Nuclear Security Systems at Points of Entry in Greece

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Abstract
A nuclear security framework has been established in the country to deter, detect, and respond to criminal and other intentional unauthorized acts involving nuclear and other radioactive materials. Nuclear security is an integral part of the national general security plan. The various elements of the nuclear security architecture were developed based on the national threat assessment, taking into account increasing security concerns internationally and significant changes in the global threat environment. Cooperation between the International Atomic Energy Agency, the U.S. Department of Energy, and Greek authorities has been initiated for the development and implementation of a comprehensive program adopting a multi-area coverage approach to nuclear security. As part of this program, a comprehensive nuclear security architecture was put in place, including installation and operation of state-of-the-art systems at the points of entry and exit to detect criminal and other intentional unauthorized acts involving nuclear and other radioactive materials.[1-10]

Introduction
An integrated approach to nuclear terrorism has been adopted by the international community after the resolution of IAEA General Conference in September 2002. Accordingly, illicit trafficking of nuclear and other radioactive material was identified as a global concern. The availability of significant quantities of various nuclear and other radioactive materials, used in health, agriculture, research, industry, etc., increases the potential that such material could be diverted for criminal or intentional unauthorized acts. Therefore, strengthening the nuclear security regime, including the development of capabilities for the detection of and response to such acts involving nuclear and other radioactive material out of regulatory control, is of paramount importance.[1-10]

Global nuclear security is a state, but also a shared, responsibility. Terrorist events internationally showed that there is no limit on the actions that terrorists and other criminals may pursue to achieve their goals. As the Athens 2004 Olympic Games was the first major athletic event after September 11, 2001, the International Atomic Energy Agency (IAEA), the Greek Atomic Energy Commission (EEAE), and the U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) launched an unprecedented joint project to enhance the security of the Olympic Games.[11]

In this context, a program of the DOE Second Line of Defence (SLD), using state-of-the-art technology was implemented at Greek borders to detect illicit trafficking of nuclear and other radioactive materials. In addition to detection equipment, procedures were developed, training was provided to cover the nuclear security of the Olympic venues, and the EEAE internal emergency plan and nuclear security response to radiation incidents were upgraded. IAEA had a very important role in the development and in facilitating the implementation of the nuclear security project through the evaluation of national nuclear security framework, assessment of needs, advice on how to improve capabilities, testing and validation of the detection equipment, and in-situ technical support. Greek customs, police officers, and first responders were provided with training materials and hands-on practical training on the use of detection instruments and detection methodologies and techniques. Before and during the Games, the Agency's Illicit Trafficking Database (ITDB) supplied Greece with information and assessments of incidents, patterns, trends and threats of illicit trafficking in nuclear and other radioactive materials, which were of relevance to the assessment of the overall terrorist threat to the Games.

Since that time, Greece is assuring the sustainability of the detection systems operation. An extensive program of maintenance and repair has been established and implemented by EEAE and customs, for the most effective performance of the installed radiation portal monitors (RPM) and the distributed handheld equipment. After a certain time of operation, conditions changed, and specific upgrades of relevant systems were implemented. Some RPMs ceased their operation, some others were removed and placed to new location and additional ones must be installed. Additionally, major upgrades were performed for the more efficient operation of security issues, and precise implementation of the customs procedures related with those.

In the following sections, description of the system, the procedures used, the performance, and lessons learned are presented, regarding the security area of illicit trafficking detection of radioactive materials at borders.

The Role of the Greek Atomic Energy Commission (EEAE)

The Greek Atomic Energy Commission (EEAE) is the national competent authority for the control, regulation, and supervision in the fields of nuclear energy, nuclear technology, radiological, nuclear safety, and radiation protection. It is operating as a legal person of public law enjoying full administrative and financial independence in relation to its duties. Its mission is the protection of the public, workers, and the environment from ionizing radiation and artificially produced non-ionizing radiation.

Its main responsibilities are the legislative and regulatory work, inspections, and licensing of facilities, individual monitoring of occupationally exposed workers, calibration of ionizing radiation instruments, environmental radioactivity monitoring, emergency preparedness and response, combating illicit trafficking of nuclear and other radioactive materials, education and training, research and development, international relations, and public information. EEAE has extensive collaboration with other competent authorities in Greece and in particular with those involved in nuclear security, such as customs, national police, intelligence agency, the General Secretariat for Civil Protection, etc.

Detection Systems at Borders

Fixed RPMs for the detection of illicit trafficking of nuclear and other radioactive materials were initially installed at three main land borders with Albania (Kakavia), the Former Yugoslav Republic of Macedonia — FYROM (Evzoni), and Bulgaria (Promachon), at the Athens International Airport (AIA), and the Piraeus seaport. In 2007, when Bulgaria joined the European Union, the RPMs installed in Promachon were removed. Portable radiation detection equipment were provided to Customs for the purpose of secondary inspection, and to twenty-seven additional entry/exit points in Greece, for performing primary inspections. Details are given in the Table 1.

Table 1. Total number of RPMs installed in Greece in 2015

Site	Vehicles	Pedestrians
AIA	4	7
Seaport of Piraeus: Cargo	9	0
Evzoni	12	0
Kakavia	7	2
Seaport of Piraeus: Passenger terminal	2	4
Total	34	13

Border monitoring is a three-step process:

- **Detect —** the radiation portal monitor detects the presence of radiation
- **Locate —** the handheld search instrument locates the source of the radiation
- **Identify —** the Radioactive Isotope Identifier Device ("RIID") identifies the source of the radiation.

Figure 1. Radiation detection equipment at Piraeus Seaport (top) and at the extra-Schengen Passengers Terminal of the International Airport of Athens (bottom)

Major upgrades that were performed to accommodate current needs and ensure more efficient operation of nuclear security measures by customs can be summarized as following:

- Upgrade in the cargo area of the Athens International Airport. Two portal systems, inbound and outbound, were moved further down, about 300 meters inside secured area, according to security improvements, relevant to international security regulations in the airport.
- Upgrade in the entrance of the cargo area of the seaport of Piraeus. After the activation of second operator (Piraeus Container Terminal-PCT), the official entrance to cargo area that was operated previously by the Piraeus Port Authority (PPA), was split to two entrances, one for PPA and another for PCT. For that, out of the five portal systems that were functioning in the initial phase, nine portals were installed, five for PPA entrance and four for PCT entrance.

In both cases, private companies were involved in designing, constructing and reinstalling the portals. In both cases projects were finished successfully in time.

Radiation Portal Monitor Characteristics

RPMs are designed to detect the presence of radioactive or other nuclear materials carried by pedestrians or transported in vehicles. Differentiation has been made between pedestrian and vehicle monitors. The advantage of an RPM system is that it can passively scan a large number of vehicles or passengers per hour with minimal impact on traffic. Under normal conditions, if no radioactive material is passing through the RPM, no actions are required. Only when an alarm occurs, secondary inspection measures are required to investigate. If the alarm is confirmed as real, the occurrence of a nuclear security event is declared, and appropriate nuclear security response actions are triggered. In some cases, the situation will necessitate parallel commissioning of emergency response activities.

The RPMs are continuously measuring the gamma and neutron background. Based on the average background, the gamma and neutron alarm levels are calculated and set according to specific algorithms. Their operation is based on the following principle: a pedestrian or a vehicle passing through the portals triggers the occupancy sensor, while the radiation alarm threshold is fixed at the value just prior to that occupancy. While the RPM is occupied by the pedestrian or the vehicle, radiation measurements continue. The RPM detects nuclear or other radioactive material by comparing the occupied gamma-ray and neutron count rates to the background radiation level that was registered when the RPM was unoccupied.

An alarm occurs if the detector is occupied and the actual radiation level exceeds the alarm threshold which is higher than the background. This is described by the following condition: radiation level > alarm level > background.

A typical RPM system has two pillars, each one having the following components and characteristics:

1. Two gamma detectors (plastic scintillators);
2. Two twin-neutron detectors located behind a white polyethylene panel;
3. An occupancy sensor, informing the detector system that the portal is occupied;
4. Power supplies, signal amplifiers, and communication equipment;
5. Various electronic equipment that evaluate input from the detectors and other sensors that activate an alarm: neutron, gamma, tamper, high/low background, or internal fault. The alarm can be local at the portal, or at a remote location;
6. A backup battery allowing the system to continue functioning during brief electrical power outages. Depending on battery capacity, this could be from a few hours to as much as a day.

The gamma detectors consist of blocks constructed by scintillation plastic material, which are attached to photomultiplier tubes (PMT). When gamma radiation hits such a block, it emits light. The light within the ultraviolet spectrum is converted to visible light, then it is reflected down the foil-covered block until it enters a PMT placed at the end of the block. The PMT converts the light into electrons, which are then amplified. This amplified pulse produces a count in the system.

To reduce background radiation as much as possible, lead shielding is used behind the detector block.

The scintillation plastic material is covered with black foil to prevent the external daylight to be accounted as radiation.

Neutron detectors are metal tubes filled with He-3 gas under pressure. When He-3 nuclei absorb a neutron, a charged particle (proton) and a tritium nucleus are produced. The charged particle ionizes the gas and an electrical signal is produced, which is subsequently recorded by the circuitry as "a count." The tubes are surrounded by polyethylene. The hydrogen atoms in the polyethylene slow down the neutrons and increase the probability that an interaction occurs.

The dimensions of an RPM are:

- For pedestrians' checks, vertical dimension: up to 2m in height, horizontal dimension: 1–1.5 m wide for a single pillar and max 3m wide for a double pillar system.
- For vehicle checks, vertical dimension: up to 4m in height, horizontal dimension: 3m wide for a single pillar and max 6m wide for a double pillar system.

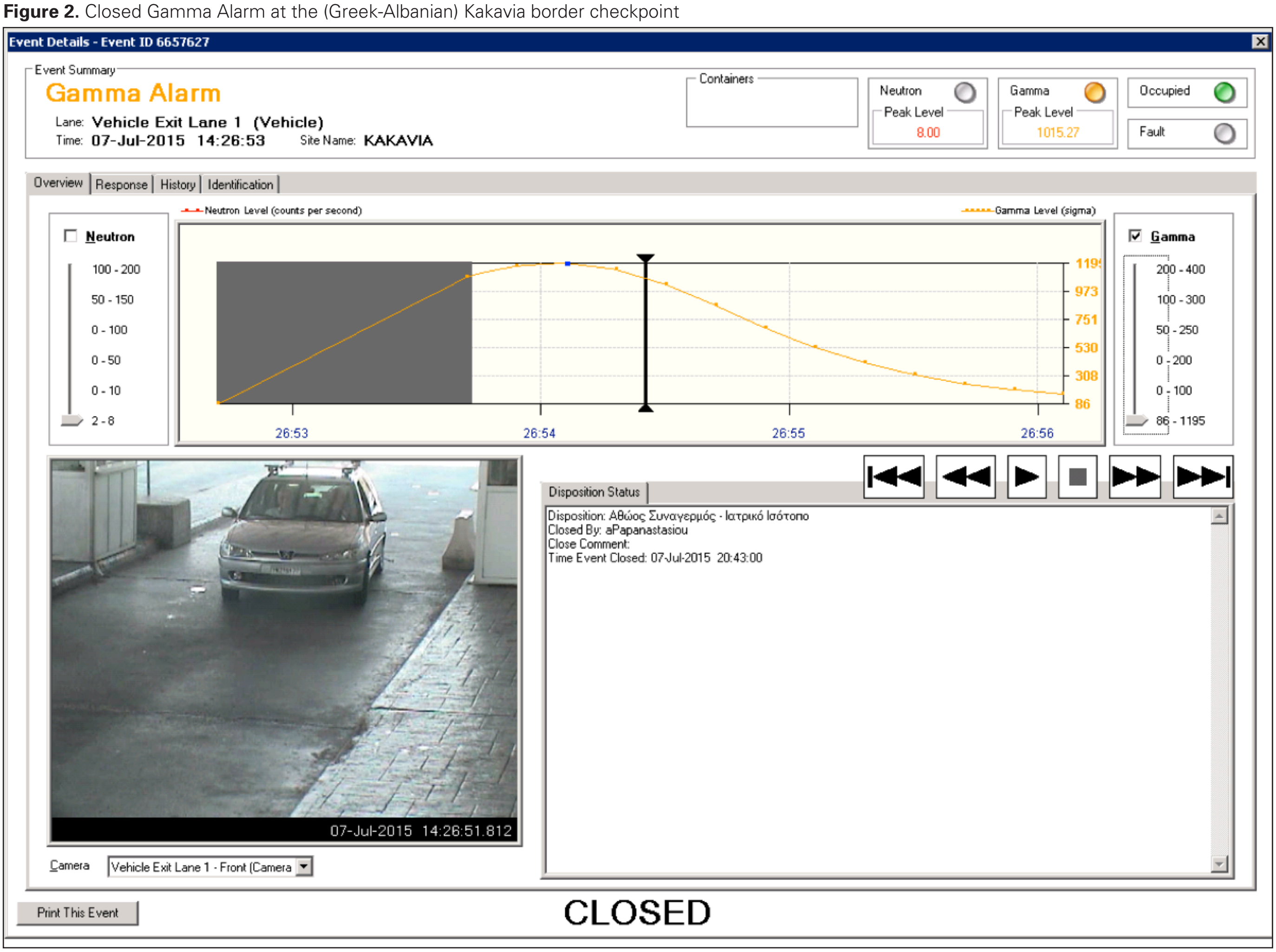
RPMs are usually equipped with several cameras arranged at different viewing angles to enable identification of the vehicle or person generating the radiation alarm. The camera images are associated with an alarm and can be stored in the RPM system computer server. Many cameras have associated lighting or infrared illuminators to help with visibility at night.

A computer, usually located in the vicinity of each site central office serves as alarm notification mechanism and also enables gate area personnel to send and receive messages to the CAS (Central Alarm System) regarding detaining, releasing or dispatching alarming vehicles or pedestrians/passengers. The server also serves as a communication tool. For all sites, the CAS handles alarms from more than one RPM. This is also the physical unit where the alarm closeout process is completed. The CAS can access information from previous alarms, and view other information that can help resolve them. The drawing in Figure 2 depicts a CAS, the alarm notification and an alarm closeout screen.

A server acts as the central communication hub and the computer processor for the entire radiation detection system. It also serves as the data storage device, where the alarm data, images, disposition of alarms, etc., are stored, serving to record the alarms in order to be available in a database with past alarm information, which can be used in closing the new ones.

Radiation detection systems indicate three types of alarms: neutron alarms, gamma alarms, and false alarms. These alarms

Figure 2. Closed Gamma Alarm at the (Greek-Albanian) Kakavia border checkpoint



may be indicated by lights located on or near the RPM accompanied by an audio signal.

Natural neutron background radiation will only generate 0 to 2 neutron counts per second, per tube. If a significantly higher number of neutrons are counted, a neutron alarm will occur. Neutron alarms are important and require special attention because there are very few innocent neutron sources. While it might be possible to have a neutron alarm due to a higher background or cosmic event, there is high likelihood that the alarm is real. The case of a neutron alarm could mean passage of special nuclear material, such as plutonium, or the legal or inadvertent transit of a neutron source. Finally, the threshold is set to 6.3 sigma, according to manufacturer recommendation.

Normally, an RPM has to be placed in areas where "person flux" is very high, e.g., in airports or borders, or in places where people enter or leave a controlled zone. Each RPM includes a gamma detector (plastic scintillators), lead shielding covering the back of detection system in order to reduce background, a neutron detector (He-3 tubes inside Polyethylene) -- a set of a couple, occupancy sensor, control and communication unit, video monitoring, alarm (sound and light) classified as neutron, gamma, tamper, high/low background, internal fault, and an uninterruptible power supply (UPS) battery backup.

Secondary Inspection with Portable Radiation Detectors

The following portable detectors are used by customs, (a) for secondary inspections where RPMs are installed, or (b) for primary detection in all other cases where no RPMs have been installed:

- Pagers (indicate the presence of a radiation field, their primary purpose is the protection and safety of the inspector; 300 pagers were distributed to customs throughout Greece).
- Survey meters (TSA PRM-470 survey instruments used for secondary inspection and determine radioactive source location and intensity; ninety-eight survey meters were distributed).
- RIID – Identifiers (to locate and identify specific radioactive isotopes; fifty-eight identifiers were distributed).

Operating Procedures

A minimum number of customs officers are necessary to work closely to portal detectors, while additional customs officers are needed in the Central Alarm Station.

According to the procedures and manufacturer recommendations, all vehicles have to pass through portal detectors at constant low velocity (~8 km/h). In addition, it is prohibited for anybody to stop between portal detectors. Portal monitors measure continuously the natural background, since there is no indication from occupation detectors. When a vehicle or a pedestrian stops in between portal detectors, it changes the radiation background giving consequently low-background measurements. In this case the system recalculates the alarm level accordingly to the new background. When the vehicle or the pedestrian moves again, an apparent sudden increase in radiation occurs, giving a false alarm.

In order to simplify operating procedures by minimizing secondary inspections, the following categorization has been applied:

- **False Alarm:** Alarm set-off without the presence of radiation.
- **Innocent Alarm:** Actual increase in radiation level but not due to inadvertent movement or illicit trafficking of radioactive materials. Medical isotopes or naturally occurring radioactive material (NORM) can be reasons for setting off such an alarm
- **Real Alarm (nuclear security event):** Actual increase in radiation level due to inadvertent movement or illicit trafficking of radioactive materials.

The Figure 3 flow chart is an example of operating procedures that customs officers have to follow in case of an alarm. This particular flow chart is from the cargo area of the seaport of Piraeus.

Personnel Training

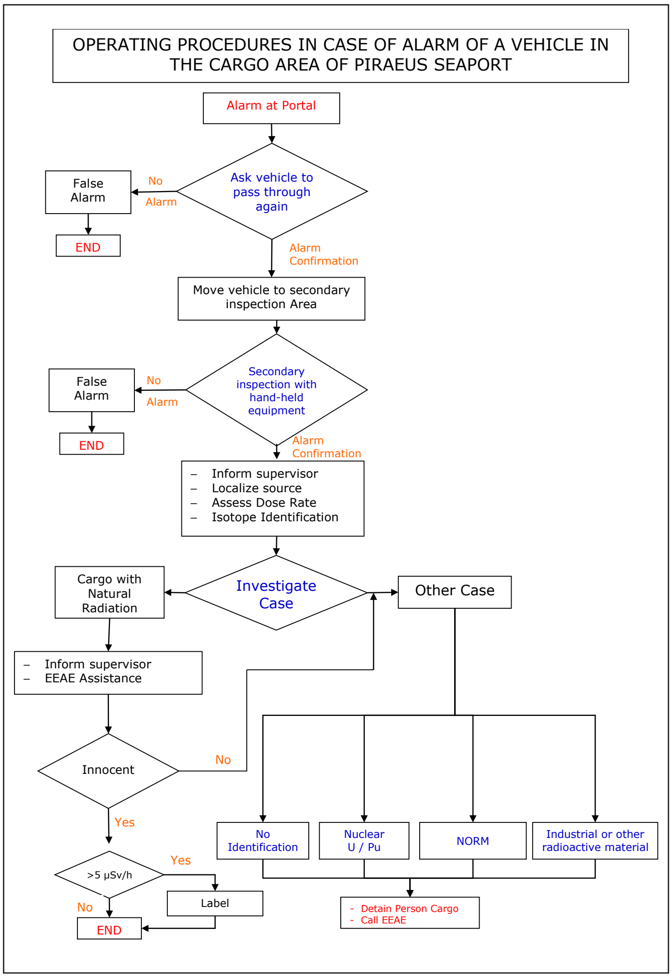
An extensive training program for the customs personnel has been put in place since the very initial phase of the project of combating illicit trafficking of nuclear and other radioactive materials.

The training program can be divided in two major periods:

- Initial phase: training performed mainly by NNSA, in collaboration with EEAE.
- Later phase: EEAE provided the whole customs training program.

The training program covers the needs of customs where the customs are equipped with both RPMs and handheld detectors for secondary inspections, as well as with handheld detectors only used for primary and secondary inspections.

Figure 3. Operating procedures flow chart



In both cases, the training program covers five major fields:

- General training — combating illicit trafficking of nuclear and other radioactive materials
- Basics about radiation and radioprotection
- Radiation portal detectors — construction and operation
- Handheld detectors used for secondary inspections
- Procedures followed by customs officers
- National response plan
- Integration with emergency response procedures

The two different audiences are handled according to this scheme. Operators of RPMs are trained individually. The training of the custom officers using handheld detectors, which in practice corresponds to the majority of employers, follows the scheme of "train the trainers." Training is planned for trainers from all sites, with the obligation of the directors in each one individual customs directorate to organize its own training course within a certain time frame. The same training cycle is repeated regularly.

Detectors Performance

The present analysis is based on the daily files stored by the system and proves the good performance of RPMs. These daily files incorporate the operational history of all RPMs since the start date of their operation when they were installed. The continuous availability of the systems can be derived from the following plot (Figure 4), which includes all occupancies for the first five months in 2015. Additionally, it may be noted that in the same plot is presented, the individual performance of four gamma and four neutron detectors installed, providing the fraction of alarms related with occupancies.

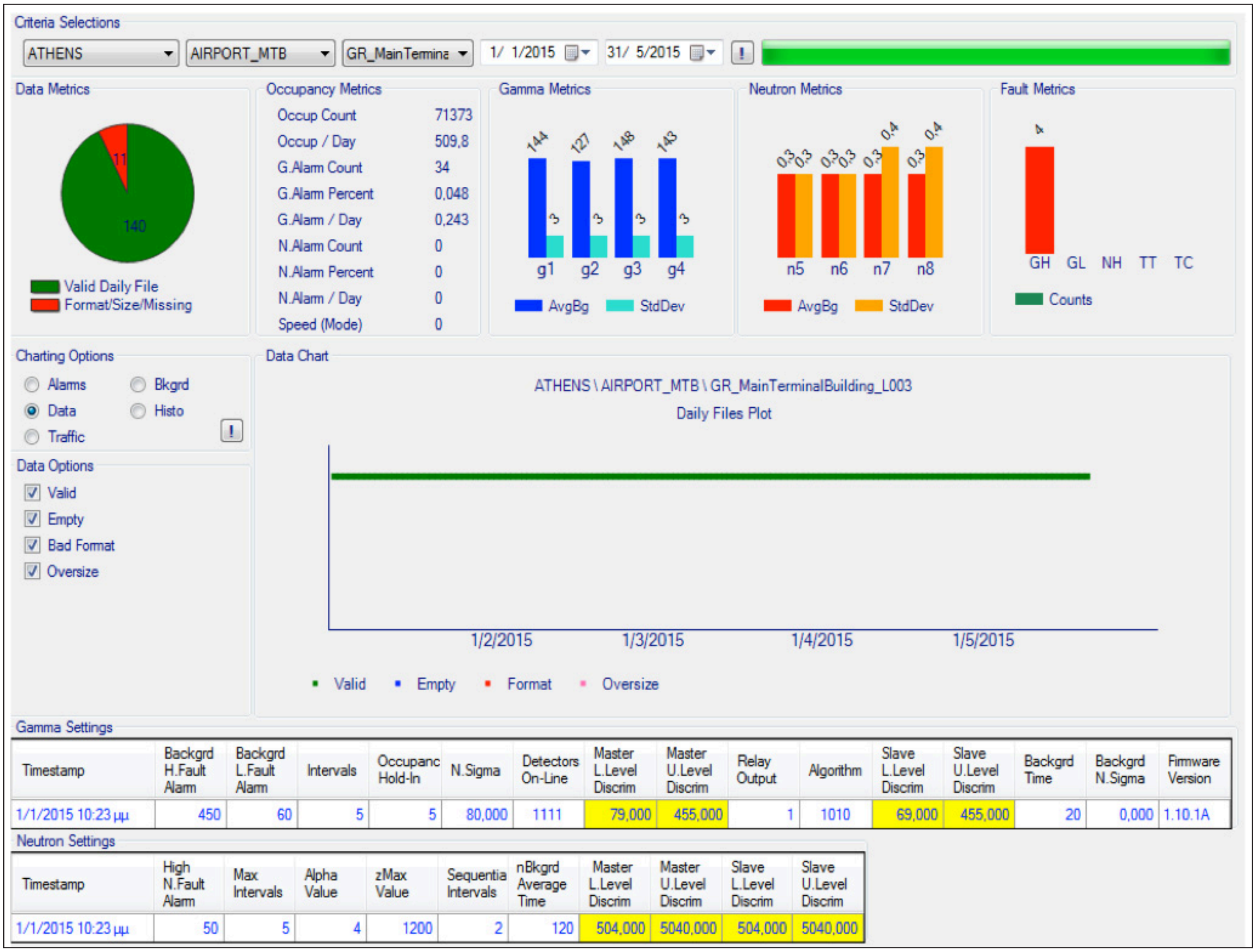
Also, daily alarms can be identified relative to occupancies as well within the day in a particular RPM, in the Main Terminal Building (MTB) at Athens International Airport, related to the time of occurrence within that day (see Figure 4). As can be observed in the graph, the alarms occur during the working hours of the airport.

Background measurements are presented in Figure 6 for a RPM in the Main Terminal Building at Athens International Airport. Usually, the background measurement on an RPM is performed while there is no occupation signal from the position detector attached to the system. According to that measurement, the alarm threshold is calculated at the time that an occupation is identified, and the system is starting, comparing the actual gamma signal with that threshold, to set-off an alarm event if the value of the above ratio is exceeded.

The ratio of all occupancies versus alarms in both flows (outbound and inbound) in the cargo area at Athens International Airport is presented. The important point is that this customs area is the only place in Greece where shipments of radioactive materials are performed routinely. According to specific procedures, customs officers are inspecting the four companies in the cargo area from where imports, exports, and transshipments are taking place.

The diagrams represent the outbound and inbound of the cargo area in Athens International Airport (AIA). The AIA, is the official entrance of almost every radioactive material transported to Greece. The diagrams indicate the radioactive materials imported to the country within the specific time period.

Figure 4. Daily file plot for the first five months of 2015



Typical Events Encountered

Event	Custom	Date		Material	Isotope
1	Evzoni	31-Oct-04	Vehicle	Coal dust	NORM
2	AIA	26-Jun-05	Pedestrian	Compass	Ra-226
3	Kakavia	2005	Pedestrian	Radiopharmaceutical	-
4	Piraeus Pedestrian	2005	Garbage truck	Lost Radioactive Source	Ra-226
5	Evzoni	8-Nov-07	Vehicle	Utilities	NORM
6	Evzoni	22-May-08	Vehicle	Scrap	Eu-152
7	Evzoni	6-Jul-10	Vehicle	Rolled iron bars	Co-60
8	Evzoni	July 2012	Vehicle	Coal	NORM
9	Evzoni	7-Sep-12	Vehicle	Coal	NORM
10	Kakavia	7-Nov-12	Vehicle	Industrial Radioactive Source	Am/Be & Cs
11	Piraeus Cargo	3-Jun-13	Vehicle	Rust	Ra-226
12	Kakavia	11-Jun-15	3 Vehicles	Wastes	NORM
13	Evzoni	6-Sep-15	Vehicle	Paper (Raw Material)	I-131
14	AIA	2-Oct-15	Pedestrian	Compass	Ra-226
15	AIA	17-Dec-15	Mail	Compass	Ra-226

Table 2. Selected examples of events from detection systems installed in customs locations in Greece

In Table 2, events from detection systems installed in customs in Greece are presented. This is not the complete list but rather an indicative sample of some important events.

Figure 5. Daily alarms

Lessons Learned

The lessons learned from the development and operation of this comprehensive nuclear security program, include:[11]

- Strong leadership from a lead agency in the country is necessary to move the project forward. Good interagency cooperation is of utmost importance.
- Well-defined continuous program with determined roles for the organization involved in maintenance and repair of all installed RPMs, and all handheld equipment distributed to detect nuclear and radioactive materials.
- A calibration program is necessary for the best performance of all RPMs and handheld equipment.
- Networking of the detection systems is of great importance for supporting customs officers on their duties detecting and for maintenance and repair purposes.
- Training is crucial. Equipment means nothing unless it is used in an efficient and effective manner. Initial training and also on-going refresher training is necessary to ensure sustainability of the system.
- Effective training of customs personnel must ensure that all personnel understand what the equipment does and resolve any safety concerns; train small groups of people to use the equipment and to carry out the secondary inspections; identify a core leadership group that will interact with the competent authority in the country designated to provide expert support on radiation issues.
- Rearrangements or new installations are always necessary since the needs of the inspecting land borders, airports, or seaports are often changing. Knowhow is of great importance for private companies that are involved in this process.
- A disadvantage is the custom staff mobility within its organization.

Figure 6. Background measurements for the first five months of 2015

- Problems with the aging of the detection systems after some years of operation. A suitable program has to be established early enough to prevent any effect on inspection procedures due to the non-operating parts of the detection network.
- Best practice is a three-month reporting system. The report includes the operating status of the infrastructure, malfunctions, procedure weak points, and findings.

Conclusions

The lessons learned from the successful implementation of a comprehensive nuclear security framework in Greece are becoming available to assist other countries in their efforts to develop and implement a nuclear security infrastructure. Sustainability measures were shown to be effective in enabling the nuclear security systems and measures in place to ensure long-term protection of the country against potential criminal or intentional unauthorized acts involving nuclear and other radioactive materials out of regulatory control. The cooperation among competent authorities in the area of nuclear security can provide a model for future similar arrangements aimed at strengthening nuclear security at major public events. In this regard, Greece will continue to work with the IAEA and other international organizations sharing the technical expertise gained through this experience, leveraging the EEAE's expertise, as well as its state-of-the-art laboratory and training facilities.

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Figure 7. Alarms versus occupancies in the outbound of AIA cargo area

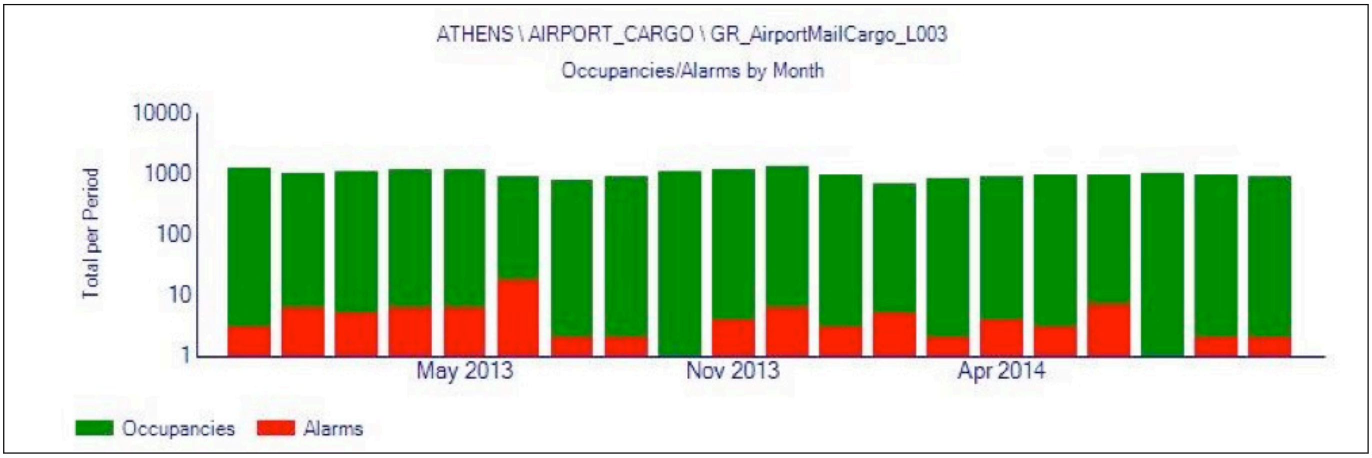
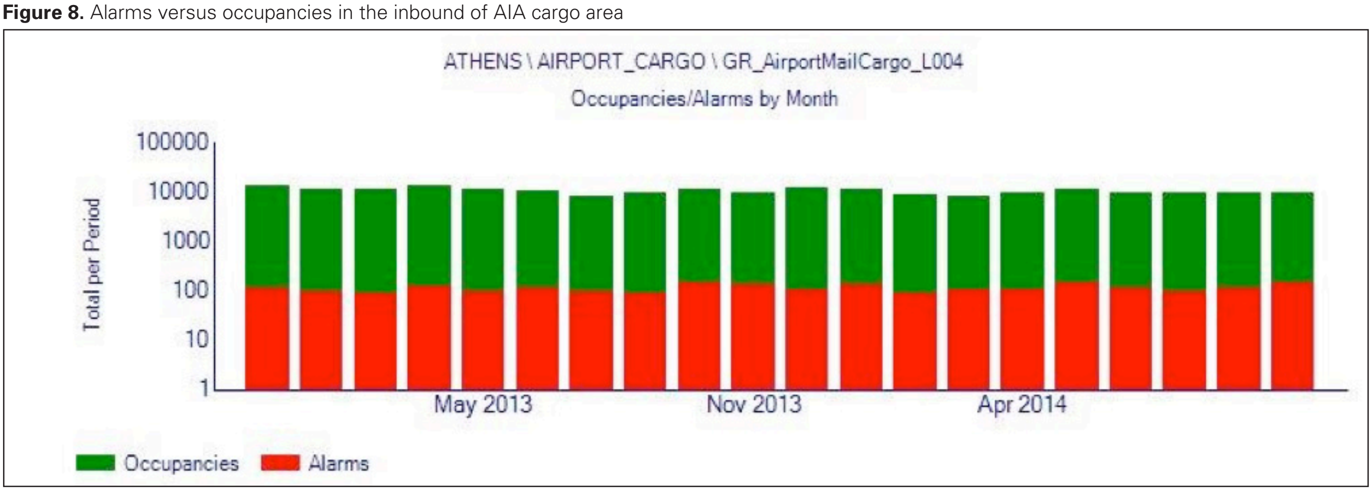


Figure 8. Alarms versus occupancies in the inbound of AIA cargo area



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