Applications of nuclear techniques relevant for civil security

Vlado Valković
Institute Ruder Bošković, Zagreb, Croatia

valkovic@irb.hr

Abstract. The list of materials which are subject to inspection with the aim of reducing the acts of terrorism includes explosives, narcotics, chemical weapons, hazardous chemicals and radioactive materials. To this we should add also illicit trafficking with human beings. The risk of nuclear terrorism carried out by sub-national groups is considered not only in construction and/or use of nuclear device, but also in possible radioactive contamination of large urban areas. 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. Contrary to that is the use of 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. Neutron scanning technology offers capabilities far beyond those of conventional inspection systems. 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 protecting armed forces and infrastructure.

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 consequence of the 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 Australian, 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 terrorism in the United Kingdom since the 1988 bombing of Pan Am Flight 103 (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 to US$ 650 billion a year. Estimated value of annual turnover of drugs is estimated to be US$ 400 billion 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, the society in order to defend itself must rely on the anti-trafficking infrastructure which encompasses responsible authorities: their personnel and adequate instrumental base.

2. The Smart Border of the Future

Border management system that keeps pace with expanding trade protects at the same time from the threats of terrorist attack, illegal immigration, illegal drugs, and other contraband. The border of the future must integrate actions abroad to screen goods and people prior to their arrival in the country, and inspections at the border and measures within the country to ensure compliance with entry and import permits.

Agreements with neighbors, major trading partners, and private industry with all extensive pre-screening of low-risk traffic, thereby allowing limited assets to focus attention on high-risk traffic.

The use of advanced technology to track the movement of cargo and the entry and exit of individuals is essential to the task of managing the movement of hundreds of millions of individuals, conveyances, and vehicles.

Careful choice of materials to be controlled must be made. The list of materials which are subject to inspection with the aim of reducing the acts of terrorism includes explosives, narcotics, chemical weapons, hazardous chemicals and radioactive materials. To this we should add also illicit trafficking with human beings.

3. Some common explosives

The list of explosive compounds has more than 100 items including some improvised primary explosives like acetone peroxide, ddnp/dinol, double salts, hmtd, leadazide, lead picrate, mekap, mercury fulminate, "milk booster", nitromannite, sodium azide, tacc and some others. Instruction how to prepare them can be found in the open literature and on internet.

However, the most often used explosives are: Trinitrotoluene (TNT), Pentaerythritoltetranitrate (PETN), Cyclotrimetilentrinitramin (RDX), Trinitrophenylmethylnitramine (Tetryl), Tetrytol and Hexatol.

Trinitrotoluene, commonly known as TNT, is a constituent of many explosives, such as amatol, pentolite, tetrytol, hexatol, torpex, tritonal, picratol, ednatol, and composition B. It has been used under such names as Triton, Trotyl, Trilite, Trinol, and Tritolo. In a refined form, TNT is one of the most stable of high explosives and can be stored over long periods of time. It is relatively insensitive to blows or friction. TNT is used in pressed and cast form. Pressed TNT can be used as a booster or as a bursting charge for high-explosive shells and bombs.

Pentaerythritoltetranitrate (PETN) is one of the strongest known high explosives. It has also been used under such names as Pentrit, Nitropenta, Niperyt, and TEN. It is more sensitive to shock or friction than TNT or tetryl, thus it is never used alone as a booster. It is primarily used in booster and bursting charges of small caliber ammunition, in upper charges of detonators in some land mines and shells, in shaped charges, and as the explosive core of primacord. It is also used as an explosive compound in plastic explosives (PEP).
Cyclotrimetilentrinitramín (RDX) es uno de los explosivos más fuertes conocidos. Ha sido utilizado bajo nombres como Hexogene, Cyclonit, SDX, y T-4. Es principalmente utilizado en cargas de ametralladora y explosivos de compresión de pequeño calibre, en cargas superiores de detonadores en algunas minas y cañones, y en cargas de forma.

Tetryl puede ser iniciado por llama, fricción, choque, o chispas; se consume fácilmente y es probablemente detonar si se quema en grandes cantidades. Tetryl es el explosivo de compresión estándar y es suficientemente insensible en forma presa para ser utilizado de manera segura como un explosivo de compresión.

Tetrytol se trata de una mezcla de tetryl y TNT y se diseña para obtener una mezcla de tetryl que puede ser utilizada en tubos de caza para bombas químicas, en bloques de demolición, y en forma de carga de forma.

Hexatol es una mezcla de RDX y TNT. Se utiliza como la carga principal de algunas minas de terreno.

| Tabla 1. | Explosivos de compuesto nitro. 

| Nombre       | Masa molecular | C | H | N | O | Densidad (g/cm³) |
|--------------|---------------|---|---|---|---|-----------------|
| 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 | 5 | 4 | 12| 1.78           |
| Nitroglicerina| 227.09       | 3 | 5 | 3 | 9 | 1.59            |
| EGDN         | 152.1         | 2 | 4 | 2 | 6 | 1.49            |
| DNB          | 168.11        | 6 | 4 | 2 | 4 | 1.58            |
| Picric ácido | 229.12        | 6 | 3 | 3 | 7 | 1.76            |
| AN           | 80.05         | - | 4 | 2 | 3 | 1.59            |

Ratios de concentraciones de elementos para algunos explosivos se muestran en la Tabla 2.

| Tabla 2. | Relaciones C/N y C/O. 

| Nombre  | C/O | H/N  | C/N  | O/N  |
|---------|-----|------|------|------|
| NG      | 0.33| 1.67 | 1    | 3    |
| TNT     | 1.17| 1.67 | 2.33 | 2    |
| RDX     | 0.5 | 1    | 0.5  | 1    |
| PETN    | 0.42| 2    | 1.25 | 3    |
| AN      | 0   | 2    | 0    | 15   |

Ratios de concentraciones de elementos C/N y C/O para explosivos son diferentes de los valores de estas relaciones para otros tipos de materiales.

Presencia de cualquier cantidad de explosivos es de interés. Sin embargo, de especial interés es la detección de grandes cantidades transportadas en vehículos. Según el Departamento de Tesorería de los Estados Unidos, Bureau of Alcohol, Tobacco and Firearms, ATF, la amenaza de explosión de bombas vehiculares y distancias de evacuación se muestran en la Tabla 3.
How to detect the presence of explosives? Explosives and chemical agent’s detection systems can be based on the fact that the problem of explosive detection and identification can be reduced to the problem of measurement of elemental concentrations and ratios of elemental concentrations.

Different nuclear analytical techniques could be used for this purpose; however, the use of nuclear analytical techniques has some specific advantages.

Table 3. Vehicle bomb explosion hazard and evacuation distances.

| Vehicle description       | Max. explosives capacity | Lethal air blast range | Min. evacuation distance | Falling glass hazard |
|---------------------------|--------------------------|------------------------|--------------------------|----------------------|
| Compact sedan             | 227 kg in trunk          | 30 m                   | 457 m                    | 381 m                |
| Full size sedan           | 455 kg in trunk          | 38 m                   | 534 m                    | 534 m                |
| Passenger or cargo van    | 1,818 kg                 | 61 m                   | 838 m                    | 838 m                |
| Small box van (14 ft box) | 4,545 kg                 | 91 m                   | 1,143 m                  | 1,143 m              |
| Box van or fuel truck     | 13,636 kg                | 137 m                  | 1,982 m                  | 1,982 m              |
| Semi-trailer              | 27,273 kg                | 183 m                  | 2,134 m                  | 2,134 m              |

4. Nuclear terrorism

The risk of nuclear terrorism carried out by sub-national groups should be also considered not only in construction and/or use of nuclear device, but also in possible radioactive contamination of large urban areas [2-5]. The threats to security from nuclear and radiological terrorism could be grouped into the following three categories:

1. Stolen state-owned nuclear weapons or weapons' 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 U.S.-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 weapons 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 U.S. weapons currently are located at eight air force bases in six European countries-Belgium, Germany, Italy, the Netherlands, Turkey and the United Kingdom [6].

Composition of weapon-grade materials is of interest because it sets the boundary conditions on the detection methodologies [10].

Nuclear device contains fission core with weapon grade uranium or plutonium, beryllium reflector, tamper material (either uranium or tungsten), high explosive and all contained in an aluminum 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 aluminum case.
Table 4. Isotopic composition of weapon-grade materials.

| Weapon-grade uranium | Weapon-grade Plutonium |
|----------------------|------------------------|
| Isotope              | %                      | Isotope              | %                      |
| Uranium-234          | 1.0                    | Plutonium-238        | 0.005                  |
| Uranium-235          | 93.3                   | Plutonium-239        | 93.3                   |
| Uranium-238          | 5.5                    | Plutonium-240        | 6.0                    |
| Other                | 0.2                    | Plutonium-241        | 0.44                   |
|                      |                        | Plutonium-242        | 0.015                  |
|                      |                        | Other                | 0.2                    |

The presence of a nuclear device in a cargo packed in a container or a vehicle could be detected only by 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 are releasing about 56,000 neutrons per second per kg [1].

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 [1].

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).

Portable device should also be considered. U.S. 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. In the container/suitcase are also included 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) [14].

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 analyzed 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 [12-14]. 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. Radioactive materials and radionuclides of interest are shown in tables 5 and 6.

**Table 5.** Most common medical radioisotopes.

| Gallium - 67 | Iodine – 129 |
| Technetium – 99m | Iodine – 131 |
| Indium – 111 | Xenon – 133 |
| Iodine – 123 | Thallium - 201 |
| Iodine - 125 |

**Table 6.** Radionuclides frequently used in industry and research.

| Sodium-22 | Yttrium-90 | Barium-133 |
| Phosphorus-32 | Technetium-99 | Caesium-137 |
| Calcium-47 | Technetium-99m | Promethium-147 |
| Cobalt-58 | Ruthenium-106 | Gadolinium-153 |
| Cobalt-60 | Palladium-103 | Iridium-192 |
| Gallium-67 | Indium-111 | Mercury-197 |
| Selenium-75 | Iodine-123 | Thallium-201 |
| Krypton-81m | Iodine-125 | Radon-222 |
| Yttrium-88 | Iodine-129 | Radium-226 |
| Strontium-89 | Iodine-131 | Plutonium-238 |
| Strontium-90 | Xenon-133 | Californium-252 |

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 remains largely undetected [11]. 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 [21]. 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 dozen incidents involved trace amounts of plutonium sources (see table 7.).

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 of 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.

4.3 Red mercury
Reports of the trafficking of Red Mercury (claimed to have the composition Hg$_2$Sb$_2$O$_7$) have been circulating for many years. Red Mercury was touted as a mediator in nuclear weapons design, particularly as an essential ingredient in pure-fusion weapons, a view expressed most recently by Barnaby [24], a former Director of the Stockholm International Peace Research Institute. What is known about Red Mercury is that it was the Russian code name for the production of Li6D — a legitimate component of thermonuclear weapons, but not some mystical or magical ingredient for other purposes. In recent years Red Mercury has been widely discredited, and the "market" for it appears to be diminishing. Some authors claim that “red mercury” was a label on tritium containers sent from Israel to South Africa.

A metallic cylinder with the rounded ends has been brought to the laboratory with the assumption that it contains «red mercury». The object had the following dimensions: length - 54.3 mm, diameter of the base: 19.8 mm, weight: 0.1106 kg, the average density of the object: 6 615 kg/m$^3$. By shaking the ampoule one could conclude that there is a liquid inside, but from the average density of the object one could conclude that the liquid has high density. Since the unknown material was encapsulated inside the metallic cylinder the analysis has been done by using two analytical methods: activation analysis with 14 MeV neutrons and X-ray fluorescence. By using these two
methods one can separate the elemental composition of the ampoule from the elemental composition of its content.

Table 7. Incidents involving HEU and Pu (1993-2004) confirmed to the ITDB [21].

| Date       | Location                        | Material Involved | Incident Description                                                                 |
|------------|---------------------------------|-------------------|--------------------------------------------------------------------------------------|
| 1993-05-24 | Vilnius, Lithuania              | HEU/150g          | 4.4 t of beryllium including 140 kg contaminated with HEU were discovered in the storage area of a bank. |
| 1994-03    | St.Petersburg, Russia           | HEU/2,972 kg      | An individual was arrested in possession of HEU, which he had previously stolen from a nuclear facility. The material was intended for illegal sale. |
| 1994-05-10 | Tengen-Wicths, Germany          | Pu/6.2 g          | Plutonium was detected in a building during a police search.                          |
| 1994-06-13 | Landshut, Germany               | HEU/0.795 g       | A group of individuals was arrested in illegal possession of HEU.                     |
| 1994-07-25 | Munich, Germany                 | Pu/0.24 g         | A small sample of PuO₂-UO₂ mixture was confiscated in an incident related to a larger seizure at Munich Airport on 1994-08-10. |
| 1994-08-10 | Munich Airport, Germany         | Pu/363.4 g        | PuO₂-UO₂ mixture was seized at Munich airport.                                      |
| 1994-12-14 | Prague, Czech Republic          | HEU/2.73 kg       | HEU was seized by police in Prague. The material was intended for illegal sale.       |
| 1995-06    | Moscow, Russian Federation      | HEU/1.7 kg        | An individual was arrested in possession of HEU, which he had previously stolen from a nuclear facility. The material was intended for illegal sale. |
| 1995-06-06 | Prague, Czech Republic          | HEU/0.415 g       | An HEU sample was seized by police in Prague.                                        |
| 1995-06-08 | Ceske Budejovice, Czech Republic| HEU/16.9 g        | An HEU sample was seized by police in Ceske Budejovice.                               |
| 1999-05-29 | Rousse, Bulgaria                | HEU/10 g          | Customs officials arrested a man trying to smuggle HEU at the Rousse customs border check point. |
| 1999-10-02 | Kara-Balta, Kyrgyzstan          | Pu                | Two individuals were arrested trying to sell Pu.                                     |
| 2000-04-19 | Batumi, Georgia                 | HEU/770 g         | Four individuals were arrested in possession of HEU.                                  |
| 2000-09-16 | Tbilisi Airport, Georgia        | Pu/0.4 g          | Nuclear material including Pu was seized by police in Tbilisi Airport.                |
| 2000-12    | Karlsruhe, Germany              | Pu/0.001 g        | Mixed radioactive materials including a minute quantity of plutonium were stolen from the former pilot reprocessing plant. |
| 2001-01-28 | Asvestochori, Greece            | Pu/~3 g           | 245 small metal plates containing Pu were found in a buried cache in the Kouri forest near the Asvestochori village. |
| 2001-07-16 | Paris, France                   | HEU/0.5g          | Three individuals trafficking in HEU were arrested in Paris. The perpetrators were seeking buyers for the material. |
| 2003-06-26 | Sadahlo, Georgia                | HEU/~170g         | An individual was arrested in possession of HEU upon attempt to illegally transport the material across the border. |
Activation analysis induced by 14.1 MeV neutrons has shown that the ampoule and the sample contained within it have following elements: Hg, Fe, Cr, Ni, as it is seen from the gamma ray spectrum shown in figure 2. The last three elements are contained in the metallic ampoule while Hg is a component of the unknown material inside it. Antimony as a hypothetical component of the red mercury (hypothetical chemical formula of red mercury is \( \text{Hg}_2\text{Sb}_2\text{O}_7 \)) has not been observed. By using XRF it has been established that Fe, Cu and Zn are not components of the unknown sample, but rather the components of the ampoule (see figure 3. the x-ray spectrum obtained by x-ray irradiation of the ampoule).

Figure 1. The investigated object.

Figure 2. Gamma ray spectrum after bombardment with 14 MeV neutrons.
Based on the analyses performed it can be stated with the certainty that the unknown sample inside the ampoule contain the chemical element mercury. With the analytical methods used it could not be determined if a chemical compound of mercury with some other elements is present. This possibility can not be excluded so further analysis of the material inside the ampoule is recommended.

5. Drinking water - a possible terrorist target

In order to show that there is a potential risk to water supplies let us mention just one past experience. In 1993, over 300,000 people in Milwaukee, Wisconsin became ill from a biological contaminant [Cryptosporidium] that passed through the Milwaukee Water System undetected – which resulted in more than 100 deaths [15].

Recently, it has been reported [16] that US federal officials have arrested two Al Qaeda terror suspects in the US with documents in their possession about how to poison the country’s water supplies.

In general, the threat of contamination of the drinking water through terrorist activities is reduced by a number of factors. Most contaminants would need to be used in very large quantities to contaminate a large public water system thereby minimizing an actual threat.

Many public water systems, particularly those serving large towns and cities, have treatment processes already in place that will deactivate many contaminants. However, much needs to be done to assure that all public water supplies are adequately protected. The primary threats to the drinking water supplies are contamination by chemical, biological or radiological agents; damage, destruction, or sabotage of physical infrastructure; and disruption to computer systems.

Generally, biological agents considered to be weapons of mass destruction pose the greatest danger in aerosol form (i.e. direct exposure to pathogens transported in the air). In US under the leadership of the Urban Water Council, a task force of mayors has been considering the new and expanded efforts that are required to enhance security at water and wastewater treatment facilities. It is clear that emergency preparedness and emergency action plans must be reevaluated, as they can no longer be limited to natural disasters or to catastrophic equipment failure, extended power outages, fires or chemical spills. Plans now must include terrorist and sabotage threats of physical destruction, biological contamination, chemical contamination and cyber attacks.

Professional organizations and government officials have requested federal funding to conduct system assessments and participate in security planning efforts that give utilities the tools they need to improve their security systems and emergency action plans. The intended result includes revised regulations and procedures, new technologies, equipment, supplies, and training for terrorism defense.
Protecting the nation’s water systems from acts of terrorism requires that the federal government [17]:

- immediately establish a national research and development program for advanced monitoring, detection, and screening technologies and systems;
- provide funding for immediate water system security assessments; and
- assist local governments in preparedness/contingency planning and training to ensure appropriate responses in the event of an attack.

In the case of potential chemical contamination the top 20 hazardous substances from the CERCLA Priority List of Hazardous Substances should be considered [15]. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) section 104 (i), as amended by the Superfund Amendments and Reauthorization Act (SARA), requires ATSDR and the EPA to prepare a list, in order of priority, of substances that are most commonly found at facilities on the National Priorities List (NPL) and which are determined to pose the most significant potential threat to human health due to their known or suspected toxicity and potential for human exposure at these NPL sites. CERCLA also requires this list to be revised periodically to reflect additional information on hazardous substances.

The substances are: 1. Arsenic, 2. Lead, 3. Mercury, 4. Vinyl Chloride, 5. Polychlorinated Biphenyls (PCBs), 6. Benzene, 7. Cadmium, 8. Benzo[a]pyrene, 9. Polycyclic Aromatic Hydrocarbons, 10. Benzo(b)Fluoranthen, 11. Chloroform, 12. DDT, p,p’, 13. Aroclor 1254, 14. Aroclor 1260, 15. Trichloroethylene, 16. Dibenz[a,h]anthracene, 17. Dieldrin, 18. Chromium, Hexavalent, 19. Chlordane, 20. Hexachlorobutadiene.

For the analysis of water samples let us consider only the x-ray fluorescence. The XRF is, by its nature, preferentially used for solid samples and is not very suitable for the assessment of dissolved components in aqueous samples; some pre-concentration is often necessary and other trace analysis techniques as AAS, ICP-AES and ICP-MS will generally perform better than XRF in this field. However, XRF is superior to analyze the suspended fraction in aqueous samples. It is also excellent to analyze sediments; sediments are very good integrating indicators of water quality; they are easy to sample and their heavy metal concentrations are sufficiently enriched to allow high quality and simple XRF measurements.

TXRF, on the other hand, is by its nature uniquely suited for multi-element trace analysis of aqueous samples; especially for those that contain little salinity and hardness, as e.g., rain water. In such cases it outperforms most other methods. Sample preparation for TXRF analysis of water is simple. Two approaches are used. Direct analysis: an aliquot of 50-100 μg of sample is transferred onto a quartz disc, dried and measured; and freeze drying: 10 ml of water can be freeze-dried and the residue digested.

Requirements for water control are:
- Continuous monitoring for various contaminants in the influent and in the distribution system should be conducted for various agents.
- Sensitive real-time water-quality monitoring devices to test for various chemical and biological agents should be developed.

6. Sea bound transport

When considering sea bound transport three separate problems should be considered: (i) Cargo ships - with containers and/or with general cargo, (ii) Small crafts for miscellaneous use, and (iii) Pleasure boats / harbored in marinas.

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 moves by container. 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 U.S., almost half of incoming trade (by value) arrives by ship. Over 200 million cargo containers move between major seaports each year.

Why is there a 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 U.S. 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 aluminum; 40' Reefer Container aluminum; 40' High Cube Reefer Container aluminum; 45' High Cube Reefer Container aluminum; 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 have some don’t have top opening, different tare weight, different cubic capacity, different payload, and are made of different materials (Fe, Al) of different thickness.

In October of 2001, a discovery at the southern Italian port of Gioia Tauro shook the foundations on which world trade has grown 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.

In the USA the President’s 2003 Budget increases the inspection budget of the Customs Services by $619 million, for a total of $2.3 billion. The President’s Budget provides resources to purchase technologically advanced equipment that will assist in inspecting shipments so that time-consuming and labor intensive searches can be minimized. A result of these efforts a concept of «Container Security Initiative, CSI» has been developed. 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 transshipped 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.

Some operational ports implementing Container Security Initiative are:

In the 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, People's Republic of China.

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

Potential CSI ports must also be committed to:
(i) Establish an automated risk management system.
(ii) Share critical data, intelligence, and risk management information with U.S. Customs and Border Protection (CBP).
(iii) Conduct a thorough port assessment and commit to resolving port infrastructure vulnerabilities.
(iv) Maintain integrity programs, and identify and combat breaches in integrity.

Among top-priority actions and research objectives for harnessing science and technology to meet today’s threats [13] is 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 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 neighbors and on the global scene. In a Union enlarged to 25 Members, exercising this responsibility is becoming an increasingly challenging task.
- Security has always been an important overall issue for Europe. However, in recent years there has been a growing global awareness that security is not a permanent attribute of modern societies. The Commission therefore reviewed the situation in the Justice, Freedom and Security multi-annual program against terrorism and serious crime.
- Maintaining security for citizens of Europe as well as contributing to a better world requires an active contribution of the European Union with due regard for fundamental rights and democratic accountability at EU and national level.
- 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 Program (ESRP) after 2007.

7. Inspection

The list of different types of sensors include: Contact switch, Piezo-electric pressure sensor, Geophone, Microphone, Magnetic sensor, Induction loop (metal detector), Infrared sensor (thermal radiation), Break beam device, Image intensifier/night viewing device, Photo camera, Electronic still camera, TV or video camera (analog or digital), Radar, X-ray devices, Neutron sensor, Chemical sensors.

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 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. 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 [7], OCR portal and passive radiation portal in a port of Hong Kong [8]. 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.

Dose from gamma ray exposure to the object inside the cargo container is \( < 0.5 \mu Sv \) (which is a 1/10 th of a 10 hours long intercontinental flight) up to 100 \( \mu Sv \) per inspection in the case of a dual view system.
7.1 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 somewhat, it is a 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’s scanning beam geometry permits examination of areas beneath the waterline.

Some results obtained on land by Backscattering imaging [9]. Image taken at 450 keV/6.6 mA. 3’ from source. Result: Explosive simulant plainly seen. Image taken at 450 keV/6.6 mA 12’ from source. Result: Explosive simulant plainly seen. No image enhancement used. Increased distance between source and object produces the elongated image observed.

8. 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 a 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.

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 Ind 2.5984 MeV).

Table 13. Selected features of the main nuclear physics-based techniques for the non-intrusive interrogation of bulk samples. Adapted from [25].

| Technique | Radiation source | Probing radiation | Main reaction type | Detected radiation | Primary (secondary) signatures |
|-----------|------------------|-------------------|-------------------|-------------------|-------------------------------|
| Source | Details |
|--------|---------|
| TNA    | 252Cf, d-D or d-T STNG | Thermalized neutrons | (n,γ) | Prompt frays from neutron capture | H,N,Cl (others) |
| FNA    | d-D or d-T STNG | Fast neutrons | γ-rays from inelastic neutron scattering | C, O, Cl (N, others) |
| PFNA   | ns-pulsed accelerator | Fast neutrons | (n,n'γ) | γ-rays from inelastic neutron scattering | C, O, Cl (N, others) |
| PFNTS  | ns-pulsed accelerator | White spectrum of fast neutrons | All available | Source neutrons which are transmitted | H, C, N, O, others |
| API    | associated particle d-T STNG | 14 MeV neutrons with associated a particles | (n,n'γ) | γ-rays in coincidence with cc-particle | C, N, O (others) |
| PFTNA  | μs-pulsed d-T STNG | Fast neutrons during pulse, and then thermalized | (n,n'γ) | γ-rays from inelastic neutron scattering, capture and activation analysis | H,C,N,O (others) |
| FNSA   | ns-pulsed or DC accel.; STNG | Monoenergetic fast neutrons | (n,n') | Elastically and inelastically scattered neutrons | H,C,N,O (others) |

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., September 1996. (see also ref. [22]).
(ii) Coded Aperture Fast Neutron Analysis (CAFNA), as reported by R.C. Lanza [23].
(iii) system called PELAN developed by G.Vourvopoulos and co-workers [24]. 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.
**Figure 4.** Schematic presentation of the use of tagged neutrons.

### Table 14. Effective dose for various sources

| Source                                      | Effective dose (mSv)                        |
|---------------------------------------------|--------------------------------------------|
| Computed tomography                         | 35 per exposure                            |
| Natural                                     | 2.2 per year                               |
| Gamma camera x-ray tube                     | 2 per exposure                              |
| X-ray tube                                  | 0.5 per one imaging of a broken leg        |
| AP neutron system                           | 0.53 per inspection, including the gamma ray|
| Medical (average for the UK population)     | 0.37 per year                              |
| Dual view cargo inspection system           | 0.1 per inspection                          |
| Cosmic rays                                 | 0.057 for one intercont. flight (10 hours) |
| HI-SCAN systems luggage exposure            | 0.02 per inspection                         |

### 8. Neutron laboratory at the Institute Ruder Bošković, Zagreb, Croatia

The experiments reported here are performed in the Neutron Laboratory at the Institute Ruder Boskovic in Zagreb, Croatia. The laboratory is housed in an underground experimental area with the 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 μCi. 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) process. The result is continuous beam from the stationary target cooled by water with a maximum intensity ~10⁹ n/4πs. A continuous beam from rotational target cooled by water has a maximum intensity of 5×10¹⁰ n/4πs. 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 3×10⁸ n/4πs. Rectangular pulsing in microsecond and millisecond regions is also possible. With neutron beam of 0.8 mA the achieved neutron intensity was 1.6×10⁷ n/4π from pulses having the width of 4μs. With pulses having the width of 10 ms, an intensity of 4×10E8 n/4π 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 10⁸ n/4πs 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→α+n reaction; the associated alpha particle detector was fixed in such a way that the neutron beam was in horizontal plane at 90⁰ to the deuteron beam. A slit in front of the scintillator 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 γ radiation by A(n,n’γ)A processes on nuclei of hidden substances.

Figure 5 shows the arrangement in the target room: a part of a real shipping container, with the investigated materials placed inside, was used as a target. The neutron beam was entering the container from the left side of the container, while the gamma detector, NaI(Tl) or BaF₂, was placed
on the other side of the container, outside the neutron beam cone (as defined by associated alpha particle detector).

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 [18-20].

Tests were performed in two different geometries corresponding to two different ways of realization of the proposed neutron sensor. In geometry #1 the array of gamma detectors was placed on the opposite side of the container with respect to the position of neutron generator. In geometry #2 the array of gamma detectors was placed perpendicularly to the neutron beam axis.

The $\alpha$-$\gamma$ coincidence spectra were measured with the selection of $\alpha$-$\gamma$ coincidences performed by the 100 ns TAC range. 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.

Figure 5 shows the arrangements in the target room for the geometry #1. The part of a real shipping container, with the investigated materials placed inside, was used as a target; the neutron beam was entering the container from the left side of the container, while the gamma detector NaI(Tl) was placed on the other side of the container, outside the neutron beam cone at $d=87$ cm from the TNT sample.

The TAC spectrum was measured for the 30 kg of TNT (Volume 35x30x30 cm) inside the container, at the distance of 2.12 m from the neutron source. TAC scale has been converted from the difference of time of flights to distance from the source. When the measured gamma energy spectrum was analyzed with the appropriate window on TAC spectrum the characteristic energy spectrum of TNT is obtained. The distance scale was calibrated by the measurement of TAC peaks resulting from the bombardment of 63.6 kg graphite block at two different positions, $\Delta d=145$ cm, inside the container, corresponding to $t=28$ ns time of flight of 14 MeV neutrons. The measured shift in TAC spectrum was estimated to be $\Delta T=24$ ns, corresponding to the change in distance of 125 cm, being in error for 20 cm (less than the object size!).

In geometry#2 the gamma detector was placed perpendicularly to the neutron beam axis. The mass of carbon blocks was 15.9 kg in the volume 10.2x30.6x30.6 cm$^3$. The area exposed to the neutron beam was 30.6x30.6 cm$^2$, the thickness of the target was 10.2 cm. They were placed at the positions (a) 37 cm; (b) 65 cm and (c) 150 cm from the right side of container.

![Figure 5](image_url). Two views of the experimental set-up for the investigations of nature and locations of objects inside the shipping container. Target: 30 kg of TNT inside of container.
Figure 6. Gamma ray energy spectrum obtained from carbon target.

Figure 7. Time of flight spectra for two positions of carbon block inside the container.

The experimental results show the difference in the counting rates depending on the neutron source-investigated object-detector geometry. This is shown in Table 15.

Table 15. Summary of experimental results

| Geometry | #1       | #2       | #2       | #2       |
|----------|----------|----------|----------|----------|
| Position | -        | (a)      | (b)      | (c)      |
| Distance from neutron source | 212 cm | 37 cm | 65 cm | 150 cm |
| Neutron flux | 2.4x10^7 n/s | 1.17x10^7 n/s | 1.63x10^7 n/s | 1.32x10^7 n/s |
| Exposure | 11,253 s | 8,530 s | 6,127 s | 7,573 s |
| Number of tagged neutrons | 8.3x10^8 | 2.5x10^8 | 2.5x10^8 | 2.5x10^8 |
| Gamma detector distance from the object | 87 cm | 42 cm | 31 cm | 90 cm |
| Number of counts in object gamma peaks | 3,899 | 38,681 | 48,914 | 4,372 |
7. Conclusions

The possibility of determining objects’ location inside the container has been shown for the case of carbon and TNT. This information is contained in the measured TAC spectra (associated alpha particle being a start pulse, gamma ray produced within object being a stop pulse). The identification of 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 determines 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 the 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 8.

| $N_{\text{TAC,min}} \leq 3\sqrt{N_B}$ | 224 | 346 | 606 | 275 |
|-----------------------------------|-----|-----|-----|-----|
| Time required to obtain $N_{\text{TAC,min}}$ for $10^8$ n/s source | 155 s | 9 s | 13 s | 63 s |

**Figure 8.** Schematic presentation of a two sensor system.
References:

[1] Fetter S, Frolov V A, Miller M, Mozley R, Prilutsky O F, Rodionov S N, Sagdeev R Z 1990, *Science & Global Security* 1 225
[2] Homeland Security Research Corporation 2005, www.hsrc.biz
[3] Thomson S, Reinhard M, Colella M, Tuniz C 2005, preprint, to be published.
[4] GAO Testimony 2002 *Container Security, Current Efforts to Detect Nuclear Materials, New Initiatives, and Challenges* (GAO, New York)
[5] GAO 2005: *Preventing Nuclear Smuggling*, Report GAO-05-375
[6] Natural Resources Defense Council, NRDC Press Release 050209: U.S. Nuclear Weapons in Europe, http://www.nrdc.org/media/pressRelease/050209.asp
[7] Orphan V, Muenchau E, Gormley J, Richardson R, Advanced Cargo Container Scanning Technology Development, SAIC Report, unpublished
[8] Orphan V J 2004, Contribution to MTS R&T Coordination Conference, Washington, D.C., USA
[9] Baukus W J 2004, A Method for Enhancing Maritime Security through the use of Compton Backscattering Imaging, Presented at 7th MTS Research and Technology Coordination Conference
[10] IAEA-TECDOC-1312: *Detection of radioactive materials at borders*, IAEA, Vienna, 2002.
[11] Zaitseva L and Steinhäusler F, Illicit Trafficking of Weapons-Usable Nuclear Material, APS News, 8 July 2004
[12] P.D.Zimmerman, «Dirty Bombs»: The Threat Revisted, APS News – on line, March 2004.
[13] Committee on Science and Technology for Countering Terrorism; National Research Council of the National Academies, USA.
[14] Federation of American Scientists: Monterey Institute of International Affairs; Natural Resources Defense Council.
[15] http://www.cnn.com/HEALTH/9609/02/nfm/water.quality/index.html
[16] Carl Cameron, Fox News, July 30, 2002.
[17] US national action plan for safety and security in America’s cities, December 2001, The United States Conference of Mayors, Recommendations on Water and Wastewater Security.
[18] Blagus S, Sudac D, Valković V 2004 *Nucl. Instr. and Meth. B* 213 434
[19] Valković V, Blagus S, Sudac D, Nad K, Matika D 2004 *Radiat. Phys. Chem.* 71 897
[20] Sudac D, Blagus S, Valković V 2004 *Appl. Radiat. and Isotopes* 61/1 73
[21] http://www.iaea.org/NewsCenter/News/2005/traffickingstats.html
[22] Hurwitz M J, Smith R C, Noronha W P, Tran K-C 1992 in Proceedings of the contraband and cargo inspection technology international symposium, The White House: Office of National Drug Control policy, p.29.
[23] Lanza R C, Explosive detection with application to landmines; Report of an Advisory Group Meeting, IAEA, Vienna, Austria, 9-12.12.1997.
[24] Vourvopoulos G, Dep L, Paschal J, Spichiger G 1997, PELAN- A transportable neutron based UXO identification technique, Proceedings of UXO Forum ’97, Nashville, TN, 342-349
(See also: Applied Physics Institute, Department of Physics and Astronomy, Western Kentucky University, Bowling Green, KY 42101, http://www.wku.edu/API/)
[25] Barnaby F 1994 *International Defence Review* 6 94
[26] Gozani T 1985 in *Capture gamma ray spectroscopy and related topics*, Ed. Raman S, API Conf. Proc. 125 828