Detection of Improvised Explosives (IE) and Explosive Devices (IED)

A.V. Kuznetsov, O.I. Osetrov
V.G. Khlopin Radium Institute
194021 28, 2-j Murinski pr
St.-Petersburg
Russia

apl@atom.nw.ru

ABSTRACT

A brief description of existing and prospective techniques for detection of improvised explosives (IE) and improvised explosive devices (IED) is presented.

1.0 INTRODUCTION

Improvised explosive devices (IED) are devices, which contain at least one homemade component. IEDs can be divided into two classes:

- IEDs that contain industrially manufactured explosives. Such IEDs may differ from standard explosive devices by presence of homemade detonators, triggering mechanisms, etc.
- IEDs that contain improvised (homemade) explosives (IE). Such IEDs often also contain non-standard detonators etc.

Neutralization and disposal of IEDs is a difficult task:

- Design and construction of IED is unknown, therefore standard disposal methods, e.g. those used in demining, may be inapplicable. Before disposal of IEDs the sapper should use whatever methods are available to study its design; however one can never know in advance whether there is time for such a study (if, for example, the IED is equipped with a timer).
- The type, exact location and mass of the explosive charge may be difficult to determine by an external survey. Thus the chosen disposal method may turn to be inadequate.
- Detonators and triggering mechanisms of IEDs may be unreliable and can be initiated at an unpredictable time.
- IE used in IEDs may be very unstable, i.e. sensitive to external influences like shock, temperature, etc.

Kuznetsov, A.V.; Osetrov, O.I. (2007) Detection of Improvised Explosives (IE) and Explosive Devices (IED). In *Prediction and Detection of Improvised Explosive Devices (IED)* (pp. 14-1 – 14-16). Meeting Proceedings RTO-MP-SET-117, Paper 14. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int.

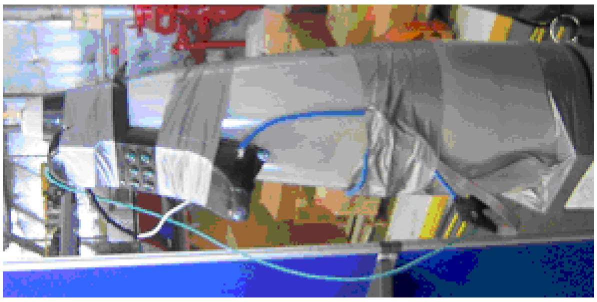

Figure 1. Components of an improvised detonator produced from a shell fuse.

2.0 IMPROVISED EXPLOSIVES AND EXPLOSIVE DEVICES

High explosives that are most often used in IEDs can be split into five categories:

- Industrially produced military explosives (TNT, C4 etc.). Such explosives are a) highly stable and have strictly regulated sensitivity to external influences; b) have rather high density (>1.5 g/cm^3), which is higher than the density of most common organic substances.
- Industrially produced explosives used in civil applications (e.g. grammonite 50/50, ammonite) sometimes are a mechanical mixture of military ES (like TNT) with substances like ammonium. Such explosives a) are highly explosive, approaching by this parameter military ES; b) usually have densities in the range 0.9-1.2 g/cm^3, which is close to densities of common organic substances; c) often contain marking agent, which facilitates detection of such ES by vapour analysis techniques.
- Explosives prepared from easily available materials and used in civilian applications (igdanites, ammonals, etc.) Such explosives a) are easy to manufacture on the spot; b) components are cheap and available; c) are rather highly explosive (e.g. explosive capacity of igdanites is half of that of TNT); d) have average density in the range 0.8-1.1 g/cm^3, which is close to the density of common organic substances; e) have rather large minimum detonating mass (more than 1 kg; smaller amounts often do not produce stable shock waves); f) are often tightly packed to prevent evaporation of liquid components and to increase their shelf life.
- Improvised (homemade) explosives used by terrorists who have access to military explosives (for example, the so-called “Chechen mix”: ammoniac saltpetre, sugar, aluminium powder, and RDX). Such explosives have average density in the range 0.8-1.1 g/cm^3, which is close to that of common organic substances.
- Improvised explosives that are made from widely available components (TATP, HMTD, etc.). Such explosives a) are cheap; b) have small minimal detonating mass (few grams) making possible production of IEDs of widely varying explosive power; c) have average density 0.9-1.2 g/cm^3, like common organic substances; d) are instable and unpredictable, sometimes detonate spontaneously during storage; e) often are tightly packed (e.g. highly volatile TATP is usually sealed by paraffin to prevent evaporation and to prolong shelf life). Less volatile HMTD is sealed in a similar way to prevent its interaction with air moisture, which makes it too unstable; f) some IE (like TATP) do not contain nitrogen. Such IEDs are particularly difficult to detect: while industrially-produced explosives are stable and require a detonator, many IEDs with unstable explosives can be initiated without a detonator – e.g. by an open fire from a lighter. Lack of detonator makes detection of such IEDs by their X-ray images very difficult.

3.0 DETECTION OF IE AND IED

Detection of IED is complicated by the following factors.

- It is impossible to foresee in advance where the IED will be found. Since the suspected IED with unknown triggering mechanism cannot be touched, the detection and disposal equipment must be moved to the site. Thus, mobile equipment must be used to detect IEDs.
- The IED can be placed near the wall, in the corner or between some obstacles, so the detection systems should work with one-side access to the suspicious object.
- Environmental conditions where the IED is found are unpredictable, so the detection equipment must work both indoor and outdoor, in summer and in winter, etc.

One can split all IED detection techniques into three groups:

- Methods of detection of non-explosive components of IED (detonators, triggering mechanisms, metallic shells, electronic circuits, etc.)
- Methods of detection of vapours or traces of explosive substances (either standard of improvised).
- Methods of detection of bulk quantities of ES (the explosive charge itself).

4.0 DETECTION OF NON-EXPLOSIVE COMPONENTS OF IED

Most common detection methods are:

- portable single-energy x-ray systems;
- non-linear junction detectors (NLJD).

4.1 X-rays

Portable single-energy x-ray systems are used to determine the construction of the found IED. Advantages of such installations are:

- high penetrating ability (2-3 cm of steel);
- high spatial resolution (10-20μm), allowing detailed image of the IED.

However, such x-ray systems require access from two sides to the examined object, and they cannot distinguish between types of materials, and thus cannot distinguish between a real IED and a dummy.

4.2 Non-linear junction detectors

Non-Linear Junction Detectors (NLJD) are used to detect junctions between metals and/or semiconductors, which can be part of the IED triggering and control mechanism (see Figure 2). NLJD can be used for standoff detection of radio-controlled IEDs. This method is:

- high speed (works in real time);
- standoff (detection range – tens of meters).

However, it does not distinguish between circuits that are part of the IED mechanism and those that are part of common electronic equipment (such as mobile phones), producing too many false alarms.

Figure 2. Non-linear junction detector NR900EMS.

5.0 DETECTION OF VAPOURS AND TRACES OF EXPLOSIVES

Various explosives have different volatility. Volatility is characterized by the pressure of saturated vapours near the surface of the explosive, and is usually expressed as relative concentration of molecules of ES and molecules of air in the considered volume in e.g. particles per trillion (ppt).

Table 1. Vapour pressure for some explosives at 25^{o}C.

	Nitroglycerine	TNT	PETN	RDX
Pressure, ppt	4.1×10^{5} ppt	7.7×10^{3} ppt	18 ppt	6.0 ppt

Table 1 lists vapour pressures for some explosives at temperature 25^{o}C. Modern equipment can detect vapours at levels of few or even fraction of ppt. However concentration of ES vapours inside the detection device is by many orders of magnitude lower than the pressure of saturated vapours on the ES surface. The vapour pressure is equal to the saturated pressure value only very close to the surface of the explosives: even at distances of several centimetres it drops drastically due to mixing with the air. Vapour pressure drops if the IED is sealed (which is almost always the case) and additionally packed in a bag (frequently so). It can further drop at low temperatures (concentration of TNT vapours drop by a factor of two when temperature drops by 5^{o}C, so at about 5-7^{o}C detection of TNT vapours becomes problematic), or in presence of strong wind.

To increase vapour concentration inside the detection device special pre-concentrators are used, which pump through air and absorb ES molecules on special material.

Devices for vapour analysis can also be used to analyse traces of ES. In this case the surface of the suspicious object is wiped by a special napkin, which is then placed in the detection device, and molecules are carried to the detector by a stream of carrier gas.

Modern vapour detectors can reliable detect ES with vapour pressure in the range 10^{5}-10^{6} ppt, for example, compounds based on nitroglycerine (dynamites). Detection of ES with vapour pressure in the range 10^{3}-10^{5} ppt (e.g. TNT) is now at the limit of the existing equipment. Detection of ES with vapour pressure less than 10^{3} ppt (RDX, PETN, C4) cannot be currently done without lengthy pre-concentration phase.

When vapour detectors are used to detect trace of ES, they can detect such traces at picogram level. RDX, PETN, C4 and most of other industrial and military ES can be found by these methods.

Vapour detection is currently done using biological, chemical and electrochemical sensors.

6.0 BIOLOGICAL SENSORS.

The following biological sensors are currently used for ES detection: dogs, rats, bees, antibodies.

Dogs and antibodies can work in large cities, while rats and bees are used for detection of land mines in countryside.

Dogs are capable of finding many industrially produced ES. E.g. US Ministry of Defence trained dogs to detect nine types of explosives.

Techniques based on antibodies use specific property of some protein molecules to selectively react with certain substance, for example TNT. Antibodies are placed on the surface of a quartz crystal, which is a part of a microbalance system. When certain substance is present, antibodies join with its molecules and leave the surface of the crystal, and the resulting reduction of weight is measured by measuring frequency shift of the crystal. The technique is used for finding vapours of industrially produced military ES: TNT, PETN, and RDX.

The main advantage of biosensors is the significant practical experience of their application (dogs). The main disadvantage is the limited number of detected ES. While a very wide variety of both industrial and improvised explosives can be used in IEDs, dogs are typically trained to find only a limited number of ES. Applicability of antibodies to detection of IE has not been proved so far.

7.0 CHEMICAL AND ELECTROCHEMICAL METHODS

The following chemical and electrochemical methods are used for detection of vapours and traces of ES:

- ion drift spectroscopy;
- ion field spectrometry;
- mass-spectrometry;
- thermo-redox technology;
- gas chromatography.

In the ion drift spectroscopy method the air containing ES vapours is pumped into the device and ionised there by a source of beta-radiation. The ionised air then drifts in an external electric field to a collector. Lighter ions (for example, nitrogen and oxygen) have high mobility, therefore they quickly reach the collector; heavier ions (for example, molecules of ES) have smaller mobility and move to the collector longer. Thus, by measuring the drift time it is possible to distinguish between molecules with different mobility. Advantage of the method is its speed (measurements take few seconds), which allows one to use the device for real-time analysis. Disadvantage of the method is its low selectivity. Mobility of ions is not an individual characteristic of a substance, it depends in a complex way on mass, size, charge and other characteristics of an ion; therefore different substances might have similar ion mobility. As a result, such devices produce significant number of false alarms, some of them due to widespread domestic chemicals – gasoline, perfumes, oils, etc.

In the ion field spectrometry separation of ions is achieved by using a special filter consisting of two perpendicular electric fields. The obtained characteristic is the same as in the ion drift spectroscopy – mobility of ions – therefore both methods have similar advantages and disadvantages.

In the mass-spectrometry method ES vapours are detected by magnetic filtration of charged ions; ions are identified by their charge-to-weight ratio. The method has very high selectivity, and can analyse both ES vapours and traces. However, mass-spectrometry devices include high-vacuum components, and are thus stationary installations. Recently, portable systems based on this method have been developed, but they are not specifically focused on detection of ES but are rather intended for general detection of dangerous organic substances in air, soil and water.

Thermo-redox (reduction-oxidation) technology is based on thermal decomposition of ES and subsequent reduction of NO_2 groups. The method is intended for detection of vapours, and is capable of determining presence of NO_2 molecules, which are part of most industrially produced ES. The method cannot detect non-nitrogen ES (like TATP), and also can not distinguish ES from other chemical substances that contain NO_2 groups.

In the gas chromatography method the carrier gas containing vapours of ES moves inside a capillary, whose internal surface is covered by a sorbent. Different impurities reach the end of the capillary at different times depending on the relation between solubility of the impurity in the sorbent and in the carrier gas. Advantage of the method is its high selectivity, a wide number of detected ES (nitro ethers, TNT, PETN, RDX, etc.), and also the possibility to use it both for vapour and trace analysis. However, applicability of the method to the detection of improvised explosives has not been investigated so far.

The chemiluminescence method allows one to detect NO_2 groups, which are often part of explosives' molecules. Analysed vapours are mixed up with ozone (O_3), and the chemical reaction is accompanied with the excitation of NO_2 molecules. Characteristic infrared light emitted by these NO_2 molecules is then detected. Since this method cannot distinguish ES from other chemical substances containing NO_2 groups, it is often preceded by another device. Another disadvantage of the method is its inability to detect non-nitrogen explosives.

Electron capture detector can detect vapours of substances that strongly capture thermal electrons. Since many common substances (e.g. atmospheric oxygen, hydrocarbons etc.) also have the ability to capture electrons, the method is usually used in combination with some other technique.

In the surface acoustic wave method an output stream from a chromatographic column is blown over a special piezoelectric crystal, and vapours condense on the crystal's surface. The change of the resonant frequency of the crystal depends on the mass and elasticity of the condensed material.

The last three methods (chemiluminescence, electron capture, surface acoustic wave) can be regarded as different realizations of the gas chromatography method, and have the same advantages and disadvantages.

Methods of detection of ES vapours and traces possess the following important advantages:

- significant experience of using these methods (dogs, gas chromatography);
- high selectivity in some cases (e.g. for gas chromatography);
- a wide range of detected ES;
- methods can be used both to investigate objects and to examine people.

However, the following difficulties are associated with vapour and trace detection methods:

- Vapour detection can find only those ES that have high enough vapour pressure: (nitro ethers, TNT), while ES like RDX, PETN, C4 can be detected only by their traces left on the surface. Good quality packing may leave no detectable traces.
- IE like TATP and HMTD are often sealed, which makes detection of their vapours practically impossible.
- Some IEDs (such as igdanites) are difficult to detect even by trace detection, since their components like diesel fuel or nitric fertilizer are very widespread, and their traces can be found on many “innocent” objects.
- Vapour and trace detection methods cannot determine the mass of the explosive, and in many cases (e.g. strong wind) cannot determine even the location of the explosive.

8.0 DETECTION OF BULK EXPLOSIVES

Direct detection of macroscopic quantities of ES is usually done by so-called active methods. The object is probed by some kind of penetrating radiation – radio waves, microwaves, X-rays, gamma-rays or neutrons – and ES are found by their characteristic response to the probing radiation.

One can mention the following groups of bulk explosives’ detection methods:

- x-ray methods;
- electromagnetic methods;
- “neutron in, gamma out” methods;
- other nuclear and non-nuclear methods (neutron and gamma-radiography, acoustic, infra-red, etc.)

8.1 X-ray methods

In x-ray systems the object is probed by x-rays with characteristic energy around 100 keV, and transmitted and/or reflected x-rays are detected.

X-ray methods produce very high-resolution images (1-20 μm) of the internal structure of the object. Sometimes, density and effective nuclear charge (Z_{eff}) of objects are also obtained.

The following variants of x-ray method are presently used:

- devices with single-energy transmitted x-rays;
- devices with two-energy x-rays;
- computer tomographs (CT);
- devices working on backscattered x-rays.

Modern single-energy x-ray devices can be made small and portable, however they can not determine either density or the effective charge of the inspected objects, and are not suitable for identification of ES. These devices are used only to visualize the internal mechanism of IEDs, as described above.

Two-energy x-ray devices provide both image and the effective charge of substances inside the inspected volume. Such devices allow one to divide all found substances into 3 groups: substances with small Z_{eff} (organics, explosives, etc.), substances with average Z_{eff}, and substances with large Z_{eff} (metals). A disadvantage of such devices is the need of two-side access to the inspected object.

X-ray computer tomographs allow one to obtain the image, effective nuclear charge, and density of substances. They also require access from several sides, so their use for detection of IEDs is very limited.

Backscattering x-ray systems provide effective nuclear charge of substances and can be used with one-side access to the object.

X-ray methods have following general advantages:

- High penetrating ability (2-3 cm of iron or 7-8 cm of aluminium).
- Very high-resolution images. (1-20µm).
- Some selectivity by effective nuclear charge (Z_{eff}) and density.
- Can be used both for objects and on people.

The major drawback of all x-ray methods is their inability to identify many commercially produced civil explosives and many IE used by terrorists (e.g. TATP, HMTD), since these ES have average densities in the range 0.8-1.2 g/cm^3, which coincides with the density range of most common organic substances and water. For example, industrially produced ammonite has Z_{eff} = 7.21, density 0.97 g/cm^3, and is practically undistinguishable from water (Z_{eff} = 7.22, density 1.0 g/cm^3) by X-ray-based methods.

8.2 Electromagnetic methods

In electromagnetic methods the object is probed by electromagnetic waves with frequencies from fractions of MHz up to hundreds of GHz. The following groups of methods suitable for ES detection can be mentioned:

- magnetic resonance methods;
- quadruple resonance methods;
- subsurface radars.

8.2.1 Magnetic resonance methods

In nuclear magnetic resonance (MR) methods the inspected object is placed into a strong homogeneous magnetic field and irradiated with probing electromagnetic radiation in the frequency range of several MHz. Transitions of atoms between discrete energy level in the external magnetic field absorb part of the energy of the probing wave. Frequencies of MR are specific enough for some chemical substances, and their measurements can be used for identification of ES. The method has the following disadvantages:

- MR devices are bulky and heavy, since a strong homogeneous magnetic field in large-enough volume must be created.
- Access to the object from several sides is needed (in many existing MR systems the sample is placed inside a magnetic coil).
- Strong external magnetic field can damage magnetic appliances.

8.2.2 Quadruple resonance methods

Nuclear quadruple resonance (QR) method allows one to detect NO_2 groups, which are part of the majority of ES. The object is irradiated with pulsed probing electromagnetic radiation. If the frequency of the probing radiation coincides with the resonant frequency of the substances' molecules, the energy of the probing radiation is efficiently absorbed. After the probing radiation is switched off the molecules return to their initial state, emitting characteristic electromagnetic waves. Resonant frequencies of various nitrogen-containing substances lie in the range from 0.5 MHz to 6 MHz.

Advantages of the QR method are:

- Selectivity (QR frequencies for different chemical substances and for different ES are unique).
- Possibility to detect a wide variety of industrially produced military and civil ES (RDX, PETN and explosives made on their basis).
- Possibility to create systems with one-side access to the object.

Disadvantages of QR are:

- Varying sensitivity to different types of ES (e.g. high sensitivity to RDX, low sensitivity to TNT).
- Existing QR systems are single-channel, i.e. during tens of seconds-long measurement cycle only one type of ES can be detected. Thus, the total inspection time depends on the number of explosives to be found, and may be quite long.
- The method cannot detect non-nitrogen ES (e.g. TATP).
- Electromagnetic waves cannot penetrate even thin layers of metallic coating.
- Sensitivity of QR to IE is not currently known.
- A large number of explosives, which can potentially be used in an IED, would require too lengthy measurements with a single-channel QR system.

8.2.3 Radars

Radars probe the inspected object with electromagnetic waves (e.g. microwaves), and the analysis of scattered waves allow one to obtain an image of concealed object and to determine its dielectric characteristics.

Work on such radar, which uses continuous microwaves with stepped frequency change, is currently carried out at Radium institute[1]. This approach has some technical advantages over classical pulsed systems, and allows automatic identification of metallic and dielectric objects.

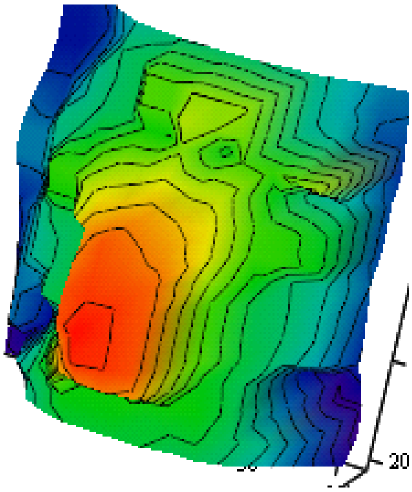

Figure 3. Example of an image by a microwave radar of explosives concealed under clothing on human body.

The method produces images of a concealed object with resolution 1-2 cm, works with one-side access, can be standoff and real-time. However, it cannot determine the type of the found explosive.

Electromagnetic methods are completely safe for objects and people. However, they cannot find explosives wrapped in metallic coating, but can detect presence of such coating, even if it is a very thin metallic film.

8.2.4 Terahertz

Recent advances in ultra-fast pulsed laser technology have led to generation and detection of broad bandwidth Terahertz (1 THz = 10^{12} Hz) radiation. Apart from producing very high-resolution images, terahertz systems can be selective, since many explosives have unique THz spectral properties when compared to the surrounding materials.

The main advantage of the terahertz technology is very high image resolution and selectivity to explosives. The main disadvantage is high attenuation in wet environments, so that even relatively thin layers of wet clothing or high air humidity can become a serious obstacle for terahertz-range electromagnetic waves.

8.3 "Neutron in, gamma out" methods

The idea of "neutron in, gamma out" methods is to irradiate inspected object with neutrons and to detect secondary gamma-radiation, which is produced in interactions between neutrons and nuclei of chemical elements constituting the object. Each chemical element is characterized by a unique “gamma-signature”, so analysis of gamma-ray spectra yields chemical composition of the object.

The following features of chemical composition distinguish ES from non-explosives:

- Most ES contain oxygen, carbon and hydrogen.
- Overwhelming majority of ES contain nitrogen.
- Partial densities of oxygen, carbon and nitrogen in ES exceed those of non-explosive organic substances.

- Partial density of oxygen in ES is higher than that of carbon (O > C), which ensured the so-called oxygen balance condition needed for detonation.
- If ES contains nitrogen its partial density is not less 0.2 from that of oxygen (O/N < 5).

Figure 4 shows partial densities O/N and C/N for widespread explosives and common non-explosive materials.

Figure 5 shows partial density of carbon+oxygen versus partial density of oxygen for military explosives, non-nitrogen ES (TATP), common non-explosive materials and food.

One can see, that by measuring partial densities of carbon, oxygen and nitrogen one can distinguish between industrial and homemade explosives on one side and non-explosive substances on the other.

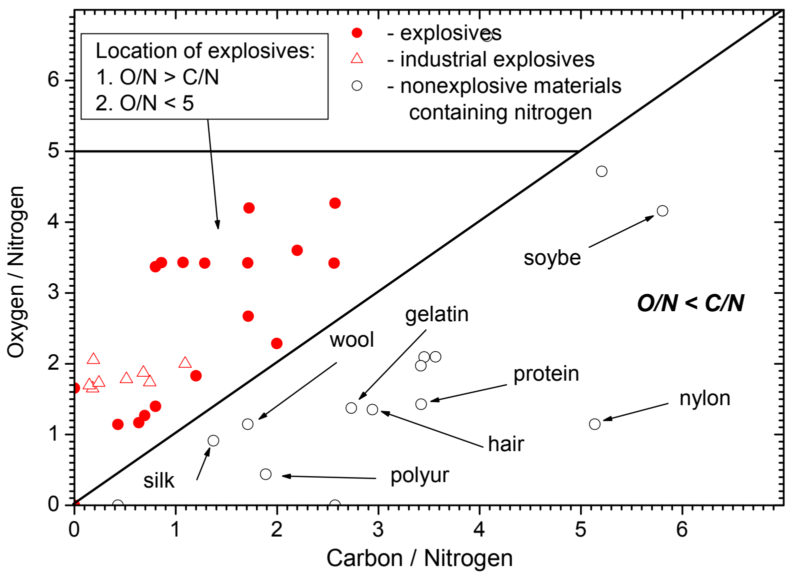

Figure 4. Ratios between partial densities of oxygen, carbon and nitrogen for military ES, civil ES, common non-explosive materials and food.

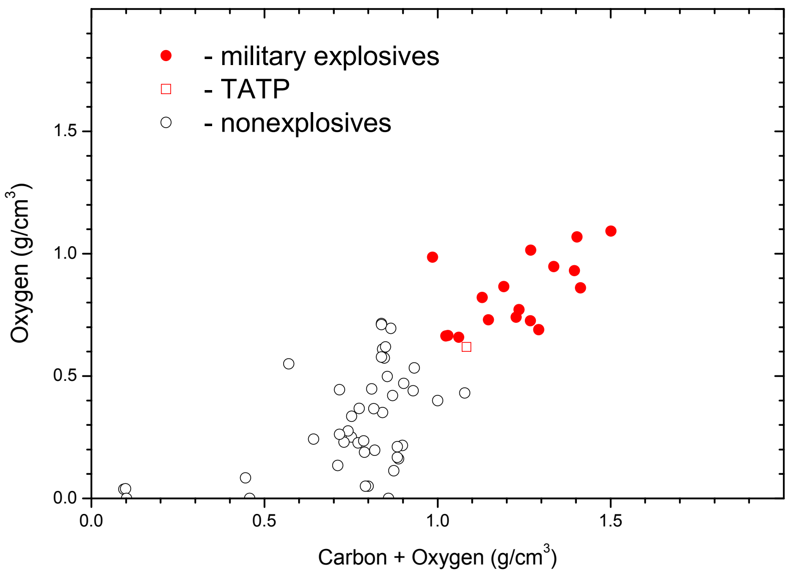

Figure 5. Partial density of carbon+oxygen versus partial density of oxygen for military explosives, non-nitrogen ES (TATP), common non-explosive materials and food.

At present the following “neutron in, gamma out” methods are used for detection of ES:

- Thermal Neutron Analysis (TNA)
- Fast Neutron Analysis (FNA)
- Pulsed Fast Neutron Analysis (PFNA)
- Pulsed Fast and Thermal Neutron Analysis (PFTNA)
- Nanosecond Neutron Analysis/ Associated Particles Technique (NNA/APT).

8.3.1 Thermal Neutron Analysis (TNA)

In TNA the object is irradiated by slow (thermal) neutrons, which produce gamma-rays in reactions of radiative capture with the nuclei of chemical elements constituting ES. E.g. reactions with nitrogen produce 10.8 MeV gamma-rays, on hydrogen –2.23 MeV gamma-rays, on chlorine –7.50 MeV and 6.11 MeV gamma-rays, etc. Gamma-rays are then detected by gamma-detector.

Thermal neutrons cannot be produced directly; they are obtained by slowing down fast neutrons using hydrogen-containing thermalizer. Fast neutrons are produced either by spontaneous source or in a D-D neutron generator.

The main advantage of the method is its relative simplicity and one-side access.

The disadvantages of TNA are:

- It finds only ES containing nitrogen.
- It cannot distinguish nitrogen in ES from that in non-explosive substances (wool, leather etc), which leads to a large number of false alarms.
- A massive thermalizer is needed, increasing the weight and dimensions of the TNA device.

8.3.2 Fast Neutron Analysis (FNA)

In FNA the object is irradiated with a continuous flux of fast neutrons with energy above 8 MeV, which produce characteristic gamma-rays in inelastic scattering reactions with nuclei of carbon, oxygen and nitrogen (4.44 MeV gamma-rays for carbon, 6.13 MeV and other lines for oxygen, 5.1 MeV and other lines for nitrogen). Detection of these secondary gamma-rays provides information about relative concentrations of carbon, oxygen and nitrogen in molecules of the inspected substance.

Advantages of FNA method are:

- selectivity, since the method is sensitive to almost all elements constituting explosives;
- one-side access to the inspected object.

The main disadvantages are:

- The method does not have spatial resolution, so if there are two objects close to each other, it will give their average chemical composition, which is related in an unknown way to the chemical composition of ES. Thus, FNA is suitable only for inspection of large homogeneous objects.
- High level of gamma-ray background leads to the low effect/noise ratio and therefore to long measurement times.

8.3.3 Pulsed Fast Neutron Analysis (PFNA)

PFNA is similar to FNA, but uses pulsed neutron flux (with pulse duration of several nanoseconds) to irradiate the inspected object. This allows one to use time of flight information to determine the location of ES inside the inspected volume. By using collimators for the neutron beam one can get a 3D distribution of carbon, oxygen and nitrogen in the investigated object.

Advantages of PFNA are:

- Highly informative and reliable method.
- Low level of gamma-background, since gamma-rays are measured only between the neutron pulses.

However, in order to have nanosecond neutron beams a PFNA device must use large particles accelerators, which are bulky and expensive.

8.3.4 Pulsed Fast and Thermal Neutron Analysis (PFTNA)

PFTNA is a combination FNA and TNA. The object is irradiated by a pulsed neutron flux (pulse duration tens of microseconds) from a D-T neutron generator equipped with a thermalizer. During the neutron pulse the system measures gamma-rays formed in inelastic scattering of 14 MeV neutrons on carbon and oxygen (FNA), and between neutron pulses – gamma-rays formed in capture reactions of thermalized neutrons with nuclei of nitrogen, hydrogen and chlorine. Thus, PFTNA is sensitive to a larger number of elements than FNA or TNA separately, which leads to its higher reliability.

Advantages of PFTNA are:

- High reliability and informativity.
- PFTNA device can be made mobile, since portable neutron generators with 10-20 μs pulses are produced commercially.
- Work with one-side access to the object.

However, like both TNA and FNA, PFTNA does not have spatial resolution and has rather low effect/noise ratio. In practice PFTNA has been only applied for detection of land mines in homogeneous soil.

8.3.5 Nanosecond Neutron Analysis / Associated Particles Technique (NNA/APT)

Nanosecond Neutron Analysis / Associated Particles Technique (NNA/APT) uses the fact, that in d(t,α)n reaction, which is used to produce fast neutrons in portable neutron generators, mono-energetic neutrons ($E \approx 14$ MeV) and alpha-particles ($E \approx 3$ MeV) are emitted simultaneously in opposite directions. If a position-sensitive alpha-particles detector is placed close to the target of the neutron generator, then each detected alpha-particle "tags" the corresponding neutron, so its time of emission and direction are known. All secondary gamma-rays, that are produced in inelastic scattering of fast neutrons on nuclei of carbon, oxygen, nitrogen, aluminium and many other light chemical elements, must reach the gamma-detector within very narrow (few nanoseconds) time intervals determined mostly by the time of flight of fast neutrons to the object. Background gamma-rays that are not correlated in time with "tagged" neutrons are rejected by the data acquisition system. Use of position sensitivity of the alpha-detector and time-of-flight analysis allow one to obtain three-dimensional spatial distribution of chemical elements in the examined object[2].

[2] *More details about NNA are given in the article by D. Vakhtin et al. in this volume.*

Figure 6. SENNA – portable sensor for explosives' detection based on Nanosecond Neutron Analysis.

Advantages of NNA/APT are:

- Very high reliability and selectivity, since the method is sensitive to all elements constituting ES, possesses spatial resolution, and allows one to obtain three-dimensional distributions of chemical elements in the examined volume.
- Portable devices can be created, since portable neutron generators with associated particle detectors are now commercially available.
- One-side access to the inspected object.

8.3.6 General advantages and disadvantages of "neutron in, gamma out" methods

The important advantage of all "neutron in, gamma out" methods is their high penetrating ability and informativity. The main disadvantage is that they cannot be used on people.

8.4 Other methods

Among other methods, that are not described in this article, one can mention metal detectors, gamma-ray and neutron backscattering and radiography, acoustic sensors, passive infra-red sensors and many other techniques, that are still to be evaluated for the task of detection of IE and IED.

9.0 CONCLUSIONS

Detection of IE and IED is a difficult task, because of a wide variety of explosive substances and triggering mechanisms that can be used by terrorists. Applicability of many existing methods to detection of IE has not been investigated.

In case of IED detection direct detection of bulk explosive charge is preferable compared to trace and vapour detection, since it provides immediate information about location of the explosive charge, and possibly type of the explosive and its mass estimation.

For inspection of people electromagnetic methods may be the best choice, since they work remotely and are safe for humans and electrical appliances.

Exact location, shape, mass and type of the explosive charge must be determined before disarming an IED. X-ray (and possible radar) images can be very useful in determining the degree of threat posed by an IED.

Vapour detectors are the most effective tools for conducting general monitoring of large areas over extended periods of time.

When suspicious objects are inspected, nuclear-based methods may provide the required information about chemical composition, location and mass of the explosive charge.

10.0 REFERENCES:

[1] D.W. Hannum, J.E.Parmeter, Survey of Commercially Available Explosives Detection Technologies and Equipment, written for The National Law Enforcement and Corrections Technology Center, a Program of the National Institute of Justice, National Institute of Justice, September 1998, NCJ 171133.

[2] Bruschini, "Commercial System for Direct Detection of Explosives (for Explosive Ordnance Disposal Tasks) ", École Polytechnique Fédérale de Lausanne (EPFL) and Vrije Universiteit Brussel (VUB), February 2001.

[3] Proc. of the NATO ARW #977941 " Detection of explosives and land mines: methods and field experience", St.-Petersburg, Russia, 11 – 14 September 2001. H.Schubert, A. Kuznetsov (eds.), NATO Science Series, Kluwer Academic Publishers, (2002).

[4] Proc. of the NATO ARW #979920 " Detection of bulk explosives: advanced techniques against terrorism ", St.-Petersburg, Russia, 16 – 21 June 2003. H.Schubert, A.Kuznetsov (eds.), NATO Science Series, Kluwer Academic Publishers, (2004)

[5] C. L. Rhykerd, D. W. Hannum, D. W. Murray, J. E. Parmeter, Guide for the Selection of Commercial Explosives Detection Systems for Law Enforcement Applications, NIJ Guide 100-99, National Institute of Justice, Office of Science and Technology, Washington, DC 20531, September 1999, NCJ 178913.

[6] A.V. Kuznetsov et al., Combined Sensor for Detection of Explosives Based on Timed Neutron Source and Continuous Microwaves. " 5th International Symposium on Technology and the Mine Problem " that took place on Monterey, California, USA, April 21-25, 2002.

[7] "Advanced Technology for Contraband Detection", Compiled and Edited by Tsahi Gozani, SAIC, March 1992.

[8] The EXPLODET project. // M.Cinausero (ed.) Progress Report 2000, DFPD 1/NP/10, March 2001.

[9] "Associated particle imaging (API)", Report of Bechtel Nevada (BN) Special Technologies Laboratory (STL), USA, DOE/NV11718-223, UC-700, May 1998.

[10] A. V. Kuznetsov, A. V. Evsenin, I. Yu. Gorshkov, O. I. Osetrov, D. N. Vakhtin. Detection of buried explosives using portable neutron sources with nanosecond timing. Applied Radiation and Isotopes, Vol. 61, Issue 1, p. 51, (2004)