Commissioning and field tests of a van-mounted system for the detection of radioactive sources and special nuclear material

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***Abstract*—MODES_SNM project aimed at developing a prototype for a mobile, modular detection system for radioactive sources and Special Nuclear Material (SNM). Its main goal was to deliver a tested prototype of a modular mobile system capable of passively detecting weak or shielded radioactive sources with accuracy higher than that of currently available systems. By the end of the project all the objectives have been successfully achieved.**

Results from the laboratory commissioning and the field tests are presented in this publication.

***Index Terms*—Radiation monitoring, National security, Neutrons, Radioactive materials, Radiation detectors, Special Nuclear Material (SNM)**

I. Introduction

THERE is no doubt that nuclear threats represent a major concern for today's world. The existence of conventional nuclear weapons and incident-related radiation contaminations are two issues well known to the public. In addition, various types of radioactive materials can be used to build Improvised Nuclear Devices (INDs) or Radiological Dispersion Devices (RDDs or "dirty bombs"); they require simpler technologies than those needed to build conventional nuclear weapons, while retaining the capability to affect large areas and populations. Therefore it is of primary importance to prevent illicit transportation of these radiological and nuclear materials.

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Today's approach to nuclear detection relies primarily on fixed inspection portals placed at Border Crossing Points (BCPs; the so-called "ports of entry") or in other transportation modes; whereas their presence still represents an advancement in security procedures, concerns have been raised about the possibility that strongly shielded or masked nuclear material might not be detected by those portals. A substantial improvement would be needed to achieve the capability to detect nuclear materials with improved detection systems anywhere within the transportation infrastructure. Hence, recent years have seen a large extension of research projects in the field of mobile/portable detection instruments, to which this work belongs.

II. MODES_SNM project overview

The project MODES_SNM (MOdular DEtection System for Special Nuclear Material) has been supported by the European Commission within the Seventh Framework Programme (FP7) and comprised seven participants from five different countries [1]. The goal of the project was to develop a mobile and modular detection system specially designed for SNM[1] but also with the capability of detecting all radioactive sources.

A special focus was put into the versatility of the system. The van mounted configuration was selected for the field demonstration to allow efficient movement of the system across several countries and to experience maximum number of operational scenarios. However, the modules were designed in a portable way such that scenarios outside the vans could be tested as well; in fact, during the course of the tests, the system was frequently deployed in a non-mobile mode. Portability was also an important design consideration for the individual system components, and maximum weights were applied to ensure that the system could be assembled/disassembled easily by field officers.

Therefore MODES_SNM system can ben considered an hybrid between different industry categories of detection instruments, most notably Portable Radiation Scanners (PRS) and Mobile and Transportable Radiation Monitors (MTRM); this dual capability reflected on the definition of performance requirements reported in Sec. IV.

[1] In this work the term SNM refers to "plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235" as defined in [2].

III. Description of the system

The MODES_SNM prototype makes use of a set of detectors based on high-pressure cells using noble gas scintillators: ^{4}He for fast neutrons and Xe for gamma rays. The technology of the high-pressure gas cells was developed by Arktis as a spin off of CERN based experiments.

^{4}He scintillation detectors feature a much better signal-to-noise ratio for fast neutrons with respect to the one of typical detectors employing ^{3}He proportional counters with polyethylene moderators [3]. In addition, the excellent gamma ray immunity of such neutron detectors (better than 10^{-6} [4]) allows detection of neutron signatures at high confidence level. Moreover ^{6}Li-lined ^{4}He tubes have been developed to detect slow neutrons. The ^{6}Li layer is significantly more sensitive to thermal neutrons, whereas only fast neutrons can produce a detectable signal in the ^{4}He. These two interactions can be discriminated with Pulse Shape Discrimination (PSD), thus allowing for independent measurements of the slow and the fast component of the neutron spectrum. Note that ^{4}He detectors do not need a moderator like ^{3}He detectors, thus the detected thermal neutron flux is exclusively due to the source and its surroundings. Consequently, the relative source strength can provide information about possible shielding of the neutron source. The active diameter and length of both detectors are 470 mm and 2", respectively. MODES_SNM system includes 8 fast neutron detectors (FND) and 2 ^{6}Li-lined thermal neutron detectors (TND).

Gamma ray Xe-based scintillation detectors have been developed with very interesting performances [5]. Xe-based scintillation detectors are robust, vibration insensitive, non-hygroscopic and scalable to cover also large solid angles. Furthermore, in the energy region typical for special nuclear materials (i.e. below 1 MeV) they offer better energy resolution (6.7 % @ 667 keV [7]) that standard NaI(Tl) detectors ($>$ 8 %). MODES_SNM system incorporates one xenon detector with an active volume of 8" $\times$ 4" (L $\times$ D) and a NaI(Tl) detector (125 mm $\times$ 125 mm $\times$ 250 mm) which is used to assure good detection efficiency at energies above 1 MeV.

Power supply to the detectors is provided by three CAEN HV modules DT5533 (4 kV, 3 mA on 4 channels). The detector read-out is performed in a fully digital fashion by using three CAEN digitizers mod. DT5730 (8 channel, 500 MS/s, 14 bit [6]). The FPGAs embedded in the digitizers allow to perform online part of the analysis such as coincidences, charge integration of the signals and PSD. A suitable information system running on a commercial low-consumption PC has been developed to manage the acquisition, integrate and analyze the data, and provide simple information to the user about the results of the inspections. A commercial Lead-based battery allows to run the entire system for up to 5 hours.

Detectors are grouped and mounted inside seven Alupanel boxes, which are held in place by a modular chassis made of Bosch profiles; the chassis is installed behind the side door of a commercial van, as shown in Fig. 1. The five horizontal boxes on the back house the ten neutron detectors; their active volume is not covered by the two gamma ray detectors mounted inside the vertical boxes on the front. The electronics and the computer system are placed behind the detectors, on the floor of the van. Operators can remotely operate the system by using any device with WiFi capability. Detailed informations can be found in [7].

Fig. 1. The configuration of the van-mounted system. The horizontal boxes house the neutron detectors; gamma ray detectors are mounted vertically on the front.

IV. International standards and requirements

Considering the hybrid nature of MODES_SNM system, a custom set of performance requirements were elaborated by referring to several publications defining the state-of-the art for different types of radiation measurement devices (e.g. [9], [10], [11], [12], [13], [14], [15]):

- **Probability of Detection (PD) and False Alarm Rate (FAR):** the PD must be at least of 0.9, or 96 per 100 trials; the FAR must not exceed 0.001 (or 1 in 1 hour). Detailed definitions of FAR, PD, Confidence Level (CL) and other statistical quantities are reported in [16], [17];
- **gamma ray sensitivity:** the system shall generate an alarm when sources are moving with a speed of 0.5 m/s (1.8 km/h) at a distance of closest approach of 1 m. The dose rate must be 0.05 μSv/h on the face of the detector;
- **neutron sensitivity:** the prototype shall generate a neutron alarm for a ^{252}Cf source emitting 1.2×10^4 neutrons/s and moving with a speed of 0.5 m/s (1.8 km/h) at a distance of closest approach of one meter;
- **single nuclide identification:** the instrument shall be able to identify every nuclide in the instrument's library within

60 seconds at an exposure rate from 0.05 μSv/h up to 5.0 μSv/h;

- **multiple nuclide identification and masking:** the prototype should be able to identify a set of high concern nuclides (see Table III) under the above conditions with NORM or radio-pharmaceuticals being simultaneously present;
- **radiation interference:** the instrument shall not trigger a neutron alarm when exposed to a ^{60}Co gamma ray source producing a dose equivalent rate averaged over the face of the neutron detector of 100 μSv/h, and it shall continue to respond to neutrons as specified in the presence of gamma radiation.

V. Detector commissioning at NCBJ Świerk

The prototype was laboratory tested and integrated as van-mounted system by the end of 2013. Once the assembly was finished, the completed system was moved to Narodowe Centrum Badań Jądrowych (NCBJ) in Świerk (Poland) for the laboratory characterization of the prototype. In the first phase several measurements were carried on for all three types of detectors in order to optimize their performances and characterize the response to gamma and neutron radiation. Further tests were then devoted to measure the False Alarm Rate, the Probability of Detection and to verify identification capabilities of various types of gamma ray and neutron sources.

All the measurements involved fixed sources and have been carried out in a large experimental hall to ensure a low scattering environment; the environmental conditions resembled as much as possible those defined as "Standard Test Conditions" (STC) [13]. Table I presents the environmental conditions during the PD and FAR tests. Observed humidity values are lower than the range defined in STC specifications; given the nature of MODES_SNM detectors, this is expected to have a negligible influence on system performances.

TABLE I
STC during detection tests

	STC	Measured values
Temperature	18 °C - 22 °C	20 °C - 22 °C
Pressure	70 kPa - 106 kPa	100 kPa - 102 kPa
Humidity	50% - 75%	34% - 36%
γ radiation background	$<$ 250 nSv/h	110 nSv/h

1) ^{4}He Fast Neutron Detectors (FNDs): The response of FNDs to both neutron and gamma ray sources was measured in order to choose optimal bias voltages and threshold settings, ensuring good neutron/gamma discrimination capability and maximum neutron detection efficiency. Neutron/gamma discrimination in FNDs is performed using the Charge Comparison PSD technique [8], where the PSD parameter is calculated as the ratio between the tail integral and the total integral of the event pulse.

Each FND was raised 0.9 m above the laboratory floor and a ^{252}Cf source was placed at the same height. The distance between the detector and the source was adjusted to obtain the prescribed flux of 0.1 n/s/cm^2; for a 558 kBq source the distance equals to 228 cm. The FAR and PD tests were performed by aggregating the neutron events from all eight detectors available in the prototype. The cycle time was fixed to 2 s. Considering a source moving at 0.5 m/s as prescribed by standards, this value corresponds to a space path of 1 m, twice the active length of a single ^{4}He FND.

Detection tests consisted of 90 minutes of sampling time with the ^{252}Cf source; the acquisition was then splitted in 449 datasets of equal duration. The number of true positives was 448, the resulting PD being about 97.4% at CL = 95%, thus satisfying the requirements.

TABLE II
Results of PD for different numbers of active detectors

Detectors	Trials	Average backgr. cps	Average neutron cps	Alarms	PD
2	449	0.08	2.73	341	70.7%
3	449	0.13	4.07	341	70.7%
4	449	0.24	5.95	417	89.4%
5	449	0.30	7.57	438	94.8%
6	449	0.36	9.11	438	94.8%
7	449	0.41	11.02	446	96.9%
8	449	0.45	12.55	448	97.4%

A typical distribution of the number of counts in the Region of Interest (RoI) defined for alarm condition is presented in Fig. 2. The profiles of background radiation and the source are clearly well separated.

Additional tests investigated the possibility for the system to operate with one or more FNDs powered off, exploiting the high sensitivity of the detectors. Table II presents the analysis of the counting statistics and achieved level of PD as a function of the number of active detectors. In all tested scenarios the alarm threshold was tuned to keep FAR below the level of 1/hour. At a Confidence Level of 95%, the requirement of PD = 90% was fulfilled even when half of the detectors were turned off.

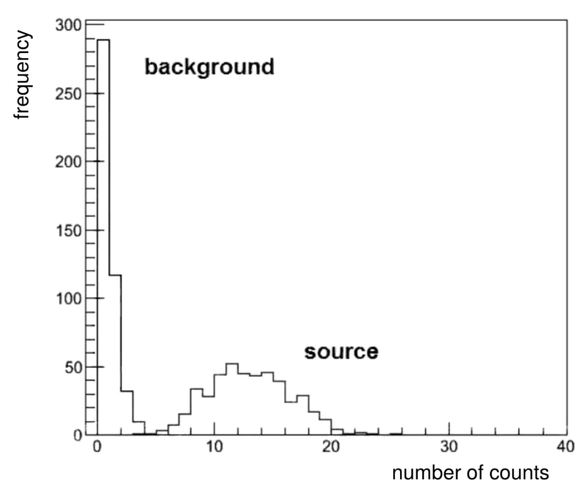

Fig. 2. Distribution of number of counts registered with FNDs for background radiation and ^{252}Cf source.

2) ^{4}He Thermal Neutron Detectors (TNDs): The aim of the TND tests was to verify the ability of the TNDs to provide information about the presence of a hydrogen-rich shield, as is the case of polyethylene. Measurements were performed in the same conditions as for FNDs by measuring the number of counts in the regions corresponding to the fast and thermal neutrons, with and without presence of a polyethylene shielding.

The shielding surrounding the source was made up of polyethylene bricks, in a way such that all walls were 100 mm thick, with the exception of the detector-facing side that was only 50 mm thick. The distance from the source to the middle of the detector box was kept constant during all the measurements, with or without the shielding.

A strong increase in the number of thermal neutron events is observed when the fission source is inserted in the shielding castle. The number of the counts in the thermal neutron region with unmoderated sources represents the background for the identification of a hydrogen-rich shield; the ratio R between the fast and thermal neutron counting can be used to infer the presence of a shield.

Considering a 60 s measurement with the ^{252}Cf source, values of this ratio were $R = 0.20 \pm 0.27\%$ without the shielding castle and $R = 3.26 \pm 0.18\%$ with the shielding in place, clearly demonstrating the possibility to identify the presence of a hydrogen-rich moderating material surrounding a source.

3) Gamma Ray Detection (GRD): The requirement for GRDs was to detect ^{241}Am, ^{137}Cs and ^{60}Co sources yielding a dose rate of 50 nSv/h on the face of the detector with PD $\geq$ 90%, CL = 95% and a maximum FAR of 0.001 (1 false alarm per hour).

The measurements were carried on in the same hall as the tests for the FNDs. Each gamma ray tube was raised to 0.9 m above the floor, with three gamma ray sources placed at the same height; distances were adjusted to produce the required dose rate of 50 nSv/h. As in the case of FNDs, the cycle time was fixed to 2 s. Tests consisted of 450 consecutive cycles for each of the three sources.

Table III presents the list of sources used together with their activities at the day of measurement and the results of the trials.

TABLE III
SOURCES USED FOR EVALUATION OF PD AND RESULTS FOR CL = 95%

Source	Typical energy [keV]	Activity [kBq]	Trials	True positives	PD
^{241}Am	59.5	18500	449	449	97.6%
^{137}Cs	662	641	450	450	97.6%
^{60}Co	1173, 1333	239	450	450	97.6%

A typical distribution for the number of counts is presented in Fig. 3; data were collected with background radiation and a ^{137}Cs source.

It is clear from Table III and Fig. 3 that the alarm requirements were easily satisfied, and the performance of the system largely exceeded the international requirements for gamma ray source detection.

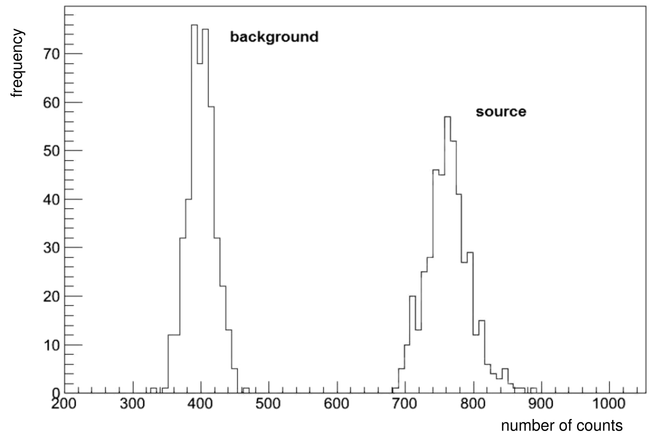

Fig. 3. Distribution of number of counts registered with GRDs for background radiation and ^{137}Cs source.

4) Gamma ray source identification: After triggering an alarm the system should identify the type of the incident radiation; Table IV presents the list of sources used to test the identification performances of the system, along with detector-source distances corresponding to the 50 nSv/h dose rate prescribed by the requirements.

TABLE IV
GAMMA RAY SOURCES USED FOR IDENTIFICATION TESTS (* = GAMMA RAYS NOT RESOLVED BY THE DETECTOR)

Source	Energy [keV]	Activity [kBq]	Distance [cm]
^{241}Am	59.5	18500	120
^{57}Co	122	3622	91
^{137}Cs	662	641	99
^{22}Na	511, 1275	316	133
^{60}Co	1173, 1333	239	121
^{109}Cd	22, 88	718	80
^{133}Ba	81, 276/303*, 356/384*	979	96
^{51}Cr	320	12800	104
^{152}Eu	122, 245, 344, 779, 1408	319	89

Results of the identification tests show that the standard 60 s time interval was sufficient to identify sources yielding 50 nSv/h at the face of the detectors, for all the sources having gamma ray energies below 1 MeV. However, at energies above 1 MeV the identification performances became unstable. In the case of ^{60}Co source, the 60 s interval was too short to identify the source, although its presence was correctly detected during the first 2 s cycle.

Since many NORM sources such ^{40}K present energy lines above 1 MeV, the gamma sensitivity of the system was increased with the addition of the NaI(Tl) detector before the beginning of the demonstration phase.

VI. MEASUREMENTS AT JRC ISPRA

To integrate static trials carried out during characterization, During 2014 the system was tested for the detection of moving gamma ray and neutron sources as well as for the detection and identification of ^{252}Cf, (α,n) neutron sources, Pu and U samples at the ITRAP Laboratory at the European Commission's Joint Research Centre (JRC) in Ispra (Italy).

A. Detection tests with moving sources

According to IAEA requirements for neutron detectors [9], the prototype shall generate a neutron alarm for a ^{252}Cf source emitting 1.2×10^4 neutrons/s and moving with a speed of 0.5 m/s (1.8 km/h) at a distance of closest approach between the source and the system of one meter. This requirement translates in a static fluence of 0.1 n/s/cm^2 at a distance of 1 m. Table V shows the results of the tests. The requirements prescribe a reference speed of 1.8 km/h, whereas our system satisfied them even for sources moving at 4.3 km/h, more than twice that of the standard; detection performances were still relevant even at four times the reference speed.

TABLE V
RESULTS FOR DYNAMIC SENSITIVITY TESTS WITH NEUTRONS

Speed [km/h]	Trials	Alarms
1.8	30	30
4.3	30	28
7.9	30	23

In the case of gamma ray sensitivity, both xenon and NaI(Tl) detectors were used to trigger the alarms. The requirements prescribes the generation of alarms when the ^{241}Am, ^{137}Cs and ^{60}Co gamma ray sources are moving with a speed of 0.5 m/s (1.8 km/h) at a distance of closest approach of one meter between the source and the front face of the prototype. During laboratory tests the distance of closest approach was varied to compensate for the activity of available sources while respecting the 0.05 μSv/h dose rate requirement. Results are shown in Table VI. Americium-241, which has a very low-energy line (59.5 keV), was always detected at standard conditions; for higher energies the system is performing exceptionally well, with 100% of the sources detected at all speeds, and taking into account that in the case of ^{137}Cs the dose was *one fifth* of the prescribed one.

TABLE VI
RESULTS FOR DYNAMIC SENSITIVITY TESTS WITH GAMMA RAYS

Source	Dose rate [nSv/h]	Speed [km/h]	Trials	Alarms
^{60}Co	50	1.8	30	30
^{60}Co	50	4.3	30	30
^{60}Co	50	7.9	30	30
^{137}Cs	10	1.8	30	30
^{137}Cs	10	4.3	30	30
^{137}Cs	10	7.9	30	30
^{241}Am	50	1.8	30	30
^{241}Am	50	4.3	30	20

Therefore, international requirements for radiation detection can be considered fully satisfied for both neutron and gamma ray sources.

B. Identification tests

After the detection sensitivity, the system's identification algorithm and library were also extensively tested with both gamma ray and neutron sources. Table VII reports the identification results, showing good performances of the prototype.

CBNM61 (1.1% ^{238}Pu, 64.9% ^{239}Pu, 24.8% ^{240}Pu, 3.9% ^{241}Pu, 4.5% ^{241}Am) and CBNM93 (0.01% ^{238}Pu, 93.5% ^{239}Pu, 6.3% ^{240}Pu, 0.1% ^{241}Pu, 0.2% ^{241}Am) were two plutonium samples, both 6 g in weight, enriched in ^{239}Pu [20]; UP8996 was a 51 g sample of 90% enriched ^{235}U. CBNM93 has a very weak gamma ray signature; at the distance set for the tests the intensity is close to the limit for alarm triggering, therefore affecting also identification performances.

TABLE VII
RESULTS FOR THE IDENTIFICATION TESTS. (1) 50 NSV/H; (2) 10 NSV/H; LEGEND FOR SHIELDING: L = 1 CM LEAD, I = 1 CM IRON, P = 8 CM POLYETHYLENE, AND COMBINATIONS

				Source identification	
Source	Shield	Trials	Alarms	Valid	System output
Am/Be	-	10	10	10	Am/Be
Am/Be	L I	10	10	10	Am/Be
Am/Be	L I P	10	10	10	Shielded Am/Be
CBNM61	-	5	5	5	Pu
CBNM61	L I	5	5	5	Pu
CBNM61	L I P	5	5	5	Shielded Pu
CBNM93	L P	9	7	7	Shielded Pu
UP8996	-	5	5	5	^{235}U
^{60}Co (1)	-	10	10	10	^{60}Co
^{137}Cs (2)	-	10	10	10	^{137}Cs
^{241}Am (1)	-	10	10	10	^{241}Am

Table VIII lists the sources that were programmed inside the gamma ray identification library before leaving for the field demonstration.

TABLE VIII
SOURCES INCLUDED IN THE GAMMA RAY IDENTIFICATION LIBRARY

Source	Class	Source	Class
ZnO	NORM	^{57}Co	Gamma
^{40}K	NORM	^{60}Co	Gamma
^{232}Th	NORM	^{109}Cd	Gamma
^{235}U	S.N.M.	^{133}Ba	Gamma
^{238}U	NORM	^{137}Cs	Gamma
^{22}Na	Gamma	^{241}Am	Gamma

VII. FIELD TESTS

After its final assembly in early April the system was left mounted on the van during both transfers and operations, and travelled for a grand total of nearly 6000 kilometers without suffering any damage or performance loss. Figure Fig. 4 shows the locations of the tests with the van-mounted system.

During the field tests the system was directly employed by end-users at the Rotterdam and Dublin seaports, at the Heathrow Airport and in Basel and Uri (Switzerland). In order to avoid possible shielding effects, tests were always conducted with the van door open.

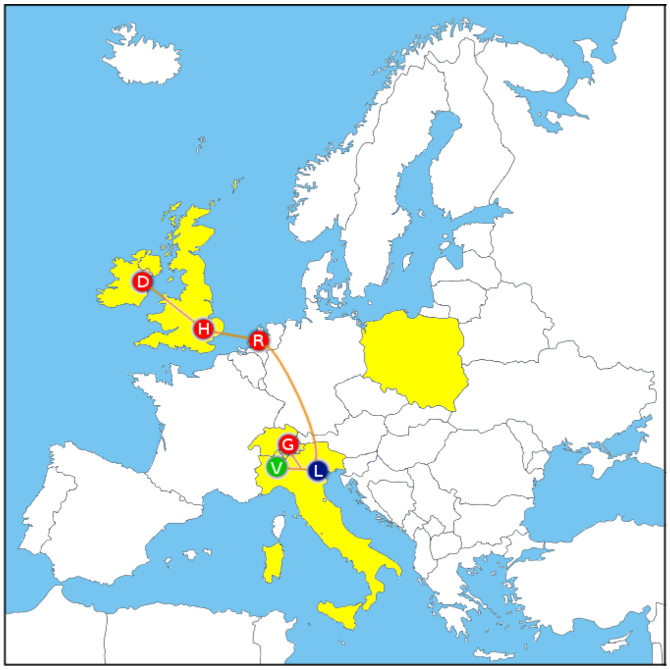

Fig. 4. Map of locations reached by MODES_SNM van: L = INFN-LNL, V = JRC Ispra, R = Rotterdam seaport, H = Heathrow airport, D = Dublin seaport, G = Switzerland. Countries of consortium partners are highlighted.

A. *Rotterdam seaport*

The port of Rotterdam is the largest port in the European Union (EU) and acts as a gateway to the EU as well as being a major global transport hub. It handles more than 12 million TEUs annually. The scanning of maritime containers to detect illicit movements of radioactive and nuclear materials is the responsibility of Dutch customs who devote considerable resources to this task. They employ a range of fixed, mobile and hand portable detection systems in this area.

Field trials on MODES_SNM system were performed by Dutch customs in Rotterdam Port during April 14th to 25th, 2014. For the most part, the system was operated in the course of normal day-to-day activities, in tandem with the existing detection equipment.

1) Tests with real cargo: On the first day, MODES_SNM system was deployed as a secondary control device; secondary inspections investigate only those cargos that have already triggered an alarm on radiation portals. The tests were repeated on day 4. A total of 6 containers alarmed at the fixed RPMs and were inspected, leading to three identifications of ^{40}K, one incorrect indication of ^{137}Cs and a couple of false alarms.

On day 2 the system was deployed in static mode as a primary control mechanism in conjunction with the fixed RPMs, scanning a total of 131 containers, identifying "NORM" materials including ceramics, minerals and chemicals.

During these first trials the False Alarm Rate was higher than expected, but with 8 false alarms in 4 days, and considering 2 to 5 hours of operation per day, performances were still within the requirement of 1 false alarm per hour. The false alarms found a technical explanation resulting in a proper correction at the end of the field test campaign.

During days 5 to 9, when the system was prepared for the transfer to the UK, MODES_SNM was deployed in "drive by" mode scanning static containers at a maximum speed of 10 km/h and at a distance of 30-50 cm from the target containers. The system identified several NORMs; it also triggered a number of false alarms, two of which also lead to incorrect identifications.

When driving the system across the container terminals numerous gamma ray alarms occurred, with a maximum of 1250 cps (less than 10% above threshold) indicating variation in backgrounds levels arising from differing natural materials used in the construction of the terminal surface.

Fig. 5. MODES_SNM performing secondary inspection at Rotterdam seaport

During all these tests, natural background variations proved to have a significant impact on the behavior of a mobile system like MODES_SNM, which didn't have an automated adjustment procedure. This effect has long being recognized and it is still being studied (see as an example [**?**], [19]); its importance justifies further efforts in its assessment.

2) Tests with radioactive samples: To further assess the system identification performances, a number of tests were then carried out on the 6th day using a variety of locally held known radioactive sources:

- a ceramic plate containing an uranium glaze was held close to the door aperture of the MODES_SNM van. No alarm occurred. However, when held close to the NaI(Tl) detector, a gamma ray alarm of 1500 cps was triggered and ^{235}U was identified in 60 seconds;
- a gas mantle containing ^{232}Th was held at a distance of 15 cm from the detector. A gamma ray alarm of 1500 cps was triggered and after 60 seconds ^{232}Th was correctly identified and ^{133}Ba was also indicated (the ^{232}Th decay chain contains also a gamma ray line close to the relevant one in ^{133}Ba);
- approximately 20 g of zirconium sand contained in a glass vial were held at a distance of 30 cm from the detector. Following a gamma ray alarm of 5500 cps, ZnO was identified, but the operators also expected the identification of ^{226}Ra; it did not happen because at the time ^{226}Ra was not present in the source library. The test

with zirconium sand was repeated, this time in “drive by” mode at a distance of 1 meter, at speeds of 10 km/h and 5 km/h. A gamma ray alarm of 1250 cps occurred at 5 km/h, no alarm occurred at 10 km/h;

- the system was driven past a lead shielded Am/Be neutron source placed on a tripod at 10 km/h at a distance of 1 m without alarming. This was repeated at 5 km/h resulting in a fast neutron alarm of 1.5 cps and identification of “shielded neutron source”. The test was repeated with the lead shielding removed from the source. Gamma ray and fast neutron alarms were triggered and both Am/Be and ^{241}Am were identified;
- a ^{133}Ba source was mounted on a tripod and a gamma ray alarm of 1490 cps at 10 km/h at a distance of 1 meter occurred. ^{133}Ba was identified.

Given the outcomes of the first days of tests, identification performances proved to be satisfactory.

Fig. 6. MODES_SNM deployed in static mode near fixed portals

B. London airport

The next stage of the tests involved the transfer of the system to the United Kingdom, to be operated in the cargo area of one of London’s airports; this site acts as a major international hub handling large volumes of cargo and passengers. Cargo arriving at terminals are transported in trucks and vans and scanned by fixed RPMs.

Field trials on the MODES_SNM system were performed by the United Kingdom Border Force (UKBF) during May 2nd to 7th, 2014. The system was operated in the course of normal day-to-day activities, mostly in static mode and in tandem with the existing detection equipment.

A total of 635 cargo carrying vehicles were scanned, passing at speed of 8-16 km/h. The system behaved as follows:

- a strong gamma ray alarm was generated while a vehicle was passing. After stopping the cargo, MODES_SNM repeatedly identified the presence of ^{60}Co, a result âĂŃconsistent with the accompanying documents and confirmed by a commercial hand-held device;
- the system returned a gamma ray alarm for a consignment of medical isotopes; over multiple tentatives, the system once proposed identification as “Am/Be shielded neutron source”, but a definitive identification was not possible. That isolated misidentification is considered the result of one false thermal neutron alarm combined with the presence of isotopes not included in the source library;
- the system successfully identified two other ^{60}Co sources shielded by stainless steel after 60 seconds.
- the False Alarm number was around 30, still close to the 1 FA/hour requirement;

In addition MODES_SNM system drove past a container known to contain ^{60}Co contaminated metal products. At a passing speed of 8-16 km/h and at a distance of 15 meters from the source the system alarmed and performed a correct source identification.

C. Dublin customs

Dublin Port is the largest port in Ireland and handles a variety of containerized, bulk and car ferry traffic. The Dublin field tests were carried out during May 9th to 16th, 2014. In addition to the continuance of evaluating the technical capability of the MODES_SNM system, the assessment of the potential for its deployment in a variety of operational scenarios was an important consideration in this phase of the field testing.

On the first day, tests were conducted in conjunction with an X-ray scanning operation at container compound in Dublin Port. No difficulties were encountered in setting up the system. The van was deployed in static mode approximately 50 meters distant from the 6 MeV mobile X-ray scanner, without experiencing any interference. The X-ray scanner incorporates an integrated Radiological/Nuclear detection system which operates in conjunction with the X-ray scanning. A total of 9 inward bound maritime containers, as well as 1 vehicle were scanned. No true positive alarms were triggered.

The following day, scanning took place at a car ferry compound where a total of 74 inward bound trailers and vehicles were scanned. No true positive alarms were triggered although 3 gamma ray alarms occurred when no target was in range.

On the third day, MODES_SNM system was brought to University College Dublin for testing with a sealed 37 GBq Pu/Be source containing 16 g of ^{239}Pu oxide mixed with beryllium metal. The source was transferred from its storage area to a smaller paraffin-filled drum which was placed in a customs van. During testing, the van containing the Pu/Be neutron source was driven past the van-mounted system, which was deployed in stationary mode. Measured neutron dose at 1 m from the shielded drum, as determined with an EG&G Berthold LB6411 neutron probe, was 5 - 6 μSv/hr. The corresponding figure for gamma ray dose rate, measured with an EG&G Berthold LB1236 proportional counter, was about 1 μSv/hr.

Passing with a speed of approximately 8 km/h and at a stand-off distance of 1 meter from the van, the source triggered gamma ray, fast neutron and thermal neutron alarms. The passing speed was increased to 20 km/h and the distance to 4 meters, which were the maximum values permitted by the site conditions, and on each occasion all three alarms were triggered.

Scanning loose or bulk materials is often problematic at BCPs. For example, there is significant trade in exporting "end of life" vehicles and other metal equipment to Africa. By its nature, this type of cargo is not always suitable for scanning by fixed detection systems. MODES_SNM was therefore deployed to scan this type of cargo in an open compound in Dublin Port in mobile or "drive by" mode. No alarms were triggered by this cargo, although a number of gamma ray alarms, caused by variation in background levels (and confirmed by elevated readings on a hand-held device) occurred. MODES_SNM was again deployed (static mode) in proximity to the X-ray container scanner, this time at a distance of approximately 30 meters, resulting in a gamma ray alarm.

The system was then deployed, again in "drive by" mode, at a warehouse where a variety of goods are stored. The van screened cargo within the warehouse passing along the aisles between the racks. No alarms were triggered. The van was then moved to the adjoining compound and screened a variety of vehicles, containers, tankers, machinery and equipment. No alarms were triggered except for elevated background alarms which occurred from time to time in various regions of the compound.

D. Swiss Heavy Goods Vehicles control center and customs

At the end of operations at Dublin seaport, the system was brought back to Padova to check the system and perform some software update. The updated MODES_SNM system was field tested at the Swiss border in Basel, Switzerland, and at the Heavy Goods Vehicles (HGV) control center in Uri, Switzerland.

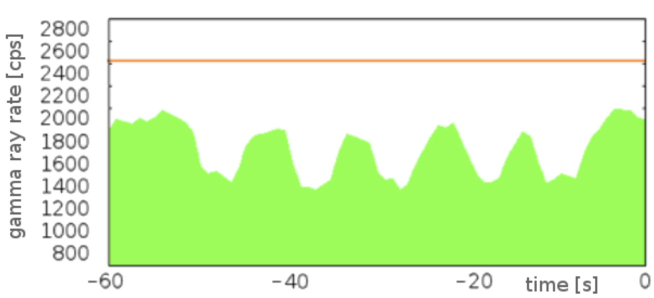

Fig. 7. Man-Machine Interface: the graphical Gamma ray rate monitor. During the shown measurement sequence, five vans passed; the reduction of background due to the shielding effect of the vans is clearly visible.

At the Swiss Customs controls in Basel, the MODES_SNM system was tested at two different sites to see the different Concept of Operations (CONOPS) involved. The system behaved as expected. No alarm occured. The background was around 1.8-2 kHz, falling to 1.2-1.5 kHz when a truck passed through (Fig. 7). This effect shows clearly the known influence of the trucks to background shielding and the sensitivity of the system.

On the second day, operations were held at HGV. The center is located in front of the Gotthard tunnel in Switzerland and about 1300-1500 trucks pass through it every day. Tests were perfomed within a 2.5 h window. 218 trucks passed by the van at a speed between 5 km/h and 25 km/h.

Four alarms occurred, a value slightly higher than the FAR requirement of 1 per hour. These alarms occurred when no truck was present and showed the same pattern on the instrument panel. By analyzing the logged data the origin of these events was identified and corrected on the software side; no more of these false alarms have occurred since then.

VIII. Results

Results from the field tests demonstrated that MODES_SNM system is very robust, having survived all transportations over more than 6000 km and end-user operation under different conditions. The end-users are able to run the system without problems and without the supervision of technical experts. The van-mounted system showed great potential; its detection performances proved to be comparable and in some cases even surpassing those of commercial systems while providing additional features which are of high importance to customers. The demonstration campaign showed only one relevant issue concerning the occasional triggering of false alarms, a problem identified and solved at the end of the field tests. At this time the system is capable of detection and identification of gamma ray sources and NORMs, neutron sources as ^{252}Cf, Am/Be, Pu/Be and SNM as Pu and U samples; it can also detect the presence of hydrogenated or lead shielding enclosing neutron sources. A commercial van was further developed after the end of the project; it is currently being tested for full compliance with ANSI N42.43 standard.

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