detector,
- Ready to operate in less than 10 seconds after automatic calibration,
- Constant adjustment of operating conditions in line with the changes in the atmosphere,
- Connection to a desktop or notebook PC (blue tooth),
- Specially designed easy to use software,
- No gas required, no filters, no additional products
- No special training required
- No cold start time
- Portable, light weight and easy to use

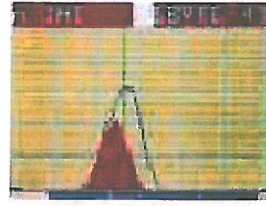
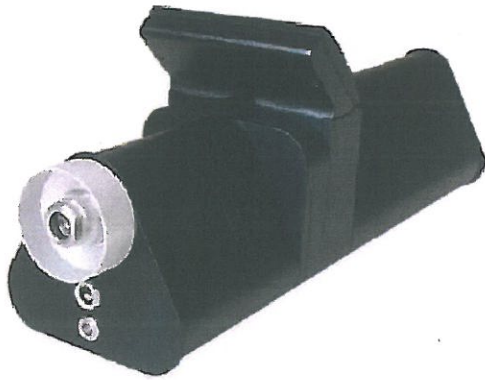
Disadvantages:

- High rate of false alarm
- Radioactive source is used
- Not useful to detect liquid explosives
- Frequent recalibration required
- Not useful for sampling in windy and dusty conditions

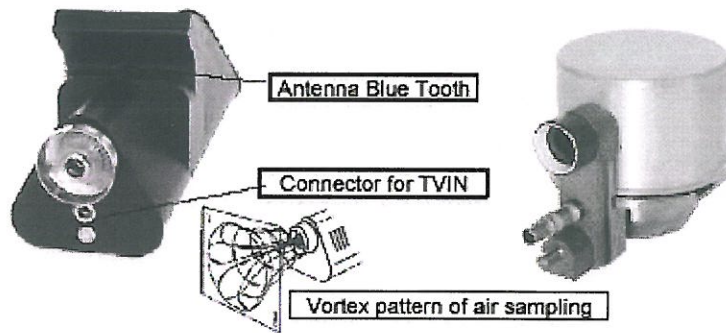
Substances detected:

TNT, NG, PETN, RDX, TATP and compositions such as C4, Semtex, Dynamite, EGDN, DMNB

Sensitivity: in vapor mode : 10^{-13} g/cm³ for TNT (0.01 ppb) in traces mode : 50 pg.



Ionogram : Display & Recording



Model HS 97

Principle: The detector detects explosives using gas chromatography coupled with electron capture detector (ECD).

Operational details: Electron Capture Detector comprises of an ionization chamber in which electrons produced from a radioactive cathode, usually tritium or Nickel-63 are injected into a stream of inert carrier gas (helium or argon), where they lose their energy by inelastic collisions with the carrier gas molecules and become thermalized. These thermal electrons are collected by an anode that produces a constant (standing) current. When an electron-capturing compound (such as an explosive) is introduced into the carrier gas, the standing current is reduced and the detector responds to the change.

In order to make the electron-capture detector more specific, This explosive detector combines ECD with gas chromatography, which separates the volatile components in the sampled air in a column containing a stationary phase. The components emerge from the column at different retention times. The detection system assesses these retention times in conjunction with the ECD output and determines whether an explosive is present or not.

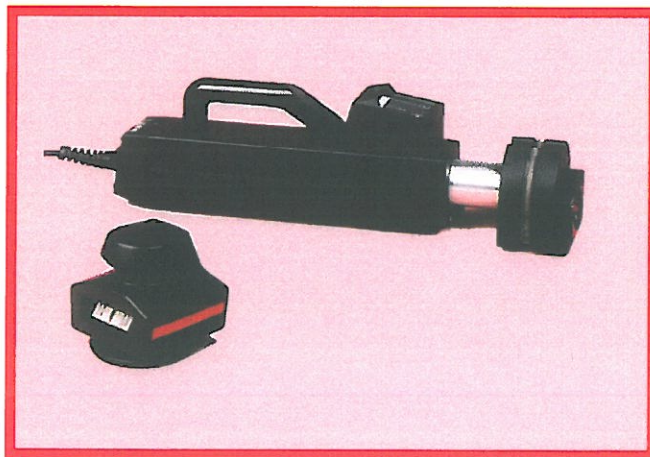
Advantages:

- ECDs have a fast response and a sensitivity of about 1 ppb (parts per billion) for most electron capturing compounds.
- The system does not have movable parts.
- Portable
- Easy to use

Disadvantage:

- Recurring running cost is due to required refill of helium or argon gas.
- This detector is not compound specific, i.e., it cannot identify the type of explosive present.
- There are also some common non-explosive substances that give rise to ECD signals, such as wide range of substituted hydrocarbons like Freon, fertilizers, and some household cleaners.
- This system employs membrane concentrators in which explosive molecules are soluble and can be transferred selectively from one side of the membrane to the other side. As a result of this more than 70% of the sampled gas is not available for analysis.

The system requires electrical power supply and battery back up is essential in fieldwork.



Testing of these explosive detectors available with Police Department for their competence of detecting liquid explosives

Quantum Sniffer QSH-150

Principle: IMS detection is based on how fast ions move and reach the detector. The mobility of ions is dependent on the shape, size and mass of explosive molecules.

Operational details: QSH-150 specializes in two important aspects above the other ion mobility spectrometers in that it has a sampling system that creates vacuum suction effect inside the air curtain produced by sampling device and employs laser ionization system. It does not contain radioactive substance for ionization. The ions formed then undergo ion-molecule reactions with the explosive molecule. Under the influence of an electric field, the mixture of reactant and product ions reaches a shutter grid that separates the reaction region and the drift region. The shutter grid is made up of sets of thin mesh wires with a bias voltage between them. On application of bias voltage, the ions are attracted to the gating grid and lose their charge. Then the grid bias is briefly turned off, and ions are transmitted into the drift region of the cell. The ions are then focused and accelerated by an electric field (typically 1,000 to 3,000 volts) along the drift region to arrive at the collector electrode. The smaller compact ions have higher mobility than the heavier ions, and therefore traverse the region and collide with the collector plate in a shorter time. The collector current is then amplified; its magnitude, as a function of time, is proportional to the number of ions arriving at that moment. In an IMS explosives detection system, time required for ions of specific explosives to drift down the IMS tube is precisely known and is programmed into the system's microprocessor.

Advantages:

- Sub nano gram to pictogram level sensitivity
- Easy to use by person after a few hours of training.
- Decontamination fast (~ 14 – 15 s) and consistent decontamination time is required.
- Good results in cold as well as warm conditions.
- Less false alarm.
- Library can be extended for new explosives

Disadvantages

- Warm-up time need to be smaller than existing.

First Defender

Principle: Detection is based Raman spectroscopy technique.

Operational details: A laser beam is focused on a sample. Inelastic Raman scattering occurs when the light interacts with the chemical inside the explosive device due to the photonmolecule. The frequencies and intensities of the Raman scattered photons are characteristic of the molecule being detected. The Raman spectrum of a material is thus used as a unique chemical signature of the material. During the operation, the Raman spectrum of the sample is collected and then matched with the Raman spectra of thousands of chemicals stored in the library of the detector. The library includes various military and industrial explosives. It also includes various chemical precursors that could be used to fabricate explosives, e.g.: hydrogen peroxide, ammonia nitrate, fuel oil,

acetone, and sulfuric acid. Spectral libraries can be added in minutes by the user for additional compounds of interest. The system is also able to analyze samples through various transparent glass and plastic containers and to identify materials mixed with other contaminants

Advantages:

- Sensitive detector
- Selectivity is high.
- Indicates name of the material detected.
- Library stores data for thousands of compounds.
- Data for new compounds can be added.

Disadvantages:

- Long warm-up time
- Does not give audio alarm
- Requires proper contact with the device containing liquid explosive or hazardous liquid. Though standoff detection is possible with fibre optic probe still the probe has to touch the explosive device
- Cannot detect liquid explosives hidden inside metallic containers or opaque glass or plastic containers.



Comparative Statement of LED Detectors

| Sr. | Particulars | SDT Mininose | Model - 97 | M08 | SRTVD | MO2M |
|-----|--|---|---|--|--|--|
| 1 | Technology | High Frej-Quartz Crystal Micro Balance | Electron Capture Detector + Gas Chromotography U.K. | Non linear dependence of Ion mobility on an electric field | Non linear dependence of Ion mobility on an electric field | Non linear dependence of Ion mobility on an electric field |
| 2 | Made in Country | Israel | U.K. | Russia | Russia | Russia |
| 3 | Contact / Vapor | Contact | Vapor | Vapor | Vapor | Vapor |
| 4 | Upgradation | Free of Cost / On Contract | Out of Manufacture | N.A. | N.A. | N.A. |
| 5 | Decontamination Time | 1 to 15 Minutes | Min - 4 seconds | 3 Seconds | 3 Seconds | 3 Seconds |
| 6 | Initial warm up time | 5 minute warm start 10 minute cold start | 30 minutes 45 minutes - 1 Hour | 3 - 10 Seconds | 20 Seconds | 3 - 10 Seconds |
| 7 | Battery back-up time | 3 Years (No additional battery provided) | 4 Hours | 5 Hours | 5 1/2 Hours | 5 Hours |
| 8 | Shelf life | Maintenance Free | | | | |
| 9 | Consumable Life | Cartridge - 400 sample Rs.400 Disk-Weekly - Rs.300 Sensor matrix - 3000 sample - Rs. 3000 | Argaon Gas - Tank capacity - 1800 PSI actual liquid - 1100 hr. 100 PSI for 1 hrs. Rs.450/- | Battery - 1 Year | Battery - 1 Year | Battery - 1 Year |
| 10 | Training Operational Maintenance Administration | Free of cost : 5 Days Operational Maintenance Administration | | Training for 2 days free of cost | Training for 2 days free of cost | 6 Days |
| 11 | AMC | 3% | | 12% | 12% | Not Known |
| 12 | Warranty | 1 Year, Life Long except consumable good | | 1 Year | 1 Year | 1 Year |
| 13 | Cost | 10 Lacs | | | 20 Lacs | 11 Lacs |
| 14 | Service | Not in Maharashtra But can be provided | | Bombay | Bombay | Bombay |
| 15 | Dupont Gas | N.A. | | N.A. | N.A. | N.A. |
| 16 | Availability of Dupont | N.A. | | Nil | Nil | Nil |
| 17 | Update the library charge | Company will update / By default 18 are available | | Update the library | | |
| 18 | Recalibration Time | 5 minutes | | 10 Seconds | <20 Seconds | <10 Seconds |
| 19 | Sampling Time | 2 - 10 seconds | | 2 Seconds | 3 Seconds | 3 Seconds |
| 20 | Intermittent Temperature / Explosive calibration | 5 minutes | | Upto 5 Seconds | 5 Seconds | 5 Seconds |
| 21 | False positive tendency | | | 2 Seconds | | |
| 22 | Temperature range in which active | 0 to 40°C | | 10-45 °C | 10-45 °C | 10-45 °C |
| 23 | Humidity Range | 25% to 90% | | | | 80 at 25°C |
| 24 | Sensitivity | 10 ⁻⁸ (in general) | | 1 x 10 ⁻¹³ gmkm ³ | 1 x 10 ⁻¹³ gmkm ³ | 1 x 10 ⁻¹³ gmkm ³ |
| 25 | Rate / Sample | 3 1/2 min / person | | 15 seconds | 15 seconds | 15 seconds |
| 26 | Special Features | Radioactive source ni.63 is used for bombarding electrons on inert gas | Radioactive source ni.63 is used for bombarding electrons on inert gas | Radio Active Material | Trishimm | Source for Ionisation |
| 27 | Weight | | | 1.3 KG Suitcase - 7 kg | 2.3 kg suitcase - 8.30 kg | 1.3 kg Handlet suitcase - 8 kg |
| 28 | S. Size | | | 305x86x116 mm | 430x150x120mm | 300x82x110mm |

PORTABLE EXPLOSIVE TRACE DETECTORS COMPETITIVE COMPARISON

| Specification | GE Ion Track Vapor Tracer2 Explosives-Only Model | Smiths Sabre 2000 Explosives-Only Model | Scintrex EVD-3500 | ISC QS-H100™ |
|---|--|---|-------------------|---------------------|
| Technology | ITMS™ | IMS | Chemiluminol | Electro/Optical IMS |
| Radioactive Source for Ionization | Yes | Yes | No | No |
| NRC Required Wipe Test | Annual | Semi-Annual | Not Required | Not Required |
| Sample Acquisition | Wiping | Wiping | Wiping | Non-Contact |
| Consumable & Operating Cost | Yes | Yes | Yes | No |
| Substance ID | Yes | Yes | No | Yes |
| Simultaneous Vapor and Particle Detection | No | No | No | Yes |
| Sample Collection and Analysis Time | 10 to 20 seconds | 15 to 20 seconds | 15-30 seconds | Real Time |
| Efficient Detection of Black Powder | No | No | No | Yes |
| Immediate Clear Down After Detection | No | No | No | Yes |
| Limit of Detection | Nanograms | Nanograms | Nanograms | Nanograms |
| Sensitivity to Air Humidity | Moderate | High | Moderate | Operates at H=95% |
| Battery Life | 90 minutes | 90 minutes | 90 minutes | 4 Hours |
| Continuous Automatic Calibration | No | No | No | Yes |
| Self Diagnostics | Yes | No | No | Yes |
| Weight Including Battery | 11 lbs | 7 lbs | 7 lbs | 15 lbs |
| Warm-up Time (From Cold Start) | 45 minutes | 20 - 30 minutes | 1 minute | 15 minutes |

TRAIL DIRECTICE – EXPLOSIVE DETECTOR

| S No. | Desired Parameter's | As Per QR |
|-------|-------------------------------|--|
| 1. | Sensitivity | The detector should be able to detect all types pf explosives in vapour mode at room temperature. It should have sensitivity of at least one part explosive in 10 ⁴ parts of air. |
| 2 | Selectivity | System should not respond to odour of non explosive substances |
| 3 | Selectivity | False alarm rate should be less than 1% |
| 4 | Detection Capability | Should be able to detect all types of explosives including explosives with low vapour pressure explosive in mixture form. |
| 5 | Carrier Gas | Detector System should not require the use of carrier gas |
| 6 | Auto Calibration | Adjustment/Resetting for further operation should be automatic |
| 7 | Warm up time | Should be less than 10 min. |
| 8 | Analysis Time | Less than 6 seconds |
| 9 | EMI | Operation should not be affected by electro magnetic interference of other electronic/electrical devices |
| 10 | Versatility | Equipment should allow search of all places example Field Area automobiles, aircraft etc. |
| 11 | Ease of operation | Controls should be simple and easy to operate by bomb technician. Should not invoive technician making or interpretation at the operator level, Grand learn capability. |
| 12 | Operating Temperature | The eqpt should be able to function at extreme range of temperature 20 ⁰ C to + 55 ⁰ C and other atmospheric variations like rain and snow |
| 13 | Endurance | On 230V AC supply equipment should work continuously on battery, continuous operation should give more than 3 hours of operation |
| 14 | Weight of eqpt & complete set | It should be light weight, one man portable and complete equipment should fit into one hand carrying case |
| 15 | Indication | Both visual and audio alarm signal |
| 16 | Power Supply | Should operate both on battery as well as external power source |
| 17 | Safety | The equipment should be safe to handle and be free from radiation hazards the operator |
| 18 | Function | Should be able to function both on vapour and particle mode. |
| 19 | Spares and Service | User hand book, tech service manual, spares kit comprising of battery charger, test samples and spare battery should be provided with the equipment. |
| 20 | State of Art | It should be state of the art eqpt with micro processor which enhances detection speed |
| 21 | Carrying case | The carrying case should be ruggedised |
| 22 | Maintenance | The equipment should be simple to maintain. |



Test Results



1. COLD CONDITION (21-23⁰C)

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | FIRST DEFENDER | MO8 | DLD | Remarks |
|-------|-----------------------|--------------------|------|--------------|--------|----------------|-----|-----|---------|
| 1. | Ethyl alcohol (P) | Instrument Failure | D* | D* (PETN) | ND | D | ND | red | |
| 2. | Ethyl alcohol (G) | Instrument Failure | D* | D* (RDX, C4) | ND | D | ND | red | |
| 3. | Isopropyl alcohol | Instrument Failure | ND | ND | ND | D | ND | red | |
| 4. | Methyl alcohol | Instrument Failure | D* | D*(RDX, C4) | ND | D | ND | red | |
| 5. | HS diesel oil (P) | Instrument Failure | ND | ND | ND | ND | ND | red | |
| 6. | Toluene | Instrument Failure | D* | D* (RDX, C4) | ND | D | ND | red | |
| 7. | Hexane | Instrument Failure | ND | ND | ND | D | ND | red | |
| 8. | Cyclohexane | Instrument Failure | ND | D* (RDX, C4) | ND | D | ND | red | |
| 9. | Chloroform | Instrument Failure | D* | ND | ND | D | ND | red | |

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | FIRST DEFENDER | MO8 | DLD | Remarks |
|-------|-----------------------|-----------------------|------|---------|--------|----------------|---------|-------|-------------------|
| 10 | Domex | ND | D | ND | ND | ND | D (RDX) | green | |
| 11 | Sparkling water | D (Plastic explosive) | D | ND | ND | ND | ND | green | SDT : plastic exp |
| 12 | Coca cola | ND | D | D (TNT) | ND | ND | D (TNT) | green | Detected :TNT |
| 13 | Butyl acetate | ND | ND | ND | ND | ND | ND | red | |
| 14 | Petrol | ND | ND | ND | ND | D | ND | red | |
| 15 | Cellocoat | D | ND | D | ND | ND | D | green | D: Plastic, RDX |
| 16 | Syncoat | ND | ND | ND | ND | ND | D | green | D: NG |
| 17 | Stovcoat | D | ND | D | ND | ND | ND | green | D:RDX,C 4 |
| 18 | Hair dye (Godrej) | ND | ND | D | ND | ND | ND | green | |
| 19 | Groundnut oil | ND | ND | ND | ND | D | ND | red | |
| 20 | Perfume | ND | ND | ND | ND | ND | ND | Red | |
| 21 | Deodorant | ND | ND | ND | ND | ND | ND | green | |
| 22 | Shampoo | ND | ND | ND | ND | ND | ND | green | |
| 23 | Plain water | ND | ND | ND | ND | D | ND | ND | |
| 24 | Tea | ND | ND | ND | ND | D | D (RDX) | D | |

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | FIRST DEFENDER | MO8 | DLD | Remarks |
|-------|-----------------------|-----|---------|----------------|---------------|----------------|-------------|-----------------------|--|
| 25 | Sugar | ND | D | ND | ND | D | ND | Not attempted | |
| 26 | Port wine no 7 | ND | D | ND | D Closed EGDN | ND | ND | ND | |
| 27 | Vodka | ND | Failure | ND | ND | ND | D (NG) | ND | |
| 28 | ANFO | D | D | ND | ND | D | ND | Not Conclusive result | Due to insufficient quantity DLD could not detected. |
| 29 | RDX/ANFO | D | ND | D(RDX, C4) | D(NG, EGDN) | D | D(NG) | red | |
| 30 | EGDN | D | D | D(NG, EGDN) | D | D | D (PETN) | red | |
| 31 | HMTD | ND | D | D(RDX, C4) | ND | ND | D (TNT) | Not Conclusive result | Due to insufficient quantity DLD could not detected. |
| 32 | TATP | ND | D | D(RDX, C4, NG) | ND | D | D(RDX, TNT) | Unable to detect | D: RDX, C4 |
| 33 | NG | D | D | D (NG) | D (NG, EGDN) | D | D (NG) | | |

- P = Plastic bottle
- G = Glass bottle
- D = Detected
- ND = Not Detected

2. WARM CONDITION (38°C)

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | FIRST DEFENDER | SRTVD | MO8 | DLD | Remarks |
|-------|-----------------------|-----|------|--------|--------|----------------|-------|-----|-----|---------|
| 1 | RDX/ANFO | ND | ND | D | D | D | ND | D | red | |

3. WARM & DUSTY CONDITION (38°C)

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | FIRST DEFENDER | SRTVD | MO8 | DLD | Remarks |
|-------|-----------------------|--------------------|------|--------------------|---------|----------------|--------------------|-----------------------|-----------------------|--|
| 1 | RDX/ANFO | D | ND | D (RDX, C4) | ND | D | ND | D(RDX, TNT, NG, EGDN) | D | |
| 2 | ANFO | | ND | | ND | D | ND | ND | Not Conclusive result | Due to insufficient quantity DLD could not detected. |
| 3 | EGDN | ND | D | D | ND | D (EGDN) | ND | ND | D | |
| 4 | HMTD | Instrument Failure | D | D | ND | ND | Instrument Failure | D (TNT) | D | |
| 5 | TATP | Instrument Failure | D | D (NG & TNT) | D (TNT) | D | Instrument Failure | D (TNT) | Not Conclusive result | |
| 6 | Ethyl alcohol (P) | ND* | ND* | Instrument Failure | D* | D | ND* | D* (RDX/NG/TNT/EGDN) | D | * Open bottle |

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | FIRST DEFENDER | SRTVD | MO8 | DL D | Remarks |
|-------|-----------------------|-------------|------|--------------------|--------|-------------------------|-------|---------------------|------|---------|
| 7 | Ethyl alcohol (G) | D* (TN T) | ND* | Instrument Failure | ND* | D (Closed) | D* | D (NG/RDX) | D | |
| 8 | Isopropyl alcohol | ND* | ND | Instrument Failure | ND* | D (Closed, 2-propanol) | D* | D (PETN) | D | |
| 9 | Methyl alcohol | ND* | D | Instrument Failure | ND* | D (Closed, Methanol) | ND | D* (NG/RDX) | D | |
| 10 | HS diesel oil (P) | ND | ND | Instrument Failure | ND | ND (Closed) | ND | D | D | |
| 11 | Toluene | D (Nitrate) | D | Instrument Failure | ND | D (Closed, Toluene) | ND | D* (RDX) | D | |
| 12 | Hexane | D (Nitrate) | D | Instrument Failure | ND | D (Closed, Hexane) | ND | ND | D | |
| 13 | Cyclohexane | D (Nitrate) | ND | ND* | ND* | D (Closed, Cyclohexane) | ND* | ND | D | |
| 14 | Chloroform | D (Nitrate) | ND | D (PETN) | ND* | D (Closed, Chloroform) | ND* | D* (NG/RDX) | D | |
| 15 | Groundnut oil | ND | ND | ND* | ND* | D | ND* | D (RDX after 45s) | D | |
| 16 | Butyl acetate | ND | D | ND | ND | D | ND* | D* (PETN after 45s) | D | |

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | FIRST DEFENDER | SRTVD | MO8 | DLD | Remarks |
|-------|---------------------------|-------------|------|--------|--------|-------------------|----------|-------------|---|---------|
| 17 | Type 3 Thinner (Stovcoat) | ND | ND | ND | ND | ND | ND* | D* (NG) | D with glass container/ND with metallic container | |
| 18 | Syncoat | ND | ND | ND | ND | ND | ND* | D* (RDX) | ND | |
| 19 | Cellocoat | ND | ND | ND | ND | ND | ND | D* (TNT/NG) | ND | |
| 20 | Petrol | ND | D | ND | ND | D | D (C-4) | D* (NG) | D | |
| 21 | Perfume | ND | ND | ND | ND | UNABLE TO PERFORM | D (C-4) | ND | D | |
| 22 | Domex | ND | ND | ND | ND | ND | ND | D* (NG) | ND | |
| 23 | Deodorant | D (TNT) | ND | ND | ND | ND | ND | ND | ND | |
| 24 | Sparkling water | ND | D | ND | ND | D | ND | ND | ND | |
| 25 | Coca Cola | ND | ND | ND | ND | ND | D* (C-4) | ND | D | |
| 26 | Shampoo (Clinic Plus) | ND | D | ND | ND | ND | ND | ND | D | |
| 27 | Hair Dye | D (Nitrate) | ND | ND | ND | ND | ND | ND | D | |
| 28 | Plain water | ND | ND | ND | ND | D | ND | ND | ND | |
| 29 | Tea | ND | ND | ND | ND | D | ND | D (RDX) | D | |

5. HUMID CONDITION

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | SRTVD | MO8 | DLD |
|-------|-----------------------|---------------------|-------------|-------------------------------|----------------------|--------------------|---------------------------|-----|
| 1 | Dome x | Instru ment Failure | ND (O&C) | ND: O D(TNT):C | ND(O&C) | Instrument Failure | ND(O &C) | red |
| 2 | Sparkl ing water | Instru ment Failure | ND(O&C) | D(NG,EGD N):C ND | ND(O&C) | Instrument Failure | ND(O &C) | ND |
| 3 | Coca cola | Instru ment Failure | ND(O&C) | D(NG,EGD N):C D(NG,TNT):O | ND(O&C) | Instrument Failure | ND(O &C) | D |
| 4 | Butyl acetate | Instru ment Failure | ND(O&C) | D(NG,EGD N) | ND(O&C) | Instrument Failure | ND:C D(PE TN):O | D |
| 5 | Petrol | Instru ment Failure | D (O&C) | ND:C D(PETN): O | ND (O&C) | Instrument Failure | ND (O&C) | D |
| | Celloc oat | Instru ment Failure | ND (O&C) | D(NG):C D (RDX):O | ND:C D: PETN | Instrument Failure | ND:C D: RDX, TNT | ND |
| 7 | Synco at | Instru ment Failure | ND (O&C) | D(NG):C D (RDX):O | D(NG):C D (RDX):O | Instrument Failure | D(NG):C D(NG):O | ND |
| 8 | Stovco at | Instru ment Failure | ND:C D:O | D(NG):C D(PETN): O | ND (O&C) | Instrument Failure | ND (O&C) | ND |
| 9 | Hair dye (Godr ej) | Instru ment Failure | ND:C D:O | D(NG):C D(TNT):O | ND (O&C) | Instrument Failure | ND (O&C) | D |
| 10 | Groun dnut oil | Instru ment Failure | ND(O&C) | ND:C D(NG,EGD N):O | ND(O&C) | Instrument Failure | ND(O &C) | D |
| 11 | Perfu me | Instru ment Failure | ND(O&C) | D(TNT):O &C | ND(O&C) | Instrument Failure | ND(O &C) | ND |
| 12 | Deodo rant | Instru ment Failure | ND:C D:O | ND:C D(NG,EGD N):O | ND(O&C) | Instrument Failure | ND(O &C) | ND |
| 13 | Shamp oo | Instru ment Failure | ND(O&C) | D (TNT):C ND:O | ND(O&C) | Instrument Failure | ND(O &C) | |

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | SRTVD | MO8 | DLD |
|-------|-----------------------|--------------------|-------------|-----------------------|---------|-------|---------|---------------|
| 14 | Plain water | Instrument Failure | ND | ND | ND | ND | ND | ND |
| 15 | Tea | Instrument Failure | ND | ND | ND | ND | D (RDX) | D |
| 16 | Sugar | Instrument Failure | D | ND | ND | ND | ND | Not attempted |
| 17 | Port wine no 7 | Instrument Failure | ND:C D:O | ND(O&C) | ND(O&C) | ND | ND(O&C) | ND |
| 18 | Vodka | Instrument Failure | ND(O&C) | ND:C D(PETN): O | ND(O&C) | ND | ND(O&C) | D |

- O = OPEN CONDITION
- C = CLOSED CONDITION
- O&C = OPEN & CLOSED
- D = Detected
- ND = Not Detected

CORROSIVE ATMOSPHERE (HNO₃)

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | SRTVD | MO8 | DLD |
|-------|-----------------------|--------------------|-------------|---------|---------|--------------------|---------------------------|-----|
| 1 | Domex | Instrument Failure | ND(O&C) | ND(O&C) | ND(O&C) | Instrument Failure | ND(O&C) | ND |
| 2 | Sparkling water | Instrument Failure | D:C ND:O | ND(O&C) | ND(O&C) | Instrument Failure | ND(O&C) | ND |
| 3 | Coca cola | Instrument Failure | D:C ND:O | ND(O&C) | ND(O&C) | Instrument Failure | ND(O&C) | ND |
| 4 | Butyl acetate | Instrument Failure | ND:C D:O | ND(O&C) | ND(O&C) | Instrument Failure | ND:C D(PETN, TNT):O | D |
| 5 | Petrol | Instrument Failure | ND(O&C) | ND(O&C) | ND(O&C) | Instrument Failure | ND(O&C) | D |
| 6 | Cellocoat | Instrument Failure | ND(O&C) | ND(O&C) | ND(O&C) | Instrument Failure | ND:C D(NG,RD X):O | ND |

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | SRTVD | MO8 | DL D |
|-------|-----------------------|---------------------|----------|--------------------|----------------|---------------------|----------------|---------------|
| 7 | Syncoat | Instru ment Failure | ND(O &C) | ND(O&C) | ND(O&C) | Instru ment Failure | D(NG) | ND |
| 8 | Stovcoat | Instru ment Failure | ND(O &C) | ND:C D(PETN, DM):O | ND(O&C) | Instru ment Failure | D(NG):C ND:O | D |
| 9 | Hair dye (Godrej) | Instru ment Failure | ND(O &C) | ND(O&C) | ND(O&C) | Instru ment Failure | ND(O&C) | D |
| 10 | Groundnut oil | Instru ment Failure | ND(O &C) | ND(O&C) | ND(O&C) | Instru ment Failure | ND(O&C) | D |
| 11 | Perfume | Instru ment Failure | ND(O &C) | ND(O&C) | ND(O&C) | Instru ment Failure | ND(O&C) | D |
| 12 | Deodorant | Instru ment Failure | D:C ND:O | ND:C D(PETN, DM):C | ND:C D(PETN):O | Instru ment Failure | ND:C D(PETN):O | ND |
| 13 | Shampoo | Instru ment Failure | ND:C D:O | D(TNT):C ND:O | ND(O&C) | Instru ment Failure | ND(O&C) | ND |
| 14 | Plain water | Instru ment Failure | ND | ND | ND | Instru ment Failure | ND | ND |
| 15 | Tea | Instru ment Failure | ND | ND | ND | Instru ment Failure | D (RDX) | D |
| 16 | Sugar | Instru ment Failure | D | ND | ND | Instru ment Failure | ND | Not attempted |
| 17 | Port wine no 7 | Instru ment Failure | D:C ND:O | ND:C D(TNT):O | ND(O&C) | Instru ment Failure | ND:C D(RDX):O | ND |
| 18 | Vodka | Instru ment Failure | D | D(PETN):C D(TNT):O | ND(O&C) | Instru ment Failure | ND(O&C) | ND |

- O = OPEN CONDITION
- C = CLOSED CONDITION
- O&C = OPEN & CLOSED
- D = Detected
- ND = Not Detected

NITRIC ACID

| Sr No | Name of the explosive | SDT | M 97 | MO2M-1 | MO2M-2 | SRTVD | MO8 | DLD |
|--------------|------------------------------|--------------------|-------------|--------------------------|---------------------------------|--------------------|-----------------|------------|
| 1 | HNO ₃ | Instrument Failure | ND:C D:O | D(TNT):C D(NG,EGDN):O | ND:C D(RDX,TNT,EGDN,PE TN):O | Instrument Failure | ND:C D(NG):O | D |



Observations



Limitations of explosive detectors

- 1 MO8, MO2M, SRTVD: False alarm rate is high
- 2 DLD bottle full of liquid should be enough big because the sensors of LED should touch the surface completely, otherwise not able to detect. If the size of the bottle and the liquid in the bottle is of smaller size than that of the sensor area it will give false alarm, ie, it will blink red and green lights at the same time.
- 3 M 97: Since not in regular use, not able to perform
- 4 SRTVD: For first sample it takes long time and for second it takes shorter time for the same sample, ie, proper cleaning is not done, i.e. decontamination is not properly done
- 5 Mininose: Many a times traces are not sufficient
- 6 Mininose and M 97: are having less battery backup. The warm up time of the M 97 is about 34 min
- 7 Imp note: Basically the explosive detectors have to be tested for sample of 1 nanogram, but since the liquid explosives are of such high volatile nature it is not possible to conduct testing
- 8 MO8: is not working properly in windy atmosphere
- 9 Mininose is useful in clean conditions only
- 10 GT200 is time consuming and requires expert handler
- 11 Mininose is of contact type and cannot be used for TATP and HMTD due to high sensitivity of the two explosives
- 12 Mininose is at failure for liquid samples as the strip of the Mininose gets stuck to instrument base
- 13 Mininose: Calibration time is long and frequent calibration is required
- 14 MO2M: In the presence of interferences (pesticides), the instrument does not operate. . The instrument did not give any signal in hot (closed) conditions. In hot (open) condition either it didn't give signal or gave false positive as in the case with chloroform and ANFO where it showed the presence of RDX & C-4. Once it gets overloaded, it has to be cleaned manually.
- 16 First Defender: The system only worked for transparent or semi transparent systems. It is incapable to detect explosives encased in a metal container or other opaque containers.

Considerations of Testing:

The idea behind the project was to evaluate the detectors available commercially keeping in mind the practical usage. The performance of the detectors was evaluated under different environmental conditions like cold, hot, humid, dusty etc. The detectors were evaluated in both open and closed bottled conditions. Detection capability was also evaluated in presence of interferences. By simulating the field conditions we could actually predict the performance of the detectors in practical scenarios. The focus was kept on liquids commonly used by passengers/ civilians ranging from shampoo, hair dye, and deodorant to solvents and explosives. Most of the above mentioned substances include the compounds used in explosive compositions specifically liquid explosives. Most of the liquid explosives used by anti-national elements are prepared as follows:

1. Liquid + Liquid = Liquid e.g. EGDN
2. Liquid + Solid = Liquid e.g.
3. Liquid + Liquid = Solid e.g. TATP
4. Liquid + Solid = Solid e.g.

These compositions are individually available in any of the commercially available products like hair dye, nail polish etc. When combined in correct proportions these might result in explosive compositions (like TATP, HMTD, EGDN etc.). Therefore, the emphasis was to detect the presence of individual components used to prepare the liquid explosives beforehand in order to avert any possible attempt by terrorists.

In addition to detection of explosive compositions, the ability of the detectors to detect non-hazardous substances like plain water, oil, drinks etc was also tested.

So also the performance of the liquid explosive detectors on battery back-up, ease of use, selectivity, false positive /negative alarm rate, warm-up time, analysis time, versatility, portability and availability of carrier gases was tested.

The evaluation of the detectors was carried out using approximately 30 odd substances.

The following are the observations:

1. SDT Mininose

This detector works in the particulate mode. The analysis time of the detector was 30 s approximately. The cleaning time ranged from 20 s- 2 min. Mininose could not detect any liquid explosive except ANFO and RDX/ANFO in cold conditions. It showed nitrate in the case of ANFO, it was able to detect HMTD and NG in outside conditions. However, the false positive signal was shown for sparkling water, celcocoat and stovcoat where it showed the presence of plastic explosive, RDX and C-4. In warm and dusty conditions, the false positive was high and it showed the presence of nitrate for toluene, hexane, cyclohexane, chloroform, hair dye and presence of TNT for ethyl alcohol and deodorant. The major problems of using this detector is that it only works in contact mode, it has high false alarm rate and on continuous use the filter/ net gets clogged with

particulates and cannot be used further unless it is changed. Since the liquid explosives are highly sensitive, the sampling may be dangerous for the operator. In addition to the above mentioned disadvantages, SDT Mininose has a limited database (library). For any new addition further cost would be incurred. Some liquids were found to dissolve the sampling film which is a big disadvantage and the spoilt film may in turn spoil the fine mesh inside the detector on which the adsorbed explosive traces are released by heating.

2. Model HS 97

This detector is a electron capture detector based system. The warm up time of this instrument is 45 min. The major disadvantage of this detector is that it's not explosive specific. It gave signal for ANFO, HMTD, TATP, EGDN and NG in cold conditions. However, the result varied in case of warm and dusty conditions where ANFO was not detected. In humid conditions Model HS 97 detected petrol in both open and closed conditions. In addition, it detected stovcoat, hair dye; deodorant and port wine 7 in humid conditions. The results are affected in corrosive conditions since there is no consistency in the results. The main problem faced during the operation was the availability of argon gas. It required refilling and the pressure of the gas has to be maintained. Since the detector is not in regular use, it was unable to perform. Has less battery backup. False alarm rate is high, gives signal for pesticide (non-explosive) material.

3. MO2M

MO2M is non-linear IMS technique It gives signal for non-explosive samples and gives indication of presence of military explosives for hazardous liquid samples. In warm and dusty conditions, wind causes intermittent signal which is not observed in cold condition. Majority of times it indicates for presence of NG, EGDN, TNT even when these materials are absent. There is no difference in change in temperature from 21-23⁰C. However the detector went out of order. False_alarm rate is high. No response to samples in closed condition. Analysis time is high about 1min

4. MO8

M08 is an improved version of MO2M. The drawbacks observed in case of MO2M are also observed in MO8. MO8 gives signal for non-explosive materials, i.e. false positive, indicating presence of explosives even when there is no explosive. Even while detecting explosives it gives indication for presence of NG, EGDN, PETN & TNT whereas the actual sample may be RDX, HMX, etc. No response for sample in closed condition. In open condition the signal generated indicates presence of military explosive while in actual the sample is hazardous liquid.

There is no significant effect of change in temperature. However, wind sometimes causes false signal. The probability of such false signal increases in dusty and windy conditions. Analysis time is more than 30s in most of the samples studied in the project. In humid and corrosive atmosphere the detector did not detect the samples studied. In rare cases where signal was obtained the detector gave indication for the presence of TNT.

The major drawback of the detector is the limited library database. Thus the false alarm rate is high. Once it gets overloaded, it has to be cleaned manually.

5. First Defender

First defender is explosive detector based on Raman Effect. The detector is equipped with the library of thousands of compounds and is capable of identifying the compound. It can detect liquid explosives and hazardous liquids as pure components. When these components are mixed the result output of the detector is mixed response which it analyzes using library data. It, however, does not give alarm or indicate that the detected material is hazardous or not. It only indicates the name of the material detected. This may be a problem for people in field since they may not be aware of all the hazardous chemicals. As with any optical detection system, it requires presence of material under analysis in line of sight. In absence of fibre optic probe the alignment is cumbersome process and sometimes needs to handle the device filled with liquid explosive. However, this difficulty may be overcome by the use of fibre optic probe which was not available during the trials carried out under this project. Important fact to be noted is that when the liquid explosive or hazardous liquids are enclosed in closed bottles that are opaque glass or made up of metal or thick plastic semi-transparent to opaque, then the detector does not detect the chemical inside such containers. Further, the warm-up time for this detector is high. The detector response is unaffected by temperature, humidity and corrosive atmosphere. The false alarm rate is low. The results are similar for cold & warm as well as warm & dusty condition. Sampling time is very long of the order of 1½hrs to 1hrs.

6. DLD

DLD identifies the liquids based on spatial distribution of their electric field. The dielectric or electrical conductivity properties of the liquids govern the signal given by DLD. It gives red signal when the liquid is hazardous and green signal when the liquid is non-hazardous. There is audio signal. The instrument is handy and suitable for field operations. There are certain drawbacks of this detector that it cannot detect hazardous chemicals enclosed in metallic containers. Further, the shape of the bottle sometimes does not permit proper alignment of the sensing area with the bottle surface and the detector flashes both green and red signal. No decision can be made in this case with the help of detector. If the thickness of the glass or plastic bottles is large then the signal by DLD will also be affected. DLD does not inform what kind of material is present in hazardous device. The conclusive detection cannot be achieved when level of liquid in bottle is less than the sensing surface of the detector. The performance of the detector is not influenced by change of temperature, humidity, and corrosive atmosphere, windy and dusty conditions.



Conclusions



Conclusions:

None of the evaluated detector showed consistency in the result. Hence the reliability of the detectors is in question. In most of the cases it was observed that though the detectors gave alarms but the identification of the explosive was wrong. Another issue is the warm up time. The warm up time for detectors like Model HS 97, First Defender are high. Also the battery back-up is less. In field conditions where the personnel would be working for hours, the battery back-up should be more. Most of the detectors failed in presence of interferences except for the Mininose and First Defender where the principle of operation is different (i.e. particulate & contact mode). SDT Mininose detector operates in particulate mode corrosive conditions does not affect the result. The same is true with hot and windy conditions. SDT Mininose requires very little training since the results are displayed on the screen. The best known detectors available with Maharashtra police department for detection of explosives were tested under the project for their performance against liquid explosive and hazardous liquid samples. Their ability to distinguish between explosive & non-explosive material, the analysis time required was tested in closed, open, cold, warm, windy, humid and corrosive atmosphere. SDT mininose is based on swipe/sampling method. The liquid in liquid explosives cause damage to the sampling film thereby rendering it least useful for detection of liquid explosives.

Model HS-97 was not able to detect liquid explosives except NG, EGDN, ANFO, RDX/ANFO. It gives false alarm both false positive as well as false negative alarm. Further its use involves recurring expenditure in terms of organization. Above all the detector is based on old technology and currently out of production. Thus it is concluded that model HS-97 is not useful for detection of liquid explosives.

MO8 is the upgrade version of MO2M, However drawback of MO2M still exists in MO8. The false alarm rate is high and is not in acceptable range. It also gives false indication of type of material detectors and its capability to detection of liquid explosive is poor.

First defender requires proper alignment and intimate contact with surface of the liquid explosive device. If the alignment is inappropriate no signal is obtained. When liquid samples are enclosed in opaque plastic or glass container and in case of metallic container the detection becomes impossible.

In open condition, the sample can be analyzed in vial; however this requires handling of explosive device which is dangerous.

DLD is a handy detector and is able to distinguish between hazardous and non hazardous material. However, DLD required that liquid sample should be present to level sufficient to cover the entire sensing area. If the liquid explosive is enclosed in metallic container DLD cannot detect it. It does not give any details of material detected. DLD is easy to use and does real time analysis. It does not require special training and can be used at entry ports like airport, railway stations, and malls etc. where huge number of samples needs to be scanned.

Summary:

The complied results of this project indicate that the detectors available with Maharashtra police department are not capable to detect liquid explosives. Since DLD is user friendly and easy to use in the field it may be considered for scanning of large number of samples in real time. As DLD does not give details of samples detected, in second phase of scanning first defender or equivalent detector may be appropriate for detailed analysis of sample.

Future Dimensions:

When any Govt purchases detectors from open markets, the terrorists may have already found ways to escape detections. The same may be applicable to detection technologies as well.

Technologies and detectors needs to be develop[ed jointly by research institutions under Govt control eg. DRDO, NCL, and the concerned personnel from Police/ Security forces. Such indigenously developed detectors can be used by the police force for longer time and with greater effectiveness as details about the technology used can be kept under control.

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Annexure



Comparative Statement : Common Ignitable Liquids used as Fire Accelerants

| Sr. | Liquid / Explosive / Material | Chemical Formula | Component | Flash Point | Melting Point | Detonation Velocity | Stabilizing Oxidizer Required | Appearance | Liquid / Solid | Vapor Density | Vapor Pressure |
|-----|-------------------------------|---|---|-------------------------------|---------------|--|-------------------------------|--|----------------|---------------|----------------|
| 1 | Acetone | C_3H_6O | Dimethyl Ketone, 2-Propanone | 4 degrees F (-20 degrees C) | | 869 degrees F (465.4 degrees C) | | A volatile, flammable, colorless, liquid ketone having a fragrant odor and miscible with water, alcohol, and most oils. Principal uses are as a solvent in lacquers, varnishes, cosmetics, nail polish remover, and in the mixture of other solvents. | Liquid | 2.0 | |
| 2 | Carbon Disulfide | CS_2 | Carbon Disulfide | 22 degrees F (-30 degrees C); | | 212 degrees F (100 degrees C); | | A volatile, flammable, colorless to yellow liquid with a rotten egg odor. Carbon Disulfide, unlike most of the other common ignitable liquids, is heavier than water and will sink. | Liquid | 2.6 | |
| 3 | Coleman Fuel | C-2538 It is a mixture of hydrocarbons & doesn't have a single formula | white gasoline, camping stove fuel, camping lantern fuel 2538 | 27 degrees F (-33 degrees C) | | Not reported; explosive limit LEL is 0.7% - UEL not reported | | A straight run, unrefined, petroleum distillate used in camping stoves and lanterns. Camp stove fuels in general have a carbon range of $C_5 - C_{11}$ | | 3.7 | |
| 4 | Ethyl Alcohol | C_2H_5OH | Ethanol, grain alcohol | 55 degrees F (13 degrees C) | | 689 degrees F (365 degrees C); explosive limits 3.5%-19.0% | | A volatile, flammable, colorless liquid having a pleasant odor and miscible in water and many organic liquids. Principal uses are in alcoholic beverages, as a solvent in pharmaceuticals, cleaning preparations, and some antifreezes. | Liquid | 1.6 | |
| 5 | Ethyl Ether | $(C_2H_5)_2O$ | Ether, Diethyl Ether | 49 degrees F (-45 degrees C) | | 356 degrees F (180 degrees C) | | A volatile, highly flammable, colorless liquid which forms explosive peroxides under the influence of air and light and has a sweetish odor and is slightly miscible in water, methanol, and oils. Principle uses as a solvent in organic synthesis, smokeless powder and industrial solvents. | Liquid | 2.6 | |

Comparative Statement : Common Ignitable Liquids used as Fire Accelerants

| Sr. | Liquid / Explosive / Material | Chemical Formula | Component | Flash Point | Melting Point | Detonation Velocity | Stabilizing Oxidizer Required | Appearance | Liquid / Solid | Vapor Density | Vapor Pressure |
|-----|---|--|--|--|---------------|--|-------------------------------|--|----------------|---------------|----------------|
| 6 | Fuel oil no. 1 - Kerosene | Carbon range of C ₉ - C ₁₇ | kerosene, range oil, coal oil, Jet - A (aviation) fuel | 110 degrees F - 162 degrees F (42 degrees C - 72 degrees C); | | 410 degrees F (210 degrees C) | | A colorless, combustible, straight run petroleum distillate liquid having a characteristic odor miscible in petroleum solvents and immiscible in water. Principal uses as an ingredient in lamp oils, charcoal starter fluids, jet engine fuels and insecticides. K-1 kerosene has a low sulfur content and is used in portable space heaters. | Liquid | 7-5 | |
| 7 | Fuel oil no. 2 Home Heating Fuel, Diesel Fuel | Carbon range of C ₉ - C ₂₃ | Home Heating Fuel, Diesel Fuel | 126 degrees F - 204 degrees F (52 degrees C - 96 degrees C) | | 494F (257C); explosive limits - not reported | | A light brown, combustible, straight run or cracked petroleum distillate consisting mostly of C ₉ - C ₂₃ range hydrocarbons. Principal uses include heating fuel in domestic or commercial atomizing type burners and as a fuel in diesel engines. | Liquid | >1 | |
| 8 | Gasoline | Gasoline is a blended mixture of aromatic and aliphatic hydrocarbons | Gas, Motor fuel | -45 degrees F (- 43 degrees C) | | 536 degrees F (280 degrees C) for 56 - 60 octane grade | | A highly flammable, blended liquid composed of more than 300 volatile hydrocarbon compounds manufactured from the fractionation or distillation of petroleum. Gasoline is the most commonly identified ignitable liquid accelerant reported by American forensic laboratories. Its principal use is as a fuel in spark ignited, internal combustion engines. | Liquid | 3.0 - 4.0 | |
| 9 | Isopropyl Alcohol | CH ₃ CHOCH ₃ | IPA, Isopropanol, 2-propanol | 54 degrees F (12 degrees C) | | 750 degrees F (399 degrees C); explosive limits 2.5%-12.0% | | A colorless, flammable liquid which is miscible in water, ether, and alcohol and having a pleasant odor. Principal uses as an ingredient in lacquers, rubbing alcohol, denaturant and lotions. | Liquid | 2.1 | |

Comparative Statement : Common Ignitable Liquids used as Fire Accelerants

| Sr. | Liquid / Explosive / Material | Chemical Formula | Component | Flash Point | Melting Point | Detonation Velocity | Stabilizing Oxidizer Required | Appearance | Liquid / Solid | Vapor Density | Vapor Pressure |
|-----|-------------------------------|---|------------------------|-----------------------------|---------------|--|-------------------------------|--|----------------|---------------|----------------|
| 10 | Lacquer | | | | | | | Composition and properties of this category of product vary by manufacturer. A spirit varnish such as shellac; any of clear or colored synthetic organic coatings that typically dry to form a film by evaporation of the solvent. | | | |
| 11 | Lacquer Thinner | | | | | | | A mixture of highly volatile solvents, miscible in water, of varying composition and properties depending on the manufacturer. | | | |
| 12 | Methyl Alcohol | CH ₃ OH | Methanol, Wood Alcohol | 54 degrees F (12 degrees C) | | 867 degrees F (484 degrees C); explosive limits 6.7% - 36% | | A colorless, flammable, poisonous liquid having a slight alcohol odor when pure, miscible in water, ethanol, ketones and most other organic solvents. Principal uses as an ingredient in antifreeze, dry gas, windshield washer fluids and as a denaturant in ethanol. | Liquid | 1.1 | |
| 13 | Methyl ethyl Ketone | CH ₃ COCH ₂ CH ₃ | MEK, 2-butanone | 16 degrees F (-9 degrees C) | | Degrees F (404 degrees C); explosive limits 1.9%-10.0% | | A colorless, flammable liquid having an acetone-like odor miscible in alcohol, ether, and slightly soluble in water. Principal use as a solvent in nitrocellulose coatings and lacquers, paint removers, cements and adhesives and in the manufacture of printed circuit boards. | Liquid | 2.5 | |
| 14 | Naphtha | | V M & P | | | | | A general term which may describe combustible products such as mineral spirits or flammable products such as petroleum ether. Flash point, explosive limits and other properties vary by manufacturer. | | | |

Comparative Statement : Common Ignitable Liquids used as Fire Accelerants

| Sr. | Liquid / Explosive / Material | Chemical Formula | Component | Flash Point | Melting Point | Detonation Velocity | Stabilizing Oxidizer Required | Appearance | Liquid / Solid | Vapor Density | Vapor Pressure |
|-----|-------------------------------|------------------|--|--|---------------|--|-------------------------------|--|----------------|---------------|----------------|
| 15 | Paint Thinner | | Mineral Spirits – a complex petroleum distillate | 104 degrees F (40 degrees C) - 110 degrees F (43 degrees C); | | 473 degrees F (245 degrees C); explosive limits 0.8% @ 212 degrees F (100 degrees C) | | A category of clear, combustible liquid having petroleum type odor. Mineral spirits are midrange petroleum distillates ranging from C8 to C12 which is present in many paint thinners, oil base stains, dry cleaning solvents, and some brands of charcoal starter fluids. | Liquid | 3.9 | |
| 16 | Toluene | $C_6H_5CH_3$ | Methylbenzene, Phenylmethane | 40 degrees F (4 degrees C) | | 896 F (480 degrees C); explosive limits 1.3%-7.0% | | A colorless, flammable liquid with a benzene-like odor, miscible in alcohol, ether, acetone and very slightly soluble in water. Principal use as a solvent in paints and coatings, paint removers, explosives (TNT), adhesive solvent for model airplanes, and as a base for polyurethane resins. | Liquid | 3.1 | |
| 17 | Turpentine | $C_{10}H_{16}$ | Oil of turpentine | 90 degrees F-115 degrees F (32 degrees C - 46 degrees C) | | 488 degrees F (253 degrees C) | | A colorless, combustible liquid derived from steam distillation of wood from pine (conifer) trees. Turpentine is miscible in oils, ether, and chloroform. Principal uses are as a drying agent or as a solvent for thinners of paints, lacquers, varnishes and used in wax-based polishes and liniments. | Liquid | >1 | |
| 18 | Xylenes | $C_6H_4(CH_3)_2$ | Dimethylbenzene | 29 degrees F (-2 degrees C) | | 867 degrees F (464 degrees C) | | A colorless, flammable liquid miscible in alcohol and ether, insoluble in water. Xylene is isolated from crude wood distillate or obtained from fractional distillation of petroleum or coal tar. Commercial xylene is a mixture of three isomers, o-, m-, and p-xylene, the m-isomer predominates. | Liquid | > 1 | |

Comparative Statement : Common Ignitable Liquids used as Fire Accelerants

| Sr. | Liquid / Explosive / Material | Chemical Formula | Component | Flash Point | Melting Point | Detonation Velocity | Stabilizing Oxidizer Required | Appearance | Liquid / Solid | Vapor Density | Vapor Pressure |
|-----|-------------------------------|---|---|------------------|---------------|-----------------------------------|-------------------------------|---|----------------|---------------|------------------|
| 19 | Isopropyl Alcohol | (CH ₃) ₂ CHOH | Isopropyl Alcohol 90-100%, Water 0-10%. | | | | | Flammable liquid and vapor. Harmful if swallowed or inhaled. Causes irritation to eyes and respiratory tract. Affects central nervous system, may be harmful if absorbed through skin. May cause irritation to skin. | | | |
| 20 | Nitric Acid | HNO ₃ | Nitric Acid 50-70%, Water 30-50% | | | | | Poison, strong oxidizer, contact with other material may cause fire. Flammability Rating: 0 - None, Reactivity Rating: 3 - Severe (Oxidizer), Contact Rating: 4 - Extreme (Corrosive), Storage Color Code: White (Corrosive). | | | |
| 21 | 2-PROPANOL | Hydroxyl, aliphatic; molecular formula: c3-h8-o | | 53 f (12 c) (cc) | | Autoignition temp.: 750 f (399 c) | | Transparent, colorless, mobile liquid with a characteristic mild alcoholic odor and a slightly bitter taste. | Liquid | 2.1 | 40 mmhg @ 23.8 c |

Comparative table of Liquid Explosives

| Comparative Table: Liquid Explosives | | | | | | | | | | | | |
|--------------------------------------|-----------------------------------|---|--|---|---------------------------------|--|-------------------------------------|-------------------------------|-------------------------------|--|---|-------------|
| Sr | Liquid Explosive | Molecular Formula | Molar Mass | Appearance | Density | Melting Point | Boiling Point | Shock Sensitivity | Friction Sensitivity | Explosive Velocity | Solubility in water | Flash Point |
| 1 | Acetone Peroxide | $C_6H_{12}O_4$ (dimer) $C_9H_{18}O_6$ (trimer) | 148.157 g/mol (dimer) 222.24 g/mol (trimer) | White crystalline solid | | 91 °C, 364 K, 196 °F | 97-160 °C | Very high / moderate when wet | Very high / moderate when wet | 5300 $\frac{m}{s}$ 17,384 ft/s 3.29 Miles per second | | |
| 2 | Hexamethylene Triperoxide Diamine | $C_6H_{12}N_2O_6$ | 208.17 g/mol | White crystalline solid | 0.88 $\frac{g}{cm^3}$ | Decomposes at 75 °C Ignites spontaneously at 133 °C | | High | High | ~4511 $\frac{m}{s}$ | | |
| 3 | Ammonium Nitrate | NH_4NO_3 | 80.04336 g/mol | white solid | 1.72 $\frac{g}{cm^3}$, solid | 169.6 °C | approx. 210 °C <i>decomp</i> | | | 5,270 $\frac{m}{s}$ | 119 g/100 ml (0 °C) 190 g/100 ml (20 °C) 286 g/100 ml (40 °C) 421 g/100 ml (60 °C) 630 g/100 ml (80 °C) 1024 g/100 ml (100 °C) | |
| 4 | Nitroglycerin | $C_3H_5N_3O_9$ | 227.09 g/mol | Clear yellow/colorless oily liquid | 1.6 $\frac{g}{cm^3}$ at 15 °C | 13.2 °C, 286 K, 56 °F | Decomposes at 50-60 °C (122-140 °F) | High | High | 7700 $\frac{m}{s}$ | | |
| 5 | Nitromethane | CH_3NO_2 | 61.04 g/mol | Colorless liquid | 1.138 $\frac{g}{cm^3}$, liquid | -29 °C (244.15 K) | 100-103 °C (373-376 K) | | | | ca. 10 g/100 mL | 35 °C |
| 6 | Nitroethane | $C_2H_5NO_2$ | 75.08 g/mol | | | -90 °C (183 K) | 112.0-116.0 °C (385.2-389.2 K) | | | | slightly soluble (4.6 g/100 ml at 20°C) | 28 °C |
| 7 | Ethylene Glycol Dinitrate | $C_2H_4N_2O_6$ | 152.1 g/mol | Oily, odorless, colourless to light yellow liquid | 1.49 $\frac{g}{cm^3}$ | -22.0 °C | Explodes at 114°C | | | | 5 g/l | |



Part II

Different Types of Detection Technologies





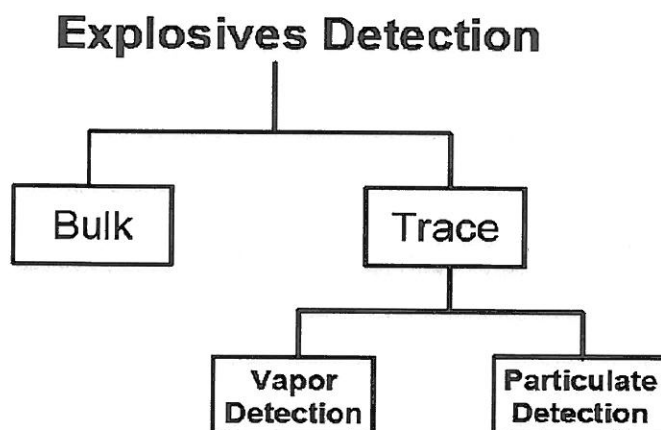
Trace Explosive Detection Technologies

Part II

Major Types of Explosive detection: Technologies

There are number of explosive detectors available in market based on different technologies. This can be suitably considered in two parts

- (i) Trace explosive detectors and
- (ii) Bulk explosive detectors



Canine detection is considered as a subset of trace detection. In recent developments use of rats and bees are being made on the experimental basis.

Trace explosive detection technologies:

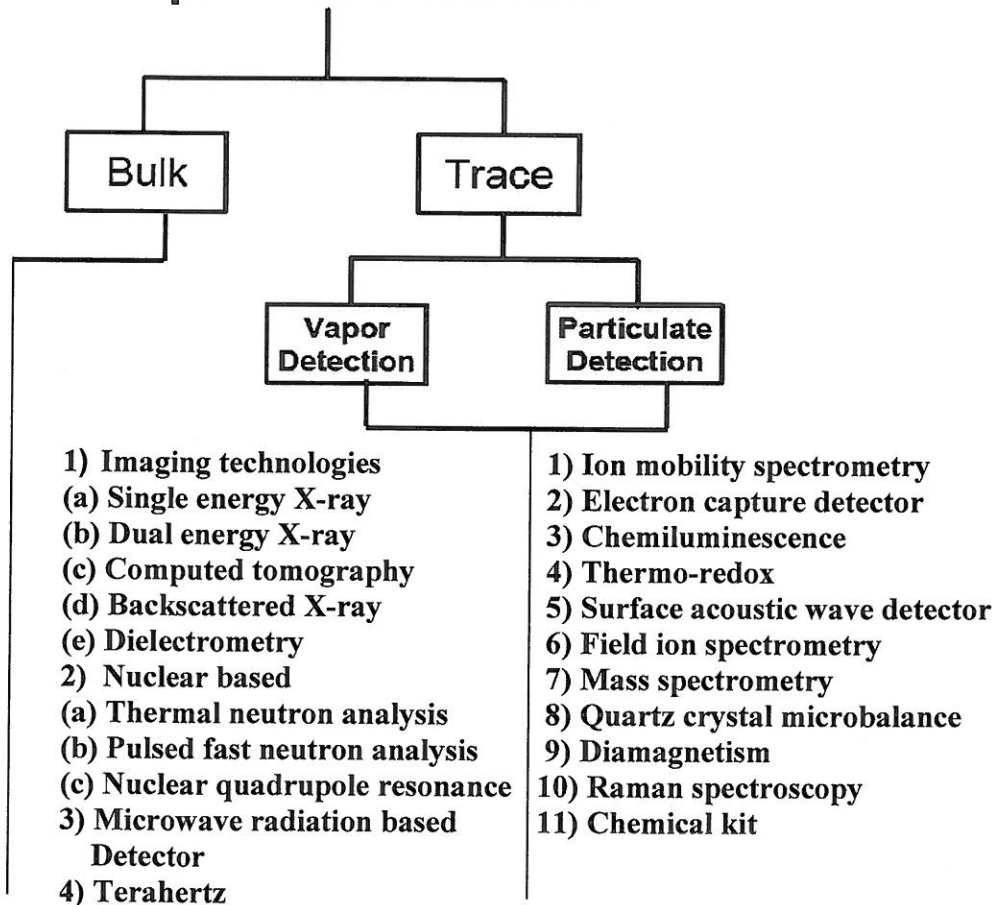
The trace explosive detectors involve the chemical detection of explosives by collecting and analyzing tiny amounts of explosive vapor or particles (a microscopic amount of explosives). Trace detection includes several different technologies using chemical sensors. Sample collection methods and the presence of interferants in atmosphere can profoundly affect the usefulness of trace detection methods.

The Trace explosive detection systems are generally available in two types

- (i) Handheld type and
- (ii) Desktop type

The devices can be classified as those which (a) detect vapours or particles emitted from the explosive materials, (b) detect dissolved or suspended solids in solutions, and (c) probe solid materials. However, they find use as alarm rather than for quantification.

Explosives Detection



1. Ion Mobility Spectrometry (IMS):

Ion mobility spectrometry (IMS) was created between 1965 and 1970 from studies on ion - molecule chemistry at atmospheric or elevated pressure with mass spectrometers and from ionization detectors for airborne vapor monitoring.

Principle: IMS detection is based on how fast ions move and reach the detector. The mobility of ions is dependent on the shape, size and mass of explosive molecules.

The sampling is done either by drawing in air near the suspected object or by swiping a surface to collect particles with swipe strip. The sample then enters the ionization region of the IMS detector, where electrons interact with the incoming explosives molecules to form negative ions. The negative ions are allowed to move into the drift region of the IMS by opening of shutter grid. The time required for the ions to reach the ion collector like Faraday cup is called the drift time. A plot of current versus drift time yields ion mobility spectrum. The drift time is used to identify a material as a

potential explosive. Typical drift times are on the order of a few milliseconds (1 millisecond = 0.001 second.)

Operational details: A conventional ion mobility spectrometer consists of the reaction region and the drift region. In the reaction region, carrier gas (clean, dry air) at atmospheric pressure is ionized by collision of β -particles (from a weak nickel-63 source) with nitrogen and oxygen (components of the carrier gas). These ions then undergo ion-molecule reactions with the explosive molecule. Under the influence of an electric field, the mixture of reactant and product ions reaches a shutter grid that separates the reaction region and the drift region. The shutter grid is made up of sets of thin mesh wires with a bias voltage between them. On application of bias voltage, the ions are attracted to the gating grid and lose their charge. Then the grid bias is briefly turned off, and ions are transmitted into the drift region of the cell. The ions are then focused and accelerated by an electric field (typically 1,000 to 3,000 volts) along the drift region (typically 8 cm) to arrive at the collector electrode (typically in a time of 10 to 20 ms). The smaller compact ions have higher mobility than the heavier ions, and therefore traverse the region and collide with the collector plate in a shorter time. The collector current is then amplified; its magnitude, as a function of time, is proportional to the number of ions arriving at that moment. In an IMS explosives detection system, time required for ions of specific explosives to drift down the IMS tube is precisely known and is programmed into the system's microprocessor.

However, the drift time is a function of pressure inside the drift region and recalibration may be required at higher altitudes. Humidity and fluctuations in power supply can also be responsible for degradation of sensitivity but this problem has been overcome in commercial systems. The microprocessor monitors the collector electrode signal at programmed drift times to detect the presence of explosive molecule ions. Typical analysis cycles require 5 to 8 s from introduction of sample to alarm notification.

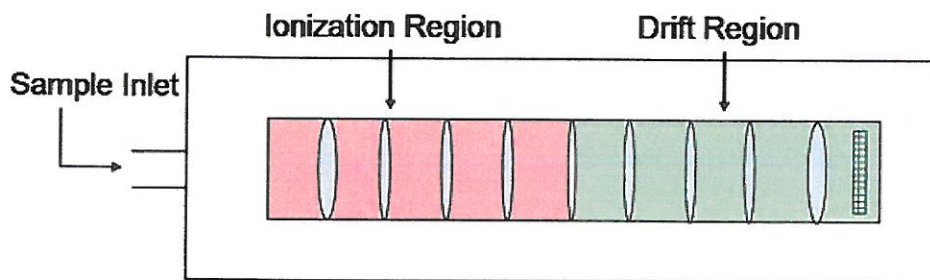


Figure: Schematic representation of ion mobility spectrometry

Advantages:

- Sub nano gram to pictogram level sensitivity
- Easy to use by person after a few hours of training.
- Throughput rate is 2 – 3 samples per minute.
- Moderate cost.

- The systems are available in portable as well desktop models. Portable models can be carried by person in field due to lesser weight.

Disadvantages:

- Warm up time of about 10 minutes required which is quite longer.
- Use of radioactive material in small quantity in some detector increases the difficulty in procuring material and obtaining legal permissions
- Periodic recalibration is required due to change in weather and elevation conditions.
- Resolution of explosive ions with similar mass and size becomes difficult.

Commercially available systems:

Some of the manufacturers have brought out improved version of IMS like Ion Trap Mobility Spectrometry (ITMS) and Micro Differential IMS.



Electron Capture Detector (ECD):

Principle: ECD comprises of an ionization chamber in which electrons produced from a radioactive cathode, usually tritium or Nickel-63 are injected into a stream of inert carrier gas (helium or argon), where they lose their energy by inelastic collisions with the carrier gas molecules and become thermalized. These thermal electrons are collected by an anode that produces a constant (standing) current. When an electron-capturing compound (such as an explosive) is introduced into the carrier gas, the standing current is reduced and the detector responds to the change.

In order to make the electron-capture detector more specific, some explosive detectors combine ECD with gas chromatography, which separates the volatile components in the sampled air in a column containing a stationary phase. The components emerge from the column at different retention times. The detection system assesses these retention times in conjunction with the ECD output and determines whether an explosive is present or not.

Advantages:

- ECDs have a fast response and a sensitivity of about 1 ppb (parts per billion) for most electron capturing compounds.
- The system does not have movable parts.
- Portable
- Easy

Disadvantage:

- Sensitivity is less than that of IMS or chemiluminescence.
- Recurring running cost is due to required refill of helium or argon gas.
- It may be mentioned that the ECD is not compound specific, i.e., it cannot identify the type of explosive present.
- There are also some common non-explosive substances that give rise to ECD signals, such as atmospheric oxygen, wide range of substituted hydrocarbons such as Freon
- , fertilizers, and some household cleaners.
- Most of the current systems employ membrane concentrators in which explosive molecules are soluble and can be transferred selectively from one side of the membrane to the other side. As a result of this more than 70% of the sampled gas is not available for analysis.

The system requires electrical power supply and battery back up is essential in fieldwork.

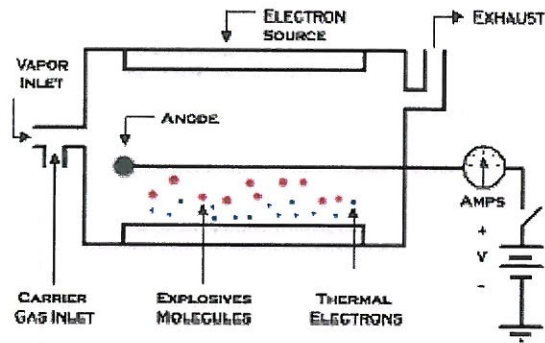


Figure: Illustrating of working of an ECD detector.

Commercially available systems: Model HS 97 from AI Cambridge (out of production).

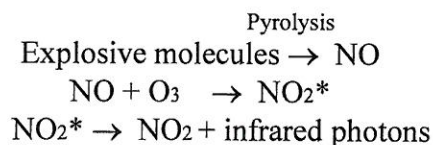


GVD4 (Graseby Dynamics Ltd., UK – not available)

III. Chemiluminescence (CL):

Principle: The chemiluminescence principle is based on the detection of infrared light emitted from electronically excited NO_2^* . Most common explosives contain nitrogen (N) in the form of either nitro (NO_2) or nitrate (NO_3) functional groups. Also taggants used in plastic explosives contain NO_2 groups. The intensity of emitted IR light is directly proportional to the amount of NO present, which is related to the amount of the original nitrogen-containing explosive material.

Operational details: The explosive molecules are pyrolysed resulting in formation of nitric oxide (NO), which is then allowed to react in an evacuated reaction chamber at a pressure of about 3 torr (0.4kPa) with ozone (O_3) to yield nitrogen dioxide in electronically excited state (NO_2^*). This NO_2^* returns to the ground state accompanied by chemilumiscence in infrared spectral region which is detected by a photomultiplier tube placed behind red filter which eliminates light with spectral frequency higher than near infrared.



The system requires electrical power supply and battery back up is essential in fieldwork.

Advantages:

- GC/CL combination has very high sensitivity and specificity
- Portable and handheld having less weight
- Easy to use by one person
- Training of few hours is sufficient
- No radioactive source
- Luminol based systems do not require carrier gas and are capable of detecting TATP (non-nitro explosive)
- No movable parts are involved in the device.

Disadvantages:

- The chemiluminescence detector cannot identify the type of explosive detected. This drawback can be overcome by combining GC with the detector as in case of ECD.
- Systems based on ozone require ozone for the Chemiluminescence reaction hence recurring cost increases
- Ozone based systems can detect only nitro based explosives.
- Some of the non-explosive nitrogen rich compounds (found in fertilizers, perfumes, etc.) can lead to false alarm.

Commercially available systems:

The Scientrex Trace Corporation, Canada claims detection of TATP by CL based model E 3500.

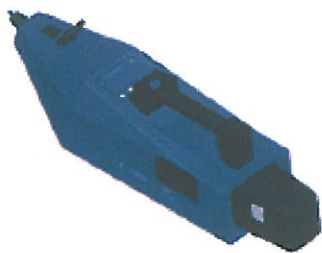


Photo furnished by: Thermo Electron Corporation

E 3500 (Scientrex Trace Corporation, Canada) & EGIS II (Thermo Electron Corporation)

IV. Thermo-Redox (TR):

Principle: It is an electrochemical technique based on the thermal decomposition of explosive molecules and the subsequent reduction of NO₂ groups. A sample is drawn into the system and is allowed to pass through a concentrator tube, which selectively traps explosives. On rapid heating NO₂ molecules are released which are detected using proprietary technology.

Operational details: The air containing the explosive sample is drawn into the system and passed through a sample concentrator tube, which selectively adsorbs explosive vapor molecules using a proprietary coating on the tube's coils. The sample is then pyrolyzed to release the NO₂, which is then transferred to a membrane separator cum sensor assembly. The membrane separator provides additional discrimination against potential chemical interferences. The gases are passed across the sensing surface of the detector and a small signal is generated. The verification of explosive vapors is accomplished by comparing the strength of the signal from the detector and the time from the start of the analysis cycle with reference to the factory set value. If both, the signal strength and time requirements are met, a positive detection alarm results.

Advantages:

- This detection system requires neither a special carrier gases nor a radioactive source.
- Portable and easy to use

Disadvantages:

- Thermo-redox system cannot identify the type of explosives and is suitable for nitro-explosives only.
- A major drawback of the thermo-redox system is that it cannot detect RDX, HMX and PETN by vapor sampling because of their very low vapor pressures.1
- Particulate sampling is essential in case of low vapour pressure explosives. The specificity can be increased by using GC before the detector as in other cases.

The system requires electrical power supply and battery backup in fieldwork.

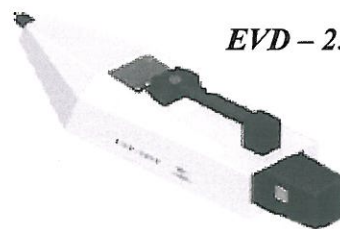
Commercially available systems:

The available systems EVD-3000 and EVD-2500 (Scintrex Trace Corporation, Canada) are depicted below.

EVD – 3000



EVD – 2500



Surface Acoustic Wave (SAW):

Principle: Surface acoustic wave (SAW) detection of explosives is based on shift in resonance frequency that occurs when these materials get deposited on the SAW crystal surface (detector surface). The frequency shift also depends upon the properties of the material being deposited, the surface temperature, and the chemical nature of the crystal surface.

Operational details: Surface acoustic wave (SAW) sensors are usually coupled with a front end gas chromatography (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. In a typical system, the exit gas from the GC is focused on to the SAW resonator crystal using a carefully positioned temperature controlled nozzle. A thermoelectric cooler maintains the SAW surface at sufficiently low temperatures to ensure efficient trapping of the molecules of interest. The precise control of temperature of the surface allows control of sensor specificity, by preventing adsorption of species with vapor pressures above a threshold value. The crystal surface can also be heated in order to desorb vapors, and thus clean the surface. This feature is useful in distinguishing between high and low vapor pressure explosives. During sampling, vapors are concentrated in a cryo-trap before being desorbed into the GC for temporal separation. Total analysis time, including sample concentration in the cryotrap, is typically 10 -15s.

Advantages:

- The system is projected to have parts per billion sensitivity to certain types of explosives.
- Sensor surface is easy to clean.
- It has 10 min startup.
- Analysis time 10 – 15 s per sample.
- Portable.
- Does not require radioactive source.
- It can detect chemicals other than explosives.

Disadvantages:

- The presence of other chemicals may make detection of explosives difficult.
- Gas container is essential for the operation of the detector.

Commercially available systems:

The available systems are Model 4100, z-Nose 4200 and Model 7100 of Electronic Sensor Technology.



Model 4100



zNose 4200

Field Ion Spectrometry (FIS):

Field ion spectrometry (FIS) is a relatively a new trace detection technology introduced in mid 90's, and offers improvement over IMS wherein separation and detection of explosives is achieved by a single setup (use of GC is not essential).

Principle: The separation of explosive molecules in sample is achieved by application of high field gradients as compared to that in IMS. The detection of ions of explosive molecules formed is detected in manner similar to that of IMS. The mobility of the ions is non-linearly dependent on the field gradient hence it is also referred to as non-linear IMS.

Operational details: The explosive molecules are ionized in similar way as in case of IMS. The ions then 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 and second is an oscillating motion transverse to the bulk flow velocity that occurs as the ions respond to an asymmetric, time-varying electric field imposed between the two plates. In response to the asymmetric field, the ions tend to migrate towards one of the plates where they are neutralized. A second DC field is simultaneously established across the plates and can be used to balance or compensate for the drift introduced by the primary field. The DC field intensity needed to compensate for the AC field induced drift depends on the mobility of the particular ion under investigation, so that only specific ions can pass through the analytical volume and into the collection area for detection. Therefore, the device can be tuned to allow to selectively pass only the ions of interest. Scanning of the DC field intensity produces a spectrum of ion current versus field intensity that is known as an ionogram.

Advantages:

- Better resolution and hence more selectivity.
- The sensor has no moving parts .
- No consumables except a replaceable calibrator and gas purification filters.
- The manufacturer has reported detection limits for explosives such as TNT, RDX, and PETN in the picogram range.
- It has response time of 2 s for a single target molecule plus another 5 s for each additional target molecule.
- Portable and easy to use.

Disadvantages:

- Use of radioactive material in small quantity in some detector increases the difficulty in procuring material and obtaining legal permissions
- Periodic recalibration is required due to change in weather and elevation conditions.
-

Commercially available systems:

The commercially available systems are SRTVD, MO2M, MO8 and FIS.



FIS (Mine Safety Applications)

Mass spectrometry

Principle: Mass spectrometry (MS) uses an explosive material's molecular weight and fragmentation patterns for identification. While there are different types of mass spectrometers, it is basically a mass filtering technique. Molecules are ionized and passed through a filter (e.g., magnetic, ion trap, time-of-flight), which allows ions to be identified based on their charge-to-mass ratio.

Operational details: The sample introduced in mass spectrometer is ionized and is allowed to accelerate through the mass analyzer section which separate ions by different

methods like application of magnetic, electric, quadrupole fields. The separated ions reach at detector like Faraday cup/plate or electron multiplier tubes like multichannel plates

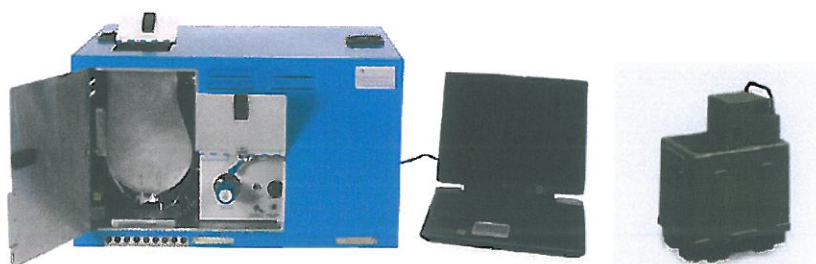
Advantages:

- Low to subpicogram detection limits.
- Very high specificity for compound identification.
- Analysis of air, gas, soil, solid, liquid, and water samples are possible.
- Does not require radioactive source.

Disadvantage:

- Requires more time for analysis.
- Design of the systems is complicated and for their servicing skilled manpower is required.
- High cost.
- Requires gas supply and vacuum pump.
- Handheld systems not available.
- Not easy to use due to technical knowledgebase required to user.
- Generator or AC power is required.
- Long warm up time (~ 45 min).

Commercially available systems:



Photos furnished by: Constellation Technology Corporation (left) and Bruker Daltonics (right)

Quartz crystal microbalance

The “biosensor” program initiated in 1995 by the Swedish Biosensor Applications AB is among one of the very few in Europe targeted specifically at humanitarian demining applications. Biosensors can be easily adopted for portable vapour detection systems, often referred as “artificial dog nose”.

Principle: A piezoelectric crystal (i.e., a Quartz Crystal Microbalance, QCM), whose surface is covered by an adsorbent polymer/antibody reacting with explosive molecules.

The antibodies detach themselves from the sensor, and the resulting variation in oscillating frequency of the crystal is measured.

Operational details: It comprises of a collection system to collect air. The air sample passes through a filter, which absorbs the molecules of the target substance. The filter is purged of its contents which are allowed to pass over the sensor surface. The explosives leaving this trap are led to the quartz crystal oscillating at different frequencies, for eg some sensors operate at about 9 MHz. The crystal has a surface layer of specially designed polymers on which explosive molecules get preferentially adsorbed. When the sensor surface is coated with antibodies, only specific explosive molecules get attached to their receptor sites and the antibody + explosive molecule adduct get detached from the surface of the crystal. As the mass of the crystal decreases, its oscillating frequency changes by 5 – 25 Hz. The processing unit senses the change in frequency and a signal is generated.

Advantages:

- Biosensors may be used for verification and area reduction purposes.
- Portable and easy to use.
- No radioactive source.

Disadvantages:

- The trap has to be regularly changed when it gets contaminated.
- Comparatively longer detection time.
- Low sensitivity as compared to SAW.

Commercially available systems:

Mini nose is quartz crystal microbalance based commercially available system.

Detector based on diamagnetism:

Principle: Diamagnetism is a universal property. The diamagnetic substances do not allow magnetic field to pass through it. The diamagnetic material in earth's magnetic field results into magnetic polarity, which can be detected by the explosive detector while cutting field lines at particular angles and at tangent, thus offering a directional detection device.

Operational details: The target source resonance reacts with the sensor card of the detector and sets up an energy field, which attracts the antenna of the detector pointing to the target. The detection system is able to identify the type of explosives. This is a standoff detection system where the operator can detect explosive from a distance reducing the hazard.

Advantage:

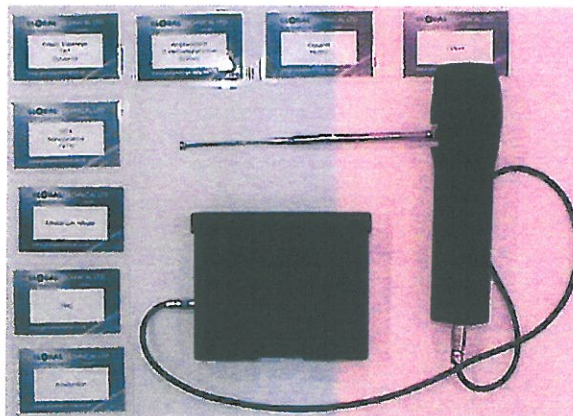
- The system requires neither power supply nor batteries for operation. It works on the static charge of the operator.
- It is ready to use in less than 1 min.
- It has been claimed by the manufacturer that the system can also detect explosives hidden under water up to the depth of 350m and under ground up to the depth of 20m. On land, the range of detection is 500m whereas during aerial survey from height (helicopters) the range can be up to 4000 – 5000m.
- Explosives hidden in buildings and vehicles can be located at a sufficient distance from the target.
- Portable.
- Can be used for searching wide area.

Disadvantages:

- For each explosive or number of explosives grouped together, the manufacturer has developed sensor cards calibrated for that/those explosive(s). The manufacturer claims that such sensor card can be prepared for any new explosive that is developed in future and also for inorganic explosive components.
- Very high false alarm rate.
- Thorough training required.
- Results vary from person to person since it works on the static charge of the user.
- It scans only one quadrant at a time (span of 90°) hence to cover a large area it is time consuming.
- More than one detector required for reducing search time implicating additional expenditure for purchase of additional equipment.

The equipment is too sensitive to be used in installation dealing with even minor quantities of explosives.

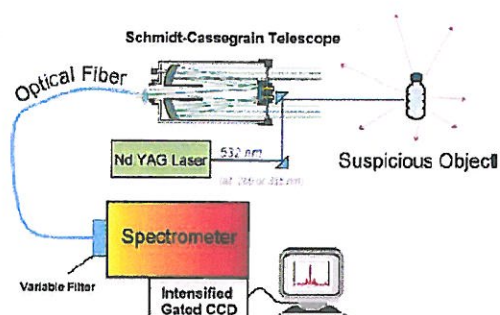
GT200



Raman spectroscopy

Principle: Raman spectroscopy involves an inelastic light scattering process that shifts the frequency of the incident photons to low energy (Stokes Raman) or high energy (Anti-Stokes Raman). The interaction of light photon with molecule, liquid or crystal of explosives their energy in vibrational and rotational states may be exchanged. Like infrared absorption spectroscopy Raman scattering spectroscopy provides unique set of vibrational modes of explosive molecule. The technique is capable of remote non-destructive detection of explosives with high sensitivity. Though Raman spectra under visible excitation are available for most explosives only recently this method has become promising tool for trace level detection at standoff distance. It can also be used as screening method for explosives at airports and other transport centers.

Operational details: The Detector is equipped with near infrared laser that analyses the sample in bottle, plastic bag or capsules resulting in fingerprint Raman spectrum. The equipment comes with library of fingerprint Raman spectra of several molecules that can be extended by user as per his requirements. The fingerprint spectrum of sample is then compared with those standard spectra stored in detector's library. The name of the compound with most closely matching spectrum is reported to be detected. The research is on for the development of resonance Raman and surface enhanced Raman spectroscopic methods for detection of explosives.



▲ 15: Operators experiment on nitromethane in a standard 33 oz soft drink bottle. The telescope can fit the narrow laser beam. The bottle used for nitromethane and the resulting bottle of nitromethane and expanded nitrate is seen on the right.

Advantages:

- No chemicals are required
- Use for both lab and field applications
- Rapid automated calibration helps to ensure operational accuracy
- May avoid human error by eliminating sample preparation and interpretation
- It can identify solids, liquids and powders in single step without sample destruction or subject to interpretation

Disadvantages:

- Longer analysis time
- Limitation for sample size
- Big sized samples cannot be used for detection
- Operating temperature range is 0 to 40°C as against desired range of -20 to 65°C.

Commercially available detectors: First Defender, Streetlab and Streetlab Mobile

Chemical reagent based (Color Change)

Principle: The addition of chemical reagents to an explosive sample results in color change characteristic of the explosive present. The chemical reagent based kit is useful for detection and identification of explosive in field and is useful for post explosion analysis or analysis of seized explosives.

Operational details: The chemical reagents may be used in the form of drop as in case of Drop-Ex kit or in the form of aerosol spray as in case of Expray kit, both marketed by Mistral Security Inc. There are three reagents in Expray kit which are sprayed in succession. The colour change after addition of first reagent indicates presence of Group A explosives like TNT, DNT, picric acid, etc. In absence of any colour reaction the second reagent is sprayed on the same sample and development of colour change indicates presence of Group B explosives (Semtex H, RDX, PETN, NG, smokeless powder, etc.), and compounds that contain nitrates are identified with the help of reagent 3. Recently reagent 4 and 5 have been developed for identification of chlorates/bromates and perchlorates.

Some explosive identification kits utilize independent tests for different types of explosives. In such chemical reagent kits the reagents are added to fresh sample every time. An explosive identification kit developed by HEMRL, Pune is one of such type and is being used by Police and Army in India.

Advantages:

- Portable
- Easy to use
- Useful for post explosion analysis and analysis of seized explosives on the field
- Training for an hour is more than sufficient
- The kit reagents may be refilled after being consumed, especially in case of kit developed by HEMRL
- Low cost
- No power source required

Disadvantages:

- Sampling of explosives is essential
- Concealed explosives are difficult to be analyzed
- The instructions of operations have to be followed precisely
- Order of sample testing is critical
- Sensitivity is limited by observable change in colour
- One or more minutes per test
- Sometimes UV lamp is required
- Number of tests per kit are limited in some kits
- Due to contamination may give false positive colour change
- Only the specific colors in the instructions can be judged a positive detection. Other discoloration is possible, but should be judged negative
- Operators may have some degree of color blindness
- Additionally, vapor sampling cannot be performed and detection is very dependent on sample concentration

Commercially available systems:



Hand-held commercial Expray field test kit for explosives detection from Mistral Security Inc.

Visible or Ultraviolet (UV) Fluorescence

Principle: When UV light is used to illuminate the samples containing explosive material the explosives materials fluoresce even when present in trace amounts. Amplifying

fluorescent polymers fluoresce in visible range of electromagnetic radiation which gets quenched on interaction with aromatic explosives.

Operational details: The amplifying fluorescent polymers have been designed such that emit fluorescent radiation in visible region even when used in thin film form. The polymers have sites that are specifically receptive to aromatic explosives like TNT, DNT, tetryl, etc. A pump is used to draw in an air sample containing explosives. The preconcentrator increases the concentration of explosives reaching detector by eliminating interfering substances and at the same time reducing the kinetic energy (speed) with which the sample passes over the sensitive surface. The interaction of explosive molecules with the amplifying polymer leads to reduction in fluorescence emission and can be detected by measuring change in intensity of the radiation emitted.

Advantages:

- Portable
- Easy to use
- Sensitivity to aromatic explosives is reported to be in the range of pictogram (10^{-12} g) to femtogram (10^{-15} g) level – comparable or better than canines
- Training for few hours may be sufficient
- High throughput rate

Disadvantages:

- Detection of non-aromatic explosives is not possible
- The detector has to be taken close to the explosive sample for detection
- The polymer being highly conjugated the stability of the sensing polymer is limited

Commercially available system:

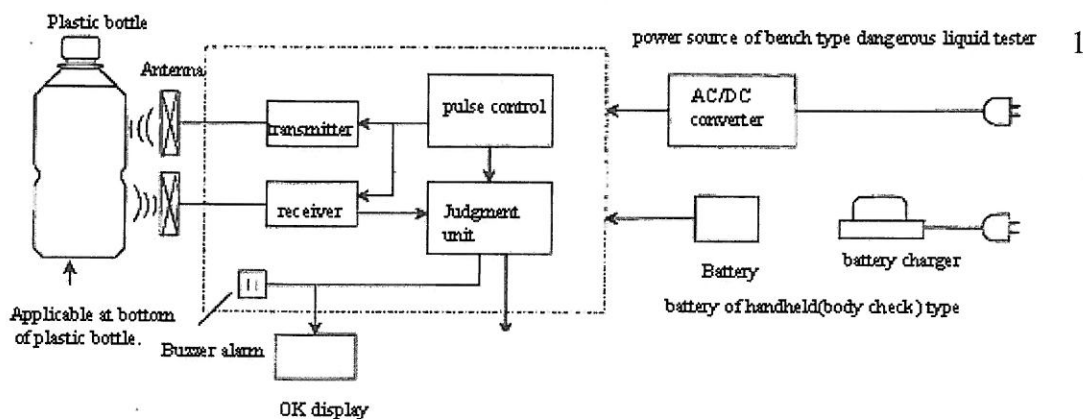


FIDO detector manufactured by Nomadics Inc

Dangerous Liquid detector

Principle: The detector detects hazardous liquids by measuring permittivity or dielectric constant of the material. The technique employed is called as quasistatic electrical tomography.

Operational details: The device is electronic and does not use ionizing or microwave radiation source. The schematic diagram of the instrument is reproduced in figure below. Sensing part is a linear array of electrodes of which one set of electrodes creates alternating electric field in the space while the other set of electrodes measure this field perturbed by the object under investigation. A list of different liquids and their permittivities are also tabulated below. It can be employed at the airports, check-points, places where there is heavy traffic of people (for example stadiums, malls and discos), etc. It is possible to distinguish substances as gasoline, incendiary mixtures, acetone, nitroglycerine, various spirits, ethers and other dangerous liquids from water, nonalcoholic and alcoholic drinks (including strong), dairy products, etc. without violation of the container sealing. When a dangerous liquid is sensed the LED glows red which is otherwise red



| Liquid | Permittivity | Conductivity, S/m |
|--------------------|--------------|---------------------|
| Water | | 81 |
| soft drinks | | 0.01 - 1 |
| Ethanol | | 25×10^{-5} |
| Acetone | | 21×10^{-5} |
| Nitroglycerine | | 19 |
| Ether | | 4.3 |
| Petrol, diesel oil | | 2×10^{-10} |

Advantages:

- Small, low weight, compact and portable.
- The system does not have movable parts.
- Easy to use.

- Can be used without opening of the container
- Detects hazardous liquids hidden in plastic or glass bottles
- Capable of detecting even if there is small air gap (~ 3mm) between bottle surface and sensing area

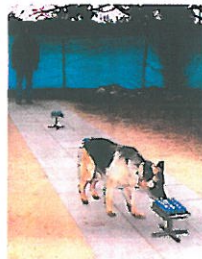
Disadvantage:

- Cannot detect hazardous liquids hidden inside metallic containers.
- Does not give audio alarm.
- Does not indicate name of the material detected.



Canine Detection of Explosives

The olfactory system of the dogs being sensitive can be trained for the search of area for any explosive device. Although daily working hours of dog are relatively short, dogs can easily cover several thousand square meters per day. They generally sense the explosive vapours. Vapour pressure (table below – data at 20°C) of most of the explosives being low, results in their low vapour concentration.



| Explosive | ng/L |
|----------------------------|--------|
| TNT (trinitrotoluene) | 70.0 |
| 1,3-DNB (di-nitro benzene) | 8140.0 |
| 2,4-DNT (di-nitro toluene) | 1440.0 |
| 2,6-DNT | 5560.0 |
| RDX | 0.04 |
| HMX | 0.38 |
| PETN | 0.09 |

Gas chromatographic study of air above PMA-1A landmine conducted at Canine Olfactory Laboratory at the Auburn University indicated presence of 1,2-DNB, 1,3-DNB, 2,4-DNT, 2,6-DNT and 3,5-DNT in the vapour while TNT was absent. It was established that the dog smell odour bouquet of mines rather than TNT. The US Army Corps of Engineers also conducted examinations with buried military grade TNT in different soils (sand, silt, clay) with varying moisture content. As expected, vapour concentration of DNB, DNT and TNT above soil were strongly influenced by type of soil and its moisture content. As expected, TNT concentrations were much lower relative to that of DNB and DNT. TNT was not even detected in clay type of soil. There are different mechanisms of transportation of TNT from mine to soil surface. Vapour-liquid, liquid-solid and vapour-solid partitioning interactions influence the transport of TNT to the earth surface. This process requires time, and hence dogs cannot detect freshly buried mines. The highest surface concentration at surface might be displaced up to 1 m from the actual position of the mine. The explosives with still lower vapour pressure may pose further problem in this regard.

Major drawback of this method is that dog training is extremely difficult and time-consuming. It lasts up to 3 years and need to be continued. Further, the dog has to adapt to different soil and vegetation as well as weather conditions. The handler and the dog form the demining "system" and cannot perform well without perfect matching. The dense and/or mixed (AT and AP mines) minefields can confuse the dogs. In spite of these drawbacks, well-run dog programs are now-a-days generally accepted by most humanitarian demining organizations for area verification (e.g. Quality Control after mine clearance activities) and minefield delineation (i.e. area reduction).

Advantages:

- A dog's nose is the best vapor sensor that evolution has to offer and it competes favorably with man-made detection technologies under many circumstances
- Portable
- High mobility in all weather conditions
- Rates of false positive and false negative alarms are very low
- Capable of following the odour to its source
- High throughput rate

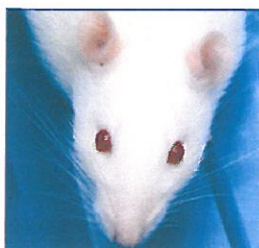
Disadvantages:

- Elaborate training program has to be undertaken to train the dogs
- The dogs and their handler form a pair and can give better results only if there is better understanding between the two
- Short working hours
- Distraction due to food and stray animals
- Due to high sensitivity of liquid explosives very difficult to train the dog

Upcoming technologies

Explosive detection by rats and bees

Rats and bees are also used for detection of mines. It is reported that rats have better sense to smell. Further, they are resistant to tropical diseases. Rats are also independent of handler and cheaper to train than dogs. Their weight and volume being small, more than one animal can be used in field. The field trials, monitored by MgM, in Tanzania under APOPO project claim an astounding 100% detection using rats.



A series of repeated trials conducted in 2001 and 2002, at University of Montana brought out that bees behave like a fine-tuned, nearly ideal detector [for 2,4-dinitrotoulene (2,4-DNT) mixed in sand] at vapor levels higher than 10 parts per trillion (ppt). In 2001, AFRL (Air Force Research Laboratory, US) and researchers calculated a detection probability of 97-99 percent at parts per billion (ppb) and parts per trillion (ppt) vapor concentrations, with a 1.0-2.5 percent probability of false positive and less than one percent probability of false negative detection. In the 2002 tests, bees consistently detected DNT targets generating 50-80 ppt vapor. Under moist conditions, detection level dropped to about 30 ppt. An increase in number of bees can bring the detection threshold even lower.

Bees are trained in much the same way as dogs, and like dogs, bees can detect suites of chemicals, such as 2,4-DNT, 2,6-DNT, TNT, and RDX over a wide range of concentrations. Presence of explosive is indicated by the numbers of bees following vapor plumes toward and over the source of odour. It has been observed that bees detect the vapor plume several meters from the source, and then navigate up to the plume source. The density of bees over an area is mapped, using visual, camera or laser-assisted counts to obtain the indication.



Bulk Detection Technologies

Bulk explosive detection

The X-ray systems and nuclear techniques that are finding application in bulk explosive detection are discussed in this chapter. Most of them belong to fixed type whereas some of them are available in vehicle mounted version. They are commonly used at airport, seaport as well as to monitor sensitive entry points. Bulk detection techniques are also reported to be effective in detection of mines. However, their efficiency of detecting mines is also affected by soil properties as noted below.

| Detection Technology | Main Relevant Soil Properties |
|------------------------------|---|
| Nuclear Quadrupole Resonance | Magnetic susceptibility Electrical conductivity Electrical permittivity Piezoelectric materials (e.g. quartz content) Magnetostrictive materials |
| Thermal Neutron Activation | Content of elements such as Fe, Ti, Cd, B, Gd, Si, O, C, N, H |
| X-ray Backscatter | Effective density Effective atomic number and weight |
| Neutron Moderation | Content of H |

X-ray Techniques:

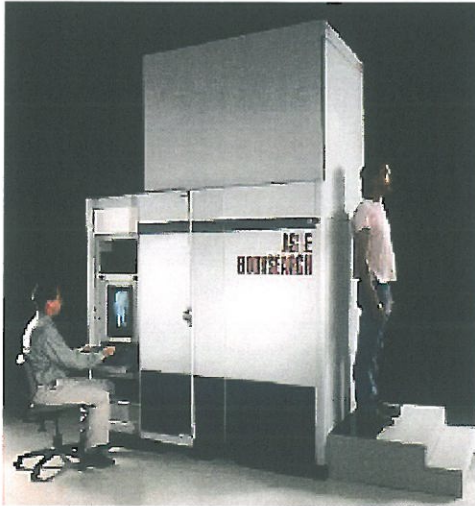
In x-ray systems, the absorption occurs basically due to x-ray interaction with the electrons of an atom via photoelectric effect. Thus, x-ray is absorbed and knocks out one of the atom's internal electron. The mass attenuation coefficient (μ) depends on the energy of the x-rays and effective atomic number (Z_{eff}), which is related to the weighted average of the atomic numbers (Z_i) of the constituent elements of a substance. Compton scattering is another phenomenon in which x-ray photon hits an electron and transfers part of its energy to it while retaining reduced energy.

- I. Transmission
- II. Dual energy x-ray
- III. Back scatter X-ray
- IV. Computed tomography

I. Transmission X-ray :

The photons of x-ray can simply pass through the material or can be absorbed or deflected. The outcome depends upon energy of the x-ray as well as the bulk characteristics of the material like density, mass absorption coefficient and effective Z-number. Single energy transmission x-ray devices are highly cost effective. However, they do not permit the search of explosives.

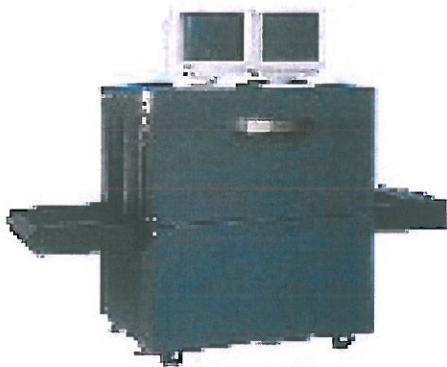
Dual energy, dual axes and backscatter technologies allow a fairly approximate determination of mass attenuation coefficient and effective Z-number. Computed tomography can extract information to calculate the density of material as well as its mass attenuation coefficient. These technologies provide low cost alternative to nuclear technologies.



AS&E Body search



Rapiscan Secure 1000



*Dynavision 910
Control Screening
(Conventional X-ray system)*



*Linescan 110
EG&G Astrophysics
(Advanced X-ray system)*

II. Dual Energy X-ray:

It is a variation of standard single energy transmission x-ray wherein; the x-ray beam penetrates the item. The transmitted x-ray adds all the objects and materials in line of sight resulting in one compound image. The employment of two x-ray tube operation voltage can provide two energy levels and better resolution. In a typical system, energies around 75-150 kV are used to image low Z-number materials. The image is displayed on monitor and software identifies the contraband by image shape and color code.

Although dual energy system is superior to single energy system, it cannot determine the material thickness, and thereby cannot unambiguously determine the Z_{eff} of the material. The inability of dual energy x-ray like transmission x-ray to separate the objects from one another, poses severe limitation for the detection of the materials having low Z_{eff} /low atomic number like plastic explosives and drugs. They are more suitable for metal detection.

The use of dual axes / dual energy system provides two images of the package at 90° and can be considered a run down version of computed tomography. Although it does not provide complete cross section reconstruction, it provides additional information for detecting explosive like materials.

III. Backscatter X-ray:

The backscatter imager distinguishes low Z materials from high Z-materials by their greater radiation scattering characteristics. Low Z-objects like explosives and drugs, which appear in low contrast in conventional x-ray system, appear as bright white material in back scatter and are separately displayed on a second monitor. A comparison with conventional image reduces the scatter and makes the low Z item more visible. In a single beam scatter imager, another detector is positioned on the source side to detect radiation backscatter by low Z-material. However, low Z-objects behind the dense material may remain hidden. A double beam backscatter detector positioned face to face examines the package from both the sides simultaneously. It can indicate the excessive amount of low Z-material, and thereby can be indicative of explosives or drugs.

A combination of backscatter x-rays together with the standard transmission system provides information that helps in separating the effects of density and effective atomic number (Z_{eff}), thus providing means of identifying high density, low Z_{eff} materials like explosives and narcotics.

The technique has scope of application for real-time detection of AT mines. Thomson-CSF Detexis (France) system is reported to produce a 2D image with a resolution of a few centimeter. Research on the subject has been carried out during the last decade at University of Florida. Problems arise from shallow penetration, system complexity, sensitivity to soil topography, sensor height variation, and safety aspects due to the use of ionizing radiation.

IV. Computed Tomography :

CT is a x-ray technique producing two-dimensional images of cross sectional slices of an object. By combining the adjacent cross sectional slices, a three dimensional image can be obtained. These images have relatively improved density resolution as compared to transmission x-ray system. It can specifically identify explosives and discriminate them from most of the innocuous materials of low Z-number as it determines the material thickness, and because explosives generally have higher densities than other innocuous materials of near Z-number. The knowledge of material thickness allows specific identification of materials like explosives.

The disadvantages of current CT scan system design are complexity, high cost, higher package dose and slower operation. The work is on for optimizing the technique and the use of dual energy as well as helical scan is being explored.

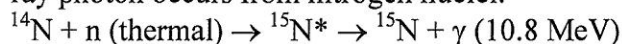
Nuclear Techniques:

Nuclear techniques are receiving great interest for such applications. Major advantage of nuclear techniques over X-ray technology is that they do not depend on human interpretation. The detection of suspicious object is automatic, and it need not be to be identified by the operator viewing the images. The systems can operate year round as there is no human interface.

- I. Thermal Neutron Activation (TNA)
- II. Pulsed Fast Neutron Activation (PFNA)
- III. Nuclear Quadrupole Resonance (NQR)

I. Thermal Neutron Activation (TNA):

Neutrons have excellent penetrating power and interact with nitrogen rich materials like explosives. On absorption of thermal neutron, an associate release of 10.8 MeV γ -ray photon occurs from nitrogen nuclei.



The intensity of the photons is an indication of the amount of nitrogen present, and thereby nitrogen rich explosives can be readily detected by TNA actuating an alarm. The neutron source is either ^{252}Cf or electronic neutron generator of intensity about 10^9 neutron/s.

Elemental ratio / density for narcotics, explosives and plastics.

| Density or Ratio → | H | C | N | O | Cl | C/O | C/N | Cl/O |
|--------------------|-------------|------|-------------|-----------|----------------|----------|-----------|---------------|
| Narcotics | High | High | Low | Low | Medium | High, >3 | High | Very High |
| Explosives | Low-Medium | Med | High | Very High | Medium to None | Low, <1 | Low, <1 | Low to Medium |
| Plastics | Medium-High | High | High to Low | Medium | Medium to None | Medium | Very High | |

The technique developed by Science Application International Corporation (SAIC) is commercially available and used at some of the airports. The present reported cost of the system is about US \$ 9 lakh. The method is effective in detecting the explosives. However, it has limitation for universal application, as it is not capable of detecting carbon and oxygen.

The SAIC Company has developed, a system (with Californium-252 as source) as confirmatory device for the Canadian Improved Landmine Detection System (ILDS) and for the VMDT vehicle (figure 37).



SAIC TNA sensor head (left) and the VMDT vehicle with TNA sensor head during field trial.

II. PFNA:

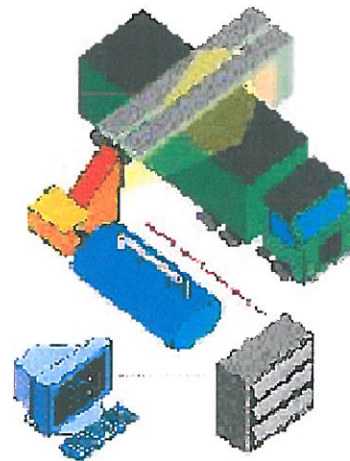
The Pulsed fast neutron activation (PFNA) analysis employing pulsed neutron generator producing 8 MeV neutrons overcomes the drawback of TNA. It produces signature γ -rays for carbon and oxygen also at 4.44 and 6.13 MeV respectively in addition to that for nitrogen. It provides a three-dimensional image of the objects as well as location of the detected material. Owing to such capability, it provides means to detection of explosives. The ratio of carbon to nitrogen and carbon to oxygen is high in case of explosives rendering PFNA highly specific to compounds like explosives. The neutrons are produced by $D(d,n)^3\text{He}$ reaction. The neutron production target is generally a thin window deuterium gas cell, enclosed in a shield assembly.

PFNA stores the atomic fingerprints of every object it scans for comparison, thereby making the system smarter. It can provide material identification for objects ranging from luggage to full size shipping containers. The preliminary testing has established throughput of 600-1000 /hour for luggage and parcels. It gives the detection accuracy greater than 90% and false alarm rate near zero.

Neutron analysis systems could typically be combined with other sensors, and used in a confirmatory role. The drawbacks of neutron-based systems are the system complexity and cost, radiation hazard, system weight (especially due to heavy shielding) and power requirements. Depth of penetration as well as minimum amount of detectable explosive also have to be carefully assessed.



SP-EDS (TNA)
Ancore Corporation

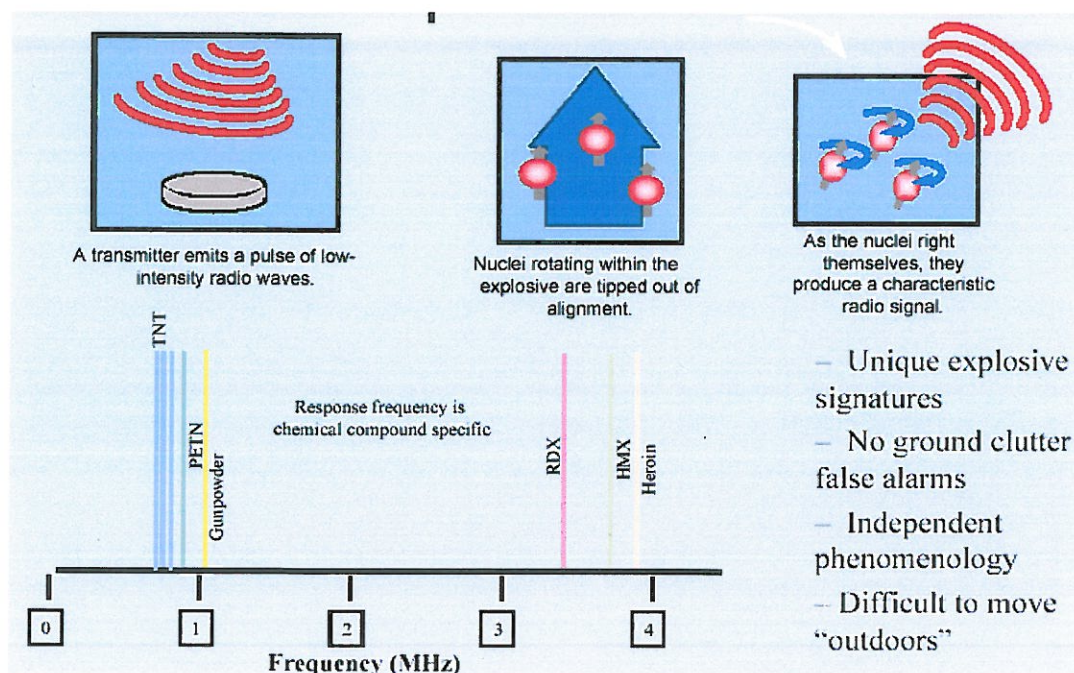


PFNA
Ancore Corporation

III. Nuclear Quadrupole Resonance (NQR):

Quadrupole resonance is emerging as a viable technique not only for detecting crystalline materials hidden in cargo and airline baggage but also filled in landmines. It is based on inherent molecular properties of crystalline materials such as explosives. The signal is associated with the magnetic spin properties of the nuclei and electronic environment surrounding them. It originates from interaction of quadrupole moment with the gradient of the electrical field in its vicinity. When a low-intensity RF signal of the correct frequency is applied to the explosive, usually in the range 0.5 to 6 MHz, the

energy state of some of the ^{14}N nuclei can be altered. After the RF stimulation is removed, the nuclei can return to their original state, releasing energy and producing a characteristic radio signal (figure 38). The signal can be detected utilizing a special radio receiver and be measured for analysis of the compounds present. Detecting the presence of explosives becomes similar to tuning a radio to a particular station and detecting the signal, and the uniqueness of a molecule's electric field renders NQR technology to be highly compound specific. A study was conducted on the specificity of the NQR technique. The results indicated unique signals were generated that for all the 10000 nitrogen containing compounds. It may be possible to even identify the substances hidden in the baggages. However, the signal to noise ratio (SNR) is low in case of molecules like TNT. This problem is being overcome by employing various methods like double resonance NQR technique, use of superconducting chips for detector and use of wavelet theory for the signal analysis. The explosive hidden in metallic casings were difficult to be detected by NQR technique due to acoustic ringing, however, recent advances in detection technologies have greatly reduced acoustic ringing. It seems that the NQR technique is highly promising technique for detection of explosives.



Schematic representation of the generation of NQR signal

Extensive research on implementation of NQR for landmine detection is on at King's College, London (KCL) under sponsorship of DERA, at DERA itself and at ERA Technology (especially equipment manufacturing). R&D was also carried out in the former Soviet Union, in Kaliningrad, at the time of the Afghanistan War.



*QScan 160
(Small parcels, bags)*



*QScan 500
(Medium package screening system)*

DARPA, the U.S. Marine Corps System Command and the U.S. Army have funded Quantum Magnetics, US for the development of handheld and vehicle mounted NQR systems. The effectiveness of prototype units (figure 39) as a confirmation detector for shallow-buried plastic-cased anti-tank mines containing kilograms of explosive has been demonstrated during tests in both the U.S. and Bosnia. The estimated cost is 5-10 times the price of current metal detectors.



NQR prototype developed in US for detection of landmines.



Addresses of Manufactures

IMS Based Explosive detectors

U S A

| Sr. No | IMS detectors | Sensitivity | Manufacturer |
|--------|--|-------------------|---|
| 1 | Qunatum Sniffer QS-H100 | parts per lion | Implant Sciences Corporation 107, Audubon Road, 5 Wakefield MA Ph.781-246-0700 Fax -781-246-1167 www.implantsciences.com |
| 2 | Itemizer | 30 pg | Mr.Pravin Surana 080-41314600/09845130160 pravin surana @ge.com. Mr.Rajesh Kapoor 011-25776519 GE Ion Track 205 Lowell Street Wilmington] MA 01887 USA Ph. 1800433-5340 Fax : 1866 249-9105 E-mail:gelontracksales@ge.com |
| 3 | ITMS Vapourtraccer | 10-50 pg | GE Ion Track 205 Lowell Street wilmington MA 01887 USA Ph:1800 433-5346 Fax: 1866 249-9105 E-mail:gelontracksales@ge.com |
| 4 | EGIS Defender Desk Top Model | 50-300 pg | Thermo Electron Corporation 220 Mil Road Chelmsford MA 01824-4178 USA 978-251-2024 www.tdxine. com E-mail:sales@tdxine.com |
| 5 | Barringer Ionscan-400 Sabre-4000 | Picogram (pg) | Barringer Instruments Inc. 30 Technology drive warren NJ 07059 USA (908)222-9100 (908)222-1557 FAX web Site : http/www.baringer.com/ E-Mail : INFO@Bii.Baringer.com Mr.Ravindra Kapoor 9871390688 / 011-26693326/3327/3332 |

UK

| | | | |
|---|---------|--------------|--|
| 6 | GVD-6 | 1 part in 10 | Graseby Dynamics Ltd. Park Avenue, Bushey Watford] Herts WD2 2BW, UK Ph: +44-(0)1923-228566 Fax: +44-(0)1923-221361 http://www.gradyn.co.uk/ E-mail-geoff.greenhough@grasebydynamics.com |
| 7 | Plastec | 1 ng | Graseby Dynamics Ltd. Park Avenue Bushey Watford, Herts WD2 2BW, UK, PH:+44-(0)1923-228566 Fax: +44-(0)1923-221361 http://www.gradyn.co.uk/ E-mail: geoff.greenhough@grasebydynamics.com |

Quartz Crysta; Microbalance (QCM) Based Explosive Detectors

Israel

| Sr. No | Explosive detector | Manufacturer | |
|--------|--------------------|--|---|
| 1 | SDTs Mini Noze | SDT-Scent Detecting Technologies Ltd 6 Galgalei Haplada St.P.O.Box 12077Herzliya Israel-46722 Ph: 09-9558000, Fax: 09-9559000 E-mail: info@scent-tech.com www scent-tech.com . | |
| 2 | Detector MO8 | Sibel, Russia | Indian Marketer Precision Operations System Mr.Rumy Tarapore, 022-67994014/25821808 9820065818 |



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- Liquid explosives and emerging threats to civil aviation by Dr. T. V. Narayana (Retd) Ex. Deputy Commissioner DCAS.
- Marketing pamphlet of dangerous liquid detector (DLD) by Precision Operation Systems India Pvt. Ltd.
- Trial directives NSG bomb detection unit Manesar Haryana
- <http://en.wikipedia.org/wiki/micromithane> dated 12/23/2008
- <http://en.wikipedia.org/wiki/egdn> dated 12/23/2008
- <http://en.wikipedia.org/wiki/nitroethane> dated 01/20/2009
- http://en.wikipedia.org/wiki/table_of_explosive_detonation_velocity dated 12/23/2008
- Marketing pamphlet of :
 - Vapor tracer, Itemizer, Street lab, Street lab mobile, walk through portal, Mobile trace by GE Security
 - EBD 2500 Scintrex Trace
 - Fido marketed by SDS Electronics
 - SDT Mini-nose™ 1000 Series
 - GT 200 Detection System marketed by Nickunj Group
 - Sniffex
 - Global engineering systems.
 - GADE 650 by Godrej
 - Alpha 6 by Comstrac
 - DGIS defender , Thermo Electron Corporation Quantum Sniffer, Cargo and Mail , Vehicle drive through from implant sciences
 - Ion scan 400B, HI-Scan 6046SI, HI-Scan 100100V, Ion Scan 500DT, Sabre 4000 from Smith Detections

- Journal of the American Chemical Society (DOI: 10.1021/ja0464903)
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- Emergence of a new terrorist explosive. Tate by Dr. A.C. Rajvanshi
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- IUPAC Compendium of Chemical Terminology 2nd Edition (1997)
- SCANNA Msc Ltd .www.scanna-msc.com
- Liquid Explosives by John von Radowitz, PA Science Correspondent, dated 10th Aug. 2006
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