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# PORT SECURITY: CONTAINER CARGO CONTROL


## ABSTRACT

*It is obvious that every act of terrorism must involve also illicit trafficking of threat materials, especially explosives, chemical substances and radioactive or nuclear material. The transport of the threat materials by using sea routes is an advantage to terrorists especially because of the possible use of ship containers.*

*The container is the basis of world trade. It is assumed that the world total movement in containers is about 200 million TEUs ("20-foot equivalent units") per year. The list of materials transported by containers which should be subject to inspection with the aim of reducing the acts of terrorism includes explosives, narcotics, chemical weapons, hazardous chemicals and radioactive materials.*

*Of special interest is nuclear terrorism. The risk of nuclear terrorism carried out by sub-national groups should be considered not only in the construction and/or use of nuclear device, but also in possible radioactive contamination of large urban areas.*

*The system of ship containers control is an essential component of «smart border» concept. Modern personnel, parcel, vehicle and cargo inspection systems are non-invasive imaging techniques based on the use of nuclear analytical techniques. The inspection systems use penetrating radiations: hard x-rays (300 keV or more) or gamma-rays from radioactive sources ($^{137}Cs$ and $^{60}Co$ with energies from 600 to 1300 keV) that produce a high resolution radiograph of the load. Unfortunately, this information is "non-specific" in that it gives no information on the nature of objects that do not match the travel documents and are not recognized by a visual analysis of the radiographic picture. Moreover, there are regions of the container where x and gamma-ray systems are "blind" due to the high average atomic number of the objects irradiated that appear as black spots in the radiographic image.*

*The systems being developed are based on the use of fast, 14 MeV, neutrons with detection of associated α-particle from nuclear reaction by which neutrons are produced ($d+t>\alpha+n$). In such a way the possibility to determine object location inside a closed container is obtained. This information is contained in the measured time interval between the detection of the associated α-particle and the detection of γ-rays produced by neutrons in the investigated object by (n, γ) and/or (n, n'γ) reactions. The object identification is performed by the analysis of coincidence gamma rays energy spectrum.*

*Results obtained so far on the implementation of NATO SfP-980526 project «Control of Illicit Trafficking in Threat Materials» and EU FP6 project «European Illicit Trafficking Countermeasures Kit, EURITRACK» have shown that it is possible to construct a multisensor system with a fast control sensor using x-rays (whole container) followed by detailed elemental analysis of suspect volume by a neutron sensor.*



## KEY WORDS

*container, terrorism, inspection, neutrons, dirty bomb*


## 1. INTRODUCTION

Terrorism is a major threat to the 21st century civilization and an enduring challenge to human ingenuity. The vulnerability of societies to terrorist attacks results in part from the proliferation of chemical, biological, and nuclear weapons of mass destruction, but is also the consequence of highly efficient and interconnected systems that we rely on for key services such as transportation, information, energy, and health care. Let us mention only some of the terrorists' attacks. September 11, 2001: New York. The collapse of the World Trade Center towers killed 2,227 American civilians, as well as 403 New York policemen and firefighters. October 2002: Bali, Indonesia. Nightclub bombing. 202 people in total killed in the bombing. Some 88 Australians, 24 British tourists died. March 11, 2004: Madrid, Spain. The terror bombings of trains in Madrid, Spain killed 191 Spaniards and injured 1,800 more. 07 July 2005: London, UK. Fifty-six people were killed in the attacks, including the four suspected bombers, with 700 injured. The incident was the deadliest single act of in the since the bombing of (which killed 270), and the deadliest bombing in London since the Second World War.

Many of these incidents are probably funded by money, materials and human resources coming out of illicit trafficking. The size of the problem is enormous; cargo crime is estimated at US$ $650x10^9$ a year. Estimated value of annual turnover of drugs is estimated to be US$ $400x10^9$ a year (8% of world trade).

It should be kept in mind that in today's society acts of terrorism must involve in some stages the illicit trafficking either of explosives, chemical agents, nuclear materials and/or humans. Therefore, in order to defend itself the society must rely on the anti-trafficking infrastructure which encompasses responsible authorities: their personnel and adequate instrumental base. For many countries the sea bound traffic is the most important means of transport. In consideration of the security of the movements of people and goods on the sea the three separate problems should be considered: (i) large cargo ships with containers, tankers and ships with general cargo, (ii) small crafts for miscellaneous use, and (iii) pleasure boats harboured in marinas or small city ports.

## 2. CARGO CONTAINER SHIPS

The container was invented during the Second World War as an efficient way of moving military equipment up to the front line without tying down too many soldiers for loading and unloading ships; the container has become indispensable to the world commerce. Today, containers have helped to make the distribution of goods so efficient that manufacturers have been able to reduce inventories to a bare minimum.

Containers also turned out to be handy ways to smuggle drugs, contraband and illegal immigrants. A victim of its own success, the container offered criminals the same benefits as those enjoyed by ocean carriers and shippers: efficiency and security.

Some comments on the size of container transport industry: 90% of world cargo is carried by containers. In many nations such as the United Kingdom (U. K.), Japan and South Korea, over 90% of trade volume arrives or leaves by sea. In the US, almost half of the incoming trade (by value) arrives by ship. Over 200 million cargo containers move between major seaports each year.

Why is there risk to sea-going containers? Containerized shipping is a major vulnerability, and the global economy depends upon it. Al Qaeda has stated that one of its goals is to destroy the US economic interests.

There are many container types: 20' Dry Freight Container steel; 40' Dry Freight Container steel; 40' High Cube Dry Container steel; 45' High Cube Dry Container steel; 20' Reefer Container aluminium; 40' Reefer Container aluminium; 40' High Cube Reefer Container aluminium; 45' High Cube Reefer Container aluminium; 20' Open Top Container steel; 40' Open Top Container steel; 20' Flat Rack Container; 20' Collapsible Flat Rack Container; 40' Flat Rack Container; 40' Collapsible Flat Rack Container; 20' Open Side/Open Top Container steel; 40' Artificial Tweendeck.

They all have different interior dimensions (L, W and H), different door opening width, some do and some do not have top opening, different tare weight, different cubic capacity, different payload, and are made of different materials (Fe, Al) of different thickness.

Some ports handle a huge number of containers. For example in Rotterdam they have to deal with 5.5 million containers a year. Less than a decade ago only 6000 containers a year were checked manually. The reason is that the physical control of a container takes at least five hours.

This had to be changed. Some events which speeded up the process are described. In October 2001, a discovery at the southern Italian port of Gioia Tauro shook the foundations on which the world trade had been growing so rapidly in the past half century. A suspected al-Qaeda terrorist was found inside a container. The Egyptian suspect, who later disappeared while on bail, was equipped in comfort for the duration of the container's intended sea voyage from Italy to Halifax in Canada. He carried plans of airports, an aviation mechanic's certificate and security passes. Intelligence sources say other containers similarly fitted out were found at the Italian port. Yet another event: in April 2003 at the port of Los Angeles, 29 Chinese nationals were apprehended as they tried to sneak out of two containers that had been unloaded from the NYK Artemis[1].

### 2.1. Tankers

While much attention has been focused on threats to marine security posed by cargo container ships, terrorists could also attempt to use tankers to stage an attack. This is obvious from the statistics: while container ships accounted for 30.5% of vessel calls to US ports in 2003, other ships carried crude oil (13.2%), petroleum products (19.3%), bulk cargo (18%) and cars and trucks (9.1%). These ships merit attention also because terrorists will look for the weak link. Detecting an atomic bomb in the tanker would be an extremely difficult task [2].

Crude oil is typically shipped in supertankers - very large crude carriers (VLCC) and ultra large crude carriers (ULCC). Their size is measured in deadweight tons (DWT), the weight of the stores, fuel and cargo they can carry. While definitions vary slightly, VLCC can carry about 200,000 to 300,000 DWT and ULCC can carry more than 300,000 DWT. A representative ULCC is 60 meters wide and 350 meters long, and has a draft (depth below the waterline) of 22 meters. The interior of a tanker is divided into multiple storage tanks.

## 3. MARITIME SECURITY

Maritime security is of special importance to countries where the economy depends on the seabound transport of people and goods. As an example we can look at the USA. The US maritime borders include 95,000 miles of open shoreline with 361 ports. The US relies on ocean transportation for 95 % of cargo tonnage that moves in and out of the country. Each year more than 7500 commercial vessels make approximately 51,000 port calls, and over six million loaded marine containers enter the US ports. Current growth predictions indicate that container cargo will quadruple in the next twenty years.

Port and cargo security includes the following areas:

(i) *Container integrity.* Determination if the door has been opened. Notification if the container has been entered by means other than the door.

(ii) *Tracking.* Tracking the container through certain points of their journey or incorporating GPS device that can monitor the position in real time.

(iii) *Scanning.* Techniques to «see inside» containers without having to physically open them and inspect the contents. To be done very fast with extremely low false rate to ensure smooth flow of commerce.

(iv) *Port and perimeter security.* Security of the port is only as good as the physical boundaries and intruder detection system. Control systems should fuse chemical threat detection, access control, parameter protection, waterway security, explosive detection, intelligent video surveillance and radioactivity detection.

The US layered approach to security has measures designed to protect the three phases of the ship's journey: overseas, in transit and on US shores. There are several measures and programs in the first phase: 24-hour Advanced manifest Rule, Container Security Initiative (CSI), Customs-trade partnership against terrorism (C-TPAT), International Ship and Port Facility Security (ISPS) Code, International Port Security Program, Operational Safe Commerce. Here we shall discuss only the concept of «Container Security Initiative, CSI» in some details. The following standards must be present in every potential CSI port:

1) Seaport must have regular, direct, and substantial container traffic to ports in the United States.

2) Customs must be able to inspect cargo originating, transiting, exiting, or being transhipped through a country.

3) Non-intrusive inspection (NII) equipment (gamma or X-ray) and radiation detection equipment must be available for use at or near the potential CSI port.

With the port of Colombo, Sri Lanka CSI has achieved a milestone – 40 operational ports. CSI has become a model of international cooperation to protect the global supply chain against terrorism. US Customs and Border Protection goal is to have 50 operational ports by the end of 2006. Some operational ports implementing Container Security Initiative are:

- *In North America:* Montreal, Vancouver & Halifax, Canada.
- *In Europe:* Rotterdam, The Netherlands. Bremerhaven & Hamburg, Germany. Antwerp and Zeebrugge, Belgium. Le Havre and Marseille, France. Gothenburg, Sweden. La Spezia, Genoa, Naples, Gioia Tauro, and Livorno, Italy. Felixstowe, Liverpool, Thamesport, Tilbury, and Southampton, United Kingdom (U. K.). Piraeus, Greece. Algeciras, Spain.
- *In Asia and the East:* Singapore. Yokohama, Tokyo, Nagoya and Kobe, Japan. Hong Kong. Pusan, South Korea. Port Klang and Tanjung Pelepas, Malaysia. Laem Chabang, Thailand. Shanghai and Shenzhen, People's Republic of China. Colombo, Sri Lanka.

Recently, CSI has achieved a milestone – 40 operational ports. As a result, approximately 75% of cargo containers destined to the USA originate in or are transhipped from a CSI port. The target is 50 operational CSI ports by the end of 2006. By that time approximately 90% of all transatlantic and transpacific cargo imported into the United States will be subjected to pre-screening.

Potential CSI ports must also be committed to:

(i) establishing an automated risk management system;

(ii) sharing critical data, intelligence, and risk management information with US Customs and Border Protection (CBP);

(iii) conducting thorough port assessment and commitment to resolving port infrastructure vulnerabilities;

(iv) maintaining the integrity programs, and identifying and combating breaches in integrity.

Among top-priority actions and research objectives for harnessing science and technology to meet today's threats [3] are also "design, test, and install coherent, layered security systems for all transportation modes, particularly shipping containers and vehicles that contain large quantities of toxic or flammable materials".

In Europe the Commission of the European Communities has taken Decision of 4th February 2005 in which it is stated that:

- Security, with Freedom and Justice, is one key area where Europe has a responsibility towards its citizens, its new neighbours and on the global scene. In a Union enlarged to 25 Members, exercising this responsibility is becoming an increasingly challenging task.
- Currently, and with a view to the long term, the Commission, encouraged by the European Parliament, the Council, and industry is implementing a "Preparatory Action on the enhancement of the European industrial potential in the field of Security Research (PASR), and planning to establish a coherent European Security Research Programme (ESRP) after 2007.

## 4. ONE POSSIBLE RISK: NUCLEAR TERRORISM

The risk of nuclear terrorism carried out by sub-national groups should also be considered not only in construction and/or use of nuclear devices, but also in possible radioactive contamination of large urban areas [3-5]. The threats to security from nuclear and radiological terrorism could be grouped into the following three categories:

1. Stolen state-owned nuclear weapons or weapon components, modified as necessary to permit terrorist use.
2. Improvised nuclear devices (INDs) fabricated from stolen or diverted special nuclear material (SNM)—plutonium and especially highly enriched uranium (HEU).
3. Attacks on nuclear reactors or spent nuclear fuel or attacks involving radiological devices.

### 4.1. Stolen state-owned nuclear weapons

This threat is real because of the presence of nuclear weapons in Europe. Following the 1987 US-Soviet INF Treaty and the collapse of the Soviet Union in 1991, Russia withdrew all of its tactical nuclear weapons from the former Soviet states. During the same period, the United States withdrew thousands of tactical nuclear weapons from Europe, but left 480 in place.

Although 480 nuclear weapons are only a fraction of what the United States deployed in Europe during the Cold War, they constitute an arsenal that is larger than that of any nuclear weapon state besides the United States or Russia. France and the United Kingdom also have approximately 350 and 185 nuclear weapons, respectively, in Europe, but the United States is the only country that deploys nuclear weapons outside its own territory. The US weapons are currently located at eight air force bases in six European countries – Belgium, Germany, Italy, the Netherlands, Turkey and the United Kingdom [6].

The composition of weapon-grade materials is of interest because it sets the boundary conditions on the detection methodologies [7]. Nuclear device contains fission core with weapon grade uranium or plutonium, berilium reflector, tamper material (either uranium or tungsten), high explosive and all contained in an aluminium case. Core is about 12 kg WgU (7 cm outside radius) or 4 kg WgPu (5 cm outside radius), Beryllium reflector is 2 cm thick, tamper (W or U) is about 3 cm thick all surrounded by 10 cm thick high explosive and contained in 1 cm thick aluminium case. Altogether, one is looking at 180 kg device in the case of WgU, with about 70 kg of high explosive, 17 kg of aluminium, about 80 kg of tamper material (depleted uranium or tungsten), 3 kg of beryllium. In the case of WgPu the device has less than 130 kg, of which 56 kg is high explosive, 21 kg aluminium 53 kg tamper material and 2 kg beryllium.

The presence of a nuclear device in the cargo packed in a container or a vehicle could be detected only by the detection on neutrons and/or gamma rays originating in this device. Therefore it is of interest to know the number of neutrons per second per kilogram from spontaneous fission and (alpha, n) reactions in WgU and WgPu as well as the rate of the gamma-ray emissions at the surface of the weapon. Spontaneous fission of U isotopes releases only few neutrons (about 1.6 neutrons per kg), while Pu isotopes release about 56,000 neutrons per second per kg [8].

Of interest is the rate of neutron emission at the surface of the four hypothetical weapon designs. One can see that the plutonium device could be easily detected from the neutron screening of the container or vehicle caring it. The rate of neutron emission at the surface of hypothetical weapon designs is for 12 kg WgU with tungsten tamper – 30 n/s, with depleted U – 1,400 n/s; while for 4 kg WgPu with tungsten or depleted uranium tamper this number is much higher about 400,000 n/s. The calculated neutron emission rates from the surfaces of these weapons are greater than the production rate from spontaneous fission. This is due to multiplication from fission and (n, 2n) reactions [8].

Contrary to that, the rate of the strongest gamma-ray emissions at the surface of the four hypothetical weapon designs (two fissile materials: 12 kg WgU and 4 kg WgPu each with two possibilities for Tamper material: tungsten or depleted uranium) is the strongest for uranium being fission and tamper material (emission rate at the surface of the hypothetical weapon of some 100,000 gamma rays of energy 1.001 MeV per second).

Most of the technical approaches for detecting atomic bomb in a tanker would fail, especially for a bomb inside oil tank. Tanker's sheer mass of oil and steel would prevent any gamma rays or neutrons from travelling the width of a tanker. For the moment it looks that only muon detection might work if daunting technical approaches could be overcome [9].

A possibility of terrorists trying to smuggle a bomb into a US port by using container is discussed by Medalia [10]. Different possible routes were discussed, the damage assessed and the response proposed. Improving the ability to detect terrorist nuclear weapons in the maritime transportation system may make a terrorist attack on a port less likely to succeed, and thus less probable.

Portable device should also be considered. US and Soviet authorities are believed to have built several hundred portable atomic bombs. The Small Atomic Demolition Munition, or SADM, might weigh around 100 pounds and be carried in two parts. Container and packing is very simple and resembles the everyday suitcase. Warhead consists of a tube (45 – 60 cm in diameter) with two pieces of uranium, which, when rammed together would cause the atomic blast. The container/suitcase also includes the firing unit and possibly a device that would have to be decoded for detonation. Destructive power of SADM is equivalent to 1 kiloton or less of TNT (Hiroshima bomb: 13 kilotons) [11].

## 4.2. Improvised Nuclear Devices

Improvised nuclear devices are nuclear weapons fabricated by terrorists, with or without state assistance, using stolen or diverted special nuclear material, SNM. The basic technical information needed to construct a workable nuclear device is readily available in the open literature. The primary impediment that prevents countries or technically competent terrorist groups from developing nuclear weapons is the availability of SNM, especially highly enriched uranium, HEU.

A threat called "dirty bomb" which would result in the dispersal of radiological material in an effort to contaminate a target population or distinct geographical area should be analysed in some details. The material could be spread by radiological dispersal devices (or RDDs) - i. e. "dirty bombs" designed to spread radioactive material through passive (aerosol) or active (explosive) means. Alternatively, the material could be used to contaminate food or water.

There are a number of possible sources of material that could be used to fashion such a device, including nuclear waste stored at a power plant (even though such waste is not highly radioactive), or radiological medical isotopes found in many hospitals or research laboratories [3,11,12 ].

Radioactive materials are often sintered in ceramic or metallic pellets. Terrorists could then crush the pellets into a powder and put the powder into an RDD. The RDD could then be placed in or near a target facility and detonated, spreading the radiological material through the force of the explosion and in the smoke of any resulting fires.

Until now, only 25 highly-credible cases of illicit trafficking in weapons-usable nuclear material have become known since the recording of such incidents was started in 1991. By comparison, there have been over 800 cases involving illicit trafficking in other nuclear and radioactive material, such as low-enriched uranium yellowcake, and medical and industrial radiation sources, during the same period of time.

The inherent uncertainties in our current knowledge on nuclear smuggling make it difficult to judge whether trafficking in weapons-usable nuclear material is really such a relatively rare phenomenon, or whether it was and still is carried out in such a clandestine, professional (in criminal terms) manner that it has remained largely undetected [13]. Countries reported 121 incidents to the IAEA in 2004 of illicit trafficking and other unauthorized activities involving nuclear and other radioactive materials, newly released statistics from the Agency's Illicit Trafficking Database (ITDB) show [14]. The ITDB report also shows that one incident was reported since 2003 that involved fissile material — highly enriched uranium (HEU) or plutonium — that is needed to make a nuclear weapon. It occurred in June 2003 when an individual was arrested in possession of 170 grams of HEU, attempting to illegally transport it across the border.

Since the database started in 1993, there have been eighteen confirmed incidents involving trafficking in HEU and plutonium. A few of these incidents involved seizures of kilogram quantities of weapons-usable nuclear material but most involved very small quantities. In some of the cases the seized material was allegedly a sample of larger quantities available for illegal sale or at risk of theft. More than two dozens incidents involved trace amounts of plutonium sources.

In the past twelve years, 220 confirmed incidents involved nuclear materials. Of these, eighteen incidents involved trafficking in HEU and plutonium. A few of these incidents involved seizures of kilogram quantities of weapons-usable nuclear material but most involved very small quantities. In some of the cases the seized material was allegedly a sample of larger quantities available for illegal sale or at risk of theft. More than two dozen incidents involved trace amounts of plutonium sources.

The majority of confirmed cases with nuclear materials involved low-grade nuclear materials, mostly in the form of reactor fuel pellets, and natural uranium, depleted uranium and thorium. While the quantities of these materials have been rather small to be significant for nuclear proliferation or use in a terrorist nuclear explosive device, these cases are indicative of gaps in the control and security of nuclear material and nuclear facilities.

The majority of confirmed incidents with nuclear materials recorded during 1993-2004 involved criminal activity, such as theft, illegal possession, illegal transfer or transaction. Some of these incidents indicate that there is a perceived demand for such materials on the "black market." Where information on motives is available, it indicates that profit-seeking is the principal motive behind such events. From 1993-2004, a total of 424 incidents were reported involving other radioactive materials mostly in the form of radioactive sources. Radioactive sources are used worldwide in a host of legitimate applications while measures to protect and control their use, storage or disposal are much less strict than those applied toward nuclear materials.

In the hands of terrorists or other criminals, some radioactive sources could be used for malicious purposes, for example in a radiological dispersal device or "dirty bomb." Uncontrolled radioactive sources also have the potential to harm human health or the environment. Unlawfully discarded or disposed radioactive sources, when melted at scrap metal recycle plants, may lead to severe environmental and economic related consequences. The majority of incidents involved radioisotopes and portable radioactive sources used for various industrial applications, such as gauging or radiography.

# 5. INSPECTION

The market for devices and systems designed to protect the world's container shipping from terrorist attacks is projected to be worth \$100 bn to \$200 bn over next 10 years.

One core element of CSI is using smarter "tamper evident" containers that will better secure containerized shipping. Designed to be "tamper evident" the Smart Box couples an internationally approved mechanical seal affixed to an alternate location on the container door with an electronic container security device designed to deter and detect tampering of the container door. If someone attempts to open the cargo door after it has been sealed, the Smart Box device on the door would reflect that there had been an attempted intrusion into the container.

Radio-Frequency Identification (RFID) technologies allow shippers and carriers to track cargo while it is within the container shipping system. The devices can record and transmit information about a container's origin, destination, contents, or processing history. RFID systems are typically designed to transmit information about cargo when the shipment passes silent portals, such as entry or exit from a port or when the cargo is loaded or unloaded from a ship. RFID devices are available as both passive and active technologies. Passive devices transmit only when in the presence of a reader that provides the required power. They have ranges up to a few meters and are typically used to track shipments at the unit or carton level. Active devices are battery-powered and can transmit over distances as far as 100 m or more. Thus, active devices have been applied to tracking cargo at the container and pallet levels [15]. More sophisticated sensor technology allows smart sensors to be placed inside a container, not just near the container's door. These sensors can generate e-mailed alerts about changes in light, humidity, or pressure that readers pick up, which could indicate that a nearby container has been tampered with.

Several manufacturers (GE, Hi. G. Tek) are producing the so-called container security devices (CSD) which together with an intelligent data network help detect unauthorized access to a container and monitor the container in transit for signs of intrusion. A palm-sized CSD fastens to the doorjamb inside any standard maritime container. The cargo manufacturer uses a wireless handheld device to arm the device with a unique identifier code. The CSD automatically communicates its status to the fixed wireless readers at ports, indicating when and where the container has been opened since it was initially sealed.

Modern cargo inspection systems are non-invasive imaging techniques using penetrating radiations (gamma and x-rays) in scanning geometry, with the detection of transmitted or radiation produced in the investigated sample. A fast scanning of standard containers (few minutes to less than 1 minute) is performed to provide the customs officers with high resolution radiograph of the load. Three different sources of electromagnetic radiation are being used: radioisotopes, power generators and accelerators. Just one accelerator manufacturer (Varian) has supplied more than 100 accelerators to cargo screening system producers, including L-3, ARACOR, Rapiscan, Smiths-Heiman and BIR. These companies provide either fixed facilities or mobile units. Altogether, customs officials at more than 50 ports around the world use high-energy Linatron (linear accelerators from Varian Medical Systems)-based systems to screen containers.

Unfortunately, this information is "non-specific" in that it gives no information on the nature of objects that do not match the travel documents. Moreover, there are regions of the container where x and gamma-ray systems are "blind".

The so-called «Dual View Technology» offers the advantage of resulting in two projections (top view and side view) of the objects hidden inside the container. These systems are best when used in combination with other sensors. For example: SAIC has installed a combination of three portals: VACIS portal [16] , OCR portal and passive radiation portal in a port of Hong Kong [17]. In such a way a 100% screening of containers is accomplished for more than 2 million containers per year. A throughput averaging 1960 containers per day is currently a common practice.

The dose from gamma ray exposure to the object inside the cargo container is $< 0.5$ $\mu$Sv (which is a 1/10 the of a 10 hours long intercontinental flight) up to 100 $\mu$Sv per inspection in the case of a dual view system.

## 5.1. The use of Compton Backscatter Imaging

Maintaining the security of an exclusion zone established around high value military vessels is a difficult task at best. Although large ships can be controlled to a certain extent, it is logistics and traffic flow nightmare to attempt to keep track of and examine the myriad of small boats that may find themselves in the vicinity of a military vessel for any number of purposes. Up until now, the only way to assure that any boat within an exclusion zone was not carrying potentially deadly explosives was to stop it, board it, and conduct a manual search. What is needed is a way to examine small boats without boarding them, while producing minimal restriction to the traffic flow.

Using its patented, proprietary Backscatter imaging technology, AS&E has conceived a system that can examine small boats for the presence of explosive materials, while the boat is on the water and under way, from distances that could approach 30 feet or more. In one embodiment of the concept, a Backscatter Imaging Module (BIM) could be located on a boat or barge and then operated by an inspector from the pilothouse to scan small vessels. (BIM could also be positioned on a dock and scan boats as they passed by, or situated within the port to scan other vehicles.) When Backscattering Imaging Module (BIM) is mounted on a small boat the system scanning beam geometry permits examination of areas beneath the waterline [18].

# 6. NUCLEAR TECHNIQUES

Nuclear techniques have been applied in the detection of hidden explosives for a number of years. Basically, they work on the principle that nuclei of the chemical elements in the investigated material can be bombarded by penetrating nuclear radiation (mainly neutrons). As results of the bombardment, nuclear reactions occur and a variety of nuclear particles, gamma and x-ray radiation is emitted, specific for each element in the bombarded material.

The problem of material (explosive, drugs, chemicals, etc.) identification can be reduced to the problem of measuring elemental concentrations and/or ratios. Nuclear reactions induced by neutrons can be used for detection of chemical elements, their concentrations, and concentration ratios or multielemental maps, within the explosives.

Neutron scanning technology offers capabilities far beyond those of conventional inspection systems. This highly sophisticated equipment could be deployed as part of a country-wide system of deterrence. The unique automatic, material-specific detection of terrorist threats can significantly increase the security at ports, border-crossing stations, airports, and even within the domestic transportation infrastructure of potential urban targets as well as protect armed forces and infrastructure wherever they are located.

The use of slow /thermal/ neutrons is convenient for elements H, N, Cl, Na, Al, Fe and Pb. The radiative capture of slow neutrons results in the characteristic gamma rays as follows: H (2.2 MeV), N (10.8 MeV), Cl (1.95 and 6.11 MeV), Na (2.98 and &. 39 MeV), Al (2.96 and 7.72 MeV), Fe (7.63 and 7.64 MeV) and Pb (6.73 and 7.36 MeV). On the other hand, the use of fast (14 MeV) neutrons is convenient for the detection of the presence of elements: C (4.4391 MeV), N (2.3129 and 5.1059 MeV), O (6.1304 MeV), Al (2.211 and 2.981 MeV) and Fe (1.2383, 1.8107 1nd 2.5984 MeV).

There are several reported neutron sensors based on gamma ray spectroscopy:

(i) Pulsed fast neutron - time of flight; PFNA-TOF with 8.2 MeV pulsed neutrons from an accelerator is described in Report by Office of National Drug Control Policy, Washington, D. C. [19].

(ii) Coded Aperture Fast Neutron Analysis (CAFNA), as reported by R. C. Lamza [20].

(iii) system called PELAN developed by G. Vourvopoulos and co-workers [21]. PELAN is a transportable neutron based UXO identification system using pulsed beam of fast neutrons.

The proposed novel techniques for explosive and fissile material detection make use of the peculiar capability of producing a tagged neutron beam to confine the inspection to a pre-determined volume element. A straightforward application of these techniques would imply coupling the inspection by tagged neutron beams to a commercial imaging device based on either x-ray or gamma-ray radiography that performs a fast scan of the container, identifies a "suspect" region and provides its coordinates to the neutron-based device for the final "confirmatory" inspection.

## 7. NEUTRON LABORATORY AT THE INSTITUTE RUĐER BOŠKOVIĆ, ZAGREB, CROATIA

The experiments reported here have been performed at the Neutron Laboratory at the Institute Ruder Boskovic in Zagreb, Croatia. The laboratory is housed in an underground experimental area with adequate shielding. A variety of neutron sources are available including: 300 KeV accelerator (used as the source of 14 MeV neutrons, d+t reaction at 150 KeV, and 2.2 MeV neutrons from d+d reaction), SODERN GENIE 12C, Cf-252 in ceramic matrix, activity 50 $\mu$Ci. The laboratory is available 24 hours, 365 days together with secured different threat materials.

The majority of experiments is done by Texas Nuclear Corporation 300 KeV electrostatic accelerator producing 14 MeV neutrons by T(d, n)$\alpha$ reaction. The result is continuous beam from the stationary target cooled by water with a maximum intensity ~$10^9$ n/4$\pi$s. A continuous beam from rotational target cooled by water has maximum intensity of $5\times10^{10}$ n/4$\pi$s. Sinusoidal pulsed (chopping and bunching) beam of 14 MeV neutrons can be obtained with pulse width of 2.6 ns; with peak deuteron current of 1 mA the measured intensity of neutron beam is $3\times10^8$ n/4$\pi$s. Rectangular pulsing in microsecond and millisecond regions is also possible. With deutron beam of 0.8 mA the achieved neutron intensity was $1.6\times10^5$ n/4$\pi$ from pulses having the width of 4$\mu$s. With pulses having the width of 10 ms, an intensity of 4×10E8 n/4$\pi$ was obtained. With a deuterium target 2.5 MeV neutrons can be obtained from D(d, n)3He reaction; a continuous beam from stationary target cooled with water energy of 2.5 MeV, intensity of $10^8$ n/4$\pi$s can be obtained.

We have tested the possibility of using the neutron beam to obtain information on the location and chemical composition of the object within the ship container. The neutron beam was obtained by means of the d+t>$\alpha$+n reaction; the associated alpha particle detector was fixed in such a way that the neutron beam was in horizontal plane at 90° to the deuteron beam. A slit in front of the scintlillator was used to define the geometrical dimensions of the beam on the interrogated object. The neutrons "tagged" in this way interact with interrogated object and produce $\gamma$ radiation by A(n, n'$\gamma$)A processes on nuclei of hidden substances.

The $\alpha$-$\gamma$ coincidence spectra were measured with the selection of $\alpha$-$\gamma$ coincidences performed by the 100 ns TAC range. Signals from anode of alpha detector photomultiplier were used as the start signal, while the signal from the gamma detector was fed to TAC as the stop signal. The information on the position of the interrogated object was contained in the TAC spectrum, while object's composition gave rise to characteristic gamma ray spectrum [22-24].

In the recently performed experiments the investigated material - target was put into the middle of the container. Target was the iron box (dimensions: 40 cm x 40 cm x 66 cm, mass: 9.2 kg) filled with the 64.4 kg of paper, 100 kg of semtex1a or carbon bricks. In the coordinate system where the middle of the target is (0, 0, 0) neutron beam enters the container from the left at (-126 cm $\hat{x}$ -10 cm $\hat{y}$ +10 cm $\hat{z}$) and exits the container at (102 cm $\hat{x}$ -14 cm $\hat{y}$ -10 cm $\hat{z}$), respectively. The detection system contained two 3" x 3" NaI(Tl) detectors at the top of the container and other two 3" x 3" NaI(Tl) detectors in the transmission position within the cone of the tagged neutron beam. Each detector was shielded with the 5 cm lead shield. In addition, the top detectors were protected from direct neutrons by using 40 x 40 x 40 $cm^3$ paraffin blocks and 10 x 10 x 30 $cm^3$ carbon block. Associated alpha detector (YAP), with quadratic a=1.8 cm collimator was placed 15 cm from the tritium target.

Density of the explosive was found experimentally to be (1.275 ± 0.04) g/$cm^3$. There were 100 packages, 1 kg each with the volume approximately 4.7 x 12.2 x 14.3 $cm^3$. Each package was folded with the paper and nylon. Density of the paper was found experimentally to be (0.74 ± 0.008) g/$cm^3$. There were 25 packages, with the volume approximately 21 x 29.7 x 5.5 $cm^3$. Each package was folded with the nylon. Iron matrix was made from iron boxes filled with reels of iron thread and has a density (0.196 ± 0.008) g/$cm^3$.

In the electronic set-up the four fast outputs from the 4-segmented PMT connected to the YAP were fed through the octal constant fraction discriminator and fan-in fan-out to the STOP of the time to amplitude converters. Outputs from the sodium iodide detectors were fed through the constant fraction discriminators and "or" logic units to the START of the time to amplitude converters. Slow signals from the gamma detectors were fed through the amplifiers, quad linear gates, and delay amplifiers to the acquisition system.

For the test of the performance of the detection system the carbon target was used. Main peak at 4.4 MeV, associated first and second escape peaks were clearly seen in both cases. In the measured energy spectra for the paper and semtex1a carbon and oxygen peaks were seen well, but not the nitrogen one. We have concluded that the energy spectrum from paper does not show any significant difference from the energy spectrum from the semtex1a.

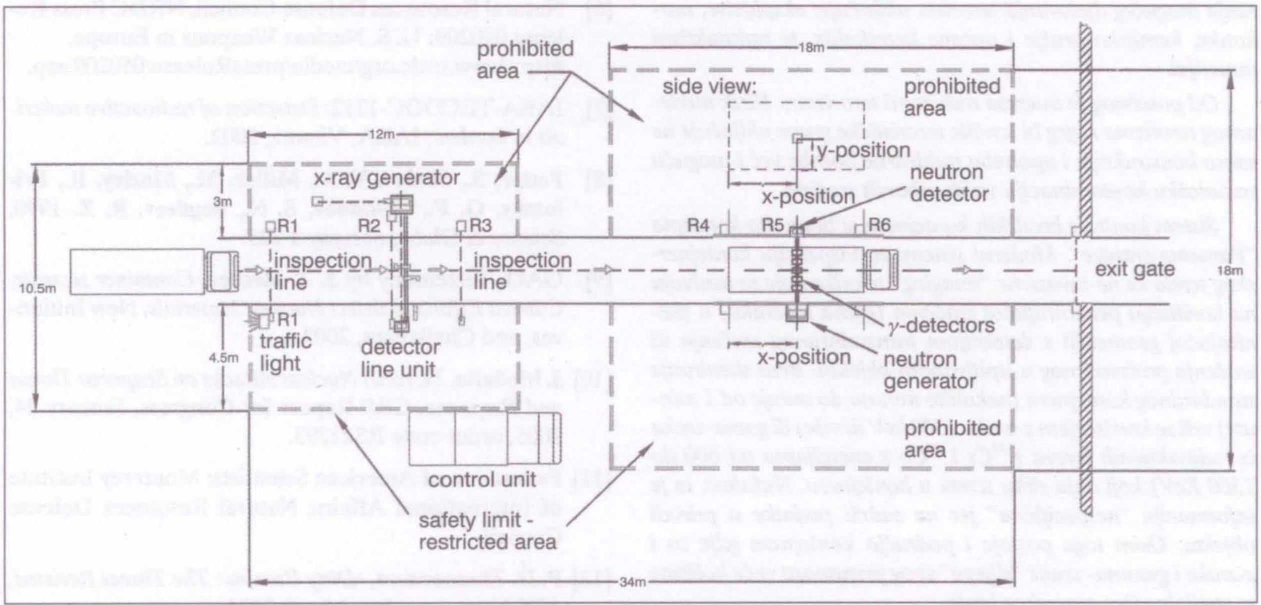


Figure1 - Schematic presentation of a two sensor system

Measurements the time and the energy spectra with the transmission detectors for the semtex1a and the paper targets in the iron matrix indicate that the only difference in those spectra is due to differences in target densities. It can be concluded that the paper and explosive in the iron matrix of density ~ 0.2 g/cm$^3$ can be detected in a given time and neutron beam intensity with the transmission detectors.

## 7. CONCLUSIONS

The possibility of determining the object's location inside a container has been shown for the case of carbon and TNT. This information is contained in the measured TAC spectra (associated alpha particle being the start pulse, gamma ray produced within object being a stop pulse). The identification of the object is done by analysis of the measured coincidence gamma spectra.

With this, a "prove of principle" has been accomplished. A multisensor system, based on the integrated use of x-ray fast scanning of the interrogated object (i. e. the whole container) with subsequent detailed elemental analysis of suspicious volumes by using fast neutrons, is a possibility.

The evaluation of the performance of the proposed two sensor instrumental portal has shown that even simultaneous presence of both explosive and fissile material, hidden inside the container, could be detected. The detection of the explosive within a suspicious volume element inside the container is performed by gamma detection produced by the tagged neutron bombardment of the volume element. The time-of-flight measurements determine the position of the volume element, while the gamma spectrum resulting from the bombardment of this volume element carries the information on the elemental contents within the volume element allowing identification of the material within it.

Such a system, with two sensors: x-rays and neutrons is planned to be implemented at the Croatian port of Rijeka. Its schematic presentation is shown in Figure 1.

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***SAŽETAK***

***SIGURNOST LUKA: KONTROLA KONTEJNERSKOG TERETA***

*Očito je da kod svakog akta terorizma mora postojati i faza nezakonitog prometa opasnih materijala, naročito eksploziva, kemijskih sredstava i radioaktivnog ili nuklearnog materijala. Prijevoz tih opasnih materijala morskim putovima predstavlja pogodnost teroristima naročito zbog mogućeg korištenja brodskih kontejnera.*

*Kontejner je osnovica svjetske trgovine. Procjena je da broj kontejnera koji se kreću po svijetu iznosi ukupno do 200 miliju-na TEU ("20-foot equivalent units"). Lista materijala koji se preveze kontejnerima a koje treba kontrolirati s ciljem reduci-*

*ranja mogućeg djelovanja terorista uključuje: eksplozive, narkotike, kemijsko oružje i opasne kemikalije, te radioaktivni materijal.*

*Od posebnog je interesa nuklearni terorizam. Rizik nuklearnog terorizma kojeg bi izvršile terorističke grupe uključuje ne samo konstrukciju i upotrebu nuklearne bombe već i moguću radiološku kontaminaciju većih urbanih sredina.*

*Sistem kontrole brodskih kontejnera je bitan dio koncepta "Pametne granice". Moderni sistemi za inspekciju kontejnerskog tereta su ne-invazivne "imaging" tehnike koje se osnivaju na korištenju penetrirajućeg zračenja (gama i x-zraka) u skenirajućoj geometriji s detekcijom transmitiranog zračenja ili zračenja proizvedenog u ispitivanom objektu. Brzo skeniranje standardnog kontejnera (nekoliko minuta do manje od 1 minute) vrši se korištenjem x-zraka (300 keV ili više) ili gama-zraka iz radioaktivnih izvora ($^{137}Cs$ i $^{60}Co$ s energijama od 600 do 1300 KeV) koji daju sliku tereta u kontejneru. Nažalost, ta je informacija "nespecifična" jer ne sadrži podatke o prirodi objekta. Osim toga postoje i područja kontejnera gdje su i x-zrake i gamma- zrake "slijepe" zbog prisutnosti veće količine materijala višeg atomskog broja.*

*Sistemi koji se razvijaju uključuju korištenje brzih, 14 MeV, neutrona uz detekciju pridružene α-čestice iz nuklearne reakcije kojom su proizvedeni neutroni (d+t→α+n). Time je dobivena mogućnost određivanja lokacije objekta koji se nalazi u zatvorenom kontejneru. Ta se informacija nalazi u mjerenom vremenskom intervalu između detekcije α-čestice i detekcije γ-zrake koju su u ispitivanom objektu proizveli neutroni (n, γ) ili (n, n'γ) reakcijama. Identifikacija objekta se pak vrši analizom energijskog spektra koincidentnih gama zraka.*

*Dosadašnji rezultati rada na NATO SfP-980526 projektu «Control of Illicit Trafficking in Threat Materials» i EU FP6 projektu «European Illicit Trafficking Countermeasures Kit, EURITRACK» pokazali su da je moguće konstruirati multisenzorski sistem koji se sastoji od brzog ispitnog senzora x-zraka (čitavi kontejner) iza kojeg slijedi detaljna elementarna analiza sumnjivog volumena korištenjem neutronskog senzora.*

*KLJUČNE RIJEČI*

*kontejner, terorizam, inspekcija, neutroni, prljava bomba.*

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