GAMMA CAMERAS AS NEW TECHNOLOGICAL DEVELOPMENTS TO STRENGTHEN NUCLEAR SECURITY DETECTION ARCHITECTURES:

Emerging potential approaches within regulatory frameworks and implementation practice, expected added value to existing measures from instrumentation-specific technical and functional characteristics

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Abstract

The use of gamma cameras is starting to become standard as a way to localize active areas on nuclear sites, and reduce the dose for the personnel while increasing the overall efficiency of the operations. This presentation intends to show how the typical performance of gamma cameras can lead to other applications such as **supplementing standard radiation detection devices deployed for nuclear security** purposes, e.g. during Major Public Events (MPE). The work performed is based on the technical and functional performance of a commercially available instrument of this type (**NuVISION**, developed by **NUVIA Group** in cooperation with the **French Atomic Energy Commission – CEA-LETI**).

Various types of radiation detection instruments are available and widely used as technical measures integrated into corresponding operational concepts and procedures, providing suitable tools for nuclear security and related areas. Gamma cameras such as NuVISION represent a **new type of instrumentation which offers a combination of existing or new functions into a single instrument**, with different potential uses and constraints. As such, gamma camera instrumentation is potentially interesting, but currently does not correspond to well-defined and critical needs in the mentioned applications.

Taking into account the overall specificities of the nuclear security applications we explored the capacity of gamma cameras to tackle **applications within the nuclear security of material outside of regulatory control (MORC)**, and more particularly for the security of **Major Public Events (MPE) and strategic locations** (including the related measures for emergency response). Another topic that could be addressed with such a tool is "**Radiological Crime Scene management**".

The work performed closely relates to several topics of the conference, mainly to **"Detecting radioactive material involved in criminal/unauthorized acts"**, but also to "Strengthening sustainability and effectiveness of nuclear security regimes related to security of radioactive material and nuclear security detection architecture".

In terms of subjects as listed in Appendix I of the conference announcement, the presented work addresses several of the listed subjects, more particularly in the following areas:

- « Current and emerging technologies »
- « Designing detection architecture »
- « Implementation of detection operation »
- « Sustainability and effectiveness of nuclear security systems and measures ».

1. INTRODUCTION

The following study provides an overview of how a new type of instrumentation gamma cameras such as NuVISION (developed by **NUVIA Group** in cooperation with the **French Atomic Energy Commission – CEA-LETI**) could be used for Nuclear security applications including Material Outside of Regulatory Control (MORC), and more particularly for security of Major Public Events (MPE) and strategic locations, but also including radiological crime scene management. As part of this work, relevant prescriptions from international reference documents issued by the IAEA (**Safety standards and Nuclear Security Series**), as well as usual practice and user requirements relating to nuclear security measures in the mentioned applications, were reviewed and analysed. Building on this reference environment, an **approach for the introduction of gamma cameras into existing detection architectures** was defined, by identifying **relevant detection targets**, as well as areas where the technical and functional characteristics of the gamma camera could bring **significant added value to current measures**. As a result, the proposed approach suggests solutions to **complement existing nuclear security measures** and **improve the coverage of the most important risks**. It makes the use of gamma cameras as an additional technical mean, integrated into nuclear security systems and measures, to **significantly improve operational constraints** in some particular scenarios, and/or **to provide an additional layer of protection** in "defence in depth" approaches.

As a leading organization of the **London 2012 Olympics** in charge of the planning and operations of the radiological screening of people and vehicles into the Olympic Park, NUVIA experienced first-hand the difficulty of setting up an effective detection architecture that could have been improved upon the release of gamma camera technology which was unavailable at the time of the games. Similarly NUVIA's involvement in the UK Border Force as part of its role in **project Cyclamen** in the UK where movements across the border of people, vehicles and freight are screened for radioactive materials is a valuable experience showing some of the shortfalls of current detection techniques.

2. CONTEXT OF THE STUDY

Nuclear security focuses on the prevention of, detection of, and response to, criminal or intentional unauthorized acts involving or directed at nuclear material, other radioactive material, associated facilities, or associate activities [1].

Nuclear security covers a lot of various areas and activities, some of them involving the use of radiation detection instrumentation. More specifically, such instrumentation is being used in the areas of**:**

- Nuclear security of materials and facilities
  - Mainly as part of the physical protection of radioactive sources and nuclear material.
- Nuclear security of material outside of regulatory control
  - Mainly as part of the controls at points of entry/exit (border monitoring), security for Major Public Events (MPE) [2] and strategic locations, radiological crime scene management.

In addition nuclear security issues may be closely linked to emergency response activities, in which radiation detection instrumentation plays an important role.

Various types of radiation detection instruments are available and widely used for these areas and have been integrated into corresponding operational concepts and procedures, providing suitable tools, with the main functions needs covered, for nuclear security and related areas.

Gamma cameras such as **NuVISION** represent a **new type of instrumentation** which offers a combination of existing or new functions into a single instrument, with different potential uses and constraints. As such, **NuVISION-type of instrumentation is potentially interesting,** but does not correspond, as per current status, to well-defined and critical needs (and therefore to an identified need) in the mentioned applications.

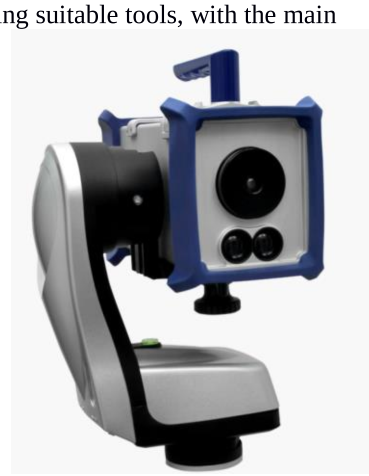

FIG. 1: NuVISION on motorized head

Taking into account the overall specificities of the nuclear security applications (technical considerations and potential needs) and of the NuVISION product, **the main areas of nuclear security worth to be considered for NuVISION** use seems to be within the nuclear security of Material Outside of Regulatory Control (MORC), and more particularly **for the security of Major Public Events (MPE) and strategic locations** (including the related measures for emergency responses).

The study will therefore focus mainly on possible concepts/conditions for potentially introducing

gamma cameras in detection architectures and approaches used for nuclear security at Major Public Events (MPE). However the proposed approaches may also be applicable for other purposes (e.g. the protection of strategic locations, which is part of measures implemented for MPE, may also need to be implemented in the absence of a MPE).

3. RADIATION DETECTION INSTRUMENTATION FOR NUCLEAR SECURITY AT MAJOR PUBLIC EVENTS-TODAY'S STATUS

3.1. An increasing trend

The area of nuclear security, in particular applied to the protection of Major Public Events, has received increased attention in the recent years.

As an example, **the IAEA assistance to its Member States in the area of Major Public Events has shown a generally increasing trend over the last years**.

A simple indicator is the number of such events for which assistance was provided by the IAEA (taken from the IAEA nuclear security reports):

— in 2013-2014: 4 Major Public Events
— in 2014-2015: 4 Major Public Events
— in 2015-2016: 9 Major Public Events
— in 2016-2017: 8 Major Public Events.

In most cases, these activities involve significant use of radiation detection instrumentation.

It should be mentioned that the above examples represent only a limited part of the worldwide activities in this area and of the corresponding need for radiation detection instrumentation, as the IAEA provides assistance in this area only upon request from the Member States (i.e. numerous states implement their own nuclear security measures without the assistance of the IAEA).

Given the current international security environment, with persistently high levels of threats over the last years, it is likely that interest in nuclear security, in particular in the area of radiation detection instrumentation for MPE, will be a real topic in the next years.

This area is therefore likely to represent significant needs in terms of radiation detection instrumentation solutions (different from existing solutions through new approaches (technical and commercial), but bringing **significant improvements)**.

3.2. Documented standard approaches – references

The area of nuclear security and related radiation detection instrumentation has been widely documented, especially over the last decade.

For the purpose of the document, information from international reference documents issued by the IAEA will be used, mainly from the following documents:

— Categorization of Radioactive Sources, IAEA Safety Guide N° RS-G-1.9 [3]
— IAEA Technical Guidance on Combating Illicit Trafficking in Nuclear and other Radioactive Material (Nuclear Security Series No. 6, NSS6) [4]
— IAEA implementing guide on Nuclear Security Systems and Measures for Major Public Events (Nuclear Security Series No. 18, NSS18) [5].

The main points to be used from these documents, as well as from usual practice and related considerations regarding radiation detection instrumentation, are detailed in the next sections.

3.3. Purpose and scope of radiation detection instrumentation use

3.3.1. Why is radiation detection instrumentation used at MPE?

Radiation detection instrumentation is one of numerous measures addressing nuclear threats at MPE. The main threats it should be reasonably considered to detect through radiation detection instrumentation at any MPE are:

— **Radiological dispersal device (RDD)** or “dirty bomb”
  A device aimed at spreading radioactive material using conventional explosives or other means.
— **Radiological exposure device (RED)**
  A device with radioactive material designed to intentionally expose members of the public to nuclear radiation.

Radiation detection instrumentation is mainly used to detect these possible threats, and to potentially manage the consequences of such an event happening.

3.3.2. Where is radiation detection instrumentation typically deployed

The typical venues and other strategic locations that may be considered for protection against a nuclear security threat can be listed as follows:

— **All locations where the MPE will occur**
  The venues could be facilities, such as conference centers, stadiums, sport facilities, religious sites, exhibition centers, hotels and public viewing areas, which may have multiple access points and various entry points to protect.
— **Locations where the participants/officials for the event would be gathered**
  Among these are media centers, press conference centers, airports, seaports, railways stations, housing (such as an Olympic village), adjacent hotels, or residences of high ranking dignitaries.
— **Specific buildings or monuments that are representative or of symbolic importance**
  and could be considered as targets for an attack, or used to increase the potential consequences of an attack.
— **Transportation systems or specific routes for commuting between the venues during a major public event**
  In addition, other strategic locations in the state (including e.g. points of entry in the State), may be considered for deployment of radiation detection instrumentation. This is not necessarily specific to the MPE period (the equipment could be permanently deployed at such locations), but it could be considered to increase these measures for the period of the MPE.

3.3.3. For which tasks is radiation detection instrumentation (mainly) used for?

Radiation detection instrumentation is used in MPE mainly for the following tasks:

— **Background radiation mapping of venues and other strategic locations**
  This is performed before the opening of the MPE, for detection of existing potential radioactive material and to serve as a baseline for radiation level in case a nuclear security event occurs.
— **Pre-event surveys, implemented prior to the imposition of full access control (« lockdown »)**
  This provides reassurance that these strategic locations are free from nuclear and other radioactive material.
— **Control of the entry points at a venue during the event**
  - To detect the presence of radioactive material that might be entering the area hidden on an individual and/or in goods, and/or in vehicles. Mainly as part of the physical protection of radioactive sources and nuclear material.
  - Mainly through radiation monitoring at controlled convergence security screening points (locations where people pass, individually or in small numbers where they can be easily isolated).

Radiation detection instruments are usually deployed in addition/combination with other security measures already in place (e.g. metal detectors, Xrays, etc.).

- Often supplemented with early detection measures, through roving security patrols equipped with specialized detection instruments outside of the secure perimeter.

— **Area monitoring with a mobile radiation detector**
Detector installed in a mobile platform, which can detect and identify fixed or moving nuclear and other radioactive material. Special search and localization techniques are used to quickly find the nuclear and other radioactive material in covert manner.

3.3.4. What kind of equipment is currently used and which functions are required from the equipment?

The main instrument types currently used in nuclear security for MPE are listed below.

Most widely used in this context are:

— **Personal radiation detectors (PRDs)**
Small, lightweight instruments worn by personnel on a belt or uniform, designed to alert the user to increasing levels of radiation intensity and to detect the presence of nuclear and other radioactive material. Used mainly to control of the entry points to the venue during the event.
— **Radionuclide identification devices (RIDs)**
Multipurpose instruments used for search and identification of nuclear and other radioactive material. Used in several of the above-mentioned tasks.
— **Portable radiation scanners (PRSs, backpack type)**
Automated gamma spectrometers and radionuclide identification software, allow mapping with a global positioning system and possess communication capabilities. Often used for pre-event radiological surveys and background mapping, may also be used for real time detection near the strategic locations.
— **Expert support and response equipment** (high-resolution spectrometers, alpha-beta contamination monitors, etc.).

Some other instruments types that can be used in this context are:

— **Radiation portal monitors (RPMs)**
Can be used at choke points for detecting the presence of nuclear and other radioactive material being carried by passengers/pedestrians or transported by vehicles.

— **Mobile radiation detection instruments for large area surveys** (airborne and/or vehicles and/or watercraft monitors)
Can be used at choke points for detecting the presence of nuclear and other radioactive material being carried by passengers/pedestrians or transported by vehicles before their arrival in the venues surroundings.

Some more detailed description can be found in NSS18 [5].

The main typical functions required from radiation detection equipment in this context are:

— Detection
— Localisation
— Identification
— Radiation protection and material quantity assessment
— Documentation of detections.

The different types of equipment listed above provide the necessary tools for performing these functions. However no single instrument is able to provide all functions while fulfilling at the same time all operational requirements, therefore the implementation of nuclear security measures always requires the deployment of a combination of different instrument types.

As a summary, current approaches for deploying radiation detection instrumentation at MPE usually provide:

- **Tight entry control of specific venues/locations**
  Potentially able to detect small amounts of radioactive materials within the entire venue and potentially subject to non-negligible rate of innocent alarms (e.g. medical isotope in-vivo).
- **“Spot” checks around security perimeters at venues and in other locations**
  Potentially able to detect small amounts of radioactive materials but not permanently and uniformly deployed (mobile patrols).

These approaches involve the deployment of several types of instrumentation, with associated multiple user training requirements.

4. POTENTIAL CONDITIONS FOR INTRODUCING HANDHELD GAMMA CAMERAS

4.1 General potential advantages in the use of handheld gamma cameras

From a general standpoint with regards to the mentioned context, the following potential advantages of the use of gamma cameras can be listed:

- Combination of most of the required functions (as detailed in the previous section) **into a single instrument (of 3 kg)**
- Automation of the identification and localization processes
- Additional **visualization function**
- Reduction of false alarms due to medical isotopes
- Real-time identification of threat and carrier among a large group of people
- Potentially reduced user training.

However, in terms of basic performance such as detection sensitivity (which should be comparable to existing types of instrument), and given the current significant cost of such devices (in the absence of a high-volume market), it is unlikely, in the current context, that gamma cameras could be considered as a viable alternative to existing, well-known detection system within standard detection architectures.

Nevertheless, **under certain conditions the operational advantages of the gamma camera could justify its introduction into existing architectures,** mainly as:

- an additional technical mean to significantly improve operational constraints in some particular scenarios, and/or
- **an additional layer of protection in the “defense in depth” approaches.**

The following sections details the main assumptions, and their justifications based on reference documents, that could provide a suitable framework for introducing gamma cameras into existing or new detection architectures.

4.2 An approach for introducing gamma cameras in existing detection architectures

4.2.1 General considerations about detection target

The main point is to understand and define **under which conditions the technical and functional characteristics of the gamma camera could bring significant added value to existing measures.** As mentioned above, the current measures mainly result in a tight control of specific venues, and spot checks for other areas. These measures are potentially able to detect small amounts of radioactive materials. **The range of applications covered by the gamma camera should complement these existing measures.** Given its similar expected detection sensitivity as existing equipment, there is no point in using the gamma camera for addressing specifically the same types of threats and situations. The main interest would therefore be to use the additional capability to **identify** and **locate** sources in an **automatic way** and on potentially **wide areas,** thus providing significant operational improvements in cases of detection of a source, and, as much as possible, addressing a wide range of scenarios of the most important concern. **The target for gamma camera use should be the detection of the most significant threats, i.e. “dangerous” sources of categories 1 to 3, in an unshielded configuration.** This would allow to consider much wider areas where the detection of sources could be ensured by the camera in a continuous way, thereby allowing to benefit from the operational advantages of gamma cameras, while complementing existing measures and improving the coverage of the most important risks. The mentioned detection target would be in accordance with the most significant needs in this area, and can be supported and justified by the following facts and considerations:

— **Regarding the target of “dangerous” sources of categories 1 to 3**

- As detailed above, the main threats to be addressed through radiation detection instrumentation at MPE are RDD and RED.
- The main radioactive sources of concern for RDD and RED are the sources of category 1, 2 and 3 with activity above dangerous level, as defined in the IAEA Safety Guide N° RS-G-1.9 [3]. This is supported by the following considerations from reference documents:

In NSS6 [4]: “For purposes of countering the threat of RDD incidents, nuclear security measures should focus on the kinds of material that have the potential for causing the greatest and most long lasting damage. A wide range of radioactive material is used in civilian applications. However, the quantities involved in many of them, if dispersed, are not sufficient to cause immediate injury or significant contamination. The focus of concern, therefore, should be on those sources that could cause injury in the short term and, if dispersed, significant levels of contamination of the environment”.

The same reasoning can be applied to RED incidents.

As per IAEA Safety Guide N° RS-G-1.9 [3]: Sources can be categorized, in five categories, as per their potential to cause harm to human health, from Category 1 (Extremely dangerous to the person) to Category 5 (Most unlikely to be dangerous to the person).

The categorization system is based on the concept of **‘dangerous sources’** — which are quantified in terms of ‘D values’ (activity value, specific to each radionuclide). To summarize, “dangerous” sources have an activity above D value, and when determining the category of a source purely on the basis of its activity, sources of categories 1 to 3 have an activity above D and sources of categories 4 and 5 have an activity below D.

— Regarding the target of unshielded sources for detection capability of the instrument:

- In most cases security arrangements for the event involve detecting prohibited objects in particular through the use of metal detectors at the entrance checkpoints in the security perimeter of the venues. These measures for metal detection allow to detect possible shielding of radioactive sources (such shielding, in order to be efficient for hiding the gamma sources, require the use of significant amounts of metal).
- In addition and as mentioned above, existing measures are usually targeted to the highest sensitivity, therefore already covering, as much as feasible, the case of shielded materials.
- In addition for the particular case of the RED once the device is activated (and therefore needing immediate response), it is unshielded.

The following sections detail some considerations to roughly quantify the size of the areas that could be covered by gamma cameras under the mentioned conditions.

4.2.2 NuVISION rough level of detection performance magnitude

The IAEA Safety Guide N° RS-G-1.9 [3]: lists the most commonly used radioactive sources in each category. Concerning sources of categories 1 to 3 (i.e. those that need to be used for the main threats to be addressed), the most commonly used sources comprise only a limited number of radionuclides (about 10 different isotopes). Taking the **example** of **Cs-137** with a source of **0.1 TBq** activity (D value (activity for a « dangerous » source as per categorization document)):

Assuming no shielding between source and detector, i.e. only in air attenuation;

The rough order of magnitude of the time needed to **detect** the source is **less than 1 second** for a distance of several **tens meters.**

The rough order of magnitude of time needed to **localize** is **less than 5 seconds** for a distance of several tens meters.

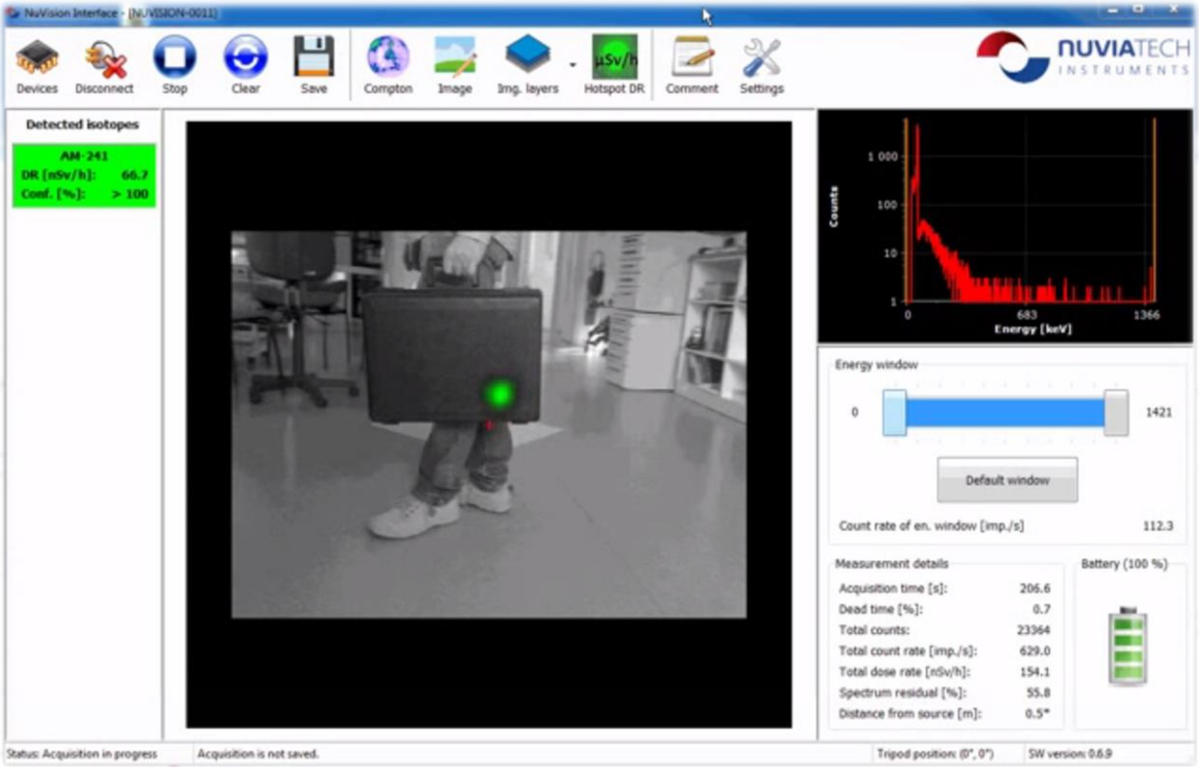

FIG. 2: Tracking and identifying a moving Am-241 source in real-time with NuVISION

Many performance evaluations have been done recently with NuVISION, including last June during a « Gamma Imaging Workshop » at JRC-Karlsruhe in the frame of the technical sub group of the Border Monitoring Working Group [6]; the goal was to conduct basic capability measurements (e g what is the imaging performance for different energies, how well can they separate two sources of same/different isotope, can they image extended sources etc…). The target was also to work with border monitoring scenarios (source hidden in NORM (Naturally Occurring Radioactive Material), shielded sources, SNM (Special Nuclear Material) masked by industrial source, multiples sources, NORM-only etc…

For **most sources from the commonly used sources of categories 1 to 3 with activity above dangerous level** listed in IAEA Safety Guide N° RS-G-1.9**, the approximate gamma dose rate** produced by an unshielded source **is on the same order or higher than that produced by the Cs-137 source** taken as an example.

Therefore, and under the condition that the response time for NuVISION to detect dose rate produced by nuclides having gamma emissions in other energies regions would be of the same order of magnitude than that assumed for Cs-137, it seems that most of the sources given in the list of most commonly used sources of categories 1 to 3 with activity above dangerous level could be detected and localized within a time of the same order of magnitude as mentioned before.

It is clear that in real cases the measurement conditions will not be as ideal as for this rough estimate (for example, the source will not constantly be in line of sight of the detector), however considering an area covering **a few tens of meters** from the gamma camera would probably be a reasonable value for an order of magnitude of the maximum detection range for the gamma camera that would fulfil most of the detection targets within acceptable detection times, as per the assumptions taken.

4.3 Specific advantages of using gamma camera in addition to existing measures

In addition to existing measures at the entry points to the venue, it should be worth introducing one (or several) gamma camera(s), as fixed and/or mobile instrument and as part of primary detection and secondary inspection measures, in order to cover the whole entry point and its surroundings. This could potentially result in:

— **Advance detection capability of potential sources of high concern**, with automated identification and localization of threats, allowing **quicker and more efficient response for the most important threats**.
— In the case of a non-innocent event, possibility to **locate among a large group of people and characterize the cause of the alarm without attracting undue attention**, which would probably be of significant interest.
— **Much easier handling of innocent alarms** (e.g. through automated localization and identification as medical isotope), which is critical due to the high flow of persons and would avoid time-consuming localization/characterization process and possible temporary closure of the entrance checkpoint, also leading to a **much lower intrusive process** for the people screened.
— Depending on actual performance and functionalities, **potential replacement or centralization of some secondary inspection and/or expert support resources** (e.g. if the information from a network of gamma cameras deployed at a venue could be made available in a control room or equivalent).

5. CONCLUSIONS

Further to the study, it's clear that a gamma camera such as NuVISION, new tool (commercially available) developed by **Nuvia Group** [7] in cooperation with the **French Atomic Energy Commission – CEA-LETI,** will be able in the coming years to be part of current detection architecture by complementing the standard equipment to detect, identify and locate potential radioactive threats.

More than ever the protection systems using today's technologies have a significant cost and many countries (in particular developing countries with porous borders) must find the appropriate budget (not only for the equipment purchase but also for the installation, training of specialists and the maintenance ….).

Gamma cameras deployed on a large scale (at an affordable cost) could bring a real added value to improve radiological detection architectures in particular for Major Public Event (MPE) and strategic locations (including the related measures for emergency response). Where it will provide an early, efficient and covert detection, identification and localization of nuclear and other radioactive materials.

6. SHORT GLOSSARY OF ABREVIATIONS

MORC	Material outside of regulatory control
NSS	Nuclear Security Series, IAEA reference documents in nuclear security
MPE	Major Public Event
PRD	Personal radiation detector
PRS	Portable radiation scanners (often a backpack-type)
RDD	Radiological dispersal device-"dirty bomb"
RED	Radiological exposure devise
RID	Radionuclide identification device
RPM	Radiation portal monitor
TBq	Tera Becquerel

7. REFERENCES

[1]. IAEA Nuclear Security Series No. 20 Objective and Essential Elements of a State's Nuclear Security Regime

[2]. **Major Public Event**: A high profile event that a State has determined to be a potential target to include, for example, sporting, political, and religious gatherings involving large numbers of spectators and participants (definition from IAEA Nuclear Security Series No.18)

[3]. IAEA Safety Guide N° RS-G-1.9 Categorization of Radioactive Sources

[4]. IAEA Nuclear Security Series No. 6, NSS6 (IAEA Technical Guidance on Combating Illicit Trafficking in Nuclear and other Radioactive Material)

[5]. IAEA Nuclear Security Series No. 18, NSS18 (IAEA implementing guide on Nuclear Security Systems and Measures for Major Public Events)

[6]. JRC-Karlsruhe « Gamma Imaging Workshop » in the frame of the technical sub group of the Border Monitoring Working Group 28 May-1 June 2018 Hamid Tazziria

[7]. NUVIA http://www.nuviatech-instruments.com/product/nuhp-nuvision