



Explosive Detection Techniques & Technologies

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Table of Contents

Introduction

Chapter 1 - ADE 651

Chapter 2 - GT200

Chapter 3 - Backscatter X-Ray

Chapter 4 - Detection Dog and Alpha 6

Chapter 5 - Gas Chromatography-Mass Spectrometry

Chapter 6 - Ion Mobility Spectrometry

Chapter 7 - Quadro Tracker

Chapter 8 - Sniffex and CTX (Explosive-Detection Device)

Chapter 9 - Taggant and Target Acquisition Minefield Detection System

Chapter 10 - Explosive Material

Introduction



A U.S. Customs and Border Protection officer with an explosive-detection dog

Explosive detection is a non-destructive inspection process to determine whether a container contains explosive material. Explosive detection is commonly used at airports, ports and for border control.

Detection tools

Dogs

Specially trained dogs can be used to detect explosives using their noses which are very sensitive to scents. While very effective, their usefulness becomes degraded as a dog becomes tired or bored.

These dogs are trained by specially trained handlers to identify the scents of several common explosive materials and notify their handler when they detect one of these scents. The dogs indicate a 'hit' by taking an action they are trained to provide, generally a passive response.

The explosive detection canine was originated at the Metropolitan Police Department in Washington, D.C. in 1970, by then trainer Charles R. Kirchner.

Honey bees

This approach couples trained honey bees with advanced video computer software to monitor the bee for the strategic reaction. Trained bees serve for 2 days, after which they are returned to their hive. This proven system is not yet commercially available. Biotechnology firm Inscentinel claim that bees are more effective than sniffer dogs.

Mechanical scent detection

Several types of machines have been developed to detect trace signatures for various explosive materials. The most common technology for this application, as seen in US airports, is ion mobility spectrometry (IMS). This method is similar to mass spectrometry (MS), where molecules are ionized and then moved in an electric field in a vacuum, except that IMS operates at atmospheric pressure. The time that it takes for an ion, in IMS, to move a specified distance in an electric field is indicative of that ion's size to charge ratio: ions with a larger cross section will collide with more gas at atmospheric pressure and will therefore be slower.

Gas chromatography (GC) is often coupled to the detection methods discussed above in order to separate molecules before detection. This not only improves the performance of the detector, but also adds another dimension of data, as the time it takes for a molecule to pass through the GC may be used as an indicator of its identity. Unfortunately, GC normally requires a bottled gas, which creates a consumable and ease of use issue for the system. GC columns operated in the field are prone to degradation from atmospheric gases and oxidation, as well as bleeding of the stationary phase. Columns must be very

fast, as well, since many of the applications demand that the complete analysis be completed in less than a minute.

Spectrometry

Technologies based on ion mobility spectrometer (IMS) include ion trap mobility spectrometry (ITMS), and differential mobility spectrometry (DMS). Amplifying fluorescent polymers (AFP) use a molecular recognition to "turn off" or quench the fluorescence of a polymer. Chemiluminescence was used frequently in the 1990s, but is less common than the ubiquitous IMS. Several attempts are being made to miniaturize, ruggedize and make MS affordable for field applications; such as an aerosol polymer that fluoresces blue under UV but is colorless when it reacts with nitrogen groups.

One technique compares reflected ultraviolet, infrared and visible light measurements on multiple areas of the suspect material. This has an advantage over olfactory methods in that a sample does not need to be prepared. A patent exists for a portable explosive detector using this method.

X-ray machines

Specially designed X-ray machines can detect explosives by looking at the density of the items being examined. They use Computed axial tomography based systems that are enhanced with dedicated software, containing an explosives threat library and false - color coding, to assist operators with their dedicated threat resolution protocols. X-ray detection is also used to detect related components such as detonators, but this can be foiled if such devices are hidden inside other electronic equipment.

Neutron activation

Specially designed machines bombard the suspect explosives with neutrons, and read the gamma radiation decay signatures to determine the chemical composition of the sample. Explosive materials all have similar ratios of carbon, hydrogen, nitrogen and oxygen, which the machine is able to detect.

Detection aids

A detection taggant can be added when explosives are made to make detection easier. The Montreal Convention 1991 is an international agreement requiring manufacturers of explosives to do this. An example is with Semtex, which now is made with DMDNB added as a detection taggant. DMDNB is a common taggant as dogs are sensitive to it. In the UK the relevant legislation is the Marking of Plastic Explosives for Detection Regulations 1996.

Bogus Devices

The US Department of Justice warned in a National Institute of Justice publication, "Guide for the Selection of Commercial Explosives Detection Systems for Law Enforcement Applications (NIJ Guide 100-99)," about the ongoing trend of "Bogus" explosives detection equipment being sold to unsuspecting consumers. The report mentions by name the Quadro Tracker, an apparent dowsing rod with a freely pivoting radio antenna rod with no functioning internal components.

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

A number of dowsing rod-style detection devices have been widely used in Iraq and Thailand, notably the ADE 651 and GT200, where they have been reported to have failed to detect bombs that have killed hundreds of people and injured thousands more.

Chapter 1

ADE 651





An Iraqi soldier at a checkpoint using an ADE 651 or similar device

The **ADE 651** is a hand-held device produced by ATSC (UK), which claims the device can detect from a distance the presence and location of various types of explosives, drugs, and other substances. The device has been sold to a number of countries in the Middle and Far East, including Iraq, for as much as \$60,000 per unit. The Iraqi government is said to have spent £52m (\$85m) on the devices. Investigations by the BBC and other organisations have reported that the device is little more than a "glorified dowsing rod" with no ability to perform its claimed functions. In January 2010, export of the device to Iraq and Afghanistan was banned by the British Government and the managing director of ATSC was arrested on suspicion of fraud, and in June 2010 several other companies were raided by British police.

The use of the device by Iraqi and Pakistani security forces has become a major international controversy. The virtually identical GT200 and Alpha 6 devices, which are widely used in Thailand, have also come under scrutiny in the wake of the revelations about the ADE 651.

Description and background

The ADE 651 consists of a swivelling antenna mounted via a hinge to a plastic handgrip. It requires no battery or other power source, its manufacturer stating that it is powered solely by the user's static electricity. To use the device, the operator must walk for a few moments to "charge" it before holding it at right angles to the body. After a substance-

specific "programmed substance detection card" is inserted, the device is supposed to swivel in the user's hand to point its antenna in the direction of the target substance. The cards are claimed to be designed to "tune into" the "frequency" of a particular explosive or other substance named on the card. According to Husam Muhammad, an Iraqi police officer and user of the ADE 651, using the device properly is more of an art than a science: "If we are tense, the device doesn't work correctly. I start slow, and relax my body, and I try to clear my mind."

The promotional material issued by ATSC claims that the ADE 651 can detect items including guns, ammunition, drugs, truffles, human bodies, contraband ivory and bank notes at distances of up to 1 kilometre (0.62 mi), underground, through walls, underwater or even from airplanes at an altitude of up to 5 kilometres (3.1 mi). The device is said to work on the principle of "electrostatic magnetic ion attraction". According to the promotional material, "by programming the detection cards to specifically target a particular substance, (through the proprietary process of electro-static matching of the ionic charge and structure of the substance), the ADE651 will "by-pass" all known attempts to conceal the target substance. It has been claimed to penetrate lead, other metals, concrete, and other matter (including hiding in the body) used in attempts to block the attraction." Prosec, a Lebanese reseller of the ADE 651, claims on its website that the device "works on nuclear quadrupole resonance (NQR) or nuclear magnetic resonance (NMR)."

The device is made by ATSC (UK) Ltd, a company based in a former dairy in Sparkford, Somerset. It has been distributed by a number of companies including Cumberland Industries UK, a company based in Kettering, Northamptonshire, and Prosec of Baabda, Lebanon. It was developed by Jim McCormick, the company's managing director, a former Merseyside Police officer whom *The Times* reports has "no scientific or technical background." McCormick told the BBC that "the theory behind dowsing and the theory behind how we actually detect explosives is very similar." According to an associate of ATSC, the devices were manufactured at a cost of £150 (\$250) each by suppliers in Britain and Romania. The associate told *The New York Times*: "Everyone at ATSC knew there was nothing inside the ADE 651."

ATSC (UK) Ltd was established as a private limited company (registered company 03407495) on 23 July 1997 under the name "Broadcasting and Telecommunications Limited"; it changed to its present name on 27 March 2008. Its accounts at Companies House record a turnover of £1.78 million for the year to 31 July 2008, with a gross profit of £1.35 million. Its sole shareholder is its owner, Jim McCormick. A sister company at the same location, ATSC Exports Ltd (registered company 06797101), was established on 21 January 2009, also as a private limited company. It has not filed any accounts as of January 2010.

Users

The ADE 651 is widely used by the Iraqi Police Service and the Iraqi Army. The Iraqi Interior Ministry bought 800 of the devices in 2008 for £20m (\$32m) and a further 700 in

2009 for £32m (\$53m), in no-bid contracts with ATSC. The Iraqi government paid up to £37,000 (\$60,000) for the devices despite the purchase price being put at around £11,500 (\$18,500). The Iraqi Army's Baghdad Operations Command announced in November 2009 that it had purchased another hundred of the devices. Jim McCormick of ATSC has said that the devices were sold for £5,000 (\$8,000) each, with the balance of the cost going on training and middlemen. According to CBS News, the training included instructions to Iraqi users to "shuffle their feet to generate static electricity to make the things work."

The ADE 651 has been used at hundreds of police and military checkpoints across Iraq, often replacing physical inspections of vehicles. It is not used by the US military. Major-General Jihad al-Jabiri of the Interior Ministry's General Directorate for Combating Explosives has defended the device: "Whether it's magic or scientific, what I care about is detecting bombs. I don't care what they say. I know more about bombs than the Americans do. In fact, I know more about bombs than anyone in the world." He told a press conference that the ADE 651 has detected "hundreds of roadside bombs and car bombs" and any deficiencies were due to defective training in the device's use. The Iraqi Interior Minister, Jawad al-Bulani, also defended the device, telling Al Iraqiya television that the ADE 651 had "managed to prevent and detect more than 16,000 bombs that would be a threat to people's life and more than 733 car bombs were defused." He said: "Iraq is considered as a market area for many companies producing such devices ... and there are other rival companies trying to belittle the efficiency of these instruments the government is buying".

In Mexico the Government of Colima bought one of these devices, paying more than \$60,000. Also, as can be seen in the photography accompanying an article about GT200 published in newspaper La-Ch.com, where can be seen a Mexican soldier using an ADE 651. It is possible that the Secretariat of National Defense (SEDENA) also bought some units.

According to a promotional website for the ADE 651, the device is also used by the Lebanese Army, the Chinese Police, the Royal Thai Police and the Interior Ministry of the Kurdistan Regional Government in Iraqi Kurdistan. The website claims that the Jordanian government requires hotels to employ ADE 651 devices to scan vehicles entering underground car parks. ATSC's Jim McCormick says that 20 countries have acquired the device, with purchasers including "the Saudis, Indian police, a Belgian drug squad, a Hong Kong correctional facility and the Chittagong navy." The police in the Belgian municipal region of Geel-Laakdal-Meerhout use the device to detect drugs. Pakistan's Airport Security Force also uses the ADE 651 as a bomb detector at the Jinnah International Airport in Karachi.

Effectiveness

The use of the ADE 651 has prompted strong criticism and eventually led to a ban on the device's export from the UK to Iraq and Afghanistan and a criminal investigation of its manufacturer. The Iraqi security forces' reliance on the device was highlighted by a *New*

York Times investigation in November 2009, which reported that United States military and technical experts believed the device was useless. US Army Major-General Richard Rowe told the newspaper that "there's [no] magic wand that can detect explosives. If there was, we would all be using it. I have no confidence that these work." Sandia National Laboratories had carried out testing of several similar devices but found that "none have ever performed better than random chance." Retired US Air Force Colonel Hal Bidlack, a former national security aide in the Clinton and Bush administrations, condemned the device as "laughable, except someone down the street from you is counting on this to keep bombs off the streets." An Iraqi guard and driver for the *New York Times*, both of whom were licensed to carry firearms, were able to drive two AK-47 rifles and ammunition through nine police checkpoints that were using the device without any of them detecting the weapons.

Iraqi civilians have complained that the device seems to have "an unerring attraction to shampoo and soapsuds". According to Iraqi police officer Jasim Hussein, "The vast majority of the people we stop, it's because of their perfume". A fellow officer, Hasan Ouda, commented that "Most people now understand it's what gets them searched, so they don't use as much." Jim McCormick of ATSC claimed that the apparent responsiveness of the ADE 651 was due to fragrances containing traces of the explosive substance RDX.

The veteran Canadian-American magician and sceptic James Randi has publicly offered one million dollars to anyone who can prove the device's effectiveness as far back as October 2008. Randi issued a statement calling the ADE 651 "a useless quack device which cannot perform any other function than separating naive persons from their money. It's a fake, a scam, a swindle, and a blatant fraud. Prove me wrong and take the million dollars." According to Randi, and as reported by the *New York Times* on November 3, 2009, nobody from ATSC has responded.

The German news magazine *Der Spiegel* reported that the ADE-651 had been tested around 2008 in Israel but was "kicked out of the country". An Israeli explosives expert told the magazine: "The thing has absolutely nothing to do with the detection of explosives." When it was displayed at an arms and security fair in Beirut in April 2009, a visiting explosives expert described it as "one big fraud". Gadi Aviran, the head of the Israeli security firm Terrorgence, said: "If someone comes to an expert, claiming that he had developed a device that can detect the smell of explosives from several meters away, the expert must know that this is physically not possible."

The FBI has repeatedly issued alerts about dowsing rod devices being used as explosive detectors. It described one such device, the Quadro Tracker, as "a fraud" and told all agencies to immediately cease using it. Another alert issued in 1999 told agencies: "Warning. Do not use bogus explosives detection devices." A US Army test of a similar device found that it was unable to detect a truck carrying a tonne of TNT when it drove up behind the operator. In June 2009, the US Army carried out a laboratory test including X-ray analysis on the ADE 651 that found it to be ineffective. According to Major Joe Scrocca, "The examination resulted in a determination that there was no possible means

by which the ADE 651 could detect explosives and therefore was determined to be totally ineffective and fraudulent. As a result of that study, the U.S. military notified all military and civilian personnel in Iraq that the bomb detection device is ineffective and should not be relied upon as a means of insuring the safety of any personnel."

The BBC's Newsnight programme investigated the ADE 651 in a report broadcast in January 2010, asking the University of Cambridge Computer Laboratory to assess one of the "programmed substance detection cards" used in the device to detect TNT. The laboratory found that the card contained only a standard radio frequency security tag of the type used in stores to prevent shoplifting. According to the laboratory's Dr. Markus Kuhn, it was "impossible" for the card to detect anything and it had "absolutely nothing to do with the detection of TNT". The card could not be programmed, had no memory, no microprocessor and no form of information could be stored on it. Despite the high cost of the devices, the cards were worth only about two to three pence (3–5¢) each. Kuhn commented: "These are the cheapest bit of electronics that you can get that look vaguely electronic and are sufficiently flat to fit inside a card." The "card reader" was found to be an empty plastic box. Psychology professor Bruce Hood has noted that the swinging of the antenna is merely due to its loose assembly and unconscious wrist movements by the user. Explosives expert Sidney Alford described the device as "immoral", telling Newsnight that "it could result in people being killed in the dozens, if not hundreds". Newsnight noted that thousands of people had indeed been killed and injured in devastating car bomb attacks in Baghdad such as the 25 October and 8 December 2009 Baghdad bombings, without the bombers being detected by the ADE 651 devices.

Jim McCormick refused to be interviewed for the Newsnight investigation, but told *The New York Times* that ATSC would remain in business: "Our company is still fully operational." He told *The Times* that ATSC had been dealing with doubters for ten years and that the device was merely being criticised because of its "primitive" appearance. He said: "We are working on a new model that has flashing lights."

Investigations and export ban

United Kingdom

In January 2010, ATSC's Jim McCormick was arrested on suspicion of fraud. The investigation was personally ordered by Colin Port, the Chief Constable of the Avon and Somerset Constabulary. In a statement given to *The Times*, the force stated:

We are conducting a criminal investigation, and as part of that, a 53-year-old man has been arrested on suspicion of fraud by misrepresentation. That man has been released on bail pending further inquiries. The force became aware of the existence of a piece of equipment around which there were many concerns, and in the interests of public safety, launched its investigation. It was reported to the Chief Constable Colin Port, through his role as the Association of Chief Police Officers lead on international development. He is chair of the International Police Assistance Board. Given the obvious sensitivities around

this matter, the fact that an arrest has been made, and in order to preserve the integrity of the investigation, we cannot discuss it any further at this time.

Following the BBC Newsnight exposé of the device, the UK Government's Department for Business, Innovation and Skills announced that its tests had shown that "the technology used in the ADE651 and similar devices is not suitable for bomb detection" and they "could cause harm to UK and other friendly forces in Iraq and Afghanistan". It had therefore decided to ban the export of the ADE 651 and similar devices to those two countries under the Export Control Act 2002, with effect from 27 January 2010. The device had not previously been subject to export restrictions as it was non-military equipment. The department offered "cooperation with any investigation [the Iraqi authorities] may wish to make into the how the device came to be bought for their military as bomb detection equipment." The banning order prohibited the export to Iraq and Afghanistan of "'electro-statically powered' equipment for detecting 'explosives'".

Iraq

The failure of the ADE 651 to prevent a series of bombings in Baghdad and the circumstances of its procurement raised concerns in Iraq even before it became the subject of media exposés. The *New York Times* reported in November 2009 that Aqeel al-Turaihi, the Iraqi Interior Ministry's inspector-general, had begun an investigation into the contracts that the ministry had signed with ATSC. The Prime Minister of Iraq, Nouri al-Maliki, also ordered an investigation into the effectiveness of the devices following a number of bomb attacks. The Iraqi parliament did not order an official investigation but Iraqi MP Nadeem al-Jabiri said: "the security and defence committee in the parliament, headed by Hadi al-Amiri, is following up this matter as part of the parliament's duty as a monitoring entity."

The BBC's revelations in January 2010 caused outrage in Iraq. A police officer told *The New York Times*: "Our government is to be blamed for all the thousands of innocent spirits who were lost since these devices have been used in Iraq." MP Ammar Tuma of the Iraqi Parliament's Security and Defense Committee said: "This company not only caused grave and massive losses of funds, but it has caused grave and massive losses of the lives of innocent Iraqi civilians, by the hundreds and thousands, from attacks that we thought we were immune to because we have this device." He told the *Asharq Al-Awsat* newspaper: "The tasks of the committee are limited to two tracks, [and that is] reaching the truth over what happened with regards to the signing of the contracts for these bomb detection devices; firstly by following up on the details of the contract and looking at the background of this, as well as the possibility of collusion by those who signed this contract, or whether this [ineffectiveness] is the result of technical weaknesses in these devices. Either of these [options] deserves accountability." He said that Defence Minister Abd al-Qadr Muhammed Jassim al-Obaidi had informed the Iraqi Parliament during emergency parliamentary hearings in 2009 that "the detection of car bombs and explosive material using these devices is very limited, and this increases the likelihood that these devices have low efficiency."

Another MP, Hussain al-Falluji, demanded that Iraqi security forces should immediately cease using the ADE 651. His proposal to establish an investigative committee and seek to recover the money spent on the devices was supported by other parliamentarians. Hadi Al-Ameri, the head of the Parliament's Security and Defense Committee, said that he would push for an official investigation to "find out how this piece of equipment was sold to Iraq." If it was determined that ATSC was responsible he planned to "seek compensation via the ministry of foreign affairs." MP Haneen Kado said: "If we rely on these devices there is no point in having checkpoints. It makes the whole of Baghdad open to terrorist attacks. We are in a dangerous situation and there could be new bombings at any time. We must investigate exactly who bought and sold these detectors and see that they answer in court."

The Supreme Board of Audit in Iraq announced an investigation into the procurement of the ADE 651, focusing on the officials who had previously given assurances of the device's technical soundness. The Iraqi Army's Baghdad Operations Command, which had previously procured 100 of the devices, distanced itself from their use. Major General Qassim al-Moussawi said: "The devices have helped us in parts of our work but in some aspects they are not useful. Their performance does not match our aspirations. There is some percent of error in their performance and these devices must be updated." Iraqi Prime Minister Nouri al-Maliki was reported to have ordered a new investigation of how the devices had been procured, looking into whether there was any corruption involved.

According to the Iraqi Interior Ministry's inspector-general Aqeel al-Turaihi, he had investigated the device in 2008 but found it "inoperative" and costly and recommended that Iraq should not buy it. He told Reuters: "There was corruption associated with this contract and we referred to this and submitted our report to the Minister of the Interior. We said that the company which you made a contract with is not well-regarded internationally in the field of explosives detectors, and the price is very high and not commensurate with the abilities of this device." Al-Turaihi said that the buying process had been "marred by suspicions over the equipment and the efficiency and value of the contracts. There were senior officials involved in these transactions." The initial investigation did, however, find it could detect some bombs and the ministry went ahead with the contract despite al-Turaihi's concerns.

Despite the controversy, the device is still being used at checkpoints across Iraq. The Iraqi Interior Ministry has defended the continued use of the ADE-651. The head of the ministry's counter-explosives unit, General Jihad al-Jabiri, told the BBC that his organisation had "conducted several tests on them, and found them successful. In addition, we have a series of achievements officially documented by the Baghdad operations centre, from all the provinces, which establish that these devices detected thousands of bombs, booby-trapped houses and car bombs, and we've noticed a reduction of bombing activities to less than 10 per cent of what it was." A senior ministry official, Assistant Deputy Minister General Tareq al-Asl, told *Asharq Al-Awsat*: "The reason the director of the company was arrested was not because the device doesn't work, but because he refused to divulge the secret of how it works to the British authorities, and the

Americans before them. I have tested it in practice and it works effectively and 100% reliably."

In February 2011, General Jihad al-Jabiri was arrested on corruption charges, centering on the ADE 651 device purchase.

Pakistan

After the ADE 651 became the focus of controversy for its role in Iraq, concerns were raised in Pakistan about its employment as a bomb detector by the Pakistani security forces. A senior official at Jinnah International Airport denied that it was using the ADE 651, claiming that the Airport Security Force had designed the device in use there, but other ASF officials acknowledged that their device "operated on the same principle as ADE-651." Pakistani scientists rejected the scientific basis on which the device was claimed to work; Professor Shahid Zaidi of Karachi University told the Pakistani newspaper *Dawn* that "there has to be an electric, magnetic or electromagnetic field for a device to work in such a manner. Furthermore static fields don't move around the way it is being claimed by some. Also don't forget that there are so many radio waves of different frequencies all around us. I just don't see how this device would work." *Dawn* challenged the ASF to test the device to confirm its effectiveness but the ASF refused, insisting that the device works.

Other similar devices

Another "remote substance detector" device, the Global Technical GT200, has come under scrutiny in Thailand in the wake of the controversy over the ADE 651. The *Bangkok Post* reports that the GT200 is virtually identical to the ADE 651 and has been described by critics as a "divining rod" which uses "controller cards", like the ADE 651, to find explosives. The *Post* attributes the death of several Royal Thai Police officers to its repeated failures to detect explosives.

The Quadro Tracker, also known as the Positive Molecular Locator, was a similar device sold by Quadro Corp. of Harleyville, South Carolina between 1993 and 1996.

Several other similar long range locator devices are being marketed in various countries, including the HEDD1 (formerly known as Sniffex Plus), marketed by Unival in Germany; Alpha 6, marketed by ComsTrac in the UK; PSD-22; and H3Tec.

An apparent recycling of the Quadro Tracker turned up as the DKLabs Lifeguard, which had a similar appearance and made ambitious claims about being able to locate survivors missing under rubble or hiding in shipping containers. It has been proven to be useless in tests by Sandia National Labs.

Chapter 2

GT200

The **GT200** is a fraudulent "remote substance detector" that is claimed by its manufacturer, UK-based Global Technical Ltd, to be able to detect from a distance various substances including explosives and drugs. The GT200 and its many iterations (Sniffex, ADE651, HEDD1) have been sold to a number of countries for a cost of up to £22,000 (\$36,000) per unit, but the devices have been criticised as little more than a "divining rod" which lack any scientific explanation for why it should work.

The device has come under scrutiny following revelations about the virtually identical ADE 651, another "substance detector" that has become the focus of a fraud investigation in the United Kingdom. The UK Government has banned the export of such devices to Iraq and Afghanistan in an order brought into force in January 2010 under the Export Control Act 2002 and has warned foreign governments that the GT200 and ADE 651 are "wholly ineffective" at detecting bombs and explosives.

The Thai press has condemned the GT200 for having "given wrong readings on several occasions and even failed to detect explosive materials, resulting in the loss of life." Although Thai Prime Minister Abhisit Vejjajiva originally defended the devices, he later recanted when tests showed that they were completely ineffective at detecting explosives. However, they would still be used in the field at the discretion of the Army, which procured the devices and continue to use them.

Description and background

The GT200 consists of three main components—a swivelling antenna mounted via a hinge to a plastic handgrip, into which sensor cards can be inserted. It requires no battery or other power source and is said to be powered solely by the user's static electricity. The device becomes active when the operator starts moving and detects various substances via "DIA/PARA magnetism". It is made by Global Technical Ltd of Ashford, Kent. The company (registered number 03300333) was established as a private limited company on

9 January 1997 with Gary Bolton as director. A number of overseas partners including Segtec, Napco, Nikunj Eximp Enterprises, Electronic K9 Singapore, Aviasatcom and Concord Consulting have distributed its products in Central America, the Middle East, India, Southeast Asia and Thailand respectively. Global Technical also had a sister company, Global Technical Training Services Ltd (registered company 03793910), which was established on 23 June 1999 but is now dissolved.

Promotional material issued about the GT200 claims that it can detect a wide variety of items including ammunition, explosives, drugs, gold, ivory, currency, tobacco and "human bodies" at ranges of up to 700 metres (2,300 ft) on the surface, depths of up to 60 metres (200 ft) underground or under 800 metres (2,600 ft) of water, or even from aircraft at an altitude of up to 4 kilometres (2.5 mi). A "Substance Sensor Card" inserted into the device is said to create an "attracting field" utilising "dia/para magnetism" between the device and the substance that is to be detected. The field is claimed to make the antenna of the GT200 lock onto a signal, indicating the direction in which the substance can be located. According to the promotional material, if the device is used correctly, it "can detect substance(s) through walls, (even lead-lined and metal ones), water, (fresh and salted), fresh and frozen food, (fish, fruit, tea, coffee, ice), vacuum flask, containers, petrol and diesel fuel and even buried in the earth" and can detect narcotics for up to two weeks after they have been ingested by a target individual.

According to the Thai newspaper *The Nation*, the GT200 is "just a new name" for a previous Global Technical product, the MOLE programmable substance detection system. It operated in the same way as the GT200, using a swinging antenna to point to a target material indicated via "programmable cards" inserted into a reader. The MOLE was tested in the United States in 2002 by Sandia National Laboratories but was found to perform no better than random chance. According to the Sandia report, the MOLE appears "physically nearly identical" to a product Sandia examined in October 1995 called the Quadro Tracker, which was marketed by a South Carolina company but which was banned in 1996 and the makers prosecuted for fraud.

A BBC Newsnight investigation of the GT200 in January 2010 found that the "sensor card" contained merely two sheets of card between which was sandwiched a sheet of paper, white on one side and black on the other, that had been cut off from a larger sheet with a knife or scissors. It contained no electronic components whatsoever. When the device's case was dismantled, it too was found to contain no electronic components. Explosives expert Sidney Alford told Newsnight: "Speaking as a professional, I would say that is an empty plastic case." Gary Bolton of Global Technical said that the lack of any electronic parts "does not mean it does not operate to the specification."

A GT200 unit was examined on Thailand's Nation Channel in an interview with Lt Col Somchai Chalermksuksan of the Thai Central Institute of Forensic Science. The host commented that "there is no battery here or way of powering it" and that the bottom half of the device was completely empty. Asked if there was anything in the sealed top half of the device, Lt Col Somchai said: "There is nothing. Once there was an accident and the

device came apart. There was nothing inside." The host concluded: "So it is just two pieces of plastic put together."

Export ban and police investigation

Following controversy over a similar device, the ADE 651, the UK Government issued an order under the Export Control Act 2002 that came into force on 27 January 2010, banning the export to Iraq and Afghanistan of "'electro-statically powered' equipment for detecting 'explosives'", on the grounds that such equipment "could cause harm to UK and other friendly forces". The export ban covers all such devices, including the GT200.

Officers from the City of London Police Overseas Anti-Corruption Unit subsequently raided the offices of Global Technical and two other makers of similar "bomb detectors". A large amount of cash and several hundred of the devices and their component parts were seized. The police said that they were investigating on suspicion of fraud by false representation and were also investigating whether bribes had been paid to secure contracts to supply the devices.

On February 27th 2011 the British government told BBC Newsnight that it had helped Global Technical sell the GT200 around the world between 2001 and 2004. Royal Engineers sales teams demonstrated the devices at arms fairs and the UK Department of Trade and Industry helped two companies sell the GT200 and similar products in Mexico and the Philippines .

Users

The GT200 is used extensively in Thailand. Reportedly, some 818 GT200 units were procured by Thai public bodies since 2004. These include 535 bought by the Royal Thai Army for use combating the South Thailand insurgency and another 222 for use in other areas, 50 purchased by the Royal Thai Police for use in Police Region 4 (Khon Kaen), 6 bought by the Central Institute of Forensic Science, 6 by the Customs Department, 4 by the Royal Thai Air Force and 1 by Chai Nat police. Other agencies such as the Border Patrol Police Bureau and the Office of the Narcotics Control Board use a similar device, the Alpha 6, procured from another company. According to the *Bangkok Post*, the Royal Thai Air Force first procured the GT200 to detect explosives and drugs at airports, followed by the army in 2006. According to Lt Gen Daopong Rattansuwan, the Deputy Chief of Staff of the Royal Thai Army, each GT200 bought by the army cost 900,000 baht (£17,000/\$27,000), rising to 1.2 million baht (£22,000/\$36,000) if 21 "sensor cards" were included with it. In total, Thailand's government and security forces have spent between 800-900 million baht (\$21 million) on the devices.

The device is also widely used in Mexico, where security forces have used it to combat drug traffickers and to search for explosives. The Mexican government has spent over 17 million pesos (\$1.3 million) buying GT200s at a cost of 286,000 pesos (\$22,000) each. According to the government of Guanajuato state, the federal government has bought more than 700 GT200s. State governments have also bought their own GT200s; the

device is reported to be in use by police in the Mexican states of Tabasco, Sonora, Sinaloa, Durango, Michoacán and Baja California. The Mexican military also utilises the GT200. In 2008 the Secretariat of National Defense had purchased 300 GT200s for use throughout the country, including at 133 strategic locations. By late 2009 the figure had increased to 521 GT200s, which had been deployed to 11 strategic checkpoints and 284 regional control stations around the country. In the violence-wracked city of Ciudad Juárez, the newspaper *Excélsior* reported that "military squads roam the streets and go from house to house, using a molecular detector known as GT200" to find weapons, drugs and money. Prison personnel in Juárez and its parent state, Chihuahua, have been provided with GT200s to detect escape tunnels being dug by prisoners.

The GT200 has been demonstrated in India for organisations including the Central Reserve Police Force, Indo-Tibetan Border Police, National Security Guards, Narcotics Control Bureau and the Bureau of Civil Aviation Security and was procured by the Dubai Customs in 2009. Hotels in Manila in the Philippines use it to detect bombs. It is also in use in Lebanon, Jordan and China.

The device is used to detect smuggled ivory in the central African states of Zambia, Uganda, Kenya, Tanzania and the Republic of the Congo. The Lusaka Agreement Task Force (LATF) and the United Nations Environment Programme bought 15 GT200s in 2005 at a cost of \$5,000 each and distributed them to the five LATF member states. In Uganda, the GT200s were installed at Entebbe International Airport, border crossings and internal checkpoints. A report submitted by Kenya to the CITES Standing Committee in 2006 stated that "three staffs from Tanzania were trained on the use of GT 200 Ivory Detector for the purposes of law enforcement against illegal dealing in ivory products, in the country. Four (4) Ivory Detectors are currently in place and are used for law enforcement activities especially at entry and exit points."

Controversy over use

Thailand

The effectiveness of the GT200 has been the subject of controversy in Thailand, where the device has been reported to have been implicated in several deaths when it failed to detect improvised explosive devices which detonated, killing civilians and personnel from the security forces.

Three members of a border patrol police unit were killed on 7 November 2008 in Panare district when the GT200 they were using failed to detect a bomb planted on a road. In Muang district of Yala Province, security forces used a GT200 to investigate the scene of the murder of two officials but were unable to detect a followup boobytrap bomb, which exploded just after they had declared the area to be clear of bombs.

Numerous people were killed and injured in two bomb attacks in October 2009 in which the GT200 was used by security forces. On 6 October 2009, a car bomb exploded opposite the Merlin Hotel in Sungai Kolok, killing one person and injuring 20, after it

had been "scanned" using a GT200 and declared to be free of explosives. A motorcycle bomb exploded on 19 October in Yala, injuring another 26 people, again after a scan with a GT200 had returned negative results for explosives.

False positives have also been reported, with civilians being arrested after a GT200 "detected" traces of explosives on them. Similar erroneous readings were reported to have caused "pandemonium" at Pattani Hospital. On one occasion the device was reported to have "incriminated the top of a coconut tree", though the alert turned out to have been triggered by a plastic bag with vegetable oil inside. Thai journalist Charoon Thongnual reported personally experiencing the GT200 showing false positives:

A device used by a defence volunteer pointed repeatedly to a motorcycle parked in front of the Pattani Provincial Court. However, a search of the motorbike discovered nothing illegal. In another incident, a device pointed at a handbag carried by a female college student in Pattani who was strolling with friends near the CS Hotel. A search of her bag found cosmetics and other items that were completely lawful.

The Bangkok Post reported on a Thai army field training session using the GT200 near Yala city in November 2009, in which a bomb squad using GT200 devices repeatedly failed to detect explosives:

Various types of explosives had been placed at different spots, unknown to the personnel using altogether four GT200 devices. After more than 30 minutes, all four devices failed to locate the explosives. Eventually, the head of the bomb disposal squad showed them where the bombs were hidden, much to the embarrassment of all concerned.

One of the writers of this story, Mr Surapan, did his own detective work as well. While the bomb squad was busy scouring the roadside bushes, he drove into town and borrowed a few sticks of dynamite from a security officer, who is a longtime friend. He wrapped the dynamite with tin foil and black carbon paper and drove back to the same location.

Mr Surapan parked his car on the roadside about a metre behind a car belonging to one of the officers. Then he placed the wrapped dynamite sticks under the bonnet of his car. All 4 GT200 devices indicated nothing unusual as the handlers walked past his car. But they led the officers to the car in front, where several automatic rifles were kept.

Hundreds are said to have been detained by Thai security forces on the basis of GT200 readings. According to Human Rights Watch, about 10% of those detained on suspicion of involvement in the insurgency have been arrested on this basis. In one village in Narathiwat province, 32 people were arrested after GT200s were used to "detect" traces of explosive substances on their bodies. Most of them were detained without charge for an extended period. Brad Adams of Human Rights Watch commented: "It is common during security sweeps in the south to see Muslim men lined up on the roadside with their shirts off while being screened by a GT200. Many of those implicated by the GT200 have been arrested and then tortured."

The Working Group on Justice for Peace, a Thai non-governmental human rights organisation, published an article in November 2009 that was strongly critical of the GT200: "The operation of the device is causing a lot of suspicion among scientists in Thailand for several reasons. According to them, the procedure of finding suspicious objects is not based on a reliable scientific method. Besides, GT200 is not being used by credible international organisations."

Government response

Concerns were raised by some within the Thai establishment. General Pathompong Kasornasuk, the former chief advisor of the Supreme Command, urged Prime Minister Abhisit Vejjajiva to investigate the procurement scheme for the GT200 devices and other elements of the counter-insurgency campaign in southern Thailand. Jetsada Denduangboripan, a scientist at Chulalongkorn University, told a committee of the House of Representatives of Thailand in January 2010 that "The GT200 cannot detect explosives. It is not scientific equipment. It works on the users' hunch. It is similar to a wood stick that people used to detect dead bodies buried in a cemetery." He used a set of pliers, a radio antenna and a piece of paper to produce a "bomb detector" that he said worked just as effectively as the GT200. The House committee on national security said that it would investigate the GT200 further and set up an inquiry into its effectiveness that would involve the military and scientists.

Deputy Interior Minister Thaworn Senneam told journalists after a fatal bomb attack in Southern Thailand on 6 October 2009 that the police had failed to detect the bomb "because the officer handling the GT200 detector was too nervous... His nervousness caused his temperature to rise which, in turn, caused the bomb detector to malfunction." He announced that in future two officers would be assigned to use the device, with the second ready to take over from the first if he was "not ready to use it."

Following media criticism, Army chief General Anupong Paochinda accused the press of working for Asia Satcom's competitors. He organized a demonstration to "prove" to the media that the devices worked. 4th Army chief Lt. General Pichet Wisaijorn told the press, "It is not Gen Anupong saying the device is effective. Officers in the South and the North and the current and former 4th Army commanders also say the same thing. We have bought them and if the users insist they are good, that's end of the discussion." Joint Military Police Civilian Taskforce commander Lt-General Kasikorn Kirisri said any issues with the GT200 scanner were due to human error. According to Col Banpot Poonpian of the Thai army's Internal Security Operations Command, the GT200 has "proved effective although it may not work perfectly". It was used only as an auxiliary tool to detect something suspicious, with two other devices being used to identify the suspicious object. A recent investigation had found that failures were the result of users relying solely on the GT200 and not using the other two devices, following which bomb disposal personnel had undergone additional training.

According to an Army commander, which makes extensive use of the device, how well it works "depends on the static electricity stored in the body of its user. If the person using

the detector is feeling weak physically, his static electricity will be down and weaken the effectiveness of the device."

After the BBC reported that the British government was to warn foreign governments that the GT200 and other similar devices were "wholly ineffective" at detecting bombs and explosives, General Anupong said that the procurement of more GT200s would be halted if the device was proven to be ineffective, although existing GT200s would continue to be used for bomb detection purposes. Other senior military figures continued to insist that the device worked as advertised, saying that it had detected explosives, weapons and narcotics in 173 out of 236 incidences, with a success rate higher than 80 per cent. Army Spokesperson Sansern Kaewkamnerd insisted that the GT200 units worked with 100% confidence and that the Army was ready to prove the units' effectiveness any time, any where. Pornthip Rojanasunand, Director of the Central Institute of Forensic Science, also defended the use of the GT200 devices, claiming that they were effective when searching for bombs and even nails under water. She said: "I do not feel embarrassed if the bomb detector is proven ineffective. Personally, I have never handled the device myself. But my people have used it and it is accurate every time. Long long time ago, people believed that the Earth is flat and anyone who said otherwise faced execution. Things which are not visible does not necessarily mean they do not exist. The devices are there and no one has the right to ban their use. I will continue to use it."

Review

At the start of February 2010, Prime Minister Abhisit Vejjajiva said that he agreed that the device should be tested to determine whether it was effective. He told the media: "It's dangerous if you think something unworkable is working. So we must test to see whether the device works. We should also discuss what we should do." If the devices were found to be ineffective, an investigation would be ordered to determine why they had been bought.

Following Abhisit's intervention, the Thai Cabinet ordered the Ministry of Science and Technology to carry out tests on the GT200. The Interior and Justice Ministries also commissioned the ministry to test the similar Alpha 6 device, which they used to search for drugs. The evaluation team included engineers, scientists, military, police and representatives from the Office of the Narcotics Control Board and the National Statistics Office. The tests were carried out by the National Electronics and Computer Technology Center at the Thailand Science Park's Sirindhorn Science Home in Pathum Thani, in a process involving 30 GT200 operators, 30 members of the investigating committee and 10 independent observers. Ten GT200 units were used in double blind tests to detect 20 grams of C4 explosive concealed in one of four identical plastic boxes. However, the testers were not allowed to examine the interior of the GT200 because of confidentiality agreements prohibiting the disclosure of "any information regarding the device."

The test results were announced by Prime Minister Abhisit on 16 February, who disclosed that the investigators found that the GT200 had correctly detected explosives only four times in 20 tests. He said: "The result has no statistical significance. The

performance is equivalent to random chance." Following the test results, he ordered security forces to stop buying the devices and review the use of those already in service. He said that the government would consider suing the GT200's manufacturer, Global Technical, and its Thai distributor Avia Satcom Co. An Army spokesman said that units on the ground would have discretion to continue using the GT200 unless they could find a substitute, though the Army would be sending proven alternatives such as sniffer dogs to assist the troops. Pornthip Rojanasunand of the Central Institute of Forensic Science said that although she knew it was "not scientific equipment", she believed that forensic scientists could still use it effectively: "We won't buy more, but we won't stop using them either."

Global Technical rejected the tests' conclusions. The company issued a statement saying that it was "surprised and disappointed" by the outcome of the tests. It claimed that the results were "completely at odds with other tests carried out by independent bodies" and with "the experience of the large number of users of this product all over the world."

Despite the outcome of the tests, Thai Army chief General Anupong Paojinda said that he would not order his soldiers to stop using the GT200. He insisted that "the device operators on the ground can use them effectively. This may not be explained scientifically, but I'm telling the truth." While not rejecting the result of the tests, he stood by the device's effectiveness and argued that "as the men on the ground are impressed with it and demanded the equipment, it is the duty of the commander to procure them." He rejected the use of sniffer dogs on the grounds that they could not detect explosives at a distance and were disliked by Muslims for religious reasons. The former army chief General Sonthi Boonyaratglin also argued that the purchase of the GT200 had been justified as there was demand from operational units, despite the high price of the device: "Price is not an issue if the device is able to save people's lives." Prime Minister Abhisit ordered the scientists who had conducted the tests to explain their findings to the military and ask them to stop using the device, but said that he did not want to confront the army. Some soldiers, however, were reported to have abandoned the GT200 and turned instead to using chopsticks and their own hands to detect bombs hidden on motorcycles.

Alpha 6 controversy

In the wake of the GT200 controversy, the procurement by the Interior and Justice Ministries of the Alpha 6 "molecular detector" device has come under scrutiny. The Thailand Science and Technology Ministry announced that it would broaden its tests to verify the claimed effectiveness of the Alpha 6.

Kenya

The use of the GT200 as a means of tracking smuggled ivory in Kenya has also been questioned. Stephen Fry, who saw the GT200 being used by Kenyan rangers in an attempt to catch poachers, described the use of the devices as "cynical, cruel and monstrous." He told the BBC's Newsnight programme: "I was horrified. They had spent a

vast sum of money on a modern equivalent of a hazel twig divining rod. There was no possibility that such a thing could work."

Mexico

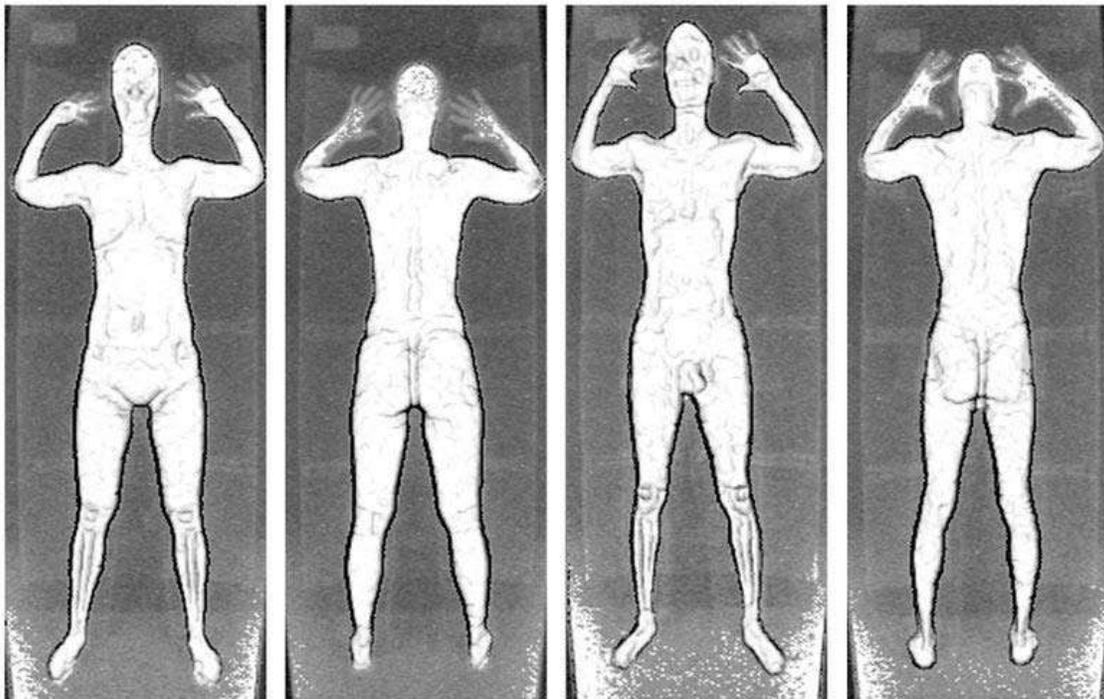
Most of the Mexican media coverage on GT200 lacked of a critical point of view, but science popularizer Martin Bonfil Olivera wrote on February 17, 2010, the first article warning about this scam. However, the impact of this article (and the next on March 10, 2010,) on the rest of the press was almost imperceptible, with only Fausto Ovalle from La-Ch.com writing about it. Only after Marc Lacey from The New York Times wrote on March 15, 2010 about the British government warning on the GT200, the scam was exposed in some Mexican newspapers. Later, Juan José Morales from Por Esto! wrote a couple of columns and Bonfil Olivera was interviewed by Ana Paula Ordorica and Enrique Acevedo for La Otra Agenda TV show.

All of this has been not enough to create public awareness on this subject. Main press and TV continues not just ignoring the subject but even justifying it. Mexican military continues doing searches and explosives are ruled out based on GT200 results.

According to data available in Federal Institute of Access to Public Information (IFAI) and press notes, the GT200 has been bought among others by the SEDENA, SEMAR, some PEMEX filials and some state police agencies. As of 2009, more than US\$16,258,534 was spent.

Chapter 3

Backscatter X-Ray



Backscatter technology produces an image that resembles a chalk etching.



Backscatter Unit

Backscatter X-ray is an advanced X-ray imaging technology. Traditional X-ray machines detect hard and soft materials by the variation in transmission through the target. In contrast, backscatter X-ray detects the radiation that reflects from the target. It has potential applications where less-destructive examination is required, and can be used if only one side of the target is available for examination.

The technology is one of two types of whole body imaging technologies being used to perform full-body scans of airline passengers to detect hidden weapons, tools, liquids, narcotics, currency, and other contraband. A competing technology is millimeter wave scanner. These airport security machines are also referred to as "body scanner", "whole body imager (WBI)", and "security scanner".

Technology

Backscatter technology is based on the X-ray Compton scattering effect of X-rays, a form of ionizing radiation. Unlike a traditional X-ray machine which relies on the transmission of X-rays through the object, backscatter X-ray detects the radiation that reflects from the object and forms an image. The backscatter pattern is dependent on the material property, and is good for imaging organic material.

In contrast to millimeter wave scanners which create a 3D image, backscatter X-ray scanners will typically only create a 2D image. For airport screening, images are taken from both sides of the human body.

Backscatter X-ray was first applied in a commercial low dose personnel scanning system by Dr. Steven W. Smith. Dr. Smith developed the Secure 1000 whole body scanner in 1992 and then sold the device and associated patents to Rapiscan Systems who now manufactures and distributes the device.

The following companies manufacture commercial backscatter X-ray devices that are used in security scanning applications:

1. American Science and Engineering (device name: Smartcheck)
2. Rapiscan Systems (a subsidiary of OSI Systems Inc.) (device name: Secure 1000)
3. Tek84 (formerly Spectrum San Diego Inc.) (device name: AIT84 Body Scanner & Castscope)

Some backscatter X-ray scanners are also used to search containers and trucks more quickly than a physical search, and potentially allow a larger percentage of shipping to be checked for smuggled items or weapons.

The "Z Backscatter Van" from AS&E is a mobile backscatter X-ray machine in a van which "from the outside looks like an ordinary delivery van, allowing it to blend in to urban and other landscapes". It is being promoted as a means of examining the contents of vehicles, containers, and dumpsters.

Concerns

Privacy



An image of Susan Hallowell, Director of the Transportation Security Administration's research lab taken with backscatter x-ray system

Backscatter x-ray technology has been proposed as an alternative to personal searches at airport and other security checkpoints easily penetrating clothing to reveal concealed weapons. It raises privacy concerns about what is seen by the person viewing the scan. Some worry that viewing the image violates confidential medical information, such as the fact a passenger uses a colostomy bag, has a missing limb or wears a prosthesis, or is transsexual, despite the fact that the person viewing the image can't see the person they are screening.

The ACLU and the Electronic Privacy Information Center are opposed to this use of the technology, currently in use in the U.S. at 78 airports, four court houses, and two correctional facilities, with another 12 airports scheduled to receive them soon. The ACLU refers to backscatter x-rays as a "virtual strip search". In one Transportation Security Administration (TSA) trial, 79 percent of the public opted to try backscatter over the traditional pat-down in secondary screening.

It is "possible for backscatter X-raying to produce photo-quality images of what's going on beneath our clothes", thus, many software implementations of the scan have been designed to distort private areas. According to the TSA, further distortion is used in the Phoenix airport's trial system where photo-quality images are replaced by chalk outlines. The TSA has also commented that screening procedures such as having the screener viewing the image located far away from the person being screened could be a possibility.

In light of this, some journalists have expressed concern that this blurring may allow people to carry weapons or certain explosives aboard by attaching the object or substance to their genitals.

The British newspaper *The Guardian* has revealed concern among British officials that the use of such scanners to scan children may be illegal under the Protection of Children Act 1978, which prohibits the creation and distribution of indecent images of children. This concern may delay the introduction of routine backscatter scanning in UK airports, which had been planned in response to the attempted Christmas Day 2009 attack on Northwest Airlines Flight 253.

The Fiqh Council of North America have also issued the following fatwa:

It is a violation of clear Islamic teachings that men or women be seen naked by other men and women. Islam highly emphasizes haya (modesty) and considers it part of faith. The Quran has commanded the believers, both men and women, to cover their private parts.

In August 2010, it was reported that U.S. Marshals (part of the Department of Justice), saved thousands of images from a low resolution MM wave scanner: This machine does not show details of human anatomy, and is a different kind of machine than the one used in airports. TSA, part of the Department of Homeland Security, reiterated that its scanners do not save images and that the scanners do not have the capability to save images when they are installed in airports. In contrast, it is claimed that TSA officials admitted that the scanners are required to be capable of saving images for the purpose of evaluation, training and testing.

TSA states that independent polling indicates that the U.S. public generally supports the deployment and use of body scanners at airports.

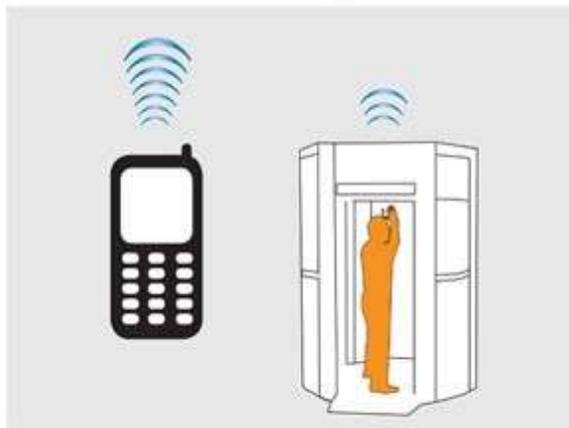
Equal Treatment of Minorities

Current Backscatter scanners installed by the TSA are unable to screen adequately for security threats inside turbans, hijab, burqas, casts, prosthetics and loose clothing. This technology limitation of current scanners often requires these persons to undergo additional screening by hand or other methods and can cause additional delay or feelings of harassment.

The next generation of backscatter scanners are able to screen these types of clothing. The next generation of scanners can equalize the screening process for all persons so that religious majorities can travel through the AIT process as easily as other passengers.

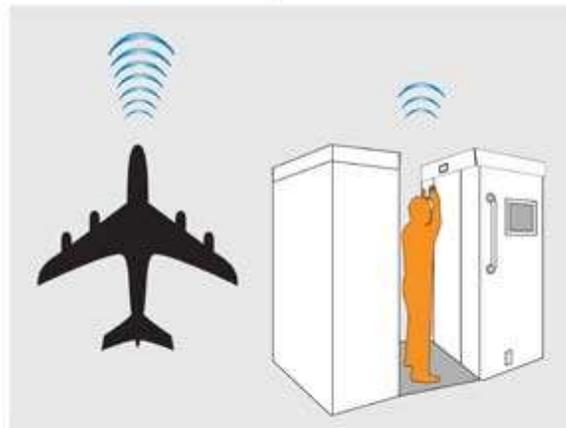
Health effects

Millimeter Wave Safety



Millimeter wave technology emits thousands of times less energy than a cell phone transmission.

Backscatter Safety



One backscatter technology scan produces the same exposure as two minutes of flying on an airplane.

The energy projected by millimeter wave technology is thousands of times less than a cell phone transmission. A single scan using backscatter technology produces exposure equivalent to two minutes of flying on an airplane.

The energy being emitted by a backscatter X-ray is a type of ionizing radiation that damages chemical bonds. Ionizing radiation is considered carcinogenic even in very small doses by some groups such as the USNRC, but considered negligible at such doses by others such as the ANS.

The United States Food and Drug Administration has created a comprehensive web page providing safety information about backscatter X-ray body scanners. The web site states that:

Since general-use x-ray systems emit ionizing radiation, the societal benefit of reliably detecting threats must be sufficient to outweigh the potential radiation risk, if any, to the individual screened. The dose from one screening with a general-use x-ray security

screening system is so low that it presents an extremely small risk to any individual. To put the radiation dose received into perspective:

1. Naturally occurring ionizing radiation is all around us. We are continuously exposed to this background radiation during ordinary living. In 42 minutes of ordinary living, a person receives more radiation from naturally occurring sources than from screening with any general-use x-ray security system.
2. The national radiation safety standard (see below) sets a dose per screening limit for the general-use category. To meet the requirements of the general-use category a full-body x-ray security system must deliver less than the dose a person receives during four minutes of airline flight. TSA has set their dose limit to ensure a person receives less radiation from one scan with a TSA general-use x-ray security system than from two minutes of airline flight.
3. A person would have to be screened more than a thousand times in one year to exceed the annual radiation dose limit for people screening that has been set by expert radiation safety organizations.

Four professors at the University of California, San Francisco, among them members of NAS and an expert in cancer and imaging, in a April 2010 letter to the presidential science and technology advisor raised several concerns about the validity of the indirect comparisons the Food and Drug Administration used in evaluating the safety of backscatter x-ray machines. They argued that the effective dose is higher than claimed by the TSA and the body scanner manufacturers because the dose was calculated as if distributed throughout the whole body whereas the most of the radiation is absorbed in the skin and tissues immediately underneath. Other professors from the radiology department at UCSF disagree with the claims of the signing four professors.

The UCSF experts requested that additional data be made public detailing the specific data regarding sensitive areas such as the skin and certain organs, as well as data on the special (high risk) population. In October 2010, the FDA and TSA responded to these concerns. The letter cites reports which show that the specific dose to the skin is some 89,000 times lower than the annual limit to the skin established by the NCRP. Regarding the UCSF concerns over the high risk population to sensitive organs, the letter states that such an individual "would have to receive more than 1000 screenings to begin to approach the annual limit".

In a December 2, 2010 letter to the House of Representatives, Dr. Steven Smith, inventor of the body scanner in 1991, has stated that the concerns of Dr. Brenner and UCSF regarding the skin dose of backscatter scanners is incorrect and the result of a confusion between dose and imaging penetration. Dr. Smith demonstrates this difference with two experiments using plastic (with a similar rate of absorption as body tissue), copper (the image subject), and an x-ray scanner. The dose penetration experiment shows that 5mm and 50mm plastic samples absorb 5% and 50% of the beam intensity respectively, whereas the imaging penetration experiment shows that 4.8mm and 10mm plastic

samples reduce the image darkness by 23% and 50% respectively. Dr. Smith states that those who calculate high skin dosage have incorrectly used the shallow imaging penetration value of a few millimeters whereas the actual dosage is calculated by the deeper dose penetration.

In response, John Sedat, a former UCSF professor of biophysics and cosigner of the original UCSF letter, said that the White House's claim that full-body scanners pose no health risks to air travelers is in "error," adding that the White House statement has "many misconceptions, and we will write a careful answer pointing out their errors."

The TSA has also made public various independent safety assessments of the Secure 1000 Backscatter X-ray Scanner.

Radiation safety authorities including the National Council on Radiation Protection and Measurements, The Health Physics Society and the American College of Radiology, have stated that there is no specific evidence that full-body scans are unsafe. The Secure 1000 Backscatter X-ray scanner was developed in 1992 by Dr. Steve Smith. The scanner has been studied extensively for almost 20 years by the leading independent radiation safety authorities in the United States. Experimental and epidemiological data do not support the proposition, however, that there is a threshold dose of radiation below which there is no increased risk of cancer.

The UK Health Protection Agency has completed an analysis of the X-ray dose from Backscatter scanners and has written that the dose is extremely low and "about the same as people receive from background radiation in an hour".

The Health Physics Society (HPS) reports that a person undergoing a backscatter scan receives approximately 0.05 μSv (or 0.005 mrems) of radiation; American Science and Engineering Inc. reports 0.09 μSv (0.009 mrems). At the high altitudes typical of commercial flights, naturally occurring cosmic radiation is considerably higher than at ground level. The radiation dose for a six hour flight is 20 μSv (2 mrems) — 200 to 400 times larger than a backscatter scan. According to U.S. regulatory agencies, "1 mrem per year is a negligible dose of radiation, and 25 mrem per year from a single source is the upper limit of safe radiation exposure".

According to a draft standard on the United States FDA website, the allowable dose from a scan would be 0.1 μSv , and that report uses a model whereby a 0.01 μSv dose increases an individual's risk of death by cancer during his or her lifetime by 5×10^{-10} .

Since the dose limit is ten times higher than 0.01 μSv , their model would predict one additional cancer death per 200 million scans. Since the airports in the UK handled 218 million passengers in 2009, if all passengers in the UK were scanned at the maximum dosage, then each year this would produce on average one additional cancer death per lifetime, instead of one death by other cause(s). In addition, additional people would be given cancer but would die from other causes.

Extrapolations of cancer risk from minuscule exposures to radiation across large populations, however, are not supported by analysis by the National Council on Radiation Protection (NCRP). On May 26, 2010 NCRP issued a press release to address such comments about full body scanners that are compliant with ANSI N43.17. In Commentary No.16 issued on May 26, 2010, it reads as follows:

As stated in NCRP Report No. 121 (1995), Principles and Application of Collective Dose in Radiation Protection, the summation of trivial average risks over very large populations or time periods into a single value produces a distorted image of risk, completely out of perspective with risks accepted every day, both voluntarily and involuntarily.

According to NCRP, the use of statistical extrapolations that predict 1 death for every 200 million persons scanned for example (as above) is an unrealistic over-estimation.

Other scientists at Columbia University have made the following statements in support of the safety of body scanners:

"A passenger would need to be scanned using a backscatter scanner, from both the front and the back, about 200,000 times to receive the amount of radiation equal to one typical CT scan," said Dr. Andrew J. Einstein, director of cardiac CT research at Columbia University Medical Center in New York City. "Another way to look at this is that if you were scanned with a backscatter scanner every day of your life, you would still only receive a tenth of the dose of a typical CT scan," he said. By comparison, the amount of radiation from a backscatter scanner is equivalent to about 10 minutes of natural background radiation in the United States, Einstein said. "I believe that the general public has nothing to worry about in terms of the radiation from airline scanning," he added. For moms-to-be, no evidence supports an increased risk of miscarriage or fetal abnormalities from these scanners, Einstein added. "A pregnant woman will receive much more radiation from cosmic rays she is exposed to while flying than from passing through a scanner in the airport," he said.

Furthermore, other scientists claim the health effects of backscatter are well understood whereas those from millimeter wave scanners are not:

"From a radiation standpoint there has been no evidence that there is really any untoward effect from the use of this device [backscatter scanner], so I would not be concerned about it from a radiation dose standpoint – the issues of personal privacy are a different thing," he said. The health effects of the more common millimeter wave scanner are largely unknown, and at least one expert believes a safety study is warranted. "I am very interested in performing a National Council on Radiation Protection and Measurements study on the use of millimeter-wave security screening systems," said Thomas S. Tenforde, council president. However, no long-term studies have been done on the health effects of millimeter wave scanners.

Experts evaluating backscatter x-ray machine technology have also argued that defects in the machines, damage from normal wear-and-tear, or software errors could focus an intense dose of radiation on just one spot of the body. For example, Dr. Peter Rez, a professor of physics at Arizona State University, has said, "The thing that worries me the most, is not what happens if the machine works as advertised, but what happens if it doesn't," adding that a potential malfunction of the machine could increase the radiation dose.

The designers and manufacturers of backscatter X-ray scanners claim that the scanners are designed to prevent the occurrence of these kinds of errors. The scanners' safety requirements include fail-safe controls and multiple overlapping interlocks. These features, combined with fault analysis, ensure that failure of any subsystem results in non-operation of the x-ray generator to prevent accidental exposures. In the United States, the TSA requires that certification to the ANSI N43.17 safety standard is performed by a third party and not by the manufacturer themselves.

The European Commission issued a report stating that backscatter x-ray scanners pose no known health risk, and that "assuming all other conditions equal", that backscatter x-ray scanners, which expose people to ionizing radiation, should not be used when millimeter-wave scanners that "have less effects on the human body" are available.

However, the European Commission report provides no data substantiating its claim that "all other conditions are equal". One area where Backscatter X-ray scanners can provide better performance than MM wave scanners, for example, is in the inspection of the shoes, groin and armpit regions of the body.

Justifications for use

The additional risk from exposure to backscatter radiation may be more acceptable to the person undergoing the scan if this is an unavoidable activity that is useful to the individual or the community as a whole. For instance, if scans are carried out in the interest of public safety then the potential benefit of discovering a weapon on a person could be to the benefit of the community but not to the person being scanned. In other words, a person may be certain they are not carrying a weapon and may gain little by being scanned but the act of undergoing a scan may benefit other passengers. Quoting from ANSI N43-17:

To put this in perspective, this same risk of death results from about one minute of riding in an automobile. Likewise, this same risk of death is experienced about each ten minutes of working in a "safe" field such as a secretary or office administrator, due to occupational deaths from accidents, homicides, and other causes. (The automobile death rate is calculated from 250 million people in the U.S., each driving an average of 10,000 miles per year, at an average speed of 30 mph, resulting in 25,000 traffic deaths per year. The occupational death rate is based on 5 deaths per 100,000 employees per year, a typical value for "safe" occupations).

Safety regulations and standards

In the US, manufacturers of security related equipment can apply for protection under the SAFETY act, which limits their financial liability in product liability cases to the amount of their insurance coverage. The Rapiscan Secure 1000 was listed in 2006.

In the US, an X-ray system can be considered to comply with requirements for general purpose security screening of humans if the device complies with American National Standards Institute (ANSI) Standard #N43.17.

In the most general sense, N43.17 states that a device can be used for general purpose security screening of humans if the dose to the subject is less than 25 μ rems (0.25 μ Sv) per examination and complies with other requirements of the standard. Twenty-five micro Rem is equal to the amount of background radiation every human is exposed to (from the air and soil) at sea level every 1.5 hours and is also equal to the radiation exposure from cosmic rays when travelling in an airplane at altitude for 2 minutes.

Many types of X-ray systems can be designed to comply with ANSI N43.17 including transmission X-ray, backscatter X-ray and gamma ray systems. Not all backscatter X-ray devices necessarily comply with ANSI N43.17; only the manufacturer or end user can confirm compliance of a particular product to the standard.

ANSI standards use a standard of measurement algorithm called "effective dose" which considers the different exposure of all parts of the body and then weights them differently. the interior of the human body is given more weight in this survey and the exterior including the skin organ are given less weight. The Rapiscan backscatter machine produces an x-ray more absorbed by the skin than most x-ray devices, but is still regulated under the ANSI standard for "effective dose" Damage done to the skin by x-rays is similar to the damage done by sunlight.

The European Union is currently considering whether it is acceptable for this technology to be deployed in European Union airports. A report is pending from the Transport Committee of the European Parliament.

Technical countermeasures

Some people wish to prevent either the loss of privacy or the possibility of health problems or genetic damage that might be associated with being subjected to a backscatter X-ray scan. One company sells X-ray absorbing underwear which is said to have X-ray absorption equivalent to 0.5 mm of lead. Another product, Flying Pasties, "are designed to obscure the most private parts of the human body when entering full body airport scanners", but their description does not seem to claim any protection from the X-ray beam penetrating the body of the person being scanned.

Chapter 4

Detection Dog and Alpha 6

Detection dog



A detection dog getting ready to search a car for explosives.

A **detection dog** or **sniffer dog** is a dog that is trained to and works at using its senses (almost always the sense of smell) to detect substances such as explosives, illegal drugs, or blood. Hunting dogs that search for game and search dogs that search for missing humans are generally not considered detection dogs. There is some overlap, as in the case of human remains detection dogs (sometimes called cadaver dogs), trained to detect human remains. They are also used for drug raids to find where the drugs are.

In the state of California, dogs are trained to detect the Quagga Mussel on boats at public boat ramps, as it is a invasive species. Sniffer dogs have also been enlisted to find bumblebee nests. The Bumblebee Conservation Trust has trained a springer spaniel to detect the colonies, assisting them with the conservation of threatened species. Some prisons have dogs trained to detect illicit cell phones in prison cells.

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Functions



Detection dog at the Canadian/American border

Detection dogs have been trained to search for many substances, including:

- Plants, animals, produce, and other agricultural items (used by customs services to detect possible invasive species such as Quagga mussel)
- Cancer
- Polycarbonate optical discs such as DVDs (used to search for bootleg recordings)
- Crime evidence
- Currency
- Drugs

- Diabetes
- Bedbugs
- Explosives
- Mobile phones (as contraband in prisons)
- Firearms
- Human remains
- Mold
- Termites

One notable quality of detection dogs is that they are able to discern individual scents even when the scents are combined or masked by other odors. In one case at an Australian prison, a detection dog foiled an attempt to smuggle drugs that had been hidden in a woman's bra and smeared with coffee, pepper and Vicks Vapo-rub. A sniffer dog can detect blood even if it has been scrubbed off surfaces. In one case, a sniffer dog sniffed a drop of blood on a wall although an attempt had been made to scrub it off. It was so small that it couldn't be seen without a microscope.

Some of these functions can be carried out by trained pigs, which also have an excellent sense of smell, and have been used to hunt truffles, underground fungi, for centuries.

Criticism of Drug Detection Dogs

Their use has been criticized as allowing the police to conduct searches without cause, in a manner that is unregulated, and for being used to target adults carrying drugs for personal use rather than commercial purposes. They have been criticized as a form of show-policing, motivated more by the state's desire to be seen to be doing something than any serious attempt to respond to the dangers of drug use.

Problems exist with detection dogs in that they can be trained to indicate the presence of drugs when none exist and the dog, of course, cannot be called to testify. Officers sometimes attempt to intimidate drivers into consenting to a search by saying that a detection dog is on the way, whether one is really on the way or not

In 2001 the Australian state of New South Wales introduced legislation to provide police with powers to use drug detection dogs without a warrant in public places such as licensed venues, music festivals and public transport. The legislation was reviewed by the NSW Ombudsman who in 2006 handed down a report highly critical of the use of dogs for drug detection. The report stated that prohibited drugs were found in only 26% of searches following an indication by a drug sniffer dog. Of these, 84% were for small amounts of cannabis deemed for personal use. The report also found that the legislation was ineffective at detecting persons in supply of prohibited drugs, with only 0.19% of indications ultimately leading to a successful prosecution for supply.

Bed bug detection dogs

Bed bug detection dogs are specially trained by handlers to identify the scent of bed bugs.

With the increased focus on green pest management and integrated pest management, bed bug detection dogs are gaining popularity in North America. Dogs are a safer alternative to pesticide use as a management strategy. If operators can find out exactly where bed bugs are located, they can minimize the area that needs to be sprayed. Dogs smell in parts per trillion, something a human cannot do, and detect bed bugs through all life cycle phases from eggs to nymphs to adults.

Bed bug detection dogs are relatively new. The National Entomology Scent Detection Canine Association, states that there are over 100 dogs currently working in the U.S., but this number is increasing, while the International Forensic Detection Canine Association, based in the US, estimates well over 200 and counting. IFEDCA, founded by a Certified Master Trainer, Bill Whitstine, also estimates that the need for bed bug dogs far outweighs the supply. Bill Whitstine was the first trainer to train and certify bed bug detection dogs in the United States and has an estimated 150 dogs internationally.

Bed bug detection dogs are a viable and scientifically-proven alternative to traditional methods of pest detection. A 2008 report by the University of Kentucky Department of Entomology endorsed bed bug detection dogs by stating that the “reliability of the dogs has been impressive provided they are properly trained.” Scientists at the university reviewed studies on the dogs and concluded that although expensive for operators, canine detection dogs were promising.

Bed bug detection is complicated by the fact that the insects can hide almost anywhere. Bed bug detection dogs solve this problem because they are small and agile, finding bugs in places humans cannot such as wall voids, crevices and furniture gaps.

With the increase in global travel and shared living accommodations, bed bugs have become more prevalent. The U.S. Environmental Protection Agency held a bed bug summit in April 2009 to address the ongoing problem of bed bugs and how to eradicate them. The certification of bed bug detection dogs was discussed.

- *NPR's All Things Considered Using Dogs to Sniff Out Bed Bugs*
- *Fox Philadelphia Bed Bug Dog and Bed Bug Control Experts discussing use of Bed Bug Dogs*

Alpha 6

The **Alpha 6** is a controversial "molecular detector" that is claimed to be able to detect from a distance various substances including explosives and drugs. The device has come under scrutiny following revelations about two similar devices, the ADE 651, which has become the focus of a fraud investigation in the United Kingdom, and the GT200, which tests have determined to perform no better than random chance.

The UK Government has banned the export of such devices to Iraq and Afghanistan in an order brought into force in January 2010 under the Export Control Act 2002 and has warned foreign governments that the GT200 and ADE 651 are "wholly ineffective" at detecting bombs and explosives. The government of Thailand, a major user of the Alpha 6, has ordered double blind testing of the device to determine whether it is effective.

Description and background

The Alpha 6 is a hand-held device comprising a swivelling antenna mounted via a hinge to a plastic handset. Promotional literature claims that the device "is programmed to oscillate at the same frequency as that of the substance to be located." It is said to be powered by static electricity generated within the user's body "when breathing occurs". The device is claimed to be able to detect the "molecular signature" of various substances, including drugs, explosives and ammunition in quantities as small as 15 nanograms, from distances of up to 300 metres (980 ft) away, through walls and underwater. The "signature" of the substance to be detected is stored on a "recognition card" sealed inside the handset.

Export ban and police investigation

Following controversy over a similar device, the ADE 651, the UK Government issued an order under the Export Control Act 2002 that came into force on 27 January 2010, banning the export to Iraq and Afghanistan of "'electro-statically powered' equipment for detecting 'explosives'", on the grounds that such equipment "could cause harm to UK and other friendly forces". The export ban covers all such devices, including the GT200.

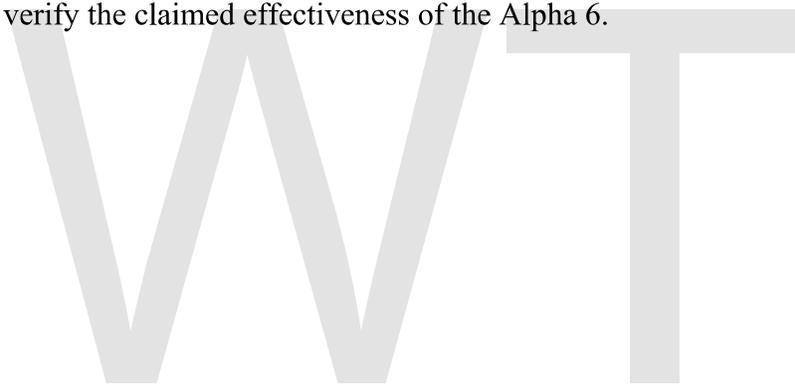
Officers from the City of London Police Overseas Anti-Corruption Unit subsequently raided the offices of Scandec and two other makers of similar "detectors". A large amount of cash and several hundred of the devices and their component parts were seized. The police said that they were investigating on suspicion of fraud by false representation and were also investigating whether bribes had been paid to secure contracts to supply the devices.

Controversy in Thailand

Thailand has been a major purchaser of the Alpha 6. The country's Interior Ministry has bought 479 of the devices and the Office of the Narcotics Control Board (ONCB), part of

the Justice Ministry, has a further 15. The ONCB began using the devices in 2007 to combat drug smuggling in northern Thailand and bought its units at a price of 400,000 baht (\$12,000) apiece. It claimed that its Alpha 6 units were highly effective, achieving a 70% success rate and helping to identify drug traffickers and smuggled drugs. The head of the OCNB, Police Lt General Krissana Phon-anan, has said that the devices work so well that the agency no longer uses dogs to detect narcotics. The Interior Ministry plans to procure more Alpha 6 devices and train 1,000 volunteers to use them. Its own Alpha 6 devices were procured at a much higher price than those of the Narcotics Control Board, at 720,000 baht (\$39,000) each. The total cost of the devices has been around 351 million baht (\$10.6 million).

Following a controversy about the effectiveness of the GT200 "remote substance detector", similar questions were raised about the Alpha 6. Thai Prime Minister Abhisit Vejjajiva ordered scientific tests of the GT200 in February 2010 to verify its claimed effectiveness. The tests found that the GT200's detection rate was no more effective than random chance. In the wake of the GT200 scandal, the Science and Technology Ministry announced that it would broaden its tests at the request of the Interior and Justice Ministries to verify the claimed effectiveness of the Alpha 6.



Chapter 5

Gas Chromatography-Mass Spectrometry



Example of a GC-MS instrument

Gas chromatography-mass spectrometry (GC-MS) is a method that combines the features of gas-liquid chromatography and mass spectrometry to identify different substances within a test sample. Applications of GC-MS include drug detection, fire

investigation, environmental analysis, explosives investigation, and identification of unknown samples. GC/MS can also be used in airport security to detect substances in luggage or on human beings. Additionally, it can identify trace elements in materials that were previously thought to have disintegrated beyond identification.

GC-MS has been widely heralded as a "gold standard" for forensic substance identification because it is used to perform a *specific test*. A specific test positively identifies the actual presence of a particular substance in a given sample. A *non-specific test* merely indicates that a substance falls into a category of substances. Although a non-specific test could statistically suggest the identity of the substance, this could lead to false positive identification.

History

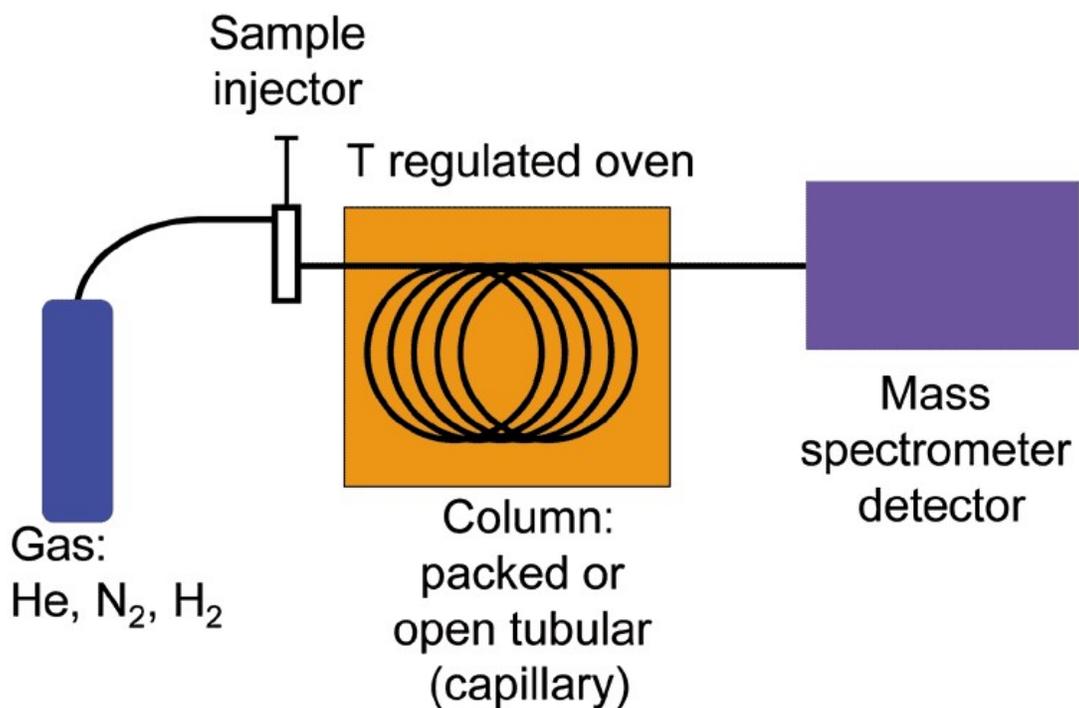
The use of a mass spectrometer as the detector in gas chromatography was developed during the 1950s by Roland Gohlke and Fred McLafferty. These sensitive devices were bulky, fragile, and originally limited to laboratory settings. The development of affordable and miniaturized computers has helped in the simplification of the use of this instrument, as well as allowed great improvements in the amount of time it takes to analyze a sample. In 1996 the top-of-the-line high-speed GC-MS units completed analysis of fire accelerants in less than 90 seconds, whereas first-generation GC/MS would have required at least 16 minutes. This has led to their widespread adoption in a number of fields.

Instrumentation



The insides of the GC-MS, with the column of the gas chromatograph in the oven on the right.

The GC-MS is composed of two major building blocks: the gas chromatograph and the mass spectrometer. The gas chromatograph utilizes a capillary column which depends on the column's dimensions (length, diameter, film thickness) as well as the phase properties (e.g. 5% phenyl polysiloxane). The difference in the chemical properties between different molecules in a mixture will separate the molecules as the sample travels the length of the column. The molecules take different amounts of time (called the retention time) to come out of (elute from) the gas chromatograph, and this allows the mass spectrometer downstream to capture, ionize, accelerate, deflect, and detect the ionized molecules separately. The mass spectrometer does this by breaking each molecule into ionized fragments and detecting these fragments using their mass to charge ratio.



GC-MS schematic

These two components, used together, allow a much finer degree of substance identification than either unit used separately. It is not possible to make an accurate identification of a particular molecule by gas chromatography or mass spectrometry alone. The mass spectrometry process normally requires a very pure sample while gas chromatography using a traditional detector (e.g. Flame Ionization Detector) detects multiple molecules that happen to take the same amount of time to travel through the column (*i.e.* have the same retention time) which results in two or more molecules to co-elute. Sometimes two different molecules can also have a similar pattern of ionized fragments in a mass spectrometer (mass spectrum). Combining the two processes reduces the possibility of error, as it is extremely unlikely that two different molecules will behave in the same way in both a gas chromatograph and a mass spectrometer. Therefore, when an identifying mass spectrum appears at a characteristic retention time in a GC-MS

analysis, it typically lends to increased certainty that the analyte of interest is in the sample.

Purge and Trap GC-MS

For the analysis of volatile compounds a Purge and Trap (P&T) concentrator system may be used to introduce samples. The target analytes are extracted and mixed with water and introduced into an airtight chamber. An inert gas such as Nitrogen (N₂) is bubbled through the water; this is known as purging. The volatile compounds move into the headspace above the water and are drawn along a pressure gradient (caused by the introduction of the purge gas) out of the chamber. The volatile compounds are drawn along a heated line onto a 'trap'. The trap is a column of adsorbent material at ambient temperature that holds the compounds by returning them to the liquid phase. The trap is then heated and the sample compounds are introduced to the GC-MS column via a volatiles interface, which is a split inlet system. P&T GC-MS is particularly suited to volatile organic compounds (VOCs) and BTEX compounds (aromatic compounds associated with petroleum).

Types of Mass Spectrometer Detectors

The most common type of mass spectrometer (MS) associated with a gas chromatograph (GC) is the quadrupole mass spectrometer, sometimes referred to by the Hewlett-Packard (now Agilent) trade name "Mass Selective Detector" (MSD). Another relatively common detector is the ion trap mass spectrometer. Additionally one may find a magnetic sector mass spectrometer, however these particular instruments are expensive and bulky and not typically found in high-throughput service laboratories. Other detectors may be encountered such as time of flight (TOF), tandem quadrupoles (MS-MS), or in the case of an ion trap MSⁿ where n indicates the number mass spectrometry stages.

Analysis

A mass spectrometer is typically utilized in one of two ways: Full Scan or Selective Ion Monitoring (SIM). The typical GC/MS instrument is capable of performing both functions either individually or concomitantly, depending on the setup of the particular instrument.

Full scan MS

When collecting data in the full scan mode, a target range of mass fragments is determined and put into the instrument's method. An example of a typical broad range of mass fragments to monitor would be m/z 50 to m/z 400. The determination of what range to use is largely dictated by what one anticipates being in the sample while being cognizant of the solvent and other possible interferences. A MS should not be set to look for mass fragments too low or else one may detect air (found as m/z 28 due to nitrogen), carbon dioxide (m/z 44) or other possible interferences. Additionally if one is to use a

large scan range then sensitivity of the instrument is decreased due to performing fewer scans per second since each scan will have to detect a wide range of mass fragments.

Full scan is useful in determining unknown compounds in a sample. It provides more information than SIM when it comes to confirming or resolving compounds in a sample. During instrument method development it may be common to first analyze test solutions in full scan mode to determine the retention time and the mass fragment fingerprint before moving to a SIM instrument method.

Selected ion monitoring

In selected ion monitoring (SIM) certain ion fragments are entered into the instrument method and only those mass fragments are detected by the mass spectrometer. The advantages of SIM are that the detection limit is lower since the instrument is only looking at a small number of fragments (e.g. three fragments) during each scan. More scans can take place each second. Since only a few mass fragments of interest are being monitored, matrix interferences are typically lower. To additionally confirm the likelihood of a potentially positive result, it is relatively important to be sure that the ion ratios of the various mass fragments are comparable to a known reference standard.

Types of Ionization

After the molecules travel the length of the column, pass through the transfer line and enter into the mass spectrometer they are ionized by various methods with typically only one method being used at any given time. Once the sample is fragmented it will then be detected, usually by an electron multiplier diode, which essentially turns the ionized mass fragment into an electrical signal that is then detected.

The ionization technique chosen is independent of using Full Scan or SIM.

Electron Ionization

By far the most common and perhaps standard form of ionization is electron ionization (EI). The molecules enter into the MS (the source is a quadrupole or the ion trap itself in an ion trap MS) where they are bombarded with free electrons emitted from a filament, not much unlike the filament one would find in a standard light bulb. The electrons bombard the molecules, causing the molecule to fragment in a characteristic and reproducible way. This "hard ionization" technique results in the creation of more fragments of low mass to charge ratio (m/z) and few, if any, molecules approaching the molecular mass unit. Hard ionization is considered by mass spectroscopists as the employ of molecular electron bombardment, whereas "soft ionization" is charge by molecular collision with an introduced gas. The molecular fragmentation pattern is dependant upon the electron energy applied to the system, typically 70 eV (electron Volts). The use of 70 eV facilitates comparison of generated spectra with National Institute of Standard (NIST-USA) library of spectra applying algorithmic matching programs and the use of methods of analysis written by many method standardization agencies.

Chemical Ionization

In chemical ionization a reagent gas, typically methane or ammonia is introduced into the mass spectrometer. Depending on the technique (positive CI or negative CI) chosen, this reagent gas will interact with the electrons and analyte and cause a 'soft' ionization of the molecule of interest. A softer ionization fragments the molecule to a lower degree than the hard ionization of EI. One of the main benefits of using chemical ionization is that a mass fragment closely corresponding to the molecular weight of the analyte of interest is produced.

Positive Chemical Ionization

In Positive Chemical Ionization (PCI) the reagent gas interacts with the target molecule, most often with a proton exchange. This produces the species in relatively high amounts.

Negative Chemical Ionization

In Negative Chemical Ionization (NCI) the reagent gas decreases the impact of the free electrons on the target analyte. This decreased energy typically leaves the fragment in great supply.

The primary goal of instrument analysis is to quantify an amount of substance. This is done by comparing the relative concentrations among the atomic masses in the generated spectrum. Two kinds of analysis are possible, comparative and original. Comparative analysis essentially compares the given spectrum to a spectrum library to see if its characteristics are present for some sample in the library. This is best performed by a computer because there are a myriad of visual distortions that can take place due to variations in scale. Computers can also simultaneously correlate more data (such as the retention times identified by GC), to more accurately relate certain data.

Another method of analysis measures the peaks in relation to one another. In this method, the tallest peak is assigned 100% of the value, and the other peaks being assigned proportionate values. All values above 3% are assigned. The total mass of the unknown compound is normally indicated by the parent peak. The value of this parent peak can be used to fit with a chemical formula containing the various elements which are believed to be in the compound. The isotope pattern in the spectrum, which is unique for elements that have many isotopes, can also be used to identify the various elements present. Once a chemical formula has been matched to the spectrum, the molecular structure and bonding can be identified, and must be consistent with the characteristics recorded by GC/MS. Typically, this identification done automatically by programs which come with the instrument, given a list of the elements which could be present in the sample.

A "full spectrum" analysis considers all the "peaks" within a spectrum. Conversely, selective ion monitoring (SIM) only monitors selected peaks associated with a specific substance. This is done on the assumption that at a given retention time, a set of ions is characteristic of a certain compound. This is a fast and efficient analysis, especially if the

analyst has previous information about a sample or is only looking for a few specific substances. When the amount of information collected about the ions in a given gas chromatographic peak decreases, the sensitivity of the analysis increases. So, SIM analysis allows for a smaller quantity of a compound to be detected and measured, but the degree of certainty about the identity of that compound is reduced.

GC-tandem MS

When a second phase of mass fragmentation is added, for example using a second quadrupole in a quadrupole instrument, it is called tandem MS (MS/MS). MS/MS can sometimes be used to quantitate low levels of target compounds in the presence of a high sample matrix background.

The first quadrupole (Q1) is connected with a collision cell (q2) and another quadrupole (Q3). Both quadrupoles can be used in scanning or static mode, depending on the type of MS/MS analysis being performed. Types of analysis include product ion scan, precursor ion scan, Selected Reaction Monitoring (SRM) (sometimes referred to as Multiple Reaction Monitoring (MRM)) and Neutral Loss Scan. For example: When Q1 is in static mode (looking at one mass only as in SIM), and Q3 is in scanning mode, one obtains a so-called product ion spectrum (also called "daughter spectrum"). From this spectrum, one can select a prominent product ion which can be the product ion for the chosen precursor ion. The pair is called a "transition" and forms the basis for SRM. SRM is highly specific and virtually eliminates matrix background.

Applications

Environmental Monitoring and Cleanup

GC-MS is becoming the tool of choice for tracking organic pollutants in the environment. The cost of GC-MS equipment has decreased significantly, and the reliability has increased at the same time, which has contributed to its increased adoption in environmental studies. There are some compounds for which GC-MS is not sufficiently sensitive, including certain pesticides and herbicides, but for most organic analysis of environmental samples, including many major classes of pesticides, it is very sensitive and effective.

Criminal Forensics

GC-MS can analyze the particles from a human body in order to help link a criminal to a crime. The analysis of fire debris using GC-MS is well established, and there is even an established American Society for Testing Materials (ASTM) standard for fire debris analysis. GCMS/MS is especially useful here as samples often contain very complex matrices and results, used in court, need to be highly accurate.

Law Enforcement

GC-MS is increasingly used for detection of illegal narcotics, and may eventually supplant drug-sniffing dogs. It is also commonly used in forensic toxicology to find drugs and/or poisons in biological specimens of suspects, victims, or the deceased.

Security

A post-September 11 development, explosive detection systems have become a part of all US airports. These systems run on a host of technologies, many of them based on GC-MS. There are only three manufacturers certified by the FAA to provide these systems, one of which is Thermo Detection (formerly Thermedics), which produces the EGIS, a GC-MS-based line of explosives detectors. The other two manufacturers are Barringer Technologies, now owned by Smith's Detection Systems, and Ion Track Instruments, part of General Electric Infrastructure Security Systems.

Food, Beverage and Perfume Analysis

Foods and beverages contain numerous aromatic compounds, some naturally present in the raw materials and some forming during processing. GC-MS is extensively used for the analysis of these compounds which include esters, fatty acids, alcohols, aldehydes, terpenes etc. It is also used to detect and measure contaminants from spoilage or adulteration which may be harmful and which is often controlled by governmental agencies, for example pesticides.

Astrochemistry

Several GC-MS have left earth. Two were brought to Mars by the Viking program. Venera 11 and 12 and Pioneer Venus analysed the atmosphere of Venus with GC-MS. The Huygens probe of the Cassini-Huygens mission landed one GC-MS on Saturn's largest moon, Titan. The material in the comet 67P/Churyumov-Gerasimenko will be analysed by the Rosetta mission with a chiral GC-MS in 2014.

Medicine

Dozens of congenital metabolic diseases also known as Inborn error of metabolism are now detectable by newborn screening tests, especially the testing using gas chromatography-mass spectrometry. GC/MS can determine compounds in urine even in minor concentration. These compounds are normally not present but appear in individuals suffering with metabolic disorders. This is an increasingly becoming a common way to diagnose IEM for earlier diagnosis and institution of treatment eventually leading to a better outcome. It is now possible to test a newborn for over 100 genetic metabolic disorders by a urine test at birth based on GC/MS.

In combination with isotopic labeling of metabolic compounds, the GC-MS is used for determining metabolic activity. Most applications are based on the use of ^{13}C as the

labeling and the measurement of $^{13}\text{C}/^{12}\text{C}$ ratios with an **isotope ratio mass spectrometer (IRMS)**; an MS with a detector designed to measure a few select ions and return values as ratios.

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Chapter 6

Ion Mobility Spectrometry

Ion mobility spectrometry (IMS) is an analytical technique used to separate and identify ionized molecules in the gas phase based on their ion mobility in a carrier buffer gas. Though heavily employed for military or security purposes, such as detecting drugs and explosives, the technique also has many laboratory analytical applications, recently being coupled with mass spectrometry and high performance liquid chromatography. IMS devices come in a wide range of sizes (often tailored for a specific application) and are capable of operating under a broad range of conditions. Systems operated at higher pressure (i.e. atmospheric conditions, 1 atm or 1013 mbar) are also accompanied by elevated temperature (above 100°C), while lower pressure systems (1-20 mbar) do not require heating.

History

IMS was first developed primarily by Earl W. McDaniel of Georgia Institute of Technology in the 1950s and 1960s when he used drift cells with low applied electric fields to study gas phase ion mobilities and reactions. In the following decades, he coupled his new technique with a magnetic-sector mass spectrometer, with others also utilizing his techniques in new ways. IMS cells have since been attached to many other mass spectrometers and high-performance liquid chromatography setups. Currently IMS is a widely-used technique implemented by many, and improvements and other uses are continually being developed.

Outside of laboratory purposes, IMS has found great usage as a detection tool. More than 10,000 IMS devices are in use worldwide in airports, and the US Army has more than 50,000 IMS devices. In industrial settings, uses of IMS include checking equipment cleanliness and detecting emission contents, such as determining the amount of hydrochloric and hydrofluoric acid in a stack gas from a process.

Ion Mobility

In the traditional method of drift-time IMS, commonly referred to as just IMS, produced ions travel through a drift tube which has an applied electric field and a carrier buffer gas that opposes the ion motion. At the end of the tube is a detector. Based on an ion's mass, charge, size and shape (the ion mobility), the migration time through the tube is characteristic of different ions, leading to the ability to distinguish different analyte species. The area of an ion that gas molecules strike is an ion's collision cross-section, related to the ion size and shape. The greater this collision cross-section is, meaning the larger the ion size, the more area available for buffer gas to collide and impede the ion's drift – the ion then requires a longer time to migrate through the drift tube.

The physical quantity **ion mobility** K is defined as the proportionality factor of an ion's drift velocity v_d in a gas and an electric field of strength E ,

$$v_d = KE$$

Ion mobilities are commonly reported as a *reduced mobilities*, correcting to standard gas density n_0 , which can be expressed in standard temperature $T_0 = 273$ K and standard pressure $p_0 = 1013$ mbar:

$$K_0 = K \frac{n}{n_0} = K \frac{T_0}{T} \frac{p}{p_0}$$

The ion mobility K can be experimentally determined by measuring the drift time t_D of an ion traversing within a homogeneous electric field the potential difference U in the drift length L :

$$K = \frac{L^2}{t_D U}$$

The ion mobility K can also be calculated by the Mason equation:

$$K = \frac{3}{16} \sqrt{\frac{2\pi}{\mu kT}} \frac{Q}{n\sigma}$$

where Q is the ion charge, n is the drift gas number density, μ is the reduced mass of the ion and the drift gas molecules, k is Boltzmann constant, T is the drift gas temperature, and σ is the ion's collision cross section with the drift gas. This relation holds approximately at a low electric field limit, where the ratio of E/n is small, at $\leq 2 \times 10^{-17}$ C•cm².

A drift tube's resolving power R can be calculated as

$$R = \frac{t}{\Delta t} = \sqrt{\frac{LEQ}{16kT \ln 2}}$$

where L is the tube length, E is the electric field strength, Q is the ion charge, k is Boltzmann's constant, and T is the drift gas temperature.

With a low electric field applied, the thermal energy of the ions is greater than the energy gained from the electric field between collisions. With these ions having similar energies as the buffer gas molecules, diffusion forces dominate ion motion.

Instrumentation

Ionization

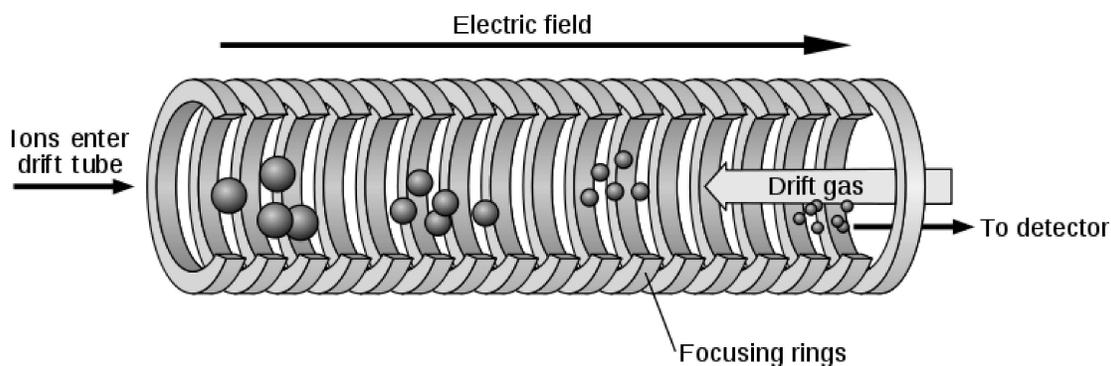
The molecules of the sample need to be ionized, usually by corona discharge, atmospheric pressure photoionization (APPI), electrospray ionization (ESI), or a radioactive source, eg. a small piece of ⁶³Ni or ²⁴¹Am, similar to the one used in ionization smoke detectors. ESI and MALDI techniques are commonly used when IMS is paired with mass spec.

Doping materials are sometimes added to the drift gas for ionization selectivity. For example, acetone can be added for chemical warfare agent detection, chlorinated solvents added for explosives, and nicotinamide added for drugs detection.

Analyzer

TOFIMS

In its simplest form an IMS system measures how fast a given ion moves in a uniform electric field through a given atmosphere.



An ion mobility spectrometer separates ions by shape and charge.

In specified intervals, a sample of the ions is let into the drift chamber; the gating mechanism is based on a charged electrode working in a similar way as the control grid in triodes works for electrons. For precise control of the ion pulse width admitted to the drift tube, more complex gating systems such as a Bradbury-Nielsen design are employed. Once in the drift tube, ions are subjected to a homogeneous electric field ranging from a few volts per centimeter up to many hundreds of volts per centimeter. This electric field then drives the ions through the drift tube where they interact with the neutral drift molecules contained within the system.

In the drift tube, chemical species separate based on the ion mobility, arriving at the detector for measurement. Ions are recorded at the detector in order from the fastest to the slowest, generating a response signal characteristic for the chemical composition of the measured sample.

For drift-time IMS, two main methods are used – either reduced pressure or ambient pressure. A reduced pressure is where the applied pressure gas is at a few torr, commonly used to measure ion collision cross-sections. Ambient pressure is what is used for stand-alone detector devices, as well as detection for gas, liquid, and supercritical fluid chromatographies. The higher pressures of ambient pressure methods allow for higher resolving power and greater separation selectivity due to a higher rate of ion-molecule interactions. Reduced pressure IMS allows for ion-focusing and an easier interface with mass spec. Though drift electric fields are normally uniform, non-uniform drift fields are also used. These non-uniform field IMS results are often calibrated to uniform field instrumentation. Non-uniform field usage is still in a relatively early developing stage.

DMS

DMS (differential mobility spectrometer) make use of the dependence of ion mobility K on electric field strength E at high electric fields. Ions are subjected to different field strengths for different amounts of time. Thereby only ions with certain mobility dependence survive. These types of IMS work as a scanable filter. They are also called FAIMS

DMA

DMA differential mobility analyzer make use of a fast gas stream perpendicular to the electric field. Thereby ions of different mobilities undergo different trajectories. This type of IMS corresponds to the sector instruments in mass spectrometry. They also work as a scanable filter. Examples include DMD (Differential Mobility Detector), first commercialized in Varian CP-4900 MicroGC.

Drift Gas

The drift gas pressure is an important parameter for the IMS instrument design and resolution. Most drift gases have a greater potential to break down at pressures higher than a few mbar, with the potential to break down increasing as the pressure increases. As

an example, high drift voltages of about 10-30 kV can be used with tubes of 1 m length and high gas pressures of 100-1000 mbar to obtain high resolutions. At higher pressures than 10 mbar, ions become more difficult to store. At lower pressures, ions can be stored more easily to obtain an accumulated continuous signal, with the trade-off of lower electric fields (around 10-30 V/cm). Elevated gas temperature assists in removing ion clusters that may distort experimental measurements.

Detector

Often the detector is a simple Faraday plate, however, more advanced ion mobility instruments are coupled with mass spectrometers where both size and mass information may be obtained simultaneously.

Ion traps

Ion trap mobility spectrometry is an instrumental analytical method for detection and analysis of chemical substances, able to detect very low concentrations of chemicals based upon the differential migration of ions through homogeneous electric field. It is a version of ion mobility spectrometry. ITMS provides a substantial performance improvement over IMS, as the shutter grid is eliminated together with the associated loss of sensitivity.

Hyphenated IMS

IMS can be combined with other separation techniques.

GC-IMS : Gas Chromatography - Ion Mobility Spectrometry

When IMS is coupled with gas chromatography, common sample introduction is with the GC capillary column directly connected to the IMS setup, with molecules ionized as they elute from GC. A similar technique is commonly used for HPLC.

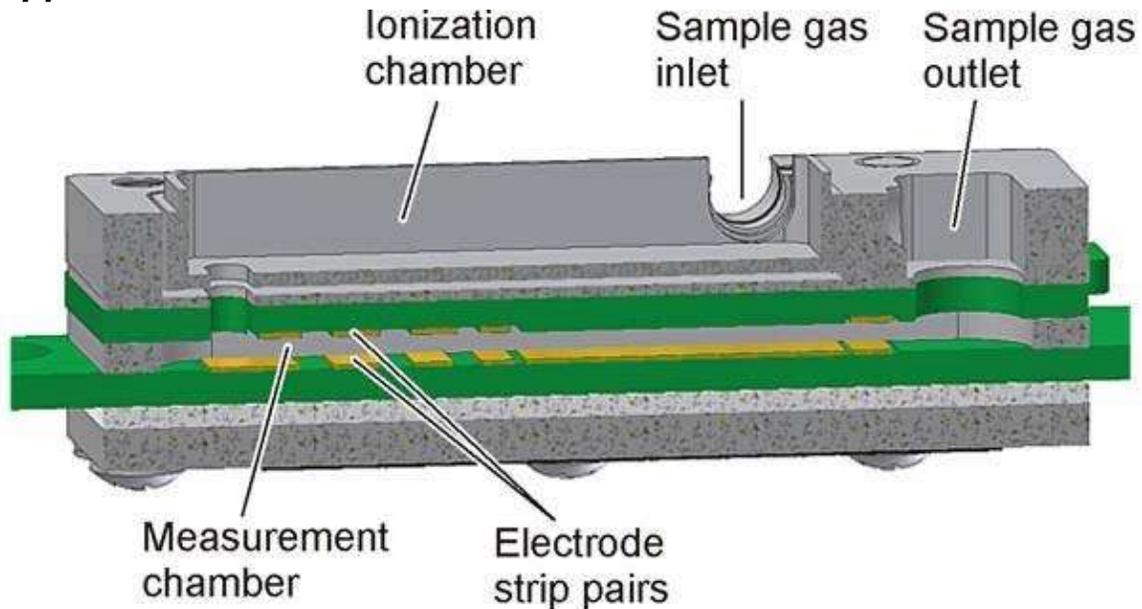
IMS-MS : Ion Mobility Spectrometry - Mass Spectrometry

When IMS is used with mass spectrometry, ion mobility spectrometry-mass spectrometry offers many advantages, including better signal to noise, isomer separation, and charge state identification. IMS has commonly been attached to several mass spec analyzers, including quadrupole, time-of-flight, and Fourier transform cyclotron resonance.

LC-IMS-MS : Liquid Chromatography - Ion Mobility Spectrometry - Mass spectrometry

Coupled with LC and MS, IMS has become widely-used to analyze biomolecules, a practice heavily developed by David E. Clemmer, now at Indiana University (Bloomington).

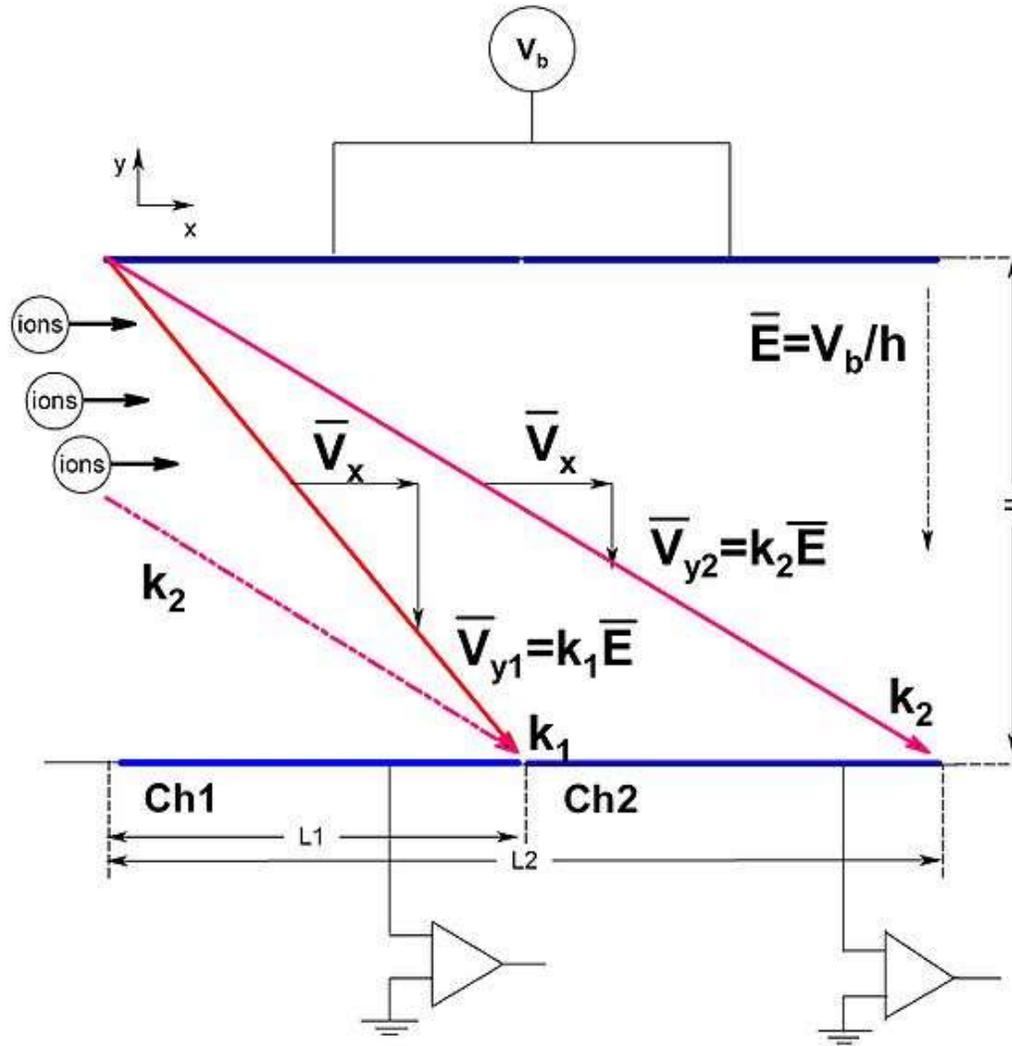
Applications



Example of IMS sensor.

Perhaps ion mobility spectrometry's greatest strength is the speed at which separations occur—typically on the order of tens of milliseconds. This feature combined with its ease of use, relatively high sensitivity, and highly compact design have allowed IMS as a commercial product to be used as a routine tool for the field detection of explosives, drugs, and chemical weapons. A major manufacturer of IMS screening devices used in airports is Smiths Detection.

In the pharmaceutical industry IMS is used in cleaning validations, demonstrating that reaction vessels are sufficiently clean to proceed with the next batch of pharmaceutical product. IMS is much faster and more accurate than HPLC and total organic carbon methods previously used. IMS is also used for analyzing the composition of drugs produced, thereby finding a place in quality assurance and control. As a research tool ion mobility is becoming more widely-used in the analysis of biological materials, specifically, proteomics and metabolomics. For example, IMS-MS using MALDI as the ionization method has helped make advances in proteomics, providing faster high-resolution separations of protein pieces in analysis.



Ions in sensor.

Aspirating IMS is an ion mobility spectrometry technology used to detect low or trace quantities of chemicals in the surrounding atmosphere. It is applied in industrial and military purposes to detect harmful substances in air. Aspiration IMS operates with open-loop circulation of sampled air. Sample flow is passed via ionization chamber and then enters to measurement area where the ions are deflected into one or more measuring electrodes by perpendicular electric field which can be either static or varying. The output of the sensor is characteristic of the ion mobility distribution and can be used for detection and identification purposes.

Chapter 7

Quadro Tracker

The **Quadro Tracker**, also known as the **Positive Molecular Locator**, was a "detection device" sold by Quadro Corp. of Harleyville, South Carolina between 1993 and 1996. Around 1,000 were sold to police departments and school districts around the United States on the basis that it could detect hidden drugs, explosives, weapons and lost golf balls. In 1996, the FBI declared it to be a fake and obtained a permanent injunction barring the device from being manufactured or sold. Three principals of Quadro Corp. were charged with mail fraud and conspiracy to commit mail fraud, but were acquitted in a trial held in January 1997.

Description and claims

The Quadro Tracker was invented by Wade L. Quattlebaum, a former used car salesman from Harleyville, South Carolina. He was said to have devised the Quadro Tracker after he was trying to invent something to find lost golf balls. It was sold through his company, the Quadro Corporation, between 1993 and 1996. Around 1,000 Quadro Trackers were sold at prices of between \$400 and \$8,000 per unit.

The device consisted of three principal components. A "locator card" purportedly containing a "signature" of the object to be detected was inserted into a plastic "card reader" about the size of a tape cassette that could be attached to the user's belt. This was connected to a hand-held unit about 4 inches (10 cm) long to which a horizontally swivelling metal antenna was attached. The antenna would point to the item being sought when a suitable locator card was inserted into the "card reader".

According to the manufacturers, the Quadro Tracker could be used to detect items as varied as drugs, weapons, explosives, specific people, golf balls, alcohol, precious metal, dead pets or wild game animals. In the most expensive version of the device, costing

\$8,000, the user could insert Polaroid photographs of the item or person to be detected. According to Quadro Corp., "Quadro units have been designed to locate people from a photograph, as well as from a fingerprint. Thus missing prisoners, or escaped prisoners can be located with ease. The machine will identify an individual, no matter what disguise or surgery is undertaken. It has been tested over a distance of 500 miles, and will track, we believe, at any distance."

The device could supposedly even detect drugs after they had been ingested by a person. A marketing brochure stated: "The tracker will also locate specific drugs in solution. This means that even a person who had been using drugs will have traces in their bodily fluids, blood, etc. Thus the Tracker will indicate people who are using drugs, as well as those who are merely carrying it. Therefore extreme caution should be taken if searching a person, or making accusations, as they may, indeed, not be carrying drugs on them!"

Quadro Corp. claimed the device worked by oscillating "static electricity produced by the body inhaling and exhaling gases into and out of the lung cavity" to "charge the free-floating neutral electrons of the signature card with the major strength of the signal". The device's mechanism supposedly contained conductors, inductors and oscillators. It was claimed to be able to detect drugs hidden in air-tight containers, a bomb inside a building from outside or a criminal suspect 15 miles away.

Users

Numerous US school boards, airports and police departments purchased the Quadro Tracker before it was banned. The Blue Valley Unified School District and Shawnee Mission School District in Kansas bought Quadro Trackers for \$955 per unit to detect drugs and ammunition in local schools. Polk County Public Schools in Florida bought several Quadro Trackers to share between its schools. Houston School District paid \$2,000 for two of the devices but never used them. School officials in the McKinney Independent School District declined to discontinue using the device even after it was banned, saying that they hoped it would be a deterrent: "We're not looking to nail a particular kid. We're looking to send a message." A similar justification was offered by the principal of Carencro High School in Louisiana: "I heard that there had been some trouble with it, but I tell you what. I'm impressed with it. And this is not necessarily going to be used to catch kids with drugs. If my having this thing keeps kids from bringing drugs on campus, it's worth its weight in gold."

The Texas Department of Public Safety used a Quadro Tracker in a failed attempt to find the body of the murdered 7-year-old Carlin Smith. Police departments in a number of counties, including Jefferson County, Florida and Madison County, Florida also bought the device. The Jefferson County, Texas narcotics task force spent \$3,250 on a Quadro Tracker. The task force's commander later said: "We played with it in the office and got mixed results. Sometimes we'd find something, sometimes not. Our rate of success was about half. I think it was either blind luck or a ouija board effect. It's not near as consistent as (drug-sniffing) dogs, but there are no vet bills."

Exposure

The Quadro Tracker enjoyed considerable commercial success before FBI agent Ron Kelly, stationed in Beaumont, Texas, learned about the device from a contact on the Narcotics Task Force of Jefferson Parish, Louisiana in 1995. He was suspicious of the claims made for the Quadro Tracker and obtained one of the devices, which he examined using the local courthouse's X-ray machine. It was immediately apparent that the Quadro Tracker was hollow; as Kelly later recalled, "It didn't take a lot of effort on our part to determine it was phony."

The FBI commissioned the FBI Laboratory's technicians and Sandia National Laboratories to examine the device. They found that the Quadro Tracker contained no electronics whatsoever. It was merely an empty plastic box in which the only metal parts were a couple of wires and the antenna, which were not connected to each other. The antenna was merely a transistor radio aerial. Attorneys for Quadro Corp. later contended that the inductors and oscillators supposed to be inside the device "aren't the type usually thought of by electronics experts". The "locator chip" was shown to be equally fake; one example put on display by the FBI contained dead ants that had been frozen and stuck onto paper with epoxy glue.

Kelly's office brought it to the attention of US Attorney Mike Bradford, who went to US District Judge Thad Heartfield to initiate action against Quadro Corp. In January 1996, Judge Heartfield issued an injunction against Quadro Corp. from "using the United States mails or private commercial interstate carriers, or causing others acting on their behalf to use the United States mails or private interstate carriers, to solicit customers or entities, promote, sell, transfer, or demonstrate the Quadro Tracker...and devices of a similar design marketed under a different name."

At the same time, the FBI sent a nationwide alert to law enforcement agencies: "A device marketed to law enforcement agencies nationwide, the Quadro Tracker . . . is a fraud. All agencies should immediately cease using the device if used as a basis for probable cause."

Bradford stated: "The company's claims about the capabilities and operations of the Quadro Tracker are fraudulent and false. There is no scientific basis whatsoever for the operation of the device." He said that Quadro Corp. had also falsely claimed in its promotional materials that the device had been tested or endorsed by the FBI, the US Drug Enforcement Administration and the National Institute of Justice, which had helped to persuade customers that the device was legitimate. Ron Kelly told the *Dallas Morning News*: "The only thing this accurately detects is your checkbook."

Fraud investigation and trial

Following the injunction against Quadro Corp., the FBI pursued a criminal investigation against the company's principals and distributors. Two Houston-based Assistant US Attorneys who had acted as distributors – Guy Womack, who later represented US Army

Specialist Charles Graner in the 2003-04 Abu Ghraib prisoner abuse scandal, and John Wagner – were implicated in the affair as licensed distributors for the Quadro Tracker in Alabama, Arkansas, New Mexico and Wyoming. A court was told in April 1996 that Womack could be a target of an investigation of possible conflicts of interest, false statements to investigators about his involvement with the Quadro Tracker and possible use of federal office equipment for private business. During the hearing, Womack pleaded the Fifth Amendment on 42 occasions, asserting his right not to incriminate himself. Womack was not charged, but he eventually resigned his post and paid a \$5,000 settlement while denying any wrongdoing.

On August 22, 1996, a federal grand jury returned indictments on mail fraud charges against Quadro Corp.; Wade L. Quattlebaum, the company's president; Raymond L. Fisk, the vice-president; Malcolm S. Roe, the company secretary; and William J. Long, a distributor. The case came to trial in January 1997. On January 29, 1997 the three men were acquitted of all charges by a federal jury.

Successors

Despite the demise of the Quadro Tracker, a succession of similar devices has appeared in widespread use in a number of countries including Iraq, Mexico and Thailand. A UK-based company, Global Technical, produced a device called the "MOLE programmable detection system" which Sandia National Laboratories described in a 2001 evaluation as "physically nearly identical" to the Quadro Tracker. Sandia reported that "the visible physical differences between the two products appear to be the product labels and the handle-programming chip – interchangeable on the Quadro Tracker, permanently fixed on the MOLE." It was found to perform no better than random chance. Global Technical subsequently produced a very similar device, the GT200, which was sold in large numbers to a number of countries as an explosives and drugs detector. This too was found to perform no better than random chance, sparking a major controversy in Thailand in 2009-2010 over its effectiveness in connection with its high-profile use in combating the South Thailand insurgency and drug smuggling. A similar device produced by a different British company, the Alpha 6, is also in widespread use in Thailand but is due to undergo double blind testing to ascertain its effectiveness.

Another British company, ATSC, produced a very similar device called the ADE 651 which was sold to Iraq as a bomb detector. After a series of devastating bomb attacks in Baghdad and elsewhere which killed hundreds of people, its export to Iraq and Afghanistan was banned by the British government in January 2010 and the company director was arrested on suspicion of fraud.

Chapter 8

Sniffex and CTX (Explosive-Detection Device)

Sniffex

Sniffex is a now debunked, portable explosives detection system produced by Homeland Safety International.

An article in *The Dallas Morning News* in April 2007 suggested that Sniffex is a divining rod and states that "In a test by the U.S. Navy, Sniffex didn't register when two trucks passed within 20 feet, hauling a half ton of explosives." The Navy's counterterrorism technology task force tested Sniffex and concluded "The Sniffex handheld explosives detector does not work." Despite this, the military bought eight for \$50,000.

Although high performance is claimed in advertising for Sniffex, such claims have not been verified by objective double blind testing. Although the tests were conducted at a public meeting by the president of the company, Sniffex did not detect test explosives when the user did not know in advance where they were located. Additionally, James Randi publicly called into question the validity of Sniffex and exchanged correspondence with the CEO offering one million dollars if Sniffex can do what the press releases claim.

The Sniffex device must not be confused with SniffEx, a prize-winning sensor developed at Oak Ridge National Laboratories (ORNL). That sensor was originally called "Sniffex" until Homeland Safety International enforced its trademark and asked ORNL to stop using the name.

In July 2008 the Securities and Exchange Commission filed lawsuits against six company officers for driving "the share price from 80 cents to about \$6 by issuing 33 news releases that contained mostly false information about the product and the company's financial situation to earn a combined \$32 million in illegal profits." In mid-July one suit was settled. In addition, the SEC charged Homeland Safety International, promoters of

Sniffex, "of being little more than the front for a \$32 million stock fraud scheme that enriched insiders at the expense of unsuspecting investors". The SEC complaint said the company "installed a figurehead CEO, named Paul B. Johnson, to hide the involvement of two Bulgarian residents who actually controlled the company" and "then issued a series of what the SEC alleges were false press releases." One of the press releases included a claim of "'impressive'" results from tests conducted by the New Mexico Institute of Mining and Technology. In reality, the tests were conducted by Johnson himself and the results were inconclusive". While the stocks rose the insiders sold, and the stock was trading at one tenth of a penny as of July 17, 2008. In July Mark B. Lindberg settled with SEC and a week later pled guilty to wire fraud.

The **HEDD1**, reportedly a "Sniffex with a battery stuck on it," is marketed by Unival Group of Bonn, the same company that marketed Sniffex in Europe.

CTX (Explosive-Detection Device)

The **CTX** explosive detection device is a family of x-ray devices developed by InVision Technologies in 1990 that uses CAT scans and sophisticated image processing software to automatically screen checked baggage for explosives. CTX scanners are by far the market leader in explosive detection systems (EDSs), accounting for approximately 150 out of 161 FAA-certified bomb scanners installed in US airports as of 2002.

CTX-5000

In 1994, the CTX-5000 became the first computed tomography explosive detection system certified by the US Federal Aviation Administration (FAA). The certification of the CTX-5000 followed nine years of development. During that time the FAA invested \$90 million in explosives detection and nearly \$8.6 million in the specific technology. From 1995 to 1997, the CTX-5000 was tested to solve the challenges involved in integrating an explosives detection system into a baggage system and to validate the estimated costs of wide-scale deployment of the systems.

CTX-5000 SP

The CTX-5000 SP scanning system, an improved version of the CTX-5000 for checked baggage, was delivered to the FAA in 1997 and placed at several of the US's busiest and largest airports. From 1997 to 2000, more than 100 of the systems have been purchased by the FAA to install in US airports, according to InVision.

CTX-5500DS

The CTX-5500DS is an automated explosives detection system that uses computed tomography to characterize materials in checked bags and automatically identify objects

that could be improvised explosive devices. The CTX-5500DS is the most widely used, FAA-certified Explosives Detection System in the world. It can be used for either standalone applications or in an integrated manner with airport baggage handling systems. It can also be configured to detect other types of contraband material. The CTX-5500DS has an FAA-certified throughput of 384 bags per hour. Its Dynamic Screening (DS) capability offers flexibility by allowing manual or automatic switching between various screening modes.

CTX-2500

The CTX-2500 is a small-sized explosives detection system that is half the length of earlier CTX models. The CTX 2500 utilizes a single rotating X-ray source to acquire positioning images and CT-slice images, thus achieving its smaller size. The CTX 2500 system is the first FAA-certified Explosives Detection System (EDS) mounted on a truck for easy mobility and access to cargo. One of the units costs approximately USD \$700,000.

CTX-9000

The CTX-9000 DSi system is the world's fastest FAA-certified Explosives Detection System, handling 542 bags per hour. It features alternate operational modes yielding even higher throughputs. The CTX-9000 DSi is designed for integrated airport installations. Its 1-meter wide conveyor coordinates with standard airport baggage handling systems. The system's architecture utilizes modular components, helping to ease scanner upgrading and servicing. The scanner contains 4 active radiation-shielding curtains. In addition, the gantry rotates at 120 RPM, enabling a slice image to be generated within half a second. A high-speed RF data link connects the rotating gantry to the stationary part of the unit. An air-conditioning unit ensures high performance and reliability in hot, dusty and humid airport environments.

Competition

In the late 1990s, L-3 Communications developed a competing computerized tomography system that also met FAA approval. In November 1999, the FAA awarded a contract worth up to USD \$75 million to L-3 to purchase up to 60 of its explosive detection systems. The eXaminer 3DX 6000 explosive detection system developed by L-3 operates similarly to the CTX system.

Chapter 9

Taggant and Target Acquisition Minefield Detection System

Taggant

A **taggant** can mean a radio frequency microchip used in automated identification and data capture. In such cases, electronic devices use radio waves to track and identify items, such as pharmaceutical products, by assigning individual serial numbers to the containers holding each product. This technology may prevent the diversion or counterfeiting of drugs by allowing wholesalers and pharmacists to determine the identity and dosage of individual products.

A **taggant** is also a chemical or physical marker added to materials to allow various forms of testing. It is believed that they generally consist of microscopic particles built up in many layers, which are made of different materials. It is a somewhat secretive process, but products that may be affected include ink, paper, perfume, and medication. Taggants allow testing marked items for qualities such as lot number and concentration (to test for dilution, for example). In particular, taggants are known to be widely used in plastic, sheet and flexible explosives.

Explosive taggants

There are two types of taggant which can be added, one to help detect the presence of a bomb in, for example, airport screening of luggage; and the other to assist the police in finding the culprits after the detonation of such a bomb.

Detection taggants

These are volatile chemicals which will slowly evaporate from the explosive and can be detected in the atmosphere by either detection dogs or specialised machines. They are

intended to allow the presence of a bomb containing the explosive to be detected. Although various technologies exist to detect untagged explosives, detection taggants help to increase their reliability and their inclusion in explosives is mandatory in many countries, for example in the United States pursuant to the Antiterrorism Act of 1996.

There is a choice between four possible detection taggant chemicals which must be added to plastic explosives under the 1998 International Civil Aviation Organization's *Convention on the Marking of Explosives for the Purpose of Identification*. In the United States the marker is always 2,3-dimethyl-2,3-dinitrobutane, usually called DMDNB or DMNB. Dogs are very sensitive to it and can detect as little as 0.5 parts per billion in the air, as can specialised ion mobility spectrometers. Other taggants in use are ethylene glycol dinitrate, known as EGDN and used to mark Semtex, ortho-mononitrotoluene (o-MNT), and para-mononitrotoluene (p-MNT).

Identification (or post detonation) taggants

These are added to the explosive so that the manufacturer and batch number can be determined if it is used illegally. The taggant must survive the explosion and not be contaminated by the environment afterwards. Several different technologies have been tried, but probably the most common are microscopic polymer particles.

Whilst detection taggants are universally used, this is not the case with identification taggants; in particular there are arguments that there may be minimal benefit in practice to law enforcement agencies compared to the cost to industry of the taggant. One reason cited is that most terrorist attacks use homemade explosives, for instance in the 1993 World Trade Center bombing, and in the Oklahoma City and Omagh bombings. Contamination of the site is also cited as a problem, since countless different taggants might be present at a crime scene from, for example, explosives used to obtain the building materials.

Switzerland passed a law in 1980 requiring taggants in explosives manufactured there, and that the code must be changed every six months. So far it is the only country which requires identification taggants. Imported explosives must be tagged only if competing products are also manufactured in Switzerland.

Taggants for Brand Protection

When used as a chemical marker, taggants can be used for authentication of products and documents. Taggants are sometimes used by brand owners and governments to authenticate commonly counterfeited items. Taggants are integrated into the material of the item itself or into the packaging. Once integrated, the taggants can only be verified with specially engineered readers.

Benefits of using Taggants for Brand Protection

- Taggants are invisible to the naked eye

- Taggants can only be detected with specially-engineered equipment
- Taggant technology is extremely difficult to reverse engineer
- Once integrated into an item, taggants make the item permanently and cannot be removed.
- Many unique codes can be manufactured if desired
- The technology is one of the more cost-effective options available on the market for the purpose of brand protection

Common Taggant Anticounterfeiting Benefits of using Taggants for Brand Protection

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Common Taggant Anticounterfeiting Applications

- Tax Stamp authentication
- Banknote authentication
- Cigarette anticounterfeiting
- Alcohol anticounterfeiting
- Pharmaceutical Anticounterfeiting
- FMCG anticounterfeiting

Other goods that Use Taggant Technology for Anticounterfeiting

- Automotive parts
- Fuel
- Energy products

Target Acquisition Minefield Detection System

Target Acquisition Minefield Detection System (ASTAMIDS) is the latest weapon in the fight against improvised explosive devices (IED). It will provide a Unit of Action (UA) asset that can be used in Tactical Operations in day or night to detect and locate surface obstacles and recently buried minefields. ASTAMIDS is currently being tested in the MQ-8B Fire Scout unmanned aerial vehicle.

Detection methods

Coherent change detection

The ASTAMIDS detects improvised explosives and minefields using two techniques. The first technique used to find explosives is a process known as coherent change detection. Change detection compares two images for inconsistencies. To detect whether or not a change has occurred, two images are taken of the same scene, but at different times. These images are then geometrically registered so that the same target pixels in each image align. After the images are registered, they are checked pixel by pixel. Where a change has not occurred between the two images, the pixels remain the same. When the pixels are different, a change has occurred.

This technique is useful for detecting change, but it does not measure direction or the magnitude of change. One of the major issues in the change detection software is defining what a “significant” change is. Trees blowing in the wind will sometimes produce a change between the pixels of the two images. This is obviously not a significant change, but the system must be sensitive enough to detect small roadside bombs. These improvised explosives may create a smaller pixel change than trees on a windy day. This problem causes the mine detection algorithms to be extremely complex. The software must differentiate changes that do not pose a threat to changes that are likely to be a minefield or roadside bomb.

Tactical synthetic aperture radar

The other technique that helps the ASTAMIDS successfully detect minefields and road side bombs uses a combination of the Tactical Synthetic Aperture Radar ability to penetrate the ground and a group of Multi-Spectral Electro-Optical sensors that cover the visible and near-infrared (VNIR) and mid-wave infrared (MWIR) portions of the spectrum, as well as a target laser rangefinder and designator.

Once an IED is found using the change detection method, the laser rangefinder and designator flashes to the point where the change was detected. A seeker is then used to find the lasers pulse rate and guides the EO / IR sensors of the ASTAMIDS to the point. Now that the sensors know what point to scan, the mission specific hardware, software, and firmware components installed in the ASTAMIDS can successfully detect mines buried under the surface.

Chapter 10

Explosive Material

An **explosive material**, also called an **explosive**, is a substance that contains a great amount of stored energy that can produce an explosion, a sudden expansion of the material after initiation, usually accompanied by the production of light, heat, sound, and pressure. An **explosive charge** is a measured quantity of explosive material.

The energy stored in an explosive material may be

- chemical energy, such as nitroglycerine or grain dust
- pressurized compressed gas, such as a gas cylinder or aerosol can
- nuclear, such as fissile isotopes of uranium-235 and plutonium-239

Explosive materials may be categorized by the speed at which they expand. Materials that detonate (explode faster than the speed of sound) are said to be **high explosives** and materials that deflagrate are said to be **low explosives**. Explosives may also be categorized by their sensitivity. Sensitive materials that can be initiated by a relatively small amount of heat or pressure are primary explosives and materials that are relatively insensitive are secondary explosives.

Type of reaction

There are different reasons and conditions that make a material explosive. Explosive material is often classified by the type of reaction that takes place.

Chemical

An explosion is a type of spontaneous chemical reaction (once initiated) that is driven by both a large negative enthalpy change (great release of heat) and a large positive entropy change (great quantities of gases are released) in going from reactants to products, thereby constituting a very thermodynamically favorable process in addition to one that

propagates very rapidly. Thus, explosives are substances that contain a large amount of energy stored in chemical bonds. The energetic stability of the gaseous products and, hence, their generation comes from the formation of strongly bonded species like carbon monoxide, carbon dioxide, and (di)nitrogen, which contain strong double and triple bonds having bond strengths of nearly 1,000 kJ/mole. Consequently, most commercial explosives are organic compounds containing $-\text{NO}_2$, $-\text{ONO}_2$ and $-\text{NHNO}_2$ groups that when detonated release gases like the aforementioned ones (e.g., nitroglycerin, TNT, HMX, PETN, nitrocellulose).

Explosives are classified as low or high explosives according to their rates of burn: low explosives burn rapidly (or deflagrate), while high explosives detonate. While these definitions are distinct, the problem of precisely measuring rapid decomposition makes practical classification of explosives difficult.

Decomposition

The chemical decomposition of an explosive may take years, days, hours, or a fraction of a second. The slower processes of decomposition take place in storage and are of interest only from a stability standpoint. Of more interest are the two rapid forms of decomposition, deflagration and detonation.

Deflagration

In deflagration, the decomposition of the explosive material is propagated by a flame front, which moves slowly through the explosive material in contrast to detonation. Deflagration is a characteristic of low explosive material.

Detonation

This term is used to describe an explosive phenomenon whereby the decomposition is propagated by the explosive shock wave traversing the explosive material. The shock front is capable of passing through the high explosive material at great speeds, typically thousands of meters per second.

Exotic

In addition to chemical explosives, there exist varieties of more exotic explosive material, and theoretical methods of causing explosions. Examples include nuclear explosives, antimatter, and abruptly heating a substance to a plasma state with a high-intensity laser or electric arc.

Laser and arc heating are used in practice in laser detonators, exploding-bridgewire detonators, and exploding foil initiators, where a shock wave and then detonation in conventional chemical explosive material is created by laser or electric arc heating. Laser and electric energy are not currently practically used directly for the majority of the energy, only to initiate reactions.

Properties of explosive materials

To determine the suitability of an explosive substance for a particular use, its physical properties must first be investigated. The usefulness of an explosive can only be appreciated when the properties and the factors affecting them are fully understood. Some of the more important characteristics are discussed below:

Availability and cost

Availability and cost of explosives is determined by the availability of the raw materials and the cost, complexity, and safety of the manufacturing operations.

Sensitivity

Regarding an explosive, this refers to the ease with which it can be ignited or detonated—i.e., the amount and intensity of shock, friction, or heat that is required. When the term sensitivity is used, care must be taken to clarify what kind of sensitivity is under discussion. The relative sensitivity of a given explosive to impact may vary greatly from its sensitivity to friction or heat. Some of the test methods used to determine sensitivity are as follows:

- **Impact** Sensitivity is expressed in terms of the distance through which a standard weight must be dropped to cause the material to explode.
- **Friction** Sensitivity is expressed in terms of what occurs when a weighted pendulum scrapes across the material (snaps, crackles, ignites, and/or explodes).
- **Heat** Sensitivity is expressed in terms of the temperature at which flashing or explosion of the material occurs.

Sensitivity is an important consideration in selecting an explosive for a particular purpose. The explosive in an armor-piercing projectile must be relatively insensitive, or the shock of impact would cause it to detonate before it penetrated to the point desired. The explosive lenses around nuclear charges are also designed to be highly insensitive, to minimize the risk of accidental detonation.

Sensitivity to initiation

The index of the capacity of the explosive to be initiated into detonation in a sustained manner. It is defined by the power of the detonator which is certain to prime the explosive to a sustained and continuous detonation. Reference is made to the Sellier-Bellot scale that consists of a series of 10 detonators, from n. 1 to n. 10, each of which corresponds to an increasing charge weight. In practice most of the explosives on the market today are sensitive to the n. 8 detonator, where the charge corresponds to 2 grams of mercury fulminate.

Velocity of detonation

The velocity with which the reaction process propagates in the mass of the explosive. Most commercial mining explosives have detonation velocities ranging from 1800 m/s to 8000 m/s. Today, velocity of detonation can be measured with accuracy. Together with density it is an important element influencing the yield of the energy transmitted (for both, atmospheric overpressure and ground acceleration).

Stability

Stability is the ability of an explosive to be stored without deterioration.

The following factors affect the stability of an explosive:

- **Chemical constitution.** In the strictest technical sense, the word "stability" is a thermodynamic term referring to the energy of a substance relative to a reference state or to some other substance. However, in the context of explosives, stability is commonly used to refer to the ease of detonation, which is concerned with kinetics (i.e. the rate of decomposition). It is perhaps best, then, to differentiate between the terms thermodynamically stable and kinetically stable by referring to the latter as "inert." Contrarily, a kinetically unstable substance is said to be "labile." It is generally recognized that certain groups like nitro ($-\text{NO}_2$), nitrate ($-\text{ONO}_2$), and azide ($-\text{N}_3$), are intrinsically labile with respect to decomposition. Kinetically, there exists a low activation barrier to the decomposition reaction. Consequently, these compounds exhibit a high sensitivity to flame or mechanical shock. The chemical bonding in these compounds is characterized by being predominantly covalent in nature and thus they are not thermodynamically stabilized by a high ionic-lattice energy. Furthermore, they generally have positive enthalpies of formation and there is little mechanistic hindrance to internal molecular rearrangement to the more thermodynamically stable (more strongly bonded) decomposition products. For example, in lead azide, $\text{Pb}(\text{N}_3)_2$, the nitrogen atoms are already bonded to one another so there is relatively easy decomposition into Pb and N_2 .
- **Temperature of storage.** The rate of decomposition of explosives increases at higher temperatures. All of the standard military explosives may be considered to have a high degree of stability at temperatures of -10 to $+35$ °C, but each has a high temperature at which the rate of decomposition rapidly accelerates and stability is reduced. As a rule of thumb, most explosives become dangerously unstable at temperatures exceeding 70 °C.
- **Exposure to the sun.** If exposed to the ultraviolet rays of the sun, many explosive compounds that contain nitrogen groups will rapidly decompose, affecting their stability.
- **Electrical discharge.** Electrostatic or spark sensitivity to initiation is common to a number of explosives. Static or other electrical discharge may be sufficient to inspire detonation under some circumstances. As a result, the safe handling of

explosives and pyrotechnics almost always requires electrical grounding of the operator.

Power, performance, and strength

The term **power** or **performance** as applied to an explosive refers to its ability to do work. In practice it is defined as the explosive's ability to accomplish what is intended in the way of energy delivery (i.e., fragment projection, air blast, high-velocity jets, underwater shock and bubble energy, etc.). Explosive power or performance is evaluated by a tailored series of tests to assess the material for its intended use. Of the tests listed below, cylinder expansion and air-blast tests are common to most testing programs, and the others support specific applications.

- **Cylinder expansion test.** A standard amount of explosive is loaded into a long hollow cylinder, usually of copper, and detonated at one end. Data is collected concerning the rate of radial expansion of the cylinder and maximum cylinder wall velocity. This also establishes the Gurney energy or $2E$.
- **Cylinder fragmentation.** A standard steel cylinder is loaded with explosive and detonated in a sawdust pit. The fragments are collected and the size distribution analyzed.
- **Detonation pressure (Chapman-Jouguet condition).** Detonation pressure data derived from measurements of shock waves transmitted into water by the detonation of cylindrical explosive charges of a standard size.
- **Determination of critical diameter.** This test establishes the minimum physical size a charge of a specific explosive must be to sustain its own detonation wave. The procedure involves the detonation of a series of charges of different diameters until difficulty in detonation wave propagation is observed.
- **Infinite-diameter detonation velocity.** Detonation velocity is dependent on loading density (c), charge diameter, and grain size. The hydrodynamic theory of detonation used in predicting explosive phenomena does not include diameter of the charge, and therefore a detonation velocity, for an imaginary charge of Infinite diameter. This procedure requires a series of charges of the same density and physical structure, but different diameters, to be fired and the resulting detonation velocities extrapolated to predict the detonation velocity of a charge of infinite diameter.
- **Pressure versus scaled distance.** A charge of specific size is detonated and its pressure effects measured at a standard distance. The values obtained are compared with that for TNT.
- **Impulse versus scaled distance.** A charge of specific size is detonated and its impulse (the area under the pressure-time curve) measured versus distance. The results are tabulated and expressed in TNT equivalent.
- **Relative bubble energy (RBE).** A 5- to 50 kg charge is detonated in water and piezoelectric gauges measure peak pressure, time constant, impulse, and energy.

The RBE may be defined as K_x^3
 $RBE = K_s$

where K = bubble expansion period for experimental (x) or standard (s) charge.

Brisance

In addition to strength, explosives display a second characteristic, which is their shattering effect or brisance (from the French meaning to "break"), which is distinguished and separate from their total work capacity. This characteristic is of practical importance in determining the effectiveness of an explosion in fragmenting shells, bomb casings, grenades, and the like. The rapidity with which an explosive reaches its peak pressure (power) is a measure of its brisance. Brisance values are primarily employed in France and Russia.

The sand crush test is commonly employed to determine the relative brisance in comparison to TNT. No test is capable of directly comparing the explosive properties of two or more compounds; it is important to examine the data from several such tests (sand crush, trauzl, and so forth) in order to gauge relative brisance. True values for comparison require field experiments.

Density

Density of loading refers to the mass of an explosive per unit volume. Several methods of loading are available, including pellet loading, cast loading, and press loading; the one used is determined by the characteristics of the explosive. Dependent upon the method employed, an average density of the loaded charge can be obtained that is within 80–99% of the theoretical maximum density of the explosive. High load density can reduce sensitivity by making the mass more resistant to internal friction. However, if density is increased to the extent that individual crystals are crushed, the explosive may become more sensitive. Increased load density also permits the use of more explosive, thereby increasing the power of the warhead. It is possible to compress an explosive beyond a point of sensitivity, known also as "dead-pressing", in which the material is no longer capable of being reliably initiated, if at all.

Volatility

Volatility is the readiness with which a substance vaporizes. Excessive volatility often results in the development of pressure within rounds of ammunition and separation of mixtures into their constituents. Volatility affects the chemical composition of the explosive such that a marked reduction in stability may occur, which results in an increase in the danger of handling.

Hygroscopicity and water resistance

The introduction of water into an explosive is highly undesirable since it reduces the sensitivity, strength, and velocity of detonation of the explosive. Hygroscopicity is used as a measure of a material's moisture-absorbing tendencies. Moisture affects explosives adversely by acting as an inert material that absorbs heat when vaporized, and by acting

as a solvent medium that can cause undesired chemical reactions. Sensitivity, strength, and velocity of detonation are reduced by inert materials that reduce the continuity of the explosive mass. When the moisture content evaporates during detonation, cooling occurs, which reduces the temperature of reaction. Stability is also affected by the presence of moisture since moisture promotes decomposition of the explosive and, in addition, causes corrosion of the explosive's metal container.

Explosives considerably differ from one another as to their behavior in the presence of water. Gelatin dynamites containing nitroglycerine have a degree of water resistance. Explosives based on ammonium nitrate have little or no water resistance.

Toxicity

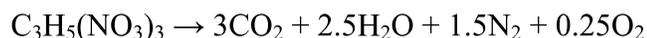
Due to their chemical structure, most explosives are toxic to some extent. Explosive product gases can also be toxic.

Explosive train

Another property of explosive material is where it exists in the explosive train of the device or system. An example of this is a pyrotechnic lead igniting a booster, which causes the main charge to detonate.

Volume of products of explosion

Avogadro's law states that equal volumes of all gases under the same conditions of temperature and pressure contain the same number of molecules, that is, the molar volume of one gas is equal to the molar volume of any other gas. The molar volume of any gas at 0°C and under normal atmospheric pressure is very nearly 22.4 liters. Thus, considering the nitroglycerin reaction,



the explosion of one mole of nitroglycerin produces 3 moles of CO₂, 2.5 moles of H₂O, 1.5 moles of N₂, and 0.25 mole of O₂, all in the gaseous state. Since a molar volume is the volume of one mole of gas, one mole of nitroglycerin produces 3 + 2.5 + 1.5 + 0.25 = 7.25 molar volumes of gas; and these molar volumes at 0°C and atmospheric pressure form an actual volume of 7.25 × 22.4 = 162.4 liters of gas.

Based upon this simple beginning, it can be seen that the volume of the products of explosion can be predicted for any quantity of the explosive. Further, by employing Charles' Law for perfect gases, the volume of the products of explosion may also be calculated for any given temperature. This law states that at a constant pressure a perfect gas expands 1/273.15 of its volume at 0 °C, for each degree Celsius of rise in temperature.

Therefore, at 15 °C (288.15 kelvin) the molar volume of an ideal gas is

$$V_{15} = 22.414 (288.15/273.15) = 23.64 \text{ liters per mole}$$

Thus, at 15 °C the volume of gas produced by the explosive decomposition of one mole of nitroglycerin becomes

$$V = (23.64 \text{ l/mol})(7.25 \text{ mol}) = 171.4 \text{ l}$$

Oxygen balance (OB% or Ω)

Oxygen balance is an expression that is used to indicate the degree to which an explosive can be oxidized. If an explosive molecule contains just enough oxygen to convert all of its carbon to carbon dioxide, all of its hydrogen to water, and all of its metal to metal oxide with no excess, the molecule is said to have a zero oxygen balance. The molecule is said to have a positive oxygen balance if it contains more oxygen than is needed and a negative oxygen balance if it contains less oxygen than is needed. The sensitivity, strength, and brisance of an explosive are all somewhat dependent upon oxygen balance and tend to approach their maximums as oxygen balance approaches zero.

Chemical composition

A chemical explosive may consist of either a chemically pure compound, such as nitroglycerin, or a mixture of a fuel and an oxidizer, such as black powder or grain dust and air.

Chemically pure compounds

Some chemical compounds are unstable in that, when shocked, they react, possibly to the point of detonation. Each molecule of the compound dissociates into two or more new molecules (generally gases) with the release of energy.

- **Nitroglycerin:** A highly unstable and sensitive liquid.
- **Acetone peroxide:** A very unstable white organic peroxide.
- **TNT:** Yellow insensitive crystals that can be melted and cast without detonation.
- **Nitrocellulose:** A nitrated polymer which can be a high or low explosive depending on nitration level and conditions.
- **RDX, PETN, HMX:** Very powerful explosives which can be used pure or in plastic explosives.
 - **C-4 (or Composition C-4):** An RDX plastic explosive plasticized to be adhesive and malleable.

The above compositions may describe the majority of the explosive material, but a practical explosive will often include small percentages of other materials. For example, dynamite is a mixture of highly sensitive nitroglycerin with sawdust, powdered silica, or most commonly diatomaceous earth, which act as stabilizers. Plastics and polymers may be added to bind powders of explosive compounds; waxes may be incorporated to make them safer to handle; aluminium powder may be introduced to increase total energy and

blast effects. Explosive compounds are also often "alloyed": HMX or RDX powders may be mixed (typically by melt-casting) with TNT to form Octol or Cyclotol.

Mixture of oxidizer and fuel

An oxidizer is a pure substance (molecule) that in a chemical reaction can contribute some atoms of one or more oxidizing elements, in which the fuel component of the explosive burns. On the simplest level, the oxidizer may itself be an oxidizing element, such as gaseous or liquid oxygen.

- **Black powder:** Potassium nitrate, charcoal and sulfur
- **Flash powder:** Fine metal powder (usually aluminium or magnesium) and a strong oxidizer (e.g. potassium chlorate or perchlorate).
- **Ammonal:** Ammonium nitrate and aluminium powder.
- **Armstrong's mixture:** Potassium chlorate and red phosphorus. This is a very sensitive mixture. It is a primary high explosive in which sulfur is substituted for some or all phosphorus to slightly decrease sensitivity.
- **Sprengel explosives:** A very general class incorporating any strong oxidizer and highly reactive fuel, although in practice the name most commonly was applied to mixtures of chlorates and nitroaromatics.
 - **ANFO:** Ammonium nitrate and fuel oil.
 - **Cheddites:** Chlorates or perchlorates and oil.
 - **Oxyliquits:** Mixtures of organic materials and liquid oxygen.
 - **Panclastites:** Mixtures of organic materials and dinitrogen tetroxide.

Classification of explosive materials

By sensitivity

Primary explosive

A **primary explosive** is an explosive that is extremely sensitive to stimuli such as impact, friction, heat, static electricity, or electromagnetic radiation. A relatively small amount of energy is required for initiation. As a very general rule, primary explosives are considered to be those compounds that are more sensitive than PETN. As a practical measure, primary explosives are sufficiently sensitive that they can be reliably initiated with a blow from a hammer; however, PETN can usually be initiated in this manner, so this is only a very broad guideline. Additionally, several compounds, such as nitrogen triiodide, are so sensitive that they cannot even be handled without detonating.

Primary explosives are often used in detonators or to trigger larger charges of less sensitive secondary explosives. Primary explosives are commonly used in blasting caps to translate a physical shock signal. In other situations, different signals such as electrical/physical shock, or in the case of laser detonation systems, light, are used to initiate an action, i.e., an explosion. A small quantity, usually milligrams, is sufficient to initiate a larger charge of explosive that is usually safer to handle.

Examples of primary high explosives are:

- Acetone peroxide
- Ammonium permanganate
- Azo-clathrates
- Copper acetylide
- Diazodinitrophenol
- Hexamethylene triperoxide diamine
- Lead azide
- Lead styphnate
- Lead picrate
- Mercury(II) fulminate
- Nitrogen trichloride
- Nitrogen triiodide
- Nitroglycerin
- Silver azide
- Silver acetylide
- Silver fulminate
- Sodium azide
- Tetacene
- Tetraamine copper complexes
- Tetrazoles

Secondary explosive

A **secondary explosive** is less sensitive than a primary explosive and require substantially more energy to be initiated. Because they are less sensitive they are usable in a wider variety of applications and are safer to handle and store. Secondary explosives are used in larger quantities in an explosive train and are usually initiated by a smaller quantity of a primary explosive.

Examples of secondary explosives include TNT and RDX.

Tertiary explosive

Tertiary explosives, also called **blasting agents**, are so insensitive to shock that they cannot be reliably detonated by practical quantities of primary explosive, and instead require an intermediate explosive booster of secondary explosive. These are primarily used in large-scale mining and construction operations, and in terrorism.

ANFO is an example of a tertiary explosive.

By velocity

Low explosives

Low explosives are compounds where the rate of decomposition proceeds through the material at less than the speed of sound. The decomposition is propagated by a flame front (deflagration) which travels much more slowly through the explosive material than a shock wave of a high explosive. Under normal conditions, low explosives undergo deflagration at rates that vary from a few centimeters per second to approximately 400 metres per second. It is possible for them to deflagrate very quickly, producing an effect similar to a detonation. This can happen under higher pressure or temperature, which usually occurs when ignited in a confined space.

A low explosive is usually a mixture of a combustible substance and an oxidant that decomposes rapidly (deflagration), however they burn slower than a high explosive which has an extremely fast burn rate.

Low explosives are normally employed as propellants. Included in this group are gun powders and light pyrotechnics, such as flares and fireworks.

High explosives

High explosives are explosive materials that detonate, meaning that the explosive shock front passes through the material at a supersonic speed. High explosives detonate with explosive velocity rates ranging from 3,000 to 9,000 meters per second. They are normally employed in mining, demolition, and military applications. They can be divided into two explosives classes differentiated by sensitivity: Primary explosive and secondary explosive. The term *high explosive* is in contrast to the term *low explosive*, which explodes (deflagrates) at a slower rate.

By composition

Priming composition

Priming compositions are primary explosives mixed with other compositions to control (lessen) the sensitivity of the mixture to the desired property.

For example, primary explosives are so sensitive that they need to be stored and shipped in a wet state to prevent accidental initiation.

By physical form

Explosives are often characterized by the physical form that the explosives are produced or used in. These use forms are commonly categorized as:

- Pressings

- Castings
- Plastic or polymer bonded
- Putties (AKA plastic explosives)
- Rubberized
- Extrudable
- Binary
- Blasting agents
- Slurries and gels
- Dynamites

Shipping label classifications

Shipping labels and tags may include both United Nations and national markings.

United Nations markings include numbered Hazard Class and Division (HC/D) codes and alphabetic Compatibility Group codes. Though the two are related, they are separate and distinct. Any Compatibility Group designator can be assigned to any Hazard Class and Division. An example of this hybrid marking would be a consumer firework, which is labeled as 1.4G or 1.4S.

Examples of national markings would include United States Department of Transportation (U.S. DOT) codes.

United Nations Organization (UNO) Hazard Class and Division (HC/D)



Explosives warning sign

The Hazard Class and Division (HC/D) is a numeric designator within a hazard class indicating the character, predominance of associated hazards, and potential for causing personnel casualties and property damage. It is an internationally accepted system that communicates the primary hazard associated with a substance using the minimum amount of markings.

Listed below are the Divisions for Class 1 (Explosives):

- **1.1 Mass Detonation Hazard.** With HC/D 1.1, it is expected that if one item in a container or pallet inadvertently detonates, the explosion will sympathetically detonate the surrounding items. The explosion could propagate to all or the majority of the items stored together causing a mass detonation. There will also be fragments from the item's casing and/or structures in the blast area.
- **1.2 Non-mass explosion, fragment-producing.** HC/D 1.2 is further divided into three subdivisions, HC/D 1.2.1, 1.2.2 and 1.2.3, to account for the magnitude of the effects of an explosion.
- **1.3 Mass fire, minor blast or fragment hazard.** Propellants and many of the pyrotechnic items fall into this category. If one item in a package or stack initiates, it will usually propagate to the other items creating a mass fire.
- **1.4 Moderate fire, no blast or fragment.** HC/D 1.4 items are listed in the table as explosives with no significant hazard. Most small arms and some pyrotechnic items fall into this category. If the energetic material in these items inadvertently initiates, most of the energy and fragments will be contained within the storage structure or the item containers themselves.
- **1.5 mass detonation hazard, very insensitive.**
- **1.6 detonation hazard without mass detonation hazard, extremely insensitive.**

Class 1 Compatibility Group

Compatibility Group codes are used to indicate storage compatibility for HC/D Class 1 (explosive) materials. Letters are used to designate 13 compatibility groups as follows.

A: Primary explosive substance (1.1A).

B: An article containing a primary explosive substance and not containing two or more effective protective features. Some articles, such as detonator assemblies for blasting and primers, cap-type, are included. (1.1B, 1.2B, 1.4B).

C: Propellant explosive substance or other deflagrating explosive substance or article containing such explosive substance (1.1C, 1.2C, 1.3C, 1.4C). These are bulk propellants, propelling charges, and devices containing propellants with or without means of ignition. Examples include single-, double-, triple-based, and composite propellants, solid propellant rocket motors and ammunition with inert projectiles.

D: Secondary detonating explosive substance or black powder or article containing a secondary detonating explosive substance, in each case without means of initiation and without a propelling charge, or article containing a primary explosive substance and containing two or more effective protective features. (1.1D, 1.2D, 1.4D, 1.5D).

E: Article containing a secondary detonating explosive substance without means of initiation, with a propelling charge (other than one containing flammable liquid, gel or hypergolic liquid) (1.1E, 1.2E, 1.4E).

F containing a secondary detonating explosive substance with its means of initiation, with a propelling charge (other than one containing flammable liquid, gel or hypergolic liquid) or without a propelling charge (1.1F, 1.2F, 1.3F, 1.4F).

G: Pyrotechnic substance or article containing a pyrotechnic substance, or article containing both an explosive substance and an illuminating, incendiary, tear-producing or smoke-producing substance (other than a water-activated article or one containing white phosphorus, phosphide or flammable liquid or gel or hypergolic liquid) (1.1G, 1.2G, 1.3G, 1.4G). Examples include Flares, signals, incendiary or illuminating ammunition and other smoke and tear producing devices.

H: Article containing both an explosive substance and white phosphorus (1.2H, 1.3H). These articles will spontaneously combust when exposed to the atmosphere.

J: Article containing both an explosive substance and flammable liquid or gel (1.1J, 1.2J, 1.3J). This excludes liquids or gels which are spontaneously flammable when exposed to water or the atmosphere, which belong in group H. Examples include liquid or gel filled incendiary ammunition, fuel-air explosive (FAE) devices, and flammable liquid fueled missiles.

K: Article containing both an explosive substance and a toxic chemical agent (1.2K, 1.3K)

L Explosive substance or article containing an explosive substance and presenting a special risk (e.g., due to water-activation or presence of hypergolic liquids, phosphides, or pyrophoric substances) needing isolation of each type (1.1L, 1.2L, 1.3L). Damaged or suspect ammunition of any group belongs in this group.

N: Articles containing only extremely insensitive detonating substances (1.6N).

S: Substance or article so packed or designed that any hazardous effects arising from accidental functioning are limited to the extent that they do not significantly hinder or prohibit fire fighting or other emergency response efforts in the immediate vicinity of the package (1.4S).

Legacy article contents

Contents below this heading have not been incorporated into the regrouped article.

Chemical explosives

Explosives usually have less potential energy than petroleum fuels, but their high rate of energy release produces a great blast pressure. TNT has a detonation velocity of 6,940 m/s compared to 1,680 m/s for the detonation of a pentane-air mixture, and the 0.34-m/s stoichiometric flame speed of gasoline combustion in air.

The properties of the explosive indicate the class into which it falls. In some cases explosives can be made to fall into either class by the conditions under which they are initiated. In sufficiently large quantities, almost all low explosives can undergo a Deflagration to Detonation Transition (DDT). For convenience, low and high explosives may be differentiated by the shipping and storage classes.

Chemical explosive reaction

A chemical explosive is a compound or mixture which, upon the application of heat or shock, decomposes or rearranges with extreme rapidity, yielding much gas and heat. Many substances not ordinarily classed as explosives may do one, or even two, of these things. For example, at high temperatures ($> 2000^{\circ}\text{C}$) a mixture of nitrogen and oxygen can be made to react with great rapidity and yield the gaseous product nitric oxide; yet the mixture is not an explosive since it does not evolve heat, but rather absorbs heat.



For a chemical to be an explosive, it must exhibit all of the following:

- Rapid expansion (i.e., rapid production of gases or rapid heating of surroundings)
- Evolution of heat
- Rapidity of reaction
- Initiation of reaction

Sensitiser

A sensitiser is a powdered or fine particulate material that is sometimes used to create voids that aid in the initiation or propagation of the detonation wave. It may be as high-tech as glass beads or as simple as seeds.

Measurement of chemical explosive reaction

The development of new and improved types of ammunition requires a continuous program of research and development. Adoption of an explosive for a particular use is based upon both proving ground and service tests. Before these tests, however, preliminary estimates of the characteristics of the explosive are made. The principles of thermochemistry are applied for this process.

Thermochemistry is concerned with the changes in internal energy, principally as heat, in chemical reactions. An explosion consists of a series of reactions, highly exothermic, involving decomposition of the ingredients and recombination to form the products of explosion. Energy changes in explosive reactions are calculated either from known chemical laws or by analysis of the products.

For most common reactions, tables based on previous investigations permit rapid calculation of energy changes. Products of an explosive remaining in a closed

calorimetric bomb (a constant-volume explosion) after cooling the bomb back to room temperature and pressure are rarely those present at the instant of maximum temperature and pressure. Since only the final products may be analyzed conveniently, indirect or theoretical methods are often used to determine the maximum temperature and pressure values.

Some of the important characteristics of an explosive that can be determined by such theoretical computations are:

- Oxygen balance
- Heat of explosion or reaction
- Volume of products of explosion
- Potential of the explosive

Balancing chemical explosion equations

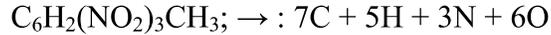
In order to assist in balancing chemical equations, an order of priorities is presented in table 1. Explosives containing C, H, O, and N and/or a metal will form the products of reaction in the priority sequence shown. Some observation you might want to make as you balance an equation:

- The progression is from top to bottom; you may skip steps that are not applicable, but you never back up.
- At each separate step there are never more than two compositions and two products.
- At the conclusion of the balancing, elemental nitrogen, oxygen, and hydrogen are always found in diatomic form.

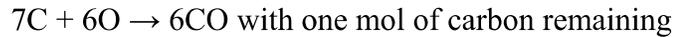
Table 1. Order of Priorities

| Priority | Composition of explosive | Products of decomposition | Phase of products |
|----------|----------------------------|---------------------------|-------------------|
| 1 | A metal and chlorine | Metallic chloride | Solid |
| 2 | Hydrogen and chlorine | HCl | Gas |
| 3 | A metal and oxygen | Metallic oxide | Solid |
| 4 | Carbon and oxygen | CO | Gas |
| 5 | Hydrogen and oxygen | H ₂ O | Gas |
| 6 | Carbon monoxide and oxygen | CO ₂ | Gas |
| 7 | Nitrogen | N ₂ | Gas |
| 8 | Excess oxygen | O ₂ | Gas |
| 9 | Excess hydrogen | H ₂ | Gas |
| 10 | Excess carbon | C | Solid |

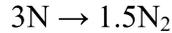
Example, TNT:



Using the order of priorities in table 1, priority 4 gives the first reaction products:



Next, since all the oxygen has been combined with the carbon to form CO, priority 7 results in:



Finally, priority 9 results in: $5\text{H} \rightarrow 2.5\text{H}_2$

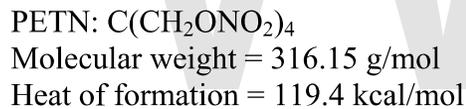
The balanced equation, showing the products of reaction resulting from the detonation of TNT is:



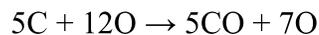
Notice that partial moles are permitted in these calculations. The number of moles of gas formed is 10. The product carbon is a solid.

Example of thermochemical calculations

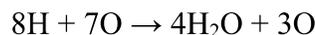
The PETN reaction will be examined as an example of thermo-chemical calculations.



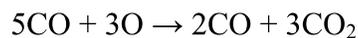
(1) Balance the chemical reaction equation. Using table 1, priority 4 gives the first reaction products:



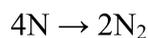
Next, the hydrogen combines with remaining oxygen:



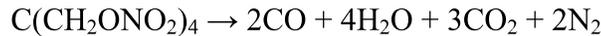
Then the remaining oxygen will combine with the CO to form CO and CO₂.



Finally the remaining nitrogen forms in its natural state (N₂).



The balanced reaction equation is:



(2) Determine the number of molar volumes of gas per mole. Since the molar volume of one gas is equal to the molar volume of any other gas, and since all the products of the PETN reaction are gaseous, the resulting number of molar volumes of gas (N_m) is:

$$N_m = 2 + 4 + 3 + 2 = 11 V_{\text{molar}}/\text{mol}$$

(3) Determine the potential (capacity for doing work). If the total heat liberated by an explosive under constant volume conditions (Q_m) is converted to the equivalent work units, the result is the potential of that explosive.

The heat liberated at constant volume (Q_{mv}) is equivalent to the heat liberated at constant pressure (Q_{mp}) plus that heat converted to work in expanding the surrounding medium. Hence, $Q_{mv} = Q_{mp} + \text{work (converted)}$.

a. $Q_{mp} = Q_{fi} \text{ (products)} - Q_{fk} \text{ (reactants)}$

where: Q_f = heat of formation (see table 1)

For the PETN reaction:

$$Q_{mp} = 2(26.343) + 4(57.81) + 3(94.39) - (119.4) = 447.87 \text{ kcal/mol}$$

(If the compound produced a metallic oxide, that heat of formation would be included in Q_{mp} .)

b. $\text{Work} = 0.572N_m = 0.572(11) = 6.292 \text{ kcal/mol}$

As previously stated, Q_{mv} converted to equivalent work units is taken as the potential of the explosive.

c. $\text{Potential } J = Q_{mv} (4.185 \times 10^6 \text{ kg})(\text{MW}) = 454.16 (4.185 \times 10^6) 316.15 = 6.01 \times 10^6 \text{ J kg}$

This product may then be used to find the relative strength (RS) of PETN, which is

d. $\text{RS} = \text{Pot (PETN)} = 6.01 \times 10^6 = 2.21 \text{ Pot (TNT)} 2.72 \times 10^6$

History

Though early thermal weapons, such as Greek fire, have existed since ancient times, the first widely used explosive in warfare and mining was black powder, invented in 9th century China. This material was sensitive to water, and evolved lots of dark smoke. During the 19th century black powder was replaced by nitroglycerine, nitrocellulose, smokeless powder, dynamite and gelignite (the two latter invented by Alfred Nobel). World War II saw an extensive use of new explosives. In turn, these have largely been replaced by modern explosives such as trinitrotoluene and C-4.

The increased availability of chemicals has allowed the construction of improvised explosive devices.