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Detection of Dangerous Materials and Illicit Objects in Cargoes and Baggage: Current Tools, Existing Problems and Possible Solutions

Yuri Melnikov, Petr Avtonomov, Valeria Kornienko, and Yuri Olshansky

Abstract

The paper is devoted to reviewing the existing means of detecting the transportation of dangerous materials and illicit objects. We analyse the currently available systems, the physical background of the corresponding techniques, and their advantages and limitations. Our purpose is to provide a broad overview of the possibilities in this field and to present our vision of what is the most appropriate response to the challenges of the modern world with respect to the increasing threat of terrorist attacks and illicit transportation of explosives, weapons, Special Nuclear Materials, and illicit narcotic drugs. To meet this objective, we compare various techniques, discuss how they correspond to the current needs, and propose a possible solution to the existing serious problems.

KEYWORDS: detection, explosoves, special nuclear materials, illicit drugs, neutron analysis, integrated systems

1. INTRODUCTION AND PROBLEM STATEMENT

Terrorist attacks have nowadays become a serious threat, and this threat only continues to grow. Attempts can be made to load weapons, explosives materials and Special Nuclear Materials (weapons-grade uranium and plutonium) onto an aircraft or ship for the purpose of transporting them to another destination in a concealed manner among personal baggage or unaccompanied cargo (for example, hidden in a large sea cargo container).

According to the Security and Accountability for Every (SAFE) Port Act in 2006, every sea port connected with the USA must check 100% of the cargo for explosive content. However, the practical implementation of the corresponding security measures at the international level raises problems. The main criticism is the high cost. In particular, the US ports received in 2007 and 2008 $210 million annually to finance security measures. One can identify the following major problems concerning seaports' security:

- All of the existing imaging systems give no definite answer for at least 5% of the cargoes under inspection. Currently, strictly following the SAFE Port Act would demand the manual inspection of containers, which is not completely reliable and very expensive, as it demands the extra involvement of qualified personnel in intensive container traffic and essentially slows down the inspection procedure. Therefore, any decrease in the amount of cargo demanding manual inspection may have an essential commercial impact (about $100 per container according to the Massachusetts Institute of Technology Report ESD-WP-2007-05, "Barriers to the Success of 100% Maritime Cargo Container Scanning" http://esd.mit.edu/WPS/2007/esd-wp-2007-05.pdf).
- Conventional systems do not allow the reliable automatic detection of radioactive material, while the international regulations (especially in the USA) are deeply concerned about this subject. The tightest corresponding current standard is ANSI N42.38-2006 – American National Standard Performance Criteria for Spectroscopy-Based Portal Monitors Used for Homeland Security http://standards.ieee.org/getN42/download/N42.38-2006.pdf, which has been adopted by the Institute of Electrical and Electronic Engineers (IEEE);
- No system able to detect Special Nuclear Materials (Highly Enriched Uranium and Weapons-Grade Plutonium) masked in a sophisticated way or hidden in the middle of big maritime containers in an amount less than 5 kg is available so far ["Detection of special nuclear material in cargo containers using neutron interrogation", Report of Lawrence Livermore National Laboratory UCRL-ID-155315];

- Conventional systems are vulnerable to false alarms, which cause time delays and the additional involvement of personnel in cargo and baggage inspection;
- There is no integrated system allowing the simultaneous detection of all types of weapons and dangerous materials. Currently, in order to perform such an inspection, it is necessary to use different types of equipment in sequence, which is an expensive and slow process.
- The conventional procedure includes the selection of suspicious cargo via indirect methods (documentation checks, intelligence service information) which are insufficiently reliable. For the technical reasons listed above (the absence of the proper equipment), only a small percentage of the selected cargos (which are selected in a relatively arbitrary manner in any case) is sent for additional inspection (for explosive and special nuclear materials).

As far as we know, currently, in the world market, there are no systems that provide a comprehensive solution to the above mentioned problems, possibly due to the physical limitations of the techniques underlying the conventional inspection systems, as well as the absence, so far, of an integrated approach which would provide compensation for these limitations and drawbacks.

2. EXPLOSIVES DETECTION

2.1. Properties of explosives

Despite the long list of terrorists' potential instruments (biological, chemical, radioactive, explosive materials), the detection of explosives has always been one of the main priorities, because explosives:

- are most frequently used as a terrorist attack instrument;
- can be relatively easily bought or produced from the available components;
- can be relatively easily transported to a target place;
- are relatively difficult to detect;
- can be relatively easily prepared for the "operation mode".

The functional components of a bomb (control system, detonator, explosive charge) can be identified by their shape. Such detection is traditionally performed by X-ray detection systems. However, plastic and liquid explosives do not have any specific shape and can be detected by their chemical contents. Table

1 below summarises some of the physical and chemical properties of basic explosives (data of Yinon (1999) and Rhykerd et al. (1999)).

Name	Molecular weight	C	H	N	O	Density, g/cm^3
TNT	227.13	7	5	3	6	1.65
RDX	222.26	3	6	6	6	1.83
HMX	296.16	4	8	8	8	1.96
Tetryl	287.15	7	5	5	8	1.73
PETN	316.2	5	8	4	12	1.78
NG	227.09	3	5	3	9	1.59
EGDN	152.1	2	4	2	6	1.49
AN	80.05	-	4	2	3	1.59
TATP	222.23	9	18	-	6	1.2
DNB	168.11	6	4	2	4	1.58
Picric acid	229.12	6	3	3	7	1.76

Table 1. Properties of basic explosives

All high explosives contain inside the molecule the oxygen necessary for the explosive reaction, with the most important oxygen carriers being organic nitro compounds, nitrates, chlorates and perchlorates. Nitrogen is also contained in the majority of the explosives listed above. Explosives are therefore composed of Carbon (C), Hydrogen (H), Nitrogen (N) and Oxygen (O) (with the few exceptions listed above), and many other organic compounds. The elemental ratios for some common basic explosives are reported by Yinon (1999) and Rhykerd et al. (1999)).

2.2. Explosives detection technologies

The non-invasive control of explosives and nuclear materials in baggage and cargo containers is based on several physical methods which can be, to some extent, classified within several groups, which we discuss below.

2.2.1. X-ray detection technologies

2.2.1.1. Background

Basic methods for the detection of dangerous objects using X-ray and Gamma-ray scanning were elaborated in the 1970s. Modern X-ray equipment is able to provide images with good resolution and penetration depth. However, X-ray inspection may fail to detect several kinds of explosives and plastic weapons, as well as liquid explosives and shielded dangerous materials. Weapons and explosives may also be masked using other objects and materials with a high density. The efficiency of the X-ray inspection depends on the solution of the operator. However, the attention of the operator is essentially decreased after a rather short time period (about 20 mins). To increase the level of security, X-ray inspection is combined with the manual inspection of baggage, including the random manual inspection of unsuspicious objects.

The application of X-ray techniques for the detection of explosives is based on the difference in density between explosives and civil materials with a similar atomic number (Z). The majority of the most widely used explosives have a density exceeding 1.4 g/cm^3. The simultaneous registration of the density distribution and the distribution of the average atomic number Z in the object under inspection allows the detection of hidden explosives with a relatively low level of false alarms. Therefore, X-ray TV systems with proper hardware and software tools for information processing are considered nowadays as the fastest, most cost effective tools for explosives detection.

The progress in the development of such systems during the last few years has been relatively impressive. As stated by Wilke (2005) and Wood (2005), the main trend is the development of systems that are able to detect explosives automatically, without the involvement of an operator.

Currently used X-ray inspection methods and X-ray TV equipment are discussed below.

2.2.1.2. X-ray transmission radiography

Standard (transmission) X-ray machines have been used for quite a long time, but as *systems more to detect weapons and clues to the explosive device* such as switches, detonators, wires, etc., *than the explosive itself* . Standard airport X-ray machines operate with electron energies of 120 keV impinging on tungsten targets, and the resulting X-ray beam has the characteristic energy of tungsten (~60keV). Higher energy machines should be capable of penetrating a few cm (2-3) of steel, and even more.

2.2.1.3. X-ray backscattering

Backscattering X-ray systems produce an image from X-rays that are scattered back from the screened object towards the source (not only transmitted as in the standard machines described above). Quantitatively, a measure of the backscattered X-rays, together with the standard absorption measurement, provides information which can help in *separating the effects of density and effective atomic number* Z_{eff}, in order to identify high density, low Z_{eff} material (the signature of explosives).

2.2.1.4. Dual energy X-ray systems

Dual energy X-ray systems yield superior material discrimination through the comparison of the attenuation of X-ray beams at two energies.

However, the result still depends essentially on the qualification of the operator, as the reliability of the automatic detection is insufficient. The current equipment effectively detects cold weapons, fire guns and unmasked explosives. However, the practice has shown that even very experienced operators experience difficulty in detecting plastic explosives [see Zhengrong et al. (2006)].

2.2.1.5. X-ray computer tomography

The further development of X-ray detection systems has been related to computer tomography (CT), which is an even more sophisticated X-ray technique in which cross sectional images ("slices") of an object are numerically reconstructed from X-ray projections at various angles around the object. These cross-sectional images can be combined to produce a three dimensional image (as in medical CAT scans). Modern computer tomography involving two X-ray sources allows not only the reconstruction of 3D images of the objects in baggage, but also shows the space distribution of the density and atomic number Z in the baggage [see http://www.airport-suppliers.com/supplier/Analogic_Corporation/]

However, despite the successful application of computer tomography for the inspection of hand luggage and small-size baggage, so far, no such systems have been developed that are suitable for the detection of explosives and nuclear materials in cargo containers. The reason is that the later task demands high-resolution detectors, powerful X-ray sources and highly efficient computational hardware and software allow very fast data processing.

2.2.2. Neutron technologies

2.2.2.1. Background

Neutron based inspection systems can detect a wide variety of substances of importance for different purposes, from national security threats (e.g., nuclear material, explosives, narcotics) to customs duties, shipment control and validation, and for the protection of the environment. The inspection is generally founded on the nuclear interactions of the neutrons with the various nuclides presented and the detection of the resultant characteristic emissions.

The penetrability of fast neutrons as probes and the gamma rays and fission neutrons as signatures make neutron interrogation applicable for large conveyances, such as cars, trucks and marine containers. It also allows their employment in the detection of shielded explosives [Carasco et al. (2008)]. The neutron-based techniques can be used in a variety of scenarios and operational modes. They can be used as stand-alones to undertake complete scans of objects such as vehicles, or for spot-checks to clear (or validate) the alarms indicated by another inspection system, such as high energy x-ray radiography [Obhoda et al. (2010)].

2.2.2.2. Thermal neutron analysis (TNA)

The basis for the technique called thermal-neutron analysis (TNA) is the detection of gamma rays from thermal neutrons captured in nitrogen. The detecting emission has a specific very-high-energy 10.8 MeV, which makes it possible to distinguish nitrogen in the presence of many other perturbing materials.

While there are other possible reactions, using thermal neutrons on nitrogen does not require an accelerator. Thermal neutrons can be generated with a radioisotope or a small accelerator, applying a moderator for energy adjustment. Therefore, systems based on thermal neutrons are comparatively small in size and require less shielding.

2.2.2.3. Fast Neutron Analysis (FNA)

Fast Neutron Analysis is based on the interaction of fast neutrons, mostly via inelastic neutron scattering, with the elements of interest, principally, the carbon, nitrogen and oxygen of the explosives.

By detecting and measuring a range of the outgoing gamma rays, it is possible to calculate the elemental proportions – how much of each element (C, N, O) is present with respect to the others – and this permits the determination of the type of substance under analysis. FNA is usually far more complex and expensive than TNA. The resulting spectra can indeed be quite complex, as numerous nuclear levels are often excited, and there is also a complex spectral background.

2.2.2.4. Pulsed Fast Neutron Analysis (PFNA)

Pulsed operations allow the use of timing information which can be useful in reducing the influence of background radiation from neutron interactions. Pulsed operations are particularly interesting when using *very short fast neutron pulses* (typically nanosecond wide, 10^{-9} sec).

To date, this technique has required rather large installations to produce a neutron beam with the required characteristics, combined with the need for fast electronics and highly sensitive and discriminating detectors.

2.2.2.5. Pulsed Fast-Thermal Neutron Analysis (PFTNA)

Pulsed Fast Thermal Neutron Analysis represents yet another form of neutron based explosive detection system. The PFTNA setup utilized pulses of fast neutrons with microsecond pauses in between and is capable of measuring gamma rays resulting from both fast and thermal neutron reactions.

2.2.2.6. Associated Particle Technique (APT)

Associated Particles Imaging technique involves "tagging" the primary neutron by the associated alpha particles that are produced through a deuterium-tritium (DT) fusion reaction in an electronic neutron generator. This method can utilize the Time of Light technique by measuring the time of alpha particles' detection and accepting for material content identification only those gamma-rays that coincide with "tagged" neutrons.

2.2.2.7. Neutron Resonance Radiography (NRR)

Fast Neutron Resonance Radiography (NRR) has been suggested for the detection of explosives and drugs in passenger suitcases. With the NRR method, fast neutron radiographic images taken at different neutron energies are used for calculating the elemental mapping of hydrogen, carbon, nitrogen, oxygen, and the sum of other elements. Thus, explosives and drugs can be located and identified by their characteristic elemental composition.

2.2.3. Explosive Trace Detectors

Explosive Trace Detection (ETD) is the detection of the presence of the constituent elements of explosive materials by collecting and analyzing trace molecular evidence from the examined object and its environment. To pinpoint the existence and identity of an explosive material using the trace detection method, the detector must first collect a microscopic residue of the explosive compound, either in vapour or in particulate form (or both).

Currently, many trace detection systems have been developed and are deployed (e.g. gas chromotographs, various spectrometers and their combinations). This is a rapidly evolving area and new techniques are constantly being introduced.

There are some scarcely avoidable problems associated with ETD technologies, including:

- Labour intensive (cost) technology;

• An inability to detect sealed explosives;
• An inability to detect weapons.

2.2.4. Nuclear Quadruple Resonance (NQR)

The basic radio frequency technique used for the detection of explosives is Nuclear Quadrupole Resonance (NQR) [Itozaki and Ota (2008)]. The basic principle of NQR is the same as that of Magnetic Resonance Imaging (MRI), employed in the medical field. The Radio Frequency (RF) wave that is irradiated and absorbed by the nuclear spin is then re-emitted when the nuclei returns to its previous steady state direction. The frequencies of this emission are specific to different materials, so the nature and amount of the explosive or other material (i.e. drugs) can be determined.

NQR technology demonstrates many advantages, such as low cost, human independent operation and the absence of any ionizing radiation, but it can detect only crystalline structured explosives and is sensitive to background radio interference.

Recently [Espy et al.(2010)], the technique of Ultra-Low Field Magnetic Resonance Imaging, that is able to detect liquid explosives, was introduced but a technological transition between medical and security applications is still required.

2.2.5. Nuclear Resonance Fluorescence (NRF)

The NRF technique [Bertozzi and Ledoux (2009)] is based on the excitation of the energy levels of the atoms of the explosive material. This causes re-scattering at frequencies specific to given isotopes. This method is very fresh and it is premature to discuss its advantages and drawbacks. However, one should note that its success depends essentially on the progress in the development of detection systems. Namely, high-resolution (with respect to narrow fluorescent lines in the interval 2 – 10 MeV) detectors are required. Currently, this is possible only at the laboratory level, where stable broad-spectrum gamma-ray sources and high resolution expensive cryogenic cooling detectors are available.

3. DETECTION OF SPECIAL NUCLEAR MATERIALS (SNM)

3.1. Special Nuclear Materials Detection Task

Isotopes U-235 and Pu-239 are defined in the Atomic Energy Act of 1954 as Special Nuclear Materials. Natural uranium contains 99.3% of U-238 and 0.7% of U-235. If it is enriched to 20% of U-235, it is defined as Highly Enriched

Uranium (HEU). In nuclear weapons, uranium enriched to 90% of U-235 is usually used. Weapons-grade plutonium (WGPu) is also a mixture of isotopes containing at least 93% Pu-293. In order to produce one unit of a nuclear weapon, it is necessary to have 26 kg of HEU or 5 kg of WGPu. These weights are equivalent to volumes of 11 cm^3 and 6 cm^3 correspondingly [Medalia (2009)].

The international smuggling of weapons grade nuclear material presents a significant security challenge. Between January 1993 and December 2003, the International Atomic Energy Agency reported 182 confirmed incidents involved nuclear material, with 18 incidents involving HEU or WGPu. [Orlov (2004)].The proliferation of nuclear weapons can take place through the borders at ports and airports, via road passengers and through the postal system.

The main difficulty with the detection of Special Nuclear Materials is related to HEU, as its radioactivity is very low. U-235 is the only isotope suitable for the production of nuclear weapons that is available in nature in sufficient amounts.

The relatively low radiation energy and high density of an HEU device make it strongly self-shielding. An HEU's typical tenth value layer (TVL or the thickness of material that attenuates a given type of radiation by a factor of ten) is about 0.3 cm, and the size of the smallest HEU sphere that can be used for an explosion ranges from 10 to about 38 cm. In other words, one can only observe the radiation from a very thin shell of the HEU; all other parts are self-shielded. The radioactivity of HEU is very low. The principal gamma ray emission of U-235 is 185 keV and it is very easily attenuated by a fully load cargo container. The neutron emission is also negligible ~ 0.006 n/s per kg [see LBNL_Nuclear_Science_Division, "Isotope Explorer", 2003, http://ie.lbl.gov/ensdf/ and LBNL_Nuclear_Science_Division, "Table of Isotopes", 2003, Lawrence Berkeley National Laboratory, website, http://ie.lbl.gov/toi/].

The big concern is the possibility of smuggling SNM in large maritime containers with sufficient shielding by lead, which could be a most threatening scenario for world commercial flow.

3.2. Techniques for SNM detection

3.2.1. Passive methods of radiation monitoring

There is various equipment available for the detection of radiological and nuclear threats using a passive method of radiation detection – registration of the gamma and neutron radiation.

The technology for gamma ray detection includes plastic scintillation detectors; scintillation detectors based on sodium iodide crystals and cooled semiconductor germanium detectors. All of those detection technologies register gamma rays as a function of gamma ray energy with different resolutions. The better accuracy of gamma ray energy measurement provides the better identification of radioactive sources.

Radiation pagers are an example of a cheap, lightweight solution that can detect an elevated level of radiation but do not posses isotope identification capabilities.

Radiation portal monitors are in wide use at border checkpoints. Many of them use

PVT plastic scintillator detectors and cannot identify the radiation source. The more advanced type of such equipment exploits sodium iodide detectors and has sufficient energy resolution but experiences difficulties in differentiating close energy lines and registers weak signals in noisy environments. Usually, they can recognize the radiation signatures of benign materials, thus reducing the false alarm rate.

Radiation isotope identifiers use high purity germanium detectors. They can identify a radioisotope by its gamma spectrum, as germanium detectors possess very high energy resolution and can determinate energy peaks precisely, but cannot be applied for container inspection, as they have short range of radiation detection.

Considering the problem of Special Nuclear Material detection, neither of the devices described above can solve it reliably. The weak radiation signature of SNM, especially in the case of fully loaded containers or lead shielding, would be strongly attenuated and undistinguishable. Increasing the sensitivity of passive detectors would require an increased inspection time and inevitably lead to a high false alarm rate.

3.2.2. High energy X-rays

High-energy X-rays that are capable of penetrating thick cargo containers (with a penetration of up to 430 mm, and 17 inches of steel penetration) are now widely being used for contraband detection in seaports, airports, and at land border crossings.

High energy radiography equipment utilizes a highly radioactive gamma ray source like cobalt-60 or cesium 137, or bremsstrahlung X-rays from a linear accelerator (with energy 2.5 – 6 MeV) that are capable of passing through loaded maritime containers and producing radiographic image of its content. Nevertheless, those systems cannot automatically differentiate between threats and benign materials.

Recently, Dual High Energy X-ray systems have been proposed for the detection of Special Nuclear Material in cargo containers. They use one or two linear accelerators to generate 6-MeV electrons, X-rays with energies from 0 to 6 MeV and, in the same manner, X-rays with energies from 0 to 9 MeV. Photons of two different energy levels interact with matter differently. The high Z materials are much more opaque to 9 MeV photons (and interact more strongly with nuclear atoms) than to 6 MeV photons, so high Z materials can be recognized. Such systems have a threshold of about Z>72, which includes tungsten, gold, lead, uranium, and plutonium. Then, a special algorithm calculates the size and Z of individual objects and, based on that data, determines alarm events.

3.2.3. The Photonuclear reaction method

High-energy X-ray systems could also exploit the characteristic of U-235 and Pu-239: they fuse when struck by photons with energy above approximately 5.6 MeV. The resulting fission products decay over many seconds, producing prompt and delayed neutrons and gamma rays, which are gathered and analyzed for SNM detection and identification. The irradiated high-energy X-rays may thus be used to detect high-Z material in general and SNM in particular. Several prototypes of dual energy radiography systems with an ability to detect SNM via the photonuclear reaction method have been developed but still remain far from being implemented as a commercial solution.

3.2.4. Neutron activation for SNM detection

Special Nuclear Materials can be reliably detected by fission unique signatures induced by probing neutrons. Those signatures include prompt and delayed neutrons and prompt and delayed gamma rays, and have continued energy spectra. They can be distinguished from the background as they possess a specific energy range and temporal due away features. The developed laboratory prototype for a scanning system based on neutron interrogation showed promising results for SNM detection in cargo containers [see Report of Lawrence Livermore National Laboratory UCRL-ID-155315.].

3.2.5. Muon Tomography

Muon is a heavy subatomic particle that is generated when a cosmic ray strikes an atom in the upper atmosphere. Most muons travel at a relativistic speed of over 95% of the speed of light. They are highly penetrating. For example, they can penetrate 1.3 m of lead, 15 m of water or tens of meters of rock and other matter before attenuating as a result of absorption or deflection by other atoms. About 10,000 muons reach every square meter of the earth's surface per minute.

Muon tomography (MT) measures the muon's trajectories before and after it penetrates the investigated object. It defines the angle of muon deflection and the point of deflection, then integrates data from numerous muon trajectories in order to form a three-dimensional image of the container based on the density and Z of its contents.

The laboratory pilot tests of MT have shown that this technology is still too immature for full scale implementation. The list of revealed problems includes the time required for adequately resolving the investigated content image and the limited material identification ability.

3.2.6. Nuclear Resonance Fluorescence

Nuclear resonance fluorescence uses photons to excite the nucleus and measures the characteristic gamma radiation that is then emitted when de-excited. The de-excitation structure is unique to the target nucleus, so this technique provides excellent elemental/isotopic identification. The detection of the high-energy characteristic lines of gamma emissions will require a high-resolution detector, such as an HPGe detector. The source of the incident photons is typically bremsstrahlung radiation.

NRF systems were proposed for SNM detection and explosive detection (as mentioned above) but the technology requires further experimentation in the laboratory.

4. ILLICIT DRUGS DETECTION

To conquer international illicit drugs trafficking, finding a tool for the reliable detection of narcotic drugs is vital. A list of controlled narcotics is regularly published by the International Narcotic Control Board [see List of Narcotic Drugs under International Control 48th edition, December 2008 http://www.incb.org/incb/en/yellow_list.html].

The technologies described below are aimed at the detection of some common narcotic drugs, like heroin and cocaine, and their modification.

4.1. Neutron analysis for narcotic drugs

Neutron analysis uses the elemental composition of drugs, particularly the C/O ratio, to distinguish them from other materials. Table 2 shows the elemental composition of drugs, the selected materials and the differences in their atomic ratios [data by Vourvopolus and Thornton (1995)].

Materials	Elemental Weight (%)					Atomic Ratios	
	H	C	N	O	Cl	C/O	N/H
Sugar	6.5	42.0	0	51.5	0	1.1	-
Coffee	6.7	49.9	2.6	36.7	0.01	1.8	0.03
Rice	7.4	39.1	1.1	51.8	0	1.0	0.01
Heroin	6.3	68.2	3.8	21.7	0	4.2	0.04
Heroin-HCI	5.7	62.1	3.4	19.7	8.6	4.2	0.04
Cocaine	6.9	67.3	4.6	21.1	0	4.2	0.05
Cocaine-HCI	6.5	60.0	4.1	18.8	10.3	4.2	0.05

Table 2: Elemental composition of drugs and selected materials

Strellis and Gozani (2005) reported that SeaPODDS (Sea Portable Drug Detection System) can facilitate the detection of threats, such as drugs, explosives, nuclear weapons and chemical weapons, lying behind hidden compartments in maritime vessels. The detection of the gamma ray signature of hydrogen, nitrogen and chlorine in narcotics has been demonstrated for maritime vessels using thermal neutron analysis and fast neutron analysis. The portable detection system has proved able to detect heroin hydrochloride, cocaine hydrochloride, heroin, and cocaine.

4.2. Trace detection methods for narcotic drugs

There are several trace detection technologies that are successfully employed in narcotics detection and are particularly useful for hand inspection and forensic analysis.

Ion mass spectrometry instrumentation is commercially available for the detection of drugs. Ions produced through atmospheric pressure ionization are pulsed through an electric field to a collector, during which the time of flight is measured.

The advantages offered by this technique are its portability, selectivity, high sensitivity (parts per billion) and low cost. The detector could potentially be used as a stand alone sensor or an online system [see Luong et al. (2005)].

Ryder (2005) mentioned that Surface Enhanced Raman Scattering (SERS) can detect drugs and narcotics molecules with very high sensitivity. Research on the identification of cocaine, heroin, amphetamines, 1, 4-benzodiazepines and various metabolites of the drugs has been conducted using SERS with high performance liquid chromatography.

Singh (2009) show the comparative status of the current narcotics detection technologies. One can conclude thatt the market implementation of bulk detection technologies for narcotic drugs detection will become an important area in the near future.

It is expected that the main drivers for the R&D of narcotics detection equipment would be the cost of sensors, devices and instrumentation, the portability and sensitivity of the whole system, as well as the detection time and safety. Evidently, a systematic layer approach that will include a drugs detection solution even for drugs concealed inside the investigated object will benefit public security.

5. POSSIBLE SOLUTION – INTEGRATED SYSTEM FOR THE DETECTION OF DANGEROUS AND ILLICIT MATERIALS

As shown above, so far, no systems are available that completely meet the requirements of homeland security and are simultaneously cost-efficient for cargo inspection. The current equipment is either both bulky and very expensive, does not provide completely reliable inspection results, or demands a time-consuming inspection procedure requiring several types of scanner (which is unacceptable given the huge and permanently increasing volume of transported cargo).

There is an obvious need for a detection system incorporating the following features:

- Universality, i.e. the ability to detect all four major types of dangerous material – weapons (both firearms and cold weapons), explosive materials, radiological materials (isotopes), and Special Nuclear Materials for Mass Destruction Weapons (weapons-grade uranium, plutonium)
- Efficiency, i.e. correspondence with the international standards on the reliability of the inspection results and grade of false alarms
- High operation speed (e.g. less than 10 min per standard 40ft sea container)
- Adjustability, i.e. the possibility of being installed in various environments, particularly where there is limited space.

A natural step towards the reliable detection of illicit materials in cargoes of various space dimensions would be the development of an integrated system that combines the best features of the most developed technologies; namely, X-ray analysis (providing the high-speed monitoring and identification of suspicious objects and areas) and neutron analysis (providing high selectivity and precise identification).

Companies developing neutron analysis technologies had to develop such integrated systems when designing inspection systems for the hand luggage of air passengers, as the demands for the inspection time per unit do not allow complete scanning. That brought sound practical experience in the field. For example, Ratec EDS-5101C system has been developed and demonstrated as an integrated solution that can detect explosives, radioactive threats and Special Nuclear Material with Thermal Neutron Analysis for passenger luggage inspection [see Schubert (2003) and Kozlovsky (2003)]. Since then, through intensive field studies, it has been realized that the successful solution for a cargo inspection system should consider an integrated approach based on the fusion of several inspection techniques.

Therefore, we believe that the demand for more advanced systems may be satisfied by the development of an integrated system that can replace the existing inspection systems of several types while also increasing the speed, reliability and cost-efficiency of the inspection. For example it should combine several advanced techniques:

- conventional X-ray inspection for the detection of weapons and the primary identification of objects that appear suspicious with respect to explosives
- the passive detection of radiological materials
- the detection of Special Nuclear Materials in suspicious objects with a photonuclear reaction method
- the Neutron Interrogation Technique (NIT) for the high-accuracy detection of explosives and, as a second level of verification, Special materials identification.

Such a layered approach would allow the avoidance of the unnecessary scanning of all objects in the active interrogation mode, thus reducing the inspection time. Moreover, it makes it possible to clarify all suspicious areas in the container via a single system inspection.

The implementation of such an integrated system would essentially diminish the main weakness of the current systems – the requirement for manual inspection – as it will decrease by many times the ratio of uncertain results arising from the automatic inspection.

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