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Detection of and response to nuclear security events

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Abstract
The paradigm of nuclear security continues to evolve. Whilst a body of work and a collective with relevant expertise is forming, the relationship and interconnectedness with the fields of nuclear safety and nuclear verification (safeguards) still needs day-to-day management to ensure States have in place an effective judicial, legislative, regulatory and policy framework which, when supported by coordinated implementation procedures, will assist in the prevention of malicious acts upon nuclear and/or associated facilities, as well as reducing the threats posed from the malicious use of lost, missing or stolen nuclear or other radioactive material to harm persons, property, society or the environment.

This is particularly the case in the detection of and response to malicious acts involving nuclear and other radioactive material out of regulatory control. Here the States' traditional response arrangements need to be enhanced and coordinated to ensure that threats posed by criminal or unauthorised acts involving such material, and any dispersal event occurring as a consequence of a successful malicious act, are adequately dealt with in terms of both the need to detect the presence of the nuclear or other radioactive material in the lead-up to a nuclear security event, as well as the proper collection and control of evidence to ensure successful prosecution of the offenders consistent with the relevant international legal instruments to which States may subscribe. This paper outlines these additional considerations.

Introduction
The IAEA maintains an Illicit Trafficking Database (ITDB) which contains confirmed reports of criminal or unauthorised acts involving nuclear or other radioactive material. The ITDB currently contains 1884 confirmed reports from the 110 States that participate.

While the circumstances of each ITDB case vary significantly, some credible reports indicate that criminal organizations have shown interest in nuclear material and facilities. The threats include criminals or terrorists acquiring and using nuclear material to build a rudimentary nuclear explosive device (in the worst case, an existing nuclear explosive device); using a radioactive source as an exposure device or achieving the dispersal of radioactivity by the construction of a radiological dispersal device; or through an act of sabotage at a nuclear facility or other installations or place where radioactive substances are used, stored or transported.

Since the consequences of the use of an improvised nuclear explosive device would be catastrophic, such events cannot be neglected although their probability may be much lower compared to the potential of an RDD or an act of sabotage. Intentional dispersal of radioactivity would, no doubt, have very significant psychological, health and economic consequences.

In responding to the threat the international community has developed a large range of international legal instruments, both binding and non-binding, which taken in their entirety outline the field of nuclear security best practice for States to consider in their ongoing efforts to combat nuclear terrorism. Although many of the international legal instruments were originally drafted to principally address non-proliferation or safety concerns they do, when combined with the newer counter-terrorism instruments originating principally after Sept 2001, contribute to the global framework that defines nuclear security. The primary instruments and documents include:

- Convention on the Physical Protection of Nuclear Material [CPPNM] and its Amendment of 2005 [1],
- International Convention for the Suppression of Acts of Nuclear Terrorism[2],
- United Nations Security Council Resolution 1540 [3]
- Code of Conduct on the Safety and Security of Radioactive Sources [4]

In the broad sense, these instruments deal with nuclear security issues, and in particular they are all related to malicious acts at the sub-national level (i.e. by non-state actors), involving nuclear or other radioactive materials. Combined these instruments require States to, inter alia:

- Criminalize, i.e. make punishable under national law certain offences, such as malicious acts and threats
- Make every effort to establish measures for preventing or protecting nuclear material and facilities and other radioactive material against such acts, and
- Take appropriate actions should such malicious acts occur. In this regard, preparations should include the recovery of material, its return and assistance and cooperation among States and the IAEA.

While recognising the sovereign right of States over matters of security, the IAEA has responded to requests to provide guidance that States can use to meet their committments and obligations with respect to these international legal instruments. The draft versions of this ’top-teir’ guidance include:

- Nuclear Security Fundamentals [5]
- Nuclear Security Recommendations on Nuclear Material and Nuclear Facilities (INFCIRC/225/Rev.5) [6];
- Nuclear Security Recommendations on Radioactive Material and Associated Facilities [7]; and
- Nuclear Security Recommendations on Nuclear and Other Radioactive Materials out of Regulatory Control [8].

While the nuclear security series covers the entire spectrum of recommendations to a State in developing and sustaining a nuclear security regime, of particular interest in the inter-relationship between nuclear safety, nuclear verification and nuclear security is the detection and assessment of alarms and alerts and for a graded response to any criminal or intentional unauthorized acts involving nuclear or other radioactive material out of regulatory control. These 'detection and response' elements of a nuclear security regime cover the confirmation of a credible threat, assessment and interdiction of an attempted act and response to a nuclear security event and are contained principally in the latter of these documents.

Background

The draft Nuclear Security Recommendations on Nuclear and Other Radioactive Materials out of Regulatory Control document (the draft document) was prepared by the IAEA Secretariat in consultation with experts drawn from Member States, and has been the subject of a Technical Meeting in March 2010. The comments from the Technical Meeting were incorporated, as appropriate, into the draft document which is currently out for 120 day Member State review.

The summary of the more important contents of the draft document are given below, but may be subject to change prior to publication once Member State comments are received. In essence the draft document recommends that for the State to have an effective nuclear security regime for nuclear and other radioactive material out of regulatory control, they need to ensure the existence of two main elements, namely:

- A comprehensive and complete set of legislative provisions through adoption of criminal and administrative laws for providing relevant administrative and enforcement powers to the various competent authorities within the State, so that they can undertake their activities in an effective manner; and
- Provision of sufficient and sustained resources to the various competent authorities to enable them to carry out their assigned functions, including:
  - Measures to prevent a criminal or an intentional unauthorized act involving nuclear and other radioactive material out of regulatory control;
  - Detection, through an instrument alarm and/or an information alert, of the presence or indications of a criminal act or an unauthorized act with nuclear security implications involving nuclear or other radioactive material that is out of regulatory control and, in particular to:
    - develop a detection strategy;
    - establish detection systems; and
    - perform the initial assessment of the instrument alarms and information alerts promptly and assess the possibility of a nuclear security event.
  - Response to the nuclear security event, in particular to:
    - notify the competent authorities
    - assess the validity and potential consequence of the nuclear security event;
    - locate, identify, categorize and characterize nuclear or other radioactive material;

- secure such material and apply other response measures appropriate to the nuclear security event, such as neutralization of the device;
- recover, detain and/or seize and place such material under regulatory control;
- collect, preserve, store, transport and analyse evidence including the application of nuclear forensics measures related to a criminal act or an unauthorized act with nuclear security implications that involves such material; and
- apprehend and subsequently prosecute or extradite alleged offenders.

Legislative, Regulatory, Policy and Administrative Controls

The draft document recommends that, as part of an overall regime, the State should establish and maintain effective legislative and regulatory controls to govern nuclear security, including those that define any conduct which they consider to be a criminal act or an intentional unauthorized act involving nuclear and other radioactive material, and establish such offences as criminal offences under domestic law.

For effective and sustainable detection and response measures, it is important to rely on multidisciplinary infrastructures implemented by several independent competent authorities in the State, and to ensure proper cooperation, coordination, information exchange and integration of clearly defined activities and responsibilities within some form of coordinating body or mechanism

The following list of organisations could have some role in, or may be a competent authority for aspects of the nuclear security regime within a State. Consequently they should, if appropriate, be considered for involvement in this coordinating body or mechanism:

- Judicial bodies;
- Legislative authorities;
- Policy authorities;
- Intelligence services;
- Military forces;
- National threat assessment bodies;
- Law enforcement bodies;
- Border Forces;
- Customs authorities;
- Police;
- Regulatory bodies;
- Medical and/or health authorities;
- National nuclear energy agencies;
- Civil Defence; and
- Emergency Services.

The draft document recommends that the coordinating body or mechanism should inter alia:

- ensure the development of a comprehensive national detection strategy based on a multilayered defence in depth approach within available resources;
- ensure development of a national response plan for any nuclear security event in a graded approach commensurate with the threat and based on available resources;
- oversee the development and implementation of the national detection and response systems;
- re-evaluate and identify possible nuclear security gaps and resource needs and initiate proper corrective actions on a regular basis;
- ensure the establishment of contact points within the competent authorities as part of an overall coordination within the State,
- encourage the timely sharing of operational information among competent authorities within the State;
- ensure the establishment and maintenance of a reliable and comprehensive set of records for each nuclear security event, and encourage the exchange of information among competent authorities concerning any such event, using a common reporting and notification format; and
- ensure appropriate coordination and cooperation with relevant authorities in other States and international organizations.

The functions of the competent authorities as outlined in the draft document should include, inter alia:

- contributing to the development of the national detection strategy and response plan;
- developing, operating and maintaining the national detection systems, assessment procedures and the national response plan and providing the resources necessary for implementing and testing the associated activities;
- providing adequate training and information to all personnel involved in carrying out nuclear security detection and response measures;
- sustaining the detection and response capabilities and ensuring operational preparedness through sound management practices, addressing instrument maintenance, personnel training, exercises and process improvements; and
- cooperating with the coordinating body, other competent authorities and bilateral and multilateral counterparts as applicable, in part to ensure the effectiveness of their detection and response procedures and responsibilities.

The competent authorities would cooperate in the exchange of relevant information on the nuclear and other radioactive material that is authorised or 'under regulatory control', with a view to strengthening the capabilities of all concerned with nuclear security. Where appropriate, they should also cooperate with their counterparts in other States.

The draft document recommends that regulatory authorities should take appropriate actions when nuclear or other radioactive material is reported to be out of regulatory control, i.e., lost, missing or stolen. In particular, they should inform promptly the other competent authorities in the event of a suspected criminal or an intentional unauthorized act.

In addition the draft document recommends assigning priorities and designing the detection and response systems based on a national threat assessment, using a risk based approach in combination with an assessment of the:

- vulnerability to a criminal act, or an unauthorized act with nuclear security implications, both within and outside their borders;
- relative attractiveness of identified targets to a nuclear security threat;
- possible consequences of a criminal act or an unauthorized act with nuclear security implications, that involves the use of nuclear or other radioactive material; and
- possible evolution of the threat or vulnerabilities

Detection Measures

Detection of nuclear and other radioactive material that is out of regulatory control can be achieved via an instrument alarm or an information alert. The draft document recommends that the State should design and implement nuclear security systems based on such indicators, and ensure that the detection measures are supported by effective response measures

In order to prevent illegal transfer of nuclear or other radioactive material and detect the falsification of relevant documents, it is recommended that competent authorities have the power to adopt measures for authenticating documentation and package labelling for authorized shipments and for verifying the declared content of the authorized shipment of nuclear or other radioactive material by appropriate means

Using the national threat assessment, the draft document recommends that competent authorities should establish nuclear security systems for detection by instruments of nuclear and other radioactive material that are out of regulatory control. The detection systems should be based on a multilayered defence in depth approach and on the premise that such material could originate from both within or outside the State, and provide the necessary detection capability and capacity.

To assist in this regard, the draft document recommends that by while taking into account the prioritization of available resources, the competent authorities should develop an appropriate detection instrument deployment plan, considering the following:

- transportation routes inside the State’s territory, at locations where likelihood of detection is maximized or in proximity to locations where nuclear or other radioactive material is produced, used, stored, consolidated or disposed;
- the existence of any strategic location;
- operational and detection performance specifications of the detection instruments, in accordance with national and international standards and technical guidelines;
- capabilities, constraints and limitations on detection instruments at both officially designated and non-designated air, land and water border crossings points;

- mobile and relocateable detection systems to provide flexibility and adjustments to evolving threat;
- detection requirements in support of law enforcement operations associated with information alerts; and
- detection of radiation at an event of national significance, such as a major public event or at a strategic location that is considered to be vulnerable to a malicious act using nuclear or other radioactive material.

Further the draft document recommends that the competent authorities should ensure that the following elements are included in the instrument deployment plan:

- initial installation, calibration, and acceptance testing of equipment; the setting up of a maintenance procedure, and the adequate training and qualification of users and technical support staff;
- systems and procedures for conducting a radiation survey or a radiation search for nuclear and other radioactive material out of regulatory control;
- defining threshold levels of an instrument alarm;
- establishing systems and procedures for performing initial alarm assessment and other secondary inspection actions such as localization, identification, categorization and characterization of nuclear and other radioactive material, including obtaining technical support from experts to assist in the assessment of an alarm that cannot be resolved on site; and
- provision and sustainment of supporting infrastructure to ensure effective detection, including personnel training, equipment maintenance, safe and secure disposition of discovered material and documented response procedures.

While the use of instruments is a major method of detecting potential malicious acts involving nuclear and other radioactive material, another major component of detection measures is the detection by the use of information. Here the draft document recommends that the State should continuously gather, store and analyse operational information with the goal of identifying any threat, suspicious activity or abnormality involving nuclear or other radioactive material that may indicate the intention to commit a malicious act within the State. The draft document also recommends cooperation with other States to provide and obtain information for better understanding of any threat, and the development of a policy on the dissemination of information to the news media with the aim of informing the public of lost, missing or stolen nuclear or other radioactive material so as to educate them in the risks associated with the material and to elicit information from the public about such material, taking care not to cause undue public concern.

As part of the information led detection measures the draft document recommends that procedures and protocols are implemented requiring health professionals, medical institutions and health authorities to immediately report the occurrence of any suspicious radiation injuries or illnesses to the relevant competent authorities, in accordance with domestic public health reporting policies. Such collection and analysis of information from medical surveillance as part of detection measures should, as appropriate, be reported and investigated by relevant competent authorities to determine the cause and consequence of the injury or illness.

It is further recommended that the competent authority with regulatory responsibility should require authorized persons to report immediately any non-compliance which they suspect could have nuclear security implications. Such a report would enable the competent authority to assess the event with the aim of preventing a consequent malicious act. Further the draft document recommends that any competent authority that receives a report that such material has been reported as lost, missing or stolen, promptly inform other relevant competent authorities.

Finally the draft document recommends that any instrument alarm or information alert should lead to the conduct of an initial assessment. The relevant competent authorities should implement procedures and protocols with the view to interdict and interrupt the potential criminal act or unauthorized act with nuclear security implications.

Response Measures

To ensure an adequate response to the detection of nuclear of other radioactive material out of regulatory control and that could be used for a criminal or intentional unauthorised act, the draft document recommends that, using legislative instruments as necessary, the State develop a comprehensive national response system for responding to such acts.

In particular the draft document recommends that the State should ensure that the responsibilities for implementing the various response measures are assigned to the relevant competent authorities, together with sufficient resources to effectively undertake these tasks.

The implementation of the response system of the State should be documented in a national response plan outlining the various response measures, and should be implemented coherently by the various competent authorities, ideally coordinated by the coordinating body. It is important that in responding to nuclear security events, the responsible competent authorities should complement and support the safety emergency response activities to mitigate and minimize the radiological consequences to human health and the environment at the international, federal, state and local levels. The coordination of competent authorities is vital for an effective response at the scene.

An important aspect of this response, as outlined in the draft document, is the recommendation that the State should adopt a graded approach to respond to the various possible nuclear security events and differing degrees of consequences. In order to determine the appropriate response and follow-on actions, the State should strive to develop its own national capability to quickly grade nuclear security events, based on health and safety concerns and on circumstantial factors and the involved nuclear or other radioactive material.

If the initial assessment described in the detection measures above are not conclusive, the draft document recommends that the relevant competent authorities ensure the establishment of procedures and protocols for final resolution of an instrument alarm which may result in the determination that a nuclear security event has occurred. The determination of a nuclear security event should lead to the activation of the national response plan by the relevant competent authority using the graded approach discussed above. For the assessment of information alerts, the competent authorities should obtain the necessary assistance from the assigned experts and the support organizations, in accordance with the established procedures and protocols.

The location of any nuclear security event should be managed as a potential crime scene. The draft document recommends that the competent authorities should ensure coordination among those involved in recovering control over the nuclear or other radioactive material, those concerned with safety and treating victims and those concerned with gathering evidence for possible subsequent investigation and prosecution.

It is important for the State to apply nuclear forensic techniques on any seized nuclear or other radioactive material in its designated laboratories for the purpose of identifying the source, history and the route of transfer, taking into account the preservation of evidence. Furthermore, traditional forensics should also be applied in designated laboratories for contaminated evidence, as necessary.

The draft document recommends that persons involved in the response should be suitably qualified and trained and should, as appropriate, be aware of the basic concepts of radiological crime scene management, evidence collection and radiation protection.

In order to manage the nuclear security event, the draft document recommends the establishment of a comprehensive national response plan (the Plan) in combination with, inter alia, the national radiological emergency plan. The Plan should serve as:

- A basis for establishing compatible operational tools needed for prompt and effective response; and
- A guide for the competent authorities who should ensure that all necessary preparedness and response tasks are given the appropriate resources and support.

The draft document recommends that the Plan:

- describes the process for various competent authorities to fulfil their obligations and responsibilities in response to nuclear security events, including steps to:
    - notify and activate all relevant competent authorities;
    - notify the relevant international organizations and potentially affected States;
    - coordinate various organizations and command and control units of a nuclear security event, including coordination of federal, state and local response organizations;
    - locate, identify and categorize nuclear and other radioactive material;
    - detain and/or seize, recover and control material or render harmless any threat or associated device;
    - collect, secure and analyse evidence;
    - isolate, classify, package and document, any nuclear or other radioactive material, for transport, carriage, storage or disposal and placement under proper regulatory control; and
    - initiate relevant investigations.
- contains an appropriate command structure with integrated command, control and communication systems to effectively respond to a nuclear security event, preferably with a single person or competent authority assigned to direct the response at the scene;

- has provisions for coordination among the competent authorities, including exchange of relevant information concerning their respective roles, responsibilities and procedures;
- describes the roles, responsibilities and procedures for the competent authorities for medical services, handling of hazardous material, radiation protection and safety and other technical support organizations and for nuclear and conventional forensic laboratories;
- arranges for informing the news media and public, as appropriate, in a coordinated, understandable and consistent manner;
- contains provisions for the transport of any seized or recovered nuclear or other radioactive material in accordance with the national transport safety and security regulations and requirements;
- identifies the standard operating procedures at the local level for nuclear security events. In addition, all local level response plans should be integrated into the Plan;
- takes into account, and coordinates with, the existing national radiological emergency plan and radiological emergency response procedures;
- incorporates the possibility of multiple and simultaneous nuclear security events. In addition, the Plan should incorporate the possibility of disruption of response infrastructure that would delay an effective response capability; and
- incorporates the mechanisms for requesting assistance, both domestically and internationally, when necessary, such as assistance for the recovery of nuclear and other radioactive material, rendering harmless the device and nuclear forensics.

The draft document further recommends that, upon detection of nuclear or other radioactive material out of regulatory control at a border crossing point, the State should work with the State of origin and other relevant States to return the material to regulatory control. The State should adopt a graded approach for such response that depends on the circumstances of the case and the nature of the material.

Nuclear forensics techniques to determine the source and route of transfer and to investigate loss of regulatory control are an important part of nuclear security. The draft document suggests that investigations may entail cooperation between or amongst States to identify the origin, history and the route of transfer of the nuclear or other radioactive material. Cooperation on nuclear forensics should be subject to the State's domestic laws, regulations and policies and the draft document recommends that for States without sufficient nuclear forensics expertise and capabilities they enter into arrangements with other States or relevant regional or international institutions for the purpose of nuclear forensics analysis and interpretation.

Perhaps the biggest deterrent to the use of nuclear and other radioactive material for criminal and other intentional unauthorised acts involving nuclear and other radioactive material is the existence of comprehensive nuclear forensics libraries. The draft document recommends that a State should consider establishing nuclear forensics libraries for their inventory of nuclear and other radioactive material. These libraries should include databases of all material produced, used and stored in the State and, if applicable, supported by sample and literature archives. The State should be capable of responding to queries of other States regarding recovered nuclear or other radioactive material that may have been produced, used or stored on the State's territory.

Conclusions

Nuclear security is a distinct and growing body of knowledge relating to the use of nuclear and other radioactive material for criminal or intentional unauthorised acts. Aspects of safeguards and safety are fundamental to a successful nuclear security regime in a State, particularly related to the accountancy of nuclear material, and the register of radioactive sources. For nuclear and other radioactive material out of regulatory control, the Secretariat and Member States of the IAEA have drafted a guidance document to assist them in establishing an effective nuclear security regime.

This draft document is currently with Member States for 120 day review and copies of the draft document are available on the Agencies website at: http://www-ns.iaea.org/security/nuclear.security.series.htm, and comments are welcome from all Member States. It is anticipated that once comments are received and reviewed, another Technical Meeting will be held at the IAEA to ratify the final version of the document, before initiating the publication process.

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New threats and new challenges for radiological decision support

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Abstract

It is described how ongoing work will extend European standard decision support systems currently integrated in the nuclear power plant preparedness in many countries, to enable estimation of the radiological consequences of atmospheric dispersion of contaminants following a terror attack in a city. Factors relating to the contaminant release processes, dispersion, deposition and post deposition migration are discussed, and non-radiological issues are highlighted in relation to decision making.

Introduction

Over recent years the world has become increasingly aware that malevolent acts involving atmospheric dispersion of radioactive matter may occur and could severely affect large urban populations, both by leading to high radiation doses from dispersed radionuclides and by causing social disruption and fear. A comprehensive and reliable decision support system that can be operated in real-time is essential to ensure that the repercussions are addressed optimally and consistently from the very beginning and seen in the context of the actual health hazards. The dispersion could be carried out in different ways, involving, e.g., 'dirty bomb' devices, simple aerosol generators placed on a rooftop, or emission from an aeroplane. Depending on both the dispersion process and the initial contaminant matrix, aerosols with very different size spectra and physicochemical characteristics can be produced. The importance of aerosolisation processes, atmospheric dispersion in complex urban terrain, and post-deposition contaminant solubility, fragmentation and migration are all discussed in relation to the dose modelling needed to form reliable consequence prognoses. The paper reports on how these issues are being dealt with in an extension of existing European standard decision support systems to cover the consequences of terror attacks. Also non-radiological perspectives of radiological terror attacks are discussed.

Methods and results

A very wide range of radionuclides could at least in theory be envisaged for use in a radiological dispersion terror attack. In reality, however, the list of radionuclides that would be of primary concern would be likely to have only of the order of ten entries. The limiting factors include availability of existing sources with sufficient strength, problems in handling strong sources, initial physicochemical form of sources, types of radiation emitted, energies and photon/particle yield, and physical half-life of the contaminant(s). There seems to be almost consensus that this list would include ^{60}Co, ^{137}Cs, ^{90}Sr, ^{192}Ir, ^{226}Ra, ^{238}Pu, ^{241}Am, and ^{252}Cf (Andersson et al., 2009), but of course authorities and planners should also keep an open eye for the unexpected, as one of the main targets of all terrorism acts is to provoke a feeling of unpredictability, unpreparedness and uncertainty, which can in itself contain a considerable potential for anxiety, distrust and social disruption. In this section, factorial dependencies of radiological consequences, as well as non-radiological implications, of malicious atmospheric radiological dispersion are discussed.

Aerosolisation, dispersion and deposition

There has been a tendency to focus on the risk that terrorists might detonate a so-called ‘dirty bomb’ radioactivity dispersion device. It is considered likely that a ‘dirty bomb’ attack would have maximum societal impact if detonated in a highly populated area (Andersson et al., 2009; Sohier & Hardeman, 2006). Unless the explosion leads to evaporation of the contaminants, followed by formation of small condensation particles, most of the contaminant particles generated by this type of explosions would be large (some of it will be spread ballistically rather than being aerosolised), but it is likely that there would also be a significant release of particles in the size range of only a few microns (Andersson et al., 2008). These latter particles could disperse with the wind over a rather large city area. The initial physicochemical form (e.g., metal, powdered, solution, ceramic) of the applied source can in general greatly influence the aerosolisation process and thus the dispersibility in the environment. Radionuclide compounds that might plausibly be applied range from the virtually insoluble to readily soluble, e.g., depending on their previous application (Andersson et al., 2009). The extent to which phase transition will occur in the explosion process, thus potentially leading to formation of smaller and highly dispersible aerosols, also depends on how successfully the bomb is dimensioned. However, experimentation has shown that phase transition does not occur in connection with contaminants on ceramic form (Harper et al., 2007). Aerosolisation spectra based on data from experimentation are being incorporated in an ongoing extension of the European standard decision support systems (DSS) to predict the consequences of ‘dirty bombs’. It should be stressed that the aerosol spectra that would arise after a ‘dirty bomb’ explosion would in many cases be completely different from those expected at some distance from a large nuclear power plant accident, and parameters applied so far in European DSS (ARGOS, RODOS) can thus not be applied for ‘dirty bomb’ scenario calculations.

One parameter that greatly influences the size of the area over which the contaminants are spread in a ‘dirty bomb’ scenario is the plume rise. This also determines the significance of plume interaction with environmental structures (e.g., buildings, trees). The initial rise of the contaminated material after the blast will occur due to buoyancy and initial momentum. As the cloud rises, its movement will cause turbulent mixing with non-buoyant ambient air. Deceleration through decreasing buoyancy will reduce the boundary turbulence to that of the ambient air, by which point the 'initial' plume will have been formed. In the new feature of the European standard DSS dealing with 'dirty bombs', the parameterisation of plume rise relates to several independent blast studies (e.g., data from a US blast test series conducted in 1963 to investigate the effect of accidental conventional explosions spreading radioactive material from a nuclear device). The plume rise strongly depends on the amount and type of explosive applied.

For modelling the subsequent airborne dispersion of the contaminants over the environment, it is important to apply methods that adequately account for the mechanisms governing the flow and deposition in relation to the given dispersion altitude and scale. Here a considerable degree of simplification is traditionally applied in decision support models, which are designed to describe the long-range transport of contaminants from high-altitude releases following large nuclear power plant accidents. Since the plume here generally passes well over the various environmental obstacles, the influences on the plume propagation in inhabited areas can be reasonably simulated through the use of different overall roughness and deposition rate parameters compared with, e.g., rural areas (Päsler-Sauer, 2007; Mikkelsen et al., 1984; Mikkelsen et al., 1997). However, investigations made over recent years have shown such simplifications to be problematic, when the contaminant dispersion partially takes place at street level, as would be the case following a 'dirty bomb' explosion. This is particularly true for scenarios involving shifting wind directions (Astrup et al., 2005). Here, higher resolution models are required to address the issues of plume interaction with and flow along obstacles in the inhabited environment. Therefore, a new atmospheric dispersion module for inhabited areas, URD (Urban Release and Dispersion), based on Gaussian puffs and a calculation grid with highly resolved buildings, has been developed at Risø-DTU. This new implement is in some of its basic features inspired by the UDM code developed by the UK Defence Science and Technology Laboratory (Hall et al., 2002), and incorporates plume interaction with environmental obstacles in three different ways. The obstacles form barriers limiting the magnitude of horizontal eddies in the atmosphere, which in turn reduces the large-scale horizontal dispersion. At the same time, the interaction will increase the small-scale turbulence over a city, which will lead to greater small-scale dispersion. Finally, obstacles like downstream building walls constitute barriers that will to some extent delay the further dispersion of parts of the contaminants (Fackrell, 1984).

Obviously, deposition of aerosols on the different surfaces in an urban complex also depends strongly on particle size. Small liquid or vapour condensation particles can be formed, which will have a low deposition velocity to surfaces in the environment. Fragmentation particles will have a considerably higher deposition velocity, leading to a more concentrated contamination pattern over a somewhat smaller area. For instance, the dry deposition velocity to a lawn is typically higher by a factor of about 30 for 20 μm particles than for 2 μm particles (see, e.g., McMahon & Denison, 1979), and due to the different processes (Brownian diffusion, impaction, interception, gravitational settling, etc.) governing the dry deposition of particles with different sizes on environmental surfaces of different materials and orientation, also the distribution of the contamination on the various surfaces in the inhabited environment will be highly dependent on particle size. This issue is also addressed in ongoing DSS extension, through the inclusion of a series of data libraries describing the deposition of aerosols in intervals of the relevant size ranges for five different deposition 'modes': dry deposition, deposition in light rain, deposition in heavy rain, deposition in snow, and dry deposition to a snow-covered environment.

As mentioned above, also other types of malicious atmospheric dispersion of radioactive aerosols may occur, and aerosol formation processes may be simple. Small particles could for instance be formed over longer time by a nebulisation arrangement, perhaps on a rooftop in a city. Figure 1 shows a particle size spectrum measured with a Berner low pressure impactor in the vicinity of an aerosolisation arrangement, where an injected air stream generated particles by nebulisation of an indium acetyl-acetonate powder dispersed in alcohol. A simple medical inhalator nebuliser was used for this arrangement. These particles have a very low deposition velocity, and could thus travel far in the wind. It is foreseen that also estimation of the consequences of this type of scenarios will be enabled in the extended European DSS systems.

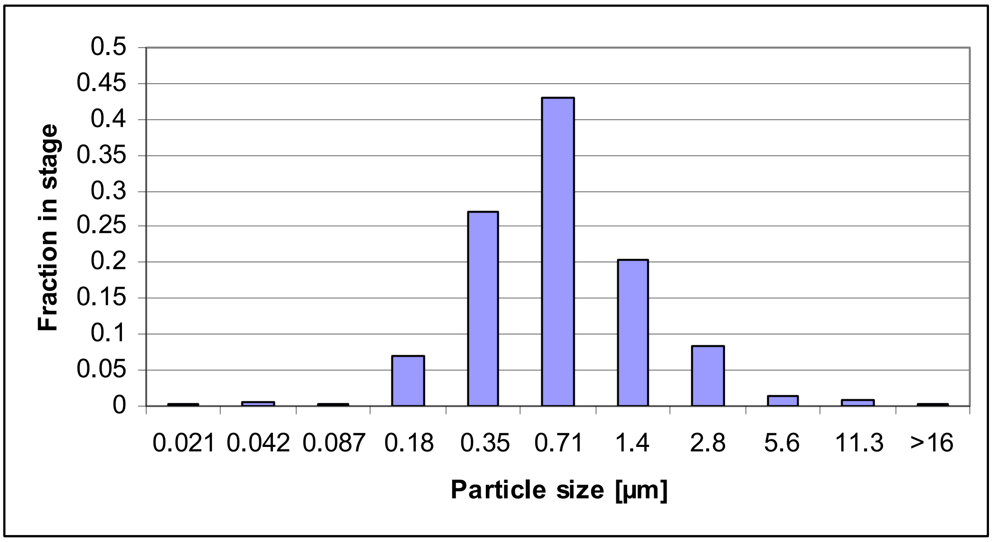

Fig. 1. An example of a size spectrum of aerosols generated by simple means through nebulisation.

Post deposition contaminant behaviour

With respect to post-deposition mobility, it is essential to distinguish between the different physicochemical forms of the deposited contaminants. For instance, aerosolisation of metals in a 'dirty bomb' has been reported to require phase transition, and the solubility and environmental behaviour of small particles created by condensation of evaporated contaminants would be expected to be very different from that of the larger particles generated by physical fragmentation of a virtually insoluble material. It is important to take into account that large particles are considerably easier to remove from surfaces in an inhabited environment, both by natural and forced processes, than are small particles and contaminants in solution. This can be illustrated by results obtained by hosing water at the same pressure on similar sandstone walls that had been contaminated by the Chernobyl accident, in Pripyat only about 3 km from the power plant, and in Vladimirovka, some 65 km away. In Pripyat, where much of the contamination was in the form of large and insoluble particles, the treatment removed some two-thirds of the caesium, but as far away as Vladimirovka, where the contaminants were primarily in the form of small, soluble condensation particles, only about one-fifth of the caesium could at the same time be removed (Roed & Andersson, 1996).

Kashparov et al. (2004) demonstrated that the dissolution in soil of deposited contaminant particles with high chemical stability could, depending on soil pH, be a process lasting over several years. This will delay the migration in soil of the contaminants initially present in a low solubility matrix. The current data in the European DSS describing the migration of contaminants in the urban complex is practically exclusively based on measurements of readily soluble ^{137}Cs from the Chernobyl accident (see Figure 2). The mechanisms that govern the fixation on most urban surfaces of radiocaesium on cationic form are highly element specific, and the values can therefore not be applied for scenarios where a different contaminant is of major importance.

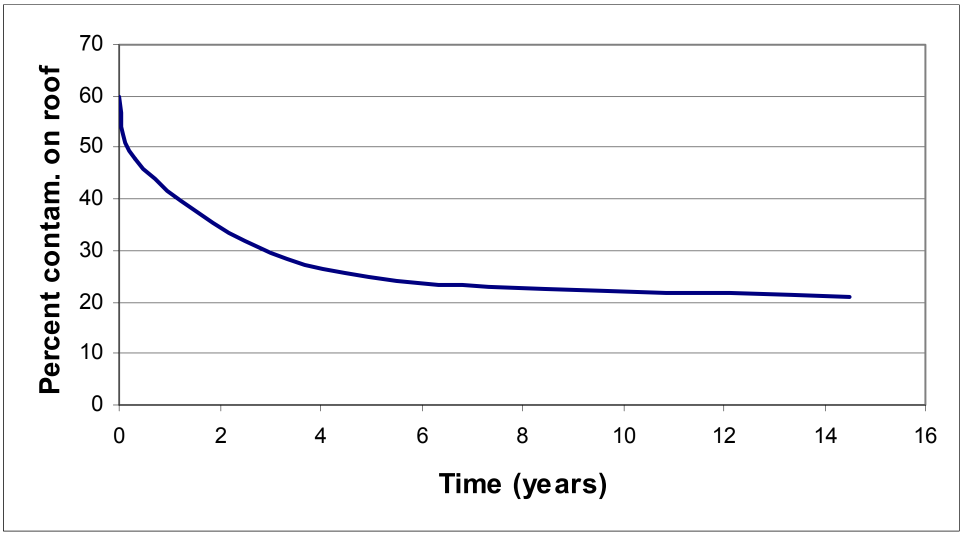

Fig. 2. Natural loss of Chernobyl radiocaesium on a clay roof through weathering over about 15 years (measurements made in Gävle city, Sweden; Andersson, 2009). The efficient long-term retention of a large part of the contamination is due to selective fixation of caesium cations in intact micaceous structures in the clay tiles.

It should also be noted that recent observations on contaminant particles from the Thule accident show evidence that natural spontaneous fragmentation of such low solubility particles can occur in, e.g., human body liquids. This means that large particles, which have high deposition velocities on human skin and in the human respiratory tract may be transformed into smaller particles that would have a longer natural clearance half-life. Thereby, the radiological consequences of the contamination would become more severe. This phenomenon requires further investigation.

Non-radiological concerns

Optimised decision making for intervention is an extremely complex process, which should take into consideration the full range of benefits and costs inflicted on the population as a whole as well as on population sub-groups. Not only radiological perspectives, but also a number of politically driven factors that can not be quantified on a generic scale will need to enter the decision matrix in the event of any contaminating incident. Such issues are often highly site and case specific, and can generally only to some extent be addressed in advance of a contaminating incident. Examples of factors that need to be included in a holistic justification/optimisation of intervention in the event of contamination of inhabited areas, but require quantification on the basis of political decisions, include the value of each unit of averted dose, the value of equity across the population, the value of public reassurance and psychological well-being, the value of maintaining societal functions, the value of lost income, the value of lost or damaged personal property, the societal value of preserving objects, and the value of avoiding environmental risks (Andersson, 2009). Involvement of citizens and stakeholders in the decision process for long-term restoration strategies is an important instrument in reaching generally acceptable and robust decisions that would not be prone to public resistance.

A number of tools have been created, which could be used to facilitate this process and help in balancing different types of factors against each other (Hämäläinen & Mustajoki, 2010; Belton & Stewart, 2002; Jackson et al., 1999; Zeevaert et al., 2001). The use of such systems in a participatory forum can, with the right facilitation and advisory support, form the basis for a case-specific ranking, which may seem reasonable and transparent to all involved, thus providing a useful platform for reaching agreement on the seemingly 'best' solution.. The weakness in the practical use of this approach lies in the valuing of weighting factors, and the summation over often many attributes to reach an estimate of the overall value of each countermeasure option may to some extent remove the focus from issues that demand undivided attention.

Specifically in relation to the psychological well-being of the affected population, it should be noted that both terror and accident victims may experience post traumatic stress disorder (PTSD) or acute stress disorder (ASD, occurring within a month of the impact). However, terror scenarios contain a number of psychological features that are different from those observed in connection with accidents. For instance trauma in connection with acts of terror can disrupt deeply held cultural assumptions about social values, and stressors of human design tend to produce specific senses of betrayal, blame and abandonment (O'Connor, 2009). A group that are at particular risk of developing lasting behavioural and emotional readjustment problems is the rescue workers, who very directly confront and witness the horrors of a terror impact. Therefore, contingency strategies should be developed carefully for this, and also other, population groups. Trauma triggers may include experience of life threatening danger or physical harm, bodily injuries, extreme violence and destruction, loss of communication, intense personal emotional demands, extreme fatigue, anticipation stress, and exposure to contamination (O'Connor, 2009). Specifically in connection with terror scenarios, 'information stress' can occur as people do not have a clue as to what is suddenly going on, and what the dangers might be, both in the very near future ('will more attacks follow soon?') and in terms of long-term consequences. Good communication strategies developed well in advance of an attack (including raising public awareness, since a well prepared public is less prone to panic) are essential in reducing the non-radiological impact. This is particularly important in connection with terror scenarios, due to their sudden and violent occurrence, which is not countered in other types of scenarios and leaves little or no time for any preparation (Danieli et al., 2005). Further discussions of non-radiological factors of concern can be found in Oughton & Forsberg (2009) and Andersson et al. (2009).

Conclusions

The above text illustrates how European decision support systems currently in operation for nuclear power plant preparedness will be extended to enable estimation of the radiological consequences of terror attacks involving atmospheric dispersion of radioactive matter. In relation to contaminant aerosolisation, dispersion and deposition, new source terms are being defined, together with release and deposition parameters that reflect the actual characteristics and dynamics of the contaminants originating from, e.g., 'dirty bomb' explosions. Also, a more refined urban aerosol dispersion model has been developed that takes into account the special features of dispersion at low altitude in a complex, inhabited terrain. It is demonstrated that also post-deposition migration parameters currently applied in the European decision support systems are inapplicable in describing the fate of contaminants from a radiological terror attack, and therefore new data libraries are being created for this purpose also. Finally, the implications of non-radiological factors for optimisation of intervention were discussed, and some factors relating to the psychological well-being of terror victims were highlighted.

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Nuclear inspections on container traffic in the port of Antwerp

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Abstract
Since 2007 Belgian Customs has been inspecting containerized shipments on the presence of nuclear smuggling with radiation portal monitors. Although no incidents of nuclear smuggling were found, several cases were found where non-natural radioactive materials were present in consumer goods.

Introduction
After the 9/11 events in the US an international programme against nuclear smuggling was started as part of the effort to tackle terrorism. The goal is to deter, detect and interdict the smuggling of special nuclear materials. One of the key aspects of this program is to equip border crossings with nuclear detection equipment.

In 2004 the Belgian government signed a memorandum of understanding with the US Department of Energy on the installation of detection equipment in the port of Antwerp. In February 2007 the inspections started in the port of Antwerp. In 2009 the seaport of Zeebrugge was also equipped. On a daily basis about 20 000 containers pass through the portal monitors in the Belgian ports causing about 150-200 alarms per day. Almost all alarms are due to the presence of NORM (naturally occurring radioactive materials).

One of the most important features of these inspections is to release containers with NORM or licensed radioactive materials in the shortest time possible. In order to minimise the effect of the inspections on the container flow, the inspections are performed in a standard three-phased approach.

The decision process is based on the Belgian regulations on radiation protection, international standards for nuclear inspections at borders, and experience from a research project with radiation portals in the port of Antwerp. [1-4] This decision process is part of a standard procedure, agreed on by Belgian Customs and the Belgian Federal Agency on Nuclear Control (FANC).

As a consequence Belgian Customs do not only look for the presence of nuclear smuggling in containers. In the decision process radiation protection concerns also play an important role, such as the safe transportation of radioactive substances (ADR class 7) and the incidental presence of radioactive material.

Material and methods

The Belgian Customs use a standard three-phased approach for nuclear inspections. In figure 1 this decision process is described in a general manner. For a more detailed standard of procedures please contact the authors.

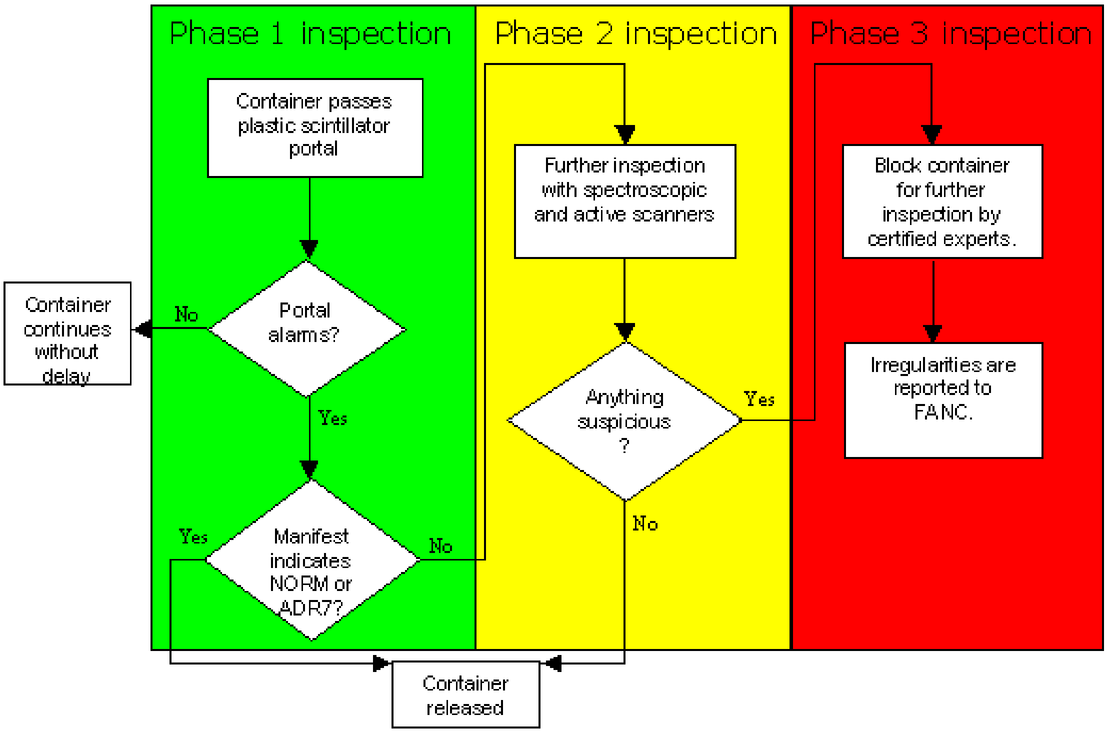

Fig. 1. Summary of the standard of procedures for nuclear inspections by Belgian Customs.

In each phase following procedures and equipment are used:

1. A primary inspection consists of a passage of the container through a radiation portal monitor equipped with both He-3 neutron detectors and plastic scintillator gamma detectors. If the portal detects an increase in radiation compared to the natural background, an alarm is raised. Containers that cause alarm are blocked and await a decision by a Custom Officer in charge. Decisions in this phase are based on the declared content of the container, which is compared to a database of known NORM materials. About 99% of the blocked containers are released in this phase because a known NORM substance is present inside. Note that licensed ADR 7 shipments are released without being blocked.
2. If the information regarding the content is not sufficient to release the container, a secondary inspection will be performed. This inspection consists of measurements of the gamma radiation present with spectroscopic equipment: (1) handheld Ge-detectors, (2) advanced spectroscopic portal monitors (ASP), or (3) car top systems. In most cases this is combined with an active scan of the container with X-ray scanners (3-6 MeV) in order to inspect the physical content of the

container. The X-ray scan image can identify smuggling scenarios such as lead shielding inside the container. In figure 2 the standard setup for secondary screening is depicted. If necessary these measurements can be performed with mobile spectroscopic systems, and a mobile active scanning unit.

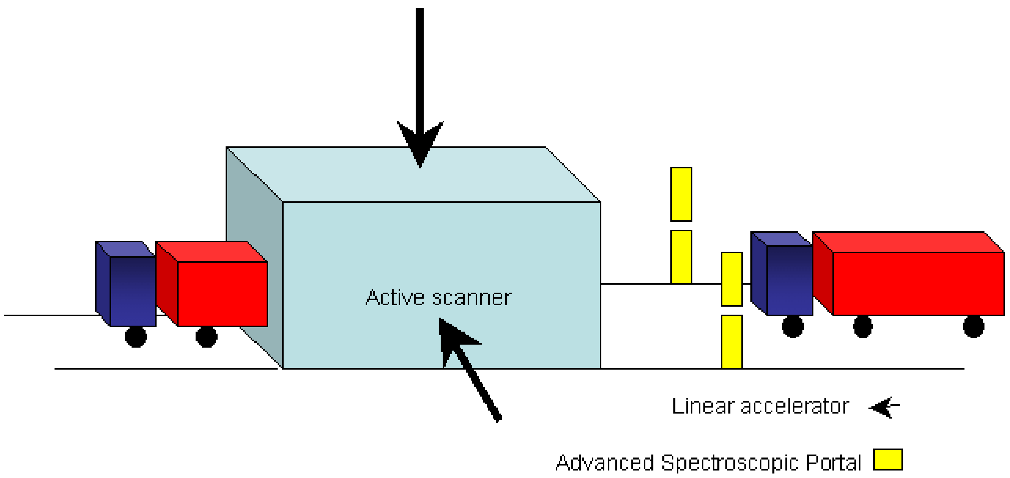

Fig. 2. Standard secondary setup in the port of Antwerp.

3. A tertiary inspection is performed in all cases were Customs cannot release the container based on the primary or the secondary inspection. In these cases a certified radiation expert or FANC itself takes over the inspection.

Results and discussion

The primary inspections with the portal monitors have a reasonably constant alarm rate, being about 1,4%. In the period 2007-2008 the installations were expanding in the port of Antwerp, resulting in growing numbers of occupancies. At present 43 portal monitors are installed in the port. In 2009 we experienced an effect of the global economic crisis resulting in a 7% decrease in occupancies.

Year	Number of Occupancies on primary portals	Number of alarms on primary portals	Alarm rate (%)
2007	1 447 386	20 501	1.42%
2008	2 868 650	40 991	1.43%
2009	2 659 259	36 785	1.38%

In most cases the primary inspection reveals the presence of NORM materials that are not subject to radiation protection regulations. The use of a NORM database has facilitated the recognition of NORM. At this point about 150 different classes of products, ores and consumer goods are present in this database.

The NORM database is used as a reference to release containers based on manifest information and alarm information. For each type of NORM an inspection limit is described. Above this limit Custom Officers will perform a secondary inspection and/or will demand more detailed information. Typically this information will consist of (1) the chemical composition of the product itself and (2) contact information of the manufacturer. The inspection limit is based on (1) statistical information taken from previous alarms on a certain type of NORM, (2) radiation protection regulations, and (3) expert judgement.

The number of secondary inspections has decreased over the years. Secondary inspections are performed on containers that cause suspicious alarms or alarms where the source of the radiation is not found after the primary inspection. At this point about one in 10 000 occupancies will result in a secondary inspection. The most important reason for this is the increased experience of Custom Officers.

Tertiary inspections revealed no cases of smuggling, but quite a large number of incidents involving contaminated materials and orphan sources. Typically one of the following scenarios arises:

1. Co-60 contamination of steel products due to the melting of a Co-60 source in a steel furnace.
2. In industrial by-products (example: concentrated metal ores) a contamination can be present, typically with Cs-137. This is due to an accidental processing of a radioactive source.
3. Cs-137 contamination of biological materials (including food) due to airborne Cs-137 after incidents (e.g. Chernobyl) or nuclear weapon tests.
4. TENORM (technically enhanced NORM) above exemption levels: e.g. radium paint on instruments, scaling on scrap…
5. Orphan sources in scrap.

Conclusions

Experience suggests that nuclear smuggling is not common. In the three years since the start of the inspections, no cases are reported in Belgium. On the other hand the installation of the equipment has proven to be a strong tool in protecting the public against the incidental occurrence of non-natural radioactive materials in consumer goods.

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Optical remote detection of alpha radiation

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Abstract
Alpha emitting radiation sources are typically hard to detect due to the short range of alpha particles in air. A remote detection of alpha radiation in air is possible by measuring the ionization-induced fluorescence of air molecules. The alpha-induced ultraviolet (UV) light is mainly emitted by molecular nitrogen and its fluorescence properties are well known. The benefit of this method is the long range of UV-photons in air. The main challenge of the optical method is to discriminate the weak fluorescence signal from the background lighting. The issue is addressed in the present paper by means of spectral filtering of the UV light. A portable demonstration device, utilizing spectral separation of fluorescence from the background lighting, is presented and the performance of the method is reported. Using specially selected room lighting, the device is able to detect a 1 kBq alpha emitter from the distance of 40 cm with one second integration time.

Introduction
Conventional alpha detectors require direct interaction with the particle which makes the localization of contamination a laborious task. Furthermore, alpha active nuclear materials pose a serious risk if they proliferate among rogue organizations. In this context, the research on novel alpha detection methods is well justified.

Previous studies have shown that remote detection of alpha radiation is possible by measuring the ionization-induced UV fluorescence of air molecules. It was shown that the UV fluorescence can be detected from a distance and even through a plexiglass of a clove box (Lamadie et al. 2005). Furthermore, the detection is possible even under a strong beta and gamma radiation background, because they do not induce as localized fluorescence as alpha radiation (Baschenko 2004). UV fluorescence is typically detected with photomultiplier tubes, but Lamadie et al. (2005) showed that it is also possible to use a CCD-camera and combine the fluorescence image with a normal photograph to gain position information. However, the camera detection requires very long integration times from several minutes to hours.

Fluorescence of air is mostly fluorescence of nitrogen, and molecular nitrogen has fluorescence peaks in the wavelength range between 300 nm to 430 nm. Table 1 shows the wavelength location of the most intense fluorescence peaks of nitrogen. The peaks are having a full-width of half-maximum of about 1 nm. The fluorescence properties of nitrogen have been intensively studied using electron excitation (Waldenmaier 2006), which might be the excitation mechanism also in the alpha radiation excited fluorescence. The secondary electrons are supposed to be responsible for the excitation of the fluorescence.

Table 1. Main fluorescence peak wavelengths of neutral (2P) and ionized (1N) nitrogen molecule. Peaks have full-width of half-maximum of about 1 nm. Two integers in parenthesis mark for vibration state in upper state and lower state, respectively.

Wavelength (nm) / transition
316 / 2P(1,0)
337 / 2P(0,0)
354 / 2P(1,2)
358 / 2P(0,1)
375 / 2P(1,3)
380 / 2P(0,2)
391 / 1N(0,0)

In this work, an optical detection method was developed with short integration time of about 1 second. The method is based on sensitive detection with photomultiplier tubes in photon counting mode, and spectral filtering of the fluorescence signal. The fluorescence peaks of nitrogen between 300 nm and 340 nm are used to record fluorescence signal, and the background reference is detected at 300 nm wavelength.

Material and methods

The optics for the demonstration device was designed with FRED Optical Engineering Software (Photon Engineering LLC). The software is based on optical ray tracing method to calculate the function and performance of the optics. A point like alpha emitter was modelled with the FRED software by assuming the alpha particles to travel 4.1 cm in air at maximum. During the alpha particle trajectory, it creates secondary low-energy electrons that are assumed to excite the fluorescence. Figure 1 (a) shows how the excitation sites are distributed around the point like alpha emitter. From these sites, the photons are emitted to random directions, as shown in fig. 1 (b). Thus, the point like alpha emitter forms a fluorescence emitting volume around itself. As the fluorescence source is not a point source, it causes some challenges to the optics and spectral wavelength separation.

The aim of the optical design is to collect as much of the emitted photons as possible. This yields to a large numerical aperture optics i.e. large collection angle for the optics. With the large collection angle and the volume emitter source, the spectral wavelength separation cannot be made by conventional spectrographs without losing the most of the photons. Thus, interference filters was selected for the demonstration device. The fluorescence is collected with a 40 nm bandpass filter (Semrock, Inc.) having the center wavelength at 320 nm. The effect of background lighting was detected by combining the fluorescence filter with a 15 nm bandpass filter having the center wavelength at 295 nm, which effectively limits the background detection to a narrow wavelength range of 299 nm – 303 nm.

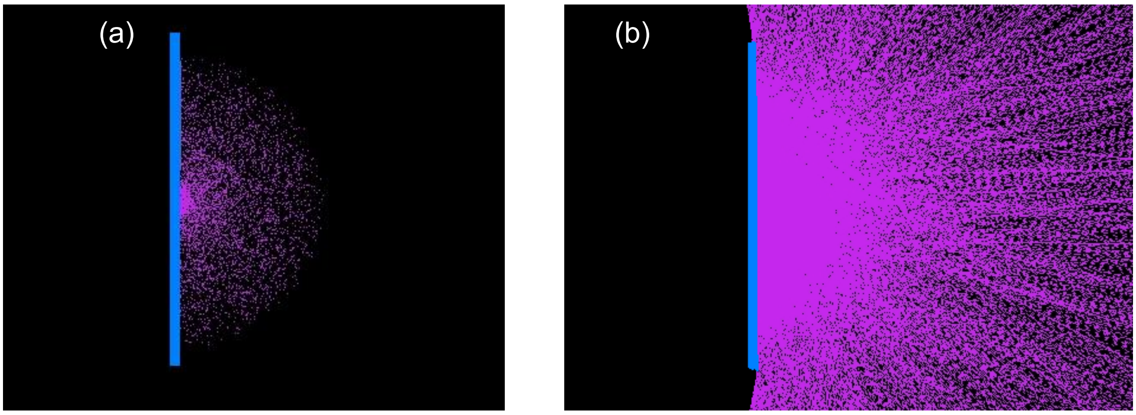

Fig. 1. Model of point like alpha emitter on surface acting as light source. (a) Alpha particles are inducing fluorescence photons in volume inside of the hemisphere having radius of 4.1 cm. (b) Fluorescence photons are emitted to random directions.

Figure 2 shows the optical design of the demonstration device without the interference filters. The design is optimized for the maximum collection efficiency for a detector having diameter of 15 mm. The total collection efficiency was calculated to be 0.12 % when the point like alpha emitter is located at 40 cm distance from the first lens having the diameter of 75 mm. The interference filters are placed in the both sides of the beam splitter in front of the detectors.

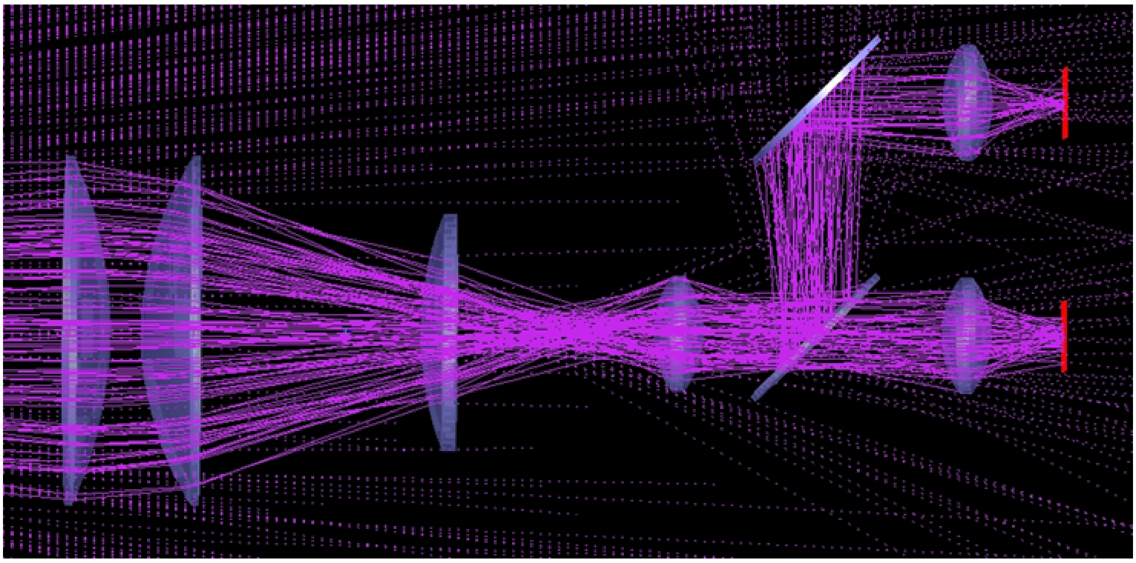

Fig. 2. Optical model of demonstration device. Vertical red lines at the right side are photomultiplier cathode surfaces. The lower channel detects the fluorescence signal at wavelength range of 300 nm – 340 nm, and the upper channel detects background lighting at 300 nm. The wavelength filters are not shown in the figure.

The optics is mounted in side of a tube, so that all the lenses are having the same optical axis. The tube is sealed in a way that no light will leak to the detector from the side. The only optical access to the detectors is through to the first lens. Channel multipliers MP 1982 (PerkinElmer Optoelectronics) were used as detectors. Figure 3 shows the demonstration device without the cover. The optics was packaged with detectors, electronics and a battery to a box having the total weight of 6 kg. The device can be used by free hands or on top of a tripod. The current detector readings are printed on a small display in the back of the device. The data can also be transferred out from the device in real time through a standard network connection.

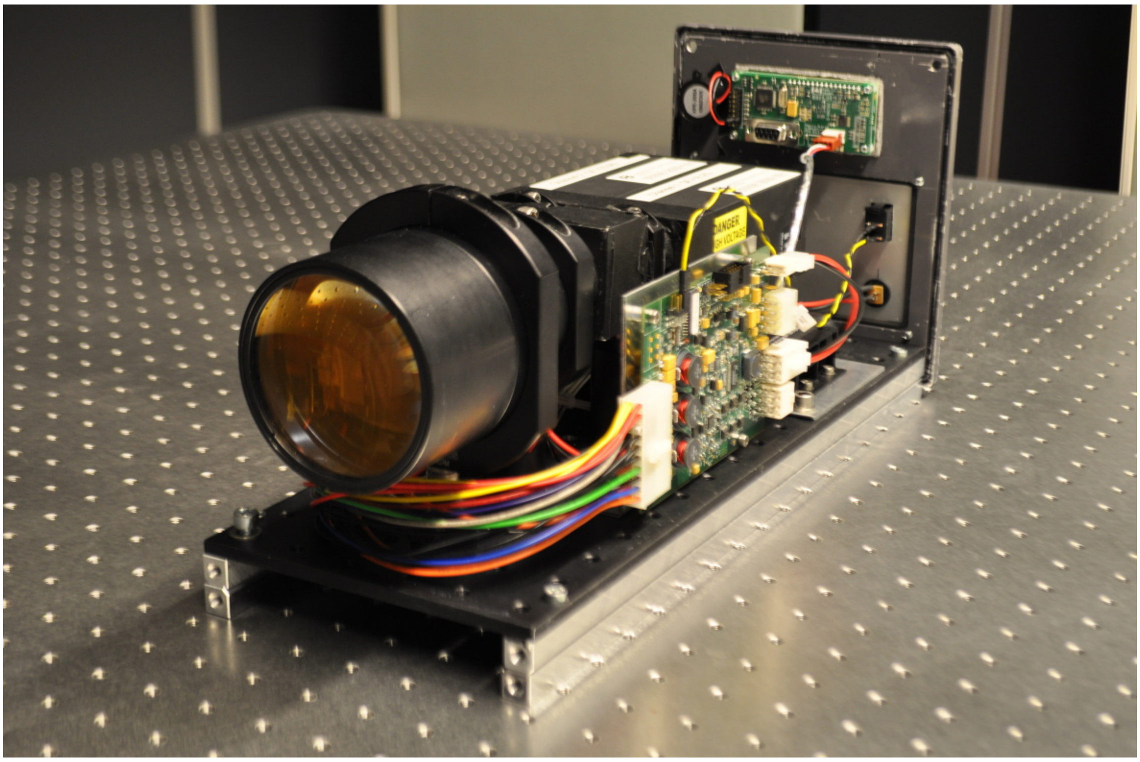

Fig. 3. Portable demonstration device for optical remote detection of alpha radiation. The cover of the device has been removed to show the optics (3" diameter), photon counting detectors, and electronics.

Results and discussion

The detection method was studied using a 10 kBq ^{241}Am source from an old smoke alarm device. The detectors counted about 3 cps dark counts in total darkness. In these conditions and without any spectral filters, the 10 kBq source yielded 150 cps signal to the detectors. The same experiment was repeated using N_2 purge as the same time. The measurement setup was covered with a box and the N_2 purge was replacing the air inside the box with nitrogen. As a result, the fluorescence signal increased to the value of 650 cps, which means more than 4 times enhancement in the signal. This is most likely due to the removal of oxygen that is effective quencher of the nitrogen fluorescence (Waldenmaier 2006). The removal of oxygen is not a relevant method in the most operational conditions, but it was valuable to notice that the fluorescence signal strength was enhanced with nitrogen purge as it can be predicted based on earlier studies with electron excitation (Waldenmaier 2006). The result of this little test is highlighted in the table 2.

Table 2. Fluorescence photon counts per second in normal atmospheric conditions and under nitrogen purge. The nitrogen purge was performed in a closed box to create a nitrogen atmosphere. Reduced quenching causes an increase in the fluorescence yield.

Fluorescence in air (cps)	Fluorescence under N_2 purge (cps)
150	650

The sensitivity of the demonstration device to the distance from the alpha emitter was studied. Figure 4 shows that the fluorescence signal is quite constant from 10 cm to 30 cm distance. The almost constant signal strength in this range is very good feature for operational work, as the operator does not need to tune the distance to the surface very accurately to get reliable readings. The fluorescence collection efficiency of the demonstration device drops rapidly as the distance gets longer than 30 cm, which is also predicted by the ray tracing model.

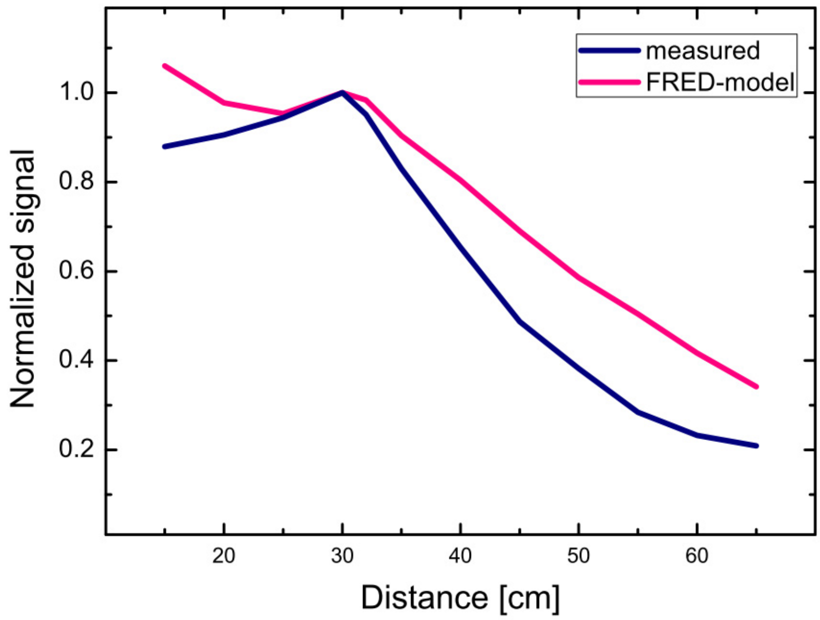

Fig. 4. Normalized fluorescence signal of demonstration device as function of distance from alpha emitter. The normalization is done at the distance of 30 cm from the alpha emitter to first lens surface of the device. The result of optical ray tracing model is shown as a reference.

The spatial sensitivity of the demonstrator device was studied by moving a point like alpha emitter transversally to the optical axis at the distance of 40 cm from the device. Figure 5 shows the measured curve as well as the one predicted by the ray tracing software. The agreement between the model and the measurement is very good, and it can be concluded that the ray tracing model is reasonably reliable. The spatial resolution of the detection is almost too good, as the 2 cm offset at the distance of 40 cm already halves the fluorescence signal. However, point like alpha emitters can be then localized very accurately.

The interference filters used in this work are having a transmittance of about 10^{-6} to 10^{-7} in the visible wavelengths. The visible light blocking efficiency of the demonstration device is enhanced by introducing three similar fluorescence filters in a row. The transmittance also drops at the bandpass wavelength, but as the transmittance of a single filter in bandpass is about 90 %, the effect is not pronounced. A small decrease in fluorescence signal is necessary to get rid of the visible background. Artificial lighting that does not produce UV light can then be used with such a filtering. The visible lighting is effectively filtered out, and the fluorescence is only marginally decreased.

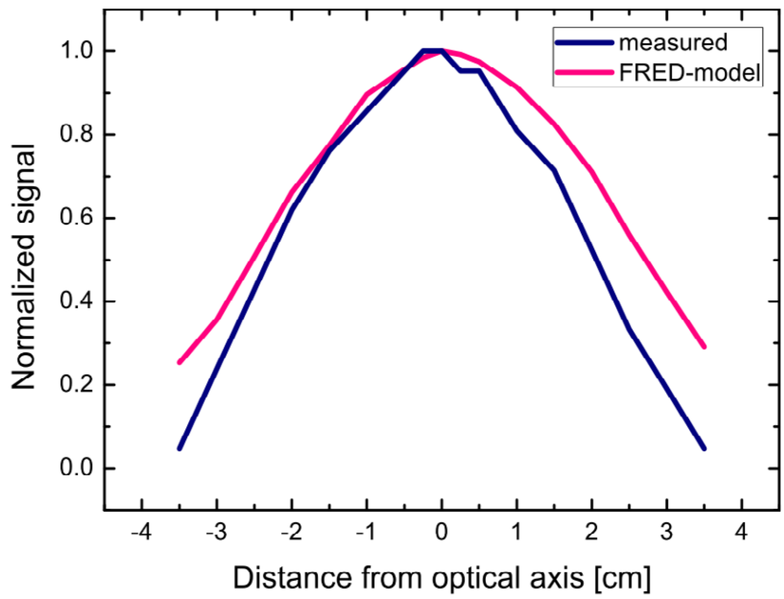

Fig. 5. Spatial distribution of normalized fluorescence signal of demonstration device as alpha emitter is moved away from the optical axis. The alpha emitter is assumed to be a point like source. The result of optical ray tracing model is shown as a reference.

Conclusions

A portable demonstration device with background compensation was constructed. The collected light consists of fluorescence signal and background light, which are divided with an optical beam splitter into two photomultiplier tubes. The both channels are filtered with interference filters to detect the fluorescence signal and the background light separately. The designed operating distance of the demonstration device was 40 cm from the point like alpha emitter. Using specially selected room lighting, the device was able to separate a 1 kBq alpha emitter from the background lighting with one second integration time. The new method looks promising for safety and security applications, where fast remote scanning of alpha radiation is required. However, the challenge of background lighting compensation needs always to be considered. The best practice is to work under artificial lighting conditions, where UV lighting can be avoided using LED-lighting or filtered lighting.

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Identpro/SIA, an identification algorithm for statistically “poor” spectra – Application to mobile or pass-by systems for real time discrimination of sources of interest

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Abstract

Source or contamination searches with mobile systems is generally limited by sudden changes in natural background leading either to setting detection thresholds at the maximum value of background fluctuations or, if set at the average level, of accepting some false positive identifications. This can be overcome by monitoring spectrum changes in real time that is then used in a process that separates the isotopes of interest from the background components or from other innocent alarms like medical isotopes.

Identpro/SIA uses an identification method that has been developed for processing statistically “poor” spectra. While laboratory measurements typically yield spectra with counts in the 100000 range, Identpro/SIA is able to process spectra with a few hundred counts from the source of interest in the presence of thousands of counts of background. Identpro/SIA uses a combined ROI / deconvolution iterative method. This method does not use a peak search technique and therefore is well adapted for low counts spectra with a having large statistical fluctuations.

It supports the full isotope library for homeland security needs as defined by the ANSI, IAEA, and IEC standards. Furthermore it has been optimized for SNM identification including NORM or Medical masking scenarios with large unbalanced ratios, much beyond current standard requirements.

One typical application is the identification and real time rejection of innocent alarms when pedestrians pass by a spectrometric portal. Other applications are source or contamination searches and mapping with car-borne or air-borne spectrometric devices.

Results of extensive testing by spectra injections, by actual source testing and from field feedback are presented.

Introduction

Classically, radionuclide identification is performed using long acquisition time to avoid the influence of statistical fluctuations. Acquisition time is obviously also related to the detector technology and size, the radiation level, the expected precision, etc.

More recently, applications such as homeland security or large area scanning for lost sources or contamination have required detection sensitivities down to a fraction of the background in time periods of a few seconds. Gross counting detection methods cannot meet in practice such a challenge due to fast changing background rates especially in indoor or in urban areas. An additional issue is the discrimination of medical radio-nuclides that are the most commonly encountered sources in unrestricted areas. Such cases are even more important when considering “masking” scenarios, i.e. intentionally hiding an illegal source, with similar spectrum characteristics, in an otherwise legal source of a medical isotope

This can be overcome in a process that is able to analyze “instant” spectra in real time, identify the radionuclide, and so discriminate the isotopes of interest from the background components or from other innocent alarms like medical isotopes.

Identpro was originally developed by Ray Gunnink in the early 2000s, and then in collaborative efforts with Mirion Technologies, continued to improve it. The C language version is named Identpro/SIA and has grown more than three times in size over early versions.

Identpro/SIA method

The IDENTPRO/SIA identification algorithm is designed and optimized for identification with poor statistics, and for detectors with poor or medium resolution (NaI, LaBr3, CZT). The algorithm first determines intensities by region of interest (ROI). Currently more than 70 ROI’s are used ranging from 20 to 2614 keV. If a net intensity is found in the complex 260-460 keV and 565-830 keV regions, the peak intensities are refined by a fitting process. After all the ROI intensities are determined, the algorithm relates these intensities to the isotopes using interference coefficients that have been stored in spreadsheet file.

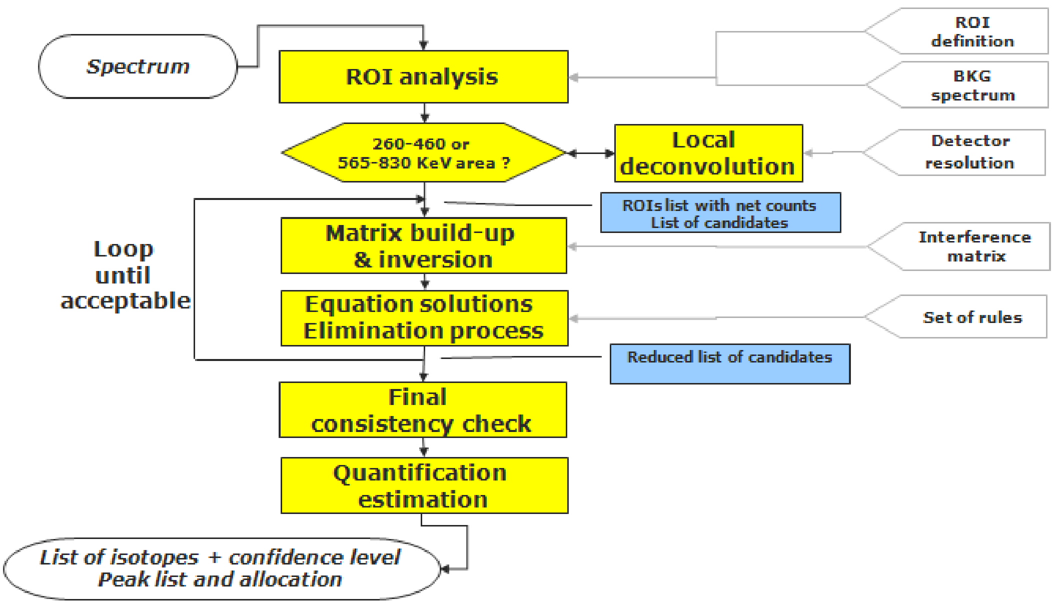


Fig 1. Flow chart of Identpro/SIA.

The next step is to solve the resulting set of linear equations by the method of least-squares, followed by rejecting isotopes yielding unacceptable results and starting a new loop with the reduced number of candidates. Finally the remaining isotopes are screened using additional criteria and decision logic tests

This method does not use a peak search technique and therefore is well adapted for low counts spectra with having large statistical fluctuations. While laboratory measurements typically yield spectra in the 100 000 counts range, Identpro/SIA is able to process spectra with a few 100 counts in the presence of 1000 counts of background

Testing the algorithm performances

Appropriate performance testing and evaluation of systems against approved standards in third party labs such as ORNL, PNNL, Austrian Research Center is mandatory, particularly for sources containing SNM. Despite the benefits we received from performance testing, one must recognize that the standard sources available in such laboratories cover only a limited number of scenarios. Furthermore the tests are go/nogo tests that do not evaluate the performance limits.

The most practical way to extensively test the identification algorithm is to use the so called injection method. Using a library of well defined spectra, i.e. with good statistics and with known intensities, one can weight, add and downscale to create sets of spectra corresponding to draws of various scenarios. It is critical that the process keep the proper statistical variation of counts within the channels, such as the Poisson law for low counts. The response of the algorithm to a set of downscaled spectra is then analyzed. The RASE program lead by the IAEA is an example of such a method.

We have used a color code to score the results of 100 draws:

Dark green: acceptable decision >95% of the cases

Light green: acceptable decision or acceptable decision +unknown >80% of the cases, wrong decision < 20% (remaining cases may be no decision)

Yellow: acceptable decision or acceptable decision +unknown >50%, wrong decision < 20% (remaining cases may be no decision)

White: acceptable decision or acceptable decision +unknown <50%, wrong decision < 20% (remaining cases may be no decision)

Orange: same as light green but added wrong isotope

Red: wrong decision substituting to right decision >20%

Table 1. Sample of the injection study output, scored with the color coded scale.

	50nSv/h		25nSv/h		15 nSv /h		10 nSv/h	
Pu93	Pu-239	98	Pu-239	92	Pu-239	53	Istat	82
	Pu-239 Unkwn	2	Istat	6	Istat	45	Pu-239	14
			Unkwn Pu-239	2	Pu-239 Ba-133	1	Pu-239 Ba-133	1
					Pu-239 Unkwn	1	Unkwn	2
							Am-241	1

We acquired hundreds of actual spectra from type testing, evaluation programs, and field feedback which allow us to downscale preferably real spectra. Real spectra have the benefit of showing unexpected cases such as unexpected secondary isotopes that are included in some sources. As an example, we observed Tl-200 and Tl-202 at low levels in medical Tl-201, high enough to be confused with masked Pu if not properly taken into account.

Single isotopes versus level and integration time

Identification of single isotopes can be challenging when one tries to go beyond the classical condition as set by current standards. For Pedestrian Portals used in dynamic mode, the reference conditions are 50 nSv/h and a passage duration of 2 to 3s.

We studied how the ID decision relates to the dose rates contribution and how it relates to the integration time.

As expected, high energy radio-nuclides such as Co60, K-40, U-238 and radio-nuclides having many peaks spread over the spectrum such as Ra-226 and daughters and Th-232 and daughters, are the most demanding cases. Isotopes with simple structure such as Cs-137, Co-57, Am-241 are easier to distinguish from background. One can note that Pu and enriched U are quite easily identified whereas DU is more difficult.

Table 2. Identification scoring for single isotopes of decreasing intensity.

	50nSv/h	25nSv/h	15 nSv/h	10 nSv/h	5 nSv/h
137Cs					
60Co					
241Am					
57Co					
67Ga					
75Se					
99mTc					
131I					
192Ir					
201Tl					
DU					
HEU					
Pu61					
Pu93					
U 20%					
U 3,1%					
U nat					
226Ra					
232Th					
40K					

Table 3. Identification scoring at 50nSv/h versus integration time.

	30s	15s	10s	5s	4s	3s	2s	1s
137Cs								
60Co								
241Am								
57Co								
67Ga								
75Se								
99mTc								
131I								
192Ir								
201Tl								
DU								
HEU								
Pu61								
Pu93								
U 20								
U 3,1%								
U nat								
226Ra								
232Th								
40K								

An example of detection and identification of very weak Pu is given below (Fig 2).

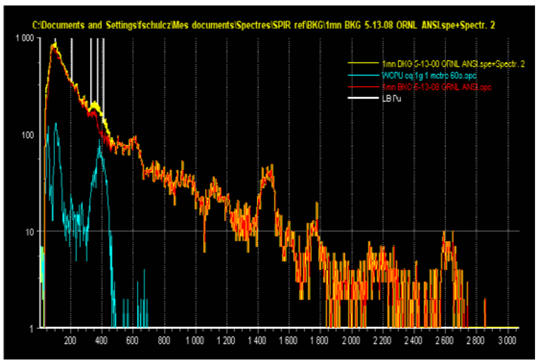


Fig 2a. Addition of low level LBPu (85cps) to Background (961cps), long spectra.

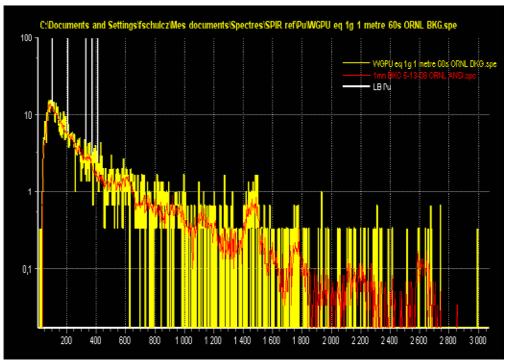
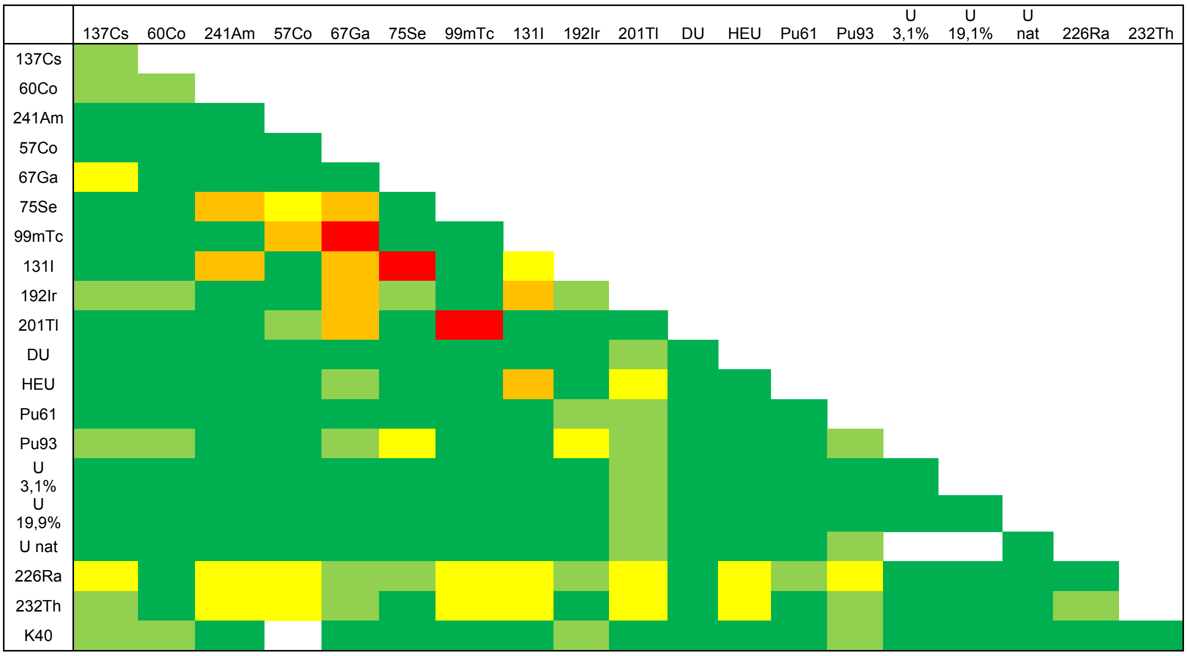


Fig 2b. Same with 3s duration. Although Pu is unnoticeable by eye, Pu warning flag is activated by Identpro/SIA.

Mixed isotopes results

We also evaluated the algorithm’s response to isotopes mixed in 1 to 1 ratios. Table 3 shows that most of the cases are properly identified. The “Red” colored cases correspond to some mixed medical radio-nuclides which are unlikely due to the short half-life of medical radio-nuclides. The algorithm tends to make a safe decision when a second isotope added to a medical one is suspect because it may be an attempt to mask a threatening radio-nuclide.

Table 4. Identification results 3*3 NaI(Tl), 60s, 50nSv/h of each radio-nuclide plus background.



Masking scenarios

The most well known masking case is Tc-99m and HEU due to the proximity of the 186keV peak of U-235 and the 141 keV Tc-99m peak. With high levels of Tc-99m, even using sophisticated pile up rejection, a pulse pile-up tends to mask HEU in very unbalanced scenario (fig 4).

A very difficult combination is certainly I-131 and Pu (fig 3) especially when the intensities are largely unbalanced.

Other cases are less known, but also very difficult. E.g. Tl-201 has a secondary peak at 167 keV that can mask the 186 keV peak of U-235. Ga-67 has a 93keV peak and a 185 keV matching the X ray region and the 186 keV peak of U-235.

Even Cs-137 can mask HEU due to the backscattering peak and can also mask Pu, especially when it is shielded because the addition of a weak source of Pu only changes slightly the Compton edge distribution of Cs-137 spectrum.

We demonstrated the ability of the spectrometric pedestrian portal SPIR-Ident to identify masked SNMs in in-vivo medicals using short 2s spectra for all 16 scenarios involving mixtures of the most popular medicals (Tc-99m, I-131, Tl-201, Ga-67) and SNMs (DU, HEU, RGPu, WGPu) in ratios of 1:10. We also tested the scenarios using

1:20 ratios. These analyses still gave good results with the exception of I-131 and Pu and Ga-67 and HEU (Table 5).

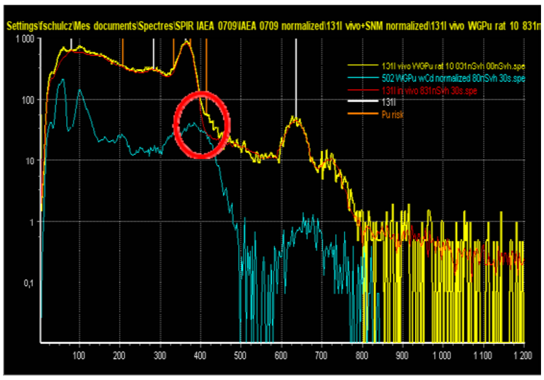


Fig 3. Addition of WGPu to in-vivo ^{131}I, ratio 1:10. Only a very slight bump can be seen on the right side of the 364 keV ^{131}I peak.

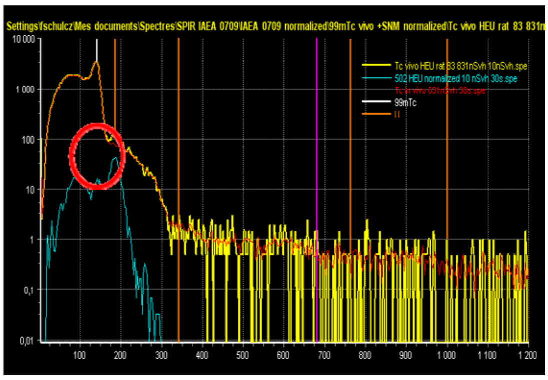


Fig 4. Addition of HEU to in-vivo ^{99m}Tc, ratio 1:10. Very low 186 keV peak hidden in ^{99m}Tc pile-up.

Table 5. Results of an injection study for SNMs masked by medicals in ratios 1:20 and 1:10 based on spectra acquired July 2009 at IAEA's lab Seibersdorf.

Version 210809	Ratio	HEU			LEU			Pu61 0507			WGPu		
time 2s		Med	SNM	autre	Med	SNM	autre	Med	SNM	autre	Med	SNM	autre
99mTc in vivo	20 / 23	100	100		100	85 7 unid		100	99	Am, 4 Unid	100	100	
	10 / 12	100	100		100	100		100	100		100	100	
99mTc	20 / 23	100	100		100	84		100	65		100	100	
	10 / 12	100	100		100	100		100	99	3cs	100	100	
131I in vivo	20 / 23	100	100	8 unid	100	73 1 unid		100	6		100	37 12 unid	
	10 / 12	100	100	8 unid	100	100		100	100	16 unid	100	100	
	7 / 8	100	100	17 unid	100	100					100	100	
131I	20 / 23	100	100		100	42		100	0		100	12	
	10 / 12	100	100		100	100		100	100	6 unid	100	98	
	7 / 8				100	100		100	100	20 unid	100	100	
67Ga in vivo	20 / 23	100	77		100	31		100	40		100	100	
	10 / 12	100	100		100	97		100	100	3 Cscs	100	100	
67Ga	20 / 23	100	2		100	35		100	97	3 Cs	100	95	
	10 / 12	100	96		100	96		100	100		100	100	
201Tl in vivo	20 / 23	100	73		100	56		100	100	4 Cs	100	100	
	10 / 12	100	90		100	95		100	100	6 Cs	100	100	
201Tl	20 / 23	100	60		100	70		100	100		100	100	
	10 / 12	100	75		100	100		100	100	3 Cs	100	100	

Experimental data: spectrometric pedestrian portal for airport

At airports or seaports, where large crowds must be checked, alarms due to medicals radio-nuclides cause a laborious and time consuming secondary inspection procedure that is annoying to front line officers as well as to innocent passengers.

Results of practical testing and of injection studies (see above) now allow us to set a dose rate threshold for medical isotopes uunder which a spectrometric portal will detect masking scenarios with acceptable performance, avoiding the need of secondary screening, and over which a secondary screening is still necessary.

Therefore, the crucial question is if such a threshold will significantly reduce the need for secondary screening. In order to gain practical experience in this question, a SPIR IDENT portal has been installed at the Vienna International Airport in early April 2009 and has been in continuous operation there since

Fig 5. SPIR-Ident layout at Vienna's airport non Schengen exit.

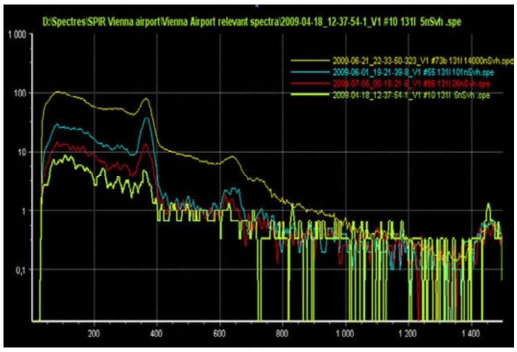


Fig 6. ^{131}I spectra 14µSv/h, 101nSv/h, 26nSv/h and 5 nSv/h maximum dose rate, captured at Vienna's airport exit.

Table 6. Results of 160 days operation with 170 medical alarms for about 1 million passengers.

all events for 160 days	all levels detected	all levels identified	max>15 nSv/h detected	max>15 nSv/h identified	max>25 nSv/h detected	max>25 nSv/h identified
201Tl	92	54	53	50	45	45
99mTc	35	30	15	15	12	12
131I	25	22	18	18	16	16
226Ra	7	3	4	2	0	0
125I?	5	0	0	0	0	0
111In	1	1	1	1	1	1
67Ga	1	1	1	1	1	1
unknown	1	1	0	0	0	0
possible Th	1	0	1	0	0	0
123I	1	1	0	0	0	0
Total	170	114	93	87	75	75
% identified		67%		94%		100%

Summarized results are the following:

- 170 cases during 160 days, one per 7000 passengers
- Tl-201 55% of the cases, Tc-99m 20% and I-131 15%
- Other isotopes are very rare but several cases of Radium
- Very low statistical alarm rate (2 per month)
- Many weak alarms 55% of the cases <25nSvh max,
- Few large alarms: 5% > 1µSv/h max

Identification capability of the SPIR-Ident spectrometric pedestrian portal has been demonstrated: 94% of the cases with peak level >15nSv/h maximum and 100% of the cases with peak level >25 nSv/h max are identified in real time when passing by. No incorrect identifications were observed and no false positives were reported despite cases with saturation

Experimental data: car-borne real time identification

Another application is source or contamination search and mapping with car-borne or airborne spectrometric devices. In the SPIR-Ident mobile implementation, a 2s spectrum is analyzed every 0.5s. Level information is continuously memorized along with the position given by a GPS. Levels are color coded on a map that can originate from Google Earth or from a preloaded map. When a detection occurs the spectra and the ID decisions are saved and a summary of the event is displayed as shown in Fig 7 and Fig 8.

Fig 7. Passing-by a legally transported source on the motorway.

Fig 8. Pedestrian and car driver with Tc-99m in the vicinity of a hospital.

The technology in SPir-Ident Mobile allows us to distinguish sudden background changes due to different road construction materials from actual alarms. Fig 7 shows a detection of a legally transported source at the moment the monitoring car passes by. The alarm duration was only 1 second but Cs-137 was identified within this duration. The monitoring car waited for the truck to get closer again to confirm the alarm which gave a second detection of about 20s. Fig 8 shows the detection and identification of persons injected with Tc-99m in the vicinity of hospital.

Poor statistical definition of actual spectra acquired during a car-borne survey can be seen in fig 9 and fig 10.

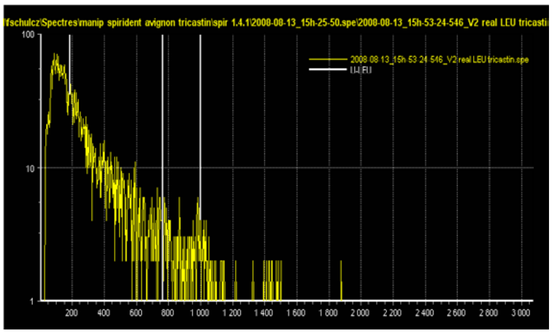


Fig 9. Uranium identification at background level when passing by an enrichment facility.

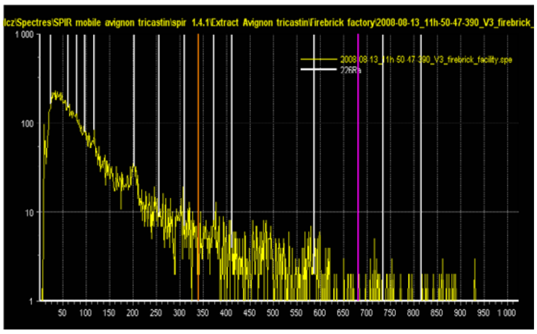


Fig 10. Ra-226 identification when passing-by a firebrick factory.

Conclusion

We gave an overview of Identpro/SIA as a valuable solution for identification of statistically "poor" spectra such as spectra processed by spectrometric portals in dynamic operation, spectra acquired in real time during mobile survey by handhelds, back-packs and larger mobile detection systems. So called "injection" studies have been widely used to improve ID algorithm and characterize the response to numerous scenarios, including demanding masking scenarios.

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Developments in radiological-nuclear support to security through the Canadian CBRNE Research and Technology Initiative (CRTI)

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Abstract
The Chemical, Biological, Radiological-Nuclear, and Explosives (CBRNE) Research and Technology Initiative (CRTI) was created to fund projects in science and technology that will strengthen Canada's preparedness for, prevention of, and response to potential CBRNE threats to public safety and security (1). Canada's federal radiological community – collectively known within CRTI as the Radiological Nuclear Cluster – has benefitted enormously from the collaboration upon which CRTI insists in order to qualify for funding.

During the past few years, the RN Cluster has taken steps towards becoming more operational, through field exercises, providing reachback support for responders and, on occasion, forward-deploying scientists and technicians for major events. This foundation, coupled with creative application of technologies developed by partners, enabled Canada's radiological community to rapidly and efficiently develop a smart, scalable solution for radiation security at the Vancouver 2010 Olympic Games.

Introduction
The Chemical, Biological, Radiological-Nuclear, and Explosives (CBRNE) Research and Technology Initiative (CRTI) was created under the leadership of Defence Research and Development Canada (DRDC) in 2002. Its mandate is to fund projects in science and technology that will strengthen Canada's preparedness for, prevention of, and response to potential CBRNE threats to public safety and security. Twenty-one federal government departments and agencies have signed an agreement to work together, through CRTI and related programs at the DRDC Centre for Security Science, to help further the meaningful application of science to address problems and challenges in the CBRNE domain.

One of the greatest strengths of the CRTI program is its insistence on collaboration. To qualify for funding, project proponents must partner with scientists and end-users from outside their own organizations, including other government departments (federal, provincial or municipal), first-responder and first-receiver groups, academia, industry, and the international community. In addition, scientists and response personnel are invited to participate in science "clusters" – one for each

C,B,RN, and E discipline, and an additional one for forensics – to share knowledge, target gaps in prevention or response capabilities, and generally identify synergies and common interests to further smart and complementary use of resources.

Recently, the clusters have taken steps towards operationalizing their science in a very real way – not only by putting new technologies into the hands of traditional response personnel, but by more actively providing reachback support for responders and, on occasion, forward-deploying scientists and technicians for major events. This paper will briefly describe the evolution of field teams within CRTI's Radiological-Nuclear Cluster, and highlight how they were deployed for radiological surveillance and support to security for the Vancouver 2010 Olympic Games.

For reasons of operational security, a number of details have been withheld from this discussion.

Preparation

Almost 20 years before CRTI was created, Prime Minister Pierre Trudeau ordered the Department of Health and Welfare (now Health Canada) to design a framework that would allow federal RN expertise to be harnessed and directed towards RN emergency response, in a hurry, if required. The current version of this framework is the *Federal Nuclear Emergency Plan* (FNEP, (2), with an updated Appendix 5 (3) that describes primary and secondary responsibilities for all federal departments with a role to play in the response *following* a radiological or nuclear emergency. Most of the departments tasked under FNEP are now also members of the RN Cluster.

When the Vancouver 2010 Olympic Games appeared on the Canadian security horizon, it became clear that a new framework was needed for departments with a role to play before a full-blown RN emergency is realized – specifically, for pre-event surveillance and support to federal security personnel[1]. Documents such as the IAEA draft planning guidance for nuclear security at major events (4), as well as communication with radiation and nuclear security organizations from countries who had hosted similar events (including Finland, Greece, and the United States) formed the planning basis, and a concept of operations was developed jointly with the Royal Canadian Mounted Police National CBRNE Response Team [2](RCMP; responsible for CBRNE security within the Olympic domain) and federal radiation scientists. Planning was made significantly easier due to good relationships between all parties, developed through CRTI-funded projects and exercises, and by leveraging a mix of mature, relevant capabilities pre-existing within the Cluster.

Team-building through exercises, 2003–2010:

One of the very first projects ever funded through CRTI involved a series of four, increasingly challenging field exercises using actual radioactive materials. The first was held in 2003; teams of scientists and technicians from four departments were sent out into a field to locate, identify, quantify and retrieve a variety of sealed sources. They had little difficulty dealing with the sources, but the experience was eye-opening in

[1] Border security and support to municipal responders were handled separately and will not be discussed in this paper.

[2] The core of the National CBRNE Response Team is composed of RCMP, military assets and biological experts from the Public Health Agency of Canada; experts from additional domains were added for the Olympics.

terms of recognizing the logistical requirements for a field deployment, not to mention the need for all-hazards expertise and police officers when dealing with unknown agents and possible terrorists.

Science Teams

Over the years, steps were taken to address the short-comings and learn the lessons identified in the first and subsequent exercises. Roles were defined, equipment upgraded, and operating procedures drafted and tested. In 2007, a few months prior to the fourth and final exercise in the original series, a concept of operations document was written for the newly-named Federal Radiological Assessment Team (FRAT). FRAT was originally conceived as an *ad hoc,* multi-agency, multi-disciplinary group of RN experts who can be deployed to the site of an incident when specialized equipment and/or expertise are required for consequence management. FRAT is not a standing organization; rather, departments and agencies provide resources to FRAT on an as-required basis depending on the nature of the incident and other operational commitments. Contributing organizations include: Atomic Energy of Canada Limited, National Defence (Defence Research and Development Ottawa and Defence Nuclear Safety Division), Health Canada and Natural Resources Canada. Personnel from these organizations train together periodically, participate in the planning and execution of exercises and, lately, join forces to provide scientific support for major events. Any one of these can supply the Team Lead for a given operation and, typically, for exended deployments, personnel from different home organizations will rotate through the lead position.

Security Teams

The exercises, as well as additional training and simulation opportunities and joint CRTI projects, provided opportunities to interact with the responder community and, specifically, the National CBRNE Response Team (National Team). It would be fair to say that the scientific community was ready to embrace the policing community well before the police were ready for the scientists. However, as the exercise series progressed, participation changed from scientists alone, to scientists and police working separately on concurrent scenarios, to finally scientists and police working together. This mutual exposure was crucial to enabling the two groups to begin to understand each other and, subsequently, to find ways to make science truly work in a security context. By March 2008, FRAT had begun to expand its field capabilities from strictly post-incident response to include pre-incident surveillance and support to interdiction and intervention.

Deployment for V2010

In December 2008, the Government of Canada approved a request from the National CBNE Response Team for chemical and radiological scientific support prior to and during the Vancouver 2010 Olympic Games. Biological scientific support had been integrated with the National Team for years; the addition of chemical and radiological capabilities provided an unparalleled degree of technical reachback. The collective C,B, and RN deployed assets, along with a mobile forensic capability, became known as “Science Town.” This paper focuses on the radiological assets; however, it should be understood that these are just one aspect of a broader initiative to complement security with operational science.

Specific support tasks fell into the following categories:

- Scientific reachback and advice
- Sample analysis
- Surveillance

Scientific Reachback and Advice

Throughout the deployment, the RN Science Advisor was the main liaison between the RCMP and the rest of the radiological science team. All information gathered by the scientists flowed through the Science Advisor to the RCMP; and all direction and information from the RCMP flowed through the Science Advisor to the rest of the radiological team.

The Science Advisor was required to have a strong background in radiation physics and health physics, good communication skills, experience working with RCMP, and a good knowledge of the expertise and skill sets that could be called upon from within the RN Cluster, if required. Four RN Science Advisors from three different organizations rotated through the six-week Olympic operation; each also served as the lead for the multi-departmental FRAT while deployed.

Sample Analysis

Samples and swipes were counted and characterized on-site by analysts using a variety of detectors in a vehicle-based platform, or "mobile laboratory." Mobile labs have been used by some cluster members for decades. In 2005, building on lessons learned from partners' earlier iterations, CRTI funded four identical mobile nuclear laboratories, strategically locating them with host organizations across Canada. The labs are very simple – they are effectively mobile bench-space with power and sufficient climate control to allow operation in the extremes of Canadian weather – making them extremely portable. In order to maintain operational readiness, they are routinely used by their hosts for decommissioning, field trials, and training and exercises. In the year prior to the Olympics, CRTI was able to fund a fifth mobile nuclear lab, piloting a new design which maintains mobility while adding workspace, networked computing, and some new features for improved detection and sample handling (especially for nuclear forensics). Future deployments will also include a trailer with mounted satellite and workspace for command and control.

During the Games, samples were collected by police and brought back to the scientists; under no circumstances were scientists to enter areas where there were unknown or significant non-radiological hazards. Samples would arrive at the forensic trailer first for basic triage, sample logging, and collection of traditional (non-CBRN) evidence. Scientific Advisors from all three disciplines and forensic experts would then discuss the situation and potential hazards in order to determine the safest and most expedient way to proceed with identification and characterization of CBRN agents. In addition to minimizing risk to scientists (by not forward deploying them) and limiting disruption to a potential crime scene, this approach also allows for centralization of equipment thereby minimizing the overall footprint of the deployed reachback.

Surveillance

RN surveillance for security purposes was something relatively new to both the scientists and the police in Canada; consequently, it took some time for the idea to gain acceptance from all stakeholders. In addition, the other elements of security planning with which RN surveillance had to mesh were extremely elastic; as a result, the strategy had to be flexible and adaptable, allowing for last-minute changes and adjustments even after installation. Because both buy-in and planning guidance were somewhat slow in coming, the team had less than a year to implement the strategy.

In addition to the short timeline, constraints were as follows:

- Discretion was paramount. The Olympics are considered a sporting event, not a security event; consequently, surveillance had to be discreet and minimally intrusive.
- Olympic venues were spread over a geographic area of more than 1000 km^2.
- Money and personnel were both very limited resources.
- A large amount of detection equipment was required for a very short time.

The solution centered on rapid detection and identification with reliable, well-characterized instruments and systems. It combined mobile and portable networked systems of spectroscopic detectors, which allowed a very few people to monitor very large areas, with less costly and sophisticated human-portable detectors, worn by police officers and other security personnel at strategic locations to add depth and redundancy. Finally, costs and procurements were justified by ensuring that almost all of the equipment was re-usable for future major events, and much would be re-deployed out to regional offices or used to replace aging inventory in environmental monitoring networks.

Discussion

The approach allowed the RN Cluster to play to its strengths, as well as to extract as much use from our limited resources as possible. Fortunately, the problem of monitoring a large area with few people is a common one in Canada and so it was possible to leverage existing capabilities – specifically those used for environmental monitoring, survey and mapping -- and re-apply them to security in a number of cases. By re-deploying or building on systems that were already extremely well understood and deploying the "normal" users to operate them, performance risk was kept to an absolute minimum, as was the need for specialized training.

In addition, using mobile and portable equipment ensured that detectors could be re-distributed throughout the Olympic domain if the threat assessment changed. Looking to the future, it is also now relatively easy to re-deploy this equipment for major events in other parts of the country.

Where possible, data was automatically captured and routed to a central location, where it could be accessed and analyzed locally or remotely. This allowed analysis duties to be shared between personnel deployed to Vancouver and those at home in Ontario, thereby ensuring that sufficient personnel were available to do the work while keeping the deployed footprint small, and minimizing wear-and-tear on personnel in the field. Again, this reduces performance risk and also helps ensure the well-being of the people in the field, increasing the likelihood that they'll be willing to participate again in future events.

It can be argued that relying on data transmission for a surveillance system is risky in that, if communications are lost, so is the ability to monitor. For the Games, redundant systems were in place, albeit less sophisticated ones, so that monitoring would continue uninterrupted even if a whole network was disabled. In addition, and on a strictly practical note, the risk was considered and accepted in light of the significantly greater situational awareness and significantly reduced personnel costs afforded by a distributed network of unmanned detectors and centralized data analysis.

Technology was a big part of what FRAT brought to the Vancouver Olympic Games. However, what the police wanted – more than detectors and data – was information from a reliable source. This what they always want, whether for a major event or a crisis in the middle of the night. For years, the only essential components for effective scientific support have been a telephone and a 24/7 phone number. The detectors and the data help during a large public event, but it is the context that an experienced RN subject matter expert can add to a detection (or suspected detection) that makes the information truly valuable. Fortunately, this context can be applied – with less precision, perhaps – even in situations where the data is collected by instruments and operators less familiar to the expert. Now that the Olympics are over, the challenge for FRAT will be to sustain the momentum built up over the past couple of years and find ways to ensure that the expertise remains accessible to those who need it.

Conclusions

The support and incentive provided by CRTI to develop capabilities in RN counter-terrorism encourages the Canadian federal radiological community to find ways to apply science and technology to security problems. This includes developing technologies and networks that can be adapted and exploited for multiple uses, both emergency and peace-time. Further, exercises, deployments, and collaborative work with Canadian police and security organizations provide opportunities to test and demonstrate the applicability of newly developed technologies for security purposes, and to reinforce the applicability of specialized expertise in helping responders deal with CBRN agents. Overall, CRTI has helped foster a climate in which scientists and responders are comfortable and well-positioned to combine their assets to defeat CBRN threats, as was evidenced by the successful deployment for the Vancouver 2010 Olympic Games.

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Radiological security measures at the United Nations Climate Change Conference in Copenhagen, 2009

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Abstract
From December 7 to 19, 2009 Denmark hosted the United Nations Climate Change Conference, COP15. For an event of such magnitude, security was a major concern. Danish Police in cooperation with UN decided to establish a dedicated CBRN (Chemical, Biological, Radiological, and Nuclear) security and emergency management project. The National Institute of Radiation Protection (NIRP) was expert advisor on the radiological security measures. These included access control and radiological surveillance at the conference site (Bella Center) and a mobile team that could perform screening tasks and emergency assistance in the Copenhagen area. Daily screenings of key locations in Copenhagen were made with carborne gamma spectrometry in cooperation with Danish Emergency Management Agency (DEMA).

The radiological security check at Bella Center was constructed to be discreet and with a minimal distraction of the traffic of delegates. The conference access control area was airport style with all together 25 lines with metal detector and x-ray machines for luggage scan. It was expected that approximately 15,000 delegates, journalists and NGO members would pass the security control over the course of the meeting.

For personal screening walk-by plastic scintillation detectors were installed. Detection of any gamma radiation above 60 keV would trigger an alarm. Police and UN-security personal were instructed to stop the traffic in the access control area in case of an alarm and to contact the radiation expert. NIRP radiation experts remotely monitored the detectors from a nearby office and could arrive at the access control area within a minute after an alarm. Their equipment included a mobile HR Ge-detector that could produce a high resolution gamma spectrum in minutes. Three incidents were recorded with persons who had received radiopharmaceuticals.

Introduction
Danish police had the main responsibility for security during the United Nations Climate Change Conference, COP15. The conference was held in Copenhagen from

December 7 to 19, 2009 and was the largest UN conference ever held outside the UN building in New York. UN had several specific requests to security including CBRN security and emergency preparedness measures. NIRP was therefore asked to plan and implement the radiological security action in accordance with the UN requirements.

NIRP is part of The Danish National Board of Health and is the Danish authority on radiation protection. This includes a 24-hour emergency service with one radiation expert on duty that can respond to any unintended incidences with radioactive materials. The radiation expert can also offer qualified assistance to police and other authorities in case of malicious acts involving radioactive or nuclear material.

However, the magnitude of the COP15 conference, required a corresponding reinforcement of the radiation security and emergency management. Internal education and training of in-house radiation protection officers started 8 month before COP15 and altogether 15 radiation protection officers took part in the event. This number does not include administrative personnel and lab technicians who were on-call duty during the cause of the event.

DEMA participated in the security actions with two vehicles equipped with carborne gamma spectrometry and with four HAZMAT (HAZardous MATerials) teams each trained to conduct sampling and measurements in case of a CBRN incident.

Material and methods

Altogether 3 different radiological security actions were arranged a) daily radiological screening of key localities, b) a mobile radiation expert team, c) access control at Bella Center, the conference venue.

Daily Radiological Screening

The purpose of the daily screenings on the streets of Copenhagen and in the vicinity of the conference centre was to observe any diversion from the normal radiological picture. The screening effort was concentrated around high security hotels and other places where VIP delegates were or could be present.

Several months in advance of the conference NIRP had contacted all licensed users of radioactive sources and companies transporting radioactive sources to ensure that NIRP was notified prior to the use of sources and transportation during the conference period. A ban on transport of high activity sources was issued. The screenings were performed by DEMA’s carborne gamma spectrometry vehicles equipped with an Exploranium 4L NaI(Tl) detector (256 in^3, 16”x 4”x 4”). Measurements were made as 2-seconds real time. For neutron detection a NUCSafe Guardian PRST neutron detector was used.

Radiation Expert Team

The mobile radiation expert team was on 24 hour on-call duty and could be requested by the Police. It could respond to any situation involving radioactive substances or suspicion of use of radioactive substances in the Copenhagen area within an hour. The team was equipped with hand-held radiation instruments including FieldSpec Na(I) gamma spectrometers for nuclide identification. They would be able to advice Police and HAZMAT teams in setting up controlled areas and could handle and secure minor radioactive sources.

Radiological Surveillance and Access Control

The radiological access control at Bella Center was probably the greatest challenge since this had to be coordinated with several other security measures and involved close cooperation between Police, UN security personnel and a private security company. The radiological security measures had to be coordinated with x-ray luggage scans and metal detection of all conference delegates and their luggage. Access to the conference centre was open 24 hour a day and altogether 25 lines with luggage scanners and metal detectors were open during conference peak hours between 7 and 10 am. Up to 5,000 individuals were passing through the access control area within this time interval. Police and UN–security required that radiological security check was discreet and that any false alarms and incidents could be solved quickly and with minimal distraction of the traffic in the access control area. The main concern was false alarms from delegates who had been examined or treated with radiopharmaceuticals, as previously observed in international events where radiological security measures was performed (IAEA, 2009).

The problem was solved by installing three walk-by detectors placed between the first security check and the entrance to the accreditation area (Fig. 1 A). The walk-by detectors were Canberra Portia highly sensitive 40 x 60 x 5 cm^3 plastic detectors that were set to record any gamma radiation above 60 keV. The alarm level was set to trigger an acoustic and visual alarm if a source corresponding to 370 kBq Cs-137 passed the detector within 1 m. A more sensitive setting was possible, but impractical, since the alarm would be triggered by a radioactive source too far from the detector, and hence it would be more difficult to identify the source in a large crowd. Police and UN-security personal were instructed to stop the traffic in the access control area in case of an alarm and contact the radiation expert. NIRP radiation experts remotely monitored the detectors from a nearby office and could arrive at the access control area within a minute after an alarm. During peak hours a NIRP expert was present at the access control area together with other security personnel. NIRP experts were equipped with Thermo RadEye B20-ER GM detectors for dose rate measurement and Thermo GX 2'' Na(I) detectors for high sensitive gamma detection (Fig 1 B). All radiation experts wore Thermo EPD personal dosimeters. In case of an alarm from a walk-by detector, with many people present, NIRP experts could find the radioactive source with hand-held detectors.

The radioactive person or object was hereafter escorted to a visitation room for nuclide identification and activity. For radionuclide identification a Canberra Falcon 5000 portable cryo-cooled HR Ge-detector was used (Fig 1 B and C). The Falcon uses Falcon 5000 software as well as Genie2000 detector software. The software nuclide library was updated with all likely radionuclides used in industry and medicine.

Fig. 1 (next page), A. The Access control area with walk-by detectors to the right equipped with acoustic and visual alarms (see arrow), B. Mobile HR Ge-detector (Falcon 5000) and hand-held detectors used during the operation, C. Measurement of a person in front of the Ge-detector, and D. Surface contamination measurements in the plenum hall.


A
B
C
D
ENTRANCE
FORCE

Table 1. List of typical radionuclides used in radiopharmaceuticals. Data from NIRP.

Radionuclide	Type of Radiation	Energies (keV)	Yield (%)	Half Life	Average dose to patients (MBq)	Medical use
H-3	Beta	19	100	12.3 years	6	PET
C-11	Gamma Beta	511 960	200 100	20.4 minutes	420	PET
N-13	Gamma Beta	511 1199	200 100	9.97 minutes	670	PET
O-15	Gamma Beta	511 1732	200 100	2.04 minutes	997	PET
F-18	Gamma Beta	511 634	200 97	1.83 hours	382	PET
Cr-51	Gamma	320	10	27.7 days	4	Blood circulation
Co-57	Gamma	122	86	271.8 days	<1	Digestion
Fe-59	Beta Beta Gamma Gamma	273 466 1099 1292	46 53 56 44	44.5 days	<1	Several uses
Ga-67	Gamma Gamma Gamma	93 185 300	39 21 17	3.26 days	192	Several uses
Se-75	Gamma Gamma Gamma	136 265 280	59 59 25	119.8 days	<1	Digestion
Kr-81m	Gamma	276	4		5587	Lung
Sr-89	Gamma Beta	909 1492	<1 100	50.5 days		Therapy
Y-90	Beta Beta	546 2284	100 100	29.1 years		Therapy
Tc-99m	Gamma	141	89	6 hours	857	Alt
In-111	Gamma Gamma	171 245	90 94	2.8 days	224	Blood circulation Digestion
I-123	Gamma	159	83	13.2 hours	306	Nerve, endo-krine + div.
I-125	Gamma Gamma Gamma	27 31 35	114 26 7	60.1 days	2	Blood circulation
I-131	Gamma Beta	365 606	82 90	8 days	522	Blood circulation Therapy
Xe-133	Gamma Beta	81 346	37 99	5.2 days	2500	Nerve
Sm-153	Gamma Beta Beta Beta	103 634 703 807	28 35 44 21	1.95 days		Therapy
Lu-177	Gamma Beta	208 490	11	6.71 days		Therapy

Table 1 lists the most commonly used radionuclides in radiopharmaceuticals in Denmark. The Falcon 5000 software is designed to suggest radionuclides from the library as soon as a significant peak is found in the spectrum. The most recent background spectrum is automatically subtracted, when a radioactive source is measured. The radiation expert on duty measured a background spectrum each day. The background spectra contained K-40, U, Th and their typical decay series isotopes.

The radiological security measures in Bella Center also included background radiation measurements at specific localities in the centre and dose rate and surface contamination measurements at plenum halls and other key localities (Fig. 1 D). For surface contamination measurements we used Thermo RadEye AB100 detectors.

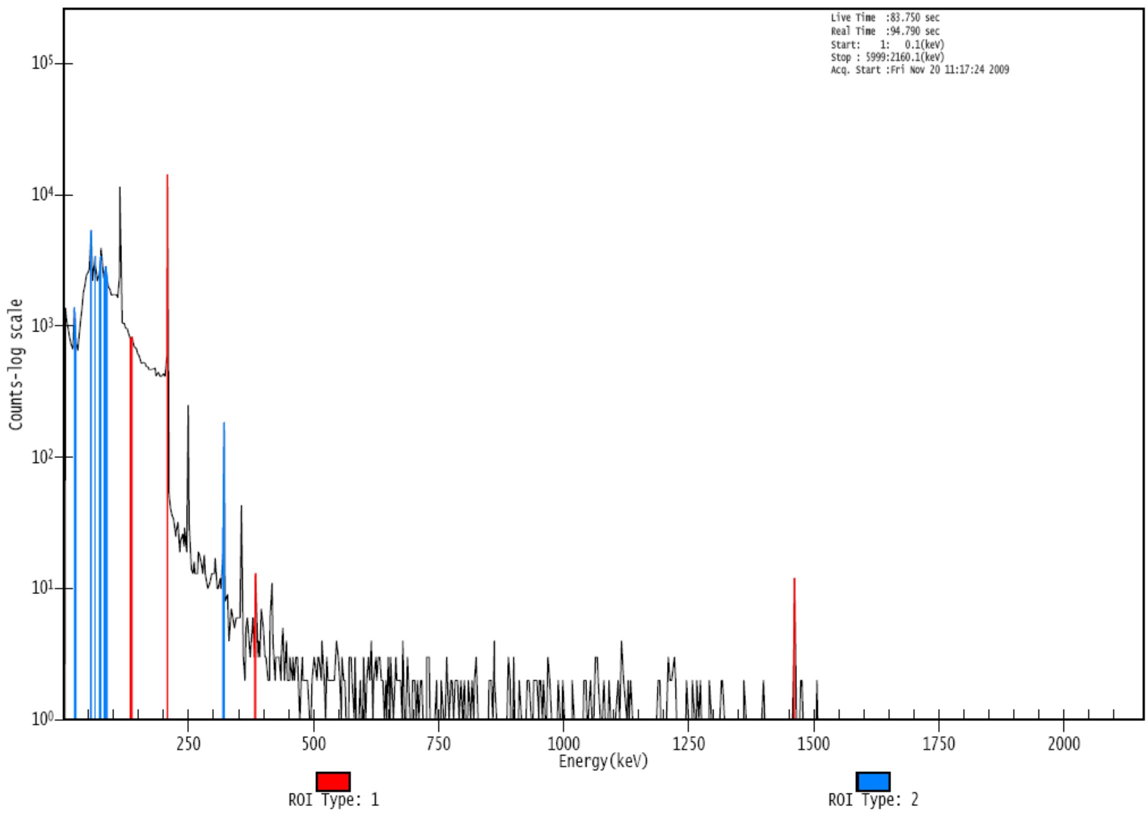

Fig. 2. High Resolution gammaspectrum taken 1 m from a patient who has been treated with radiophamaceutical containing Lu-177. A measuring time of little more that a minute is sufficient for precise radionuclide identification.

Radiological Incidents

During the entire operation 3 incidents were recorded, all at the access control area in Bella Center. All incidents were so called “innocent alarms” related to delegates or employers who had received radiopharmaceuticals. The radionuclides detected in the three cases were I-131, Tl-201 and Lu-177. In all cases, the delegate triggering the alarm of the walk-by detector was approached by a radiation expert with a handheld instrument, and the delegate was hereafter measured in the visitation room with the HR Ge-detector. Tl-201, a radionuclide used for heart diagnostics, was not on our original list of potential radiopharmaceutical, since it is not used in Denmark (Table 1). Identification was, however, fast from the Falcon 5000 nuclide library and since the delegate was aware that he had been examined, the measurement took only a few minutes.

All radioactive delegates were equipped with a certificate of the measurement with radionuclide and corresponding dose rate. They were kindly asked to report to the radiological expert on duty prior to every transit of the access control area in order to be guided past the walk-by detectors.

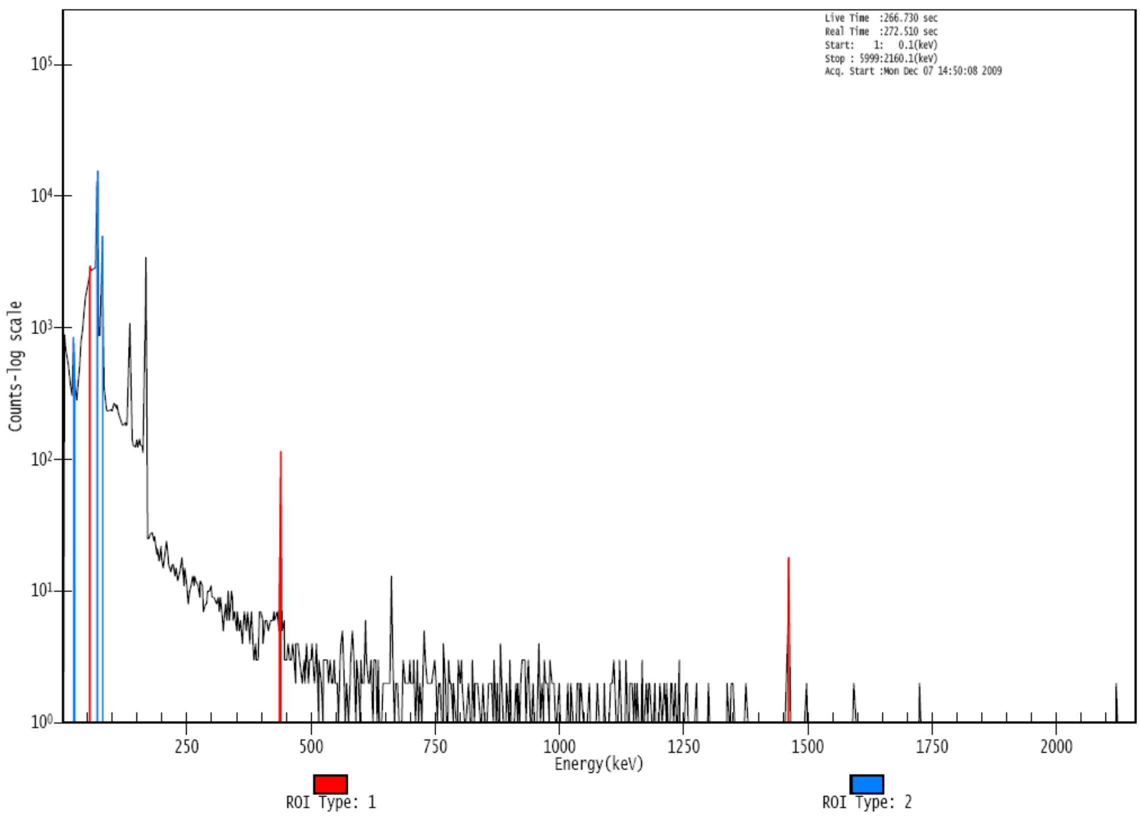

Fig. 3. High Resolution gamma spectrum taken 1 m from a patient who has been treated with Tl-201. The characteristic gamma energies from Tl-201 are at 69 and 167 keV, respectively. Note also the gamma energy from Tl-202 at 440 keV.

Gamma Spectra Recorded

Fig. 2 shows a typical gamma spectrum for a person who has received Lu-177. All gamma lines in the spectrum originate from Lu-177 (Table 1) or background U, Th and K isotopes. The background was, as previously mentioned, subtracted before the nuclide library match is performed.

The gamma spectrum for Tl-201 is shown in Fig. 3. It is well known that Tl-201 often contains traces of Tl-202, which can be seen in the spectrum at the characteristic gamma energy at 440 keV. In fact, Tl-202 is probably responsible for most of the dose rate from this particular patient since its half life is 12 days compared to 73 hours for Tl-201. The patient had received his examination a week before attending the conference and the dose rate was 0.2 μSv/h at 0.5 m from his torso at the time the gamma spectrum was obtained.

Conclusions and Lessons Learned

Events involving radioactive material intended for malicious purposes were not detected. This in itself is an important result.

We learned the following from the radiological security arrangements during COP15:

- The key element, and challenge, in the planning was the cooperation with other authorities concerned with security, which had not previously worked with radiation protection authorities.
- Training of radiation experts together with testing and preparation of equipment was of great value. It is important to test and practice any equipment prior to use during the operation.
- It is vital that instruments are purchased and tested in adequate time before an event, and that all radiation experts are familiar with the equipment used.
- It is important to recognise problems with innocent alarms and establish procedures for dealing with these. All innocent alarms recorded during COP15 came from radioisotopes for medical diagnosis or treatment. These cases were quickly recognised since a highly advances HR Ge-detector was used directly at the first “line of defence”.
- It is likewise important to reduce the possibility for innocent alarms by reducing transport of radioactive sources during the event and to require notification of use of sources in the public room.
- Considerations should be given to possible radionuclides in radio-pharmaceuticals. A nuclide library as complete as possible should be established and radiation experts should be trained accordingly.

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International action plan for strengthening the international preparedness and response system for nuclear and radiological emergencies

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Testing of a portal monitor to detect illicit trafficking of anthropogenic radioactivity in operational field use

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Abstract

Measurements were conducted at a cargo container checkpoint of the German Customs Office at the Hamburg Harbour. At this checkpoint a radiation portal monitor (RTM 910 of MIRION Technologies) has previously been installed. The RTM 910 is capable of neutron and gamma detection with a low energy-resolution. To detect the gamma radiation plastic scintillators are used. In this field experiment 30 to 40 cargo containers were controlled per hour. In this time approximately three alarms per hour were given. To examine what kind of radionuclides caused these alarms, it was necessary to analyse spectra of the radiation when such an alarm occurred. For the identification of the radioactive substances two other gamma detectors were used in addition to the RTM 910. One detector was a high purity germanium detector with an energy resolution of better than 2 keV. The other detector is based on sodium iodide and has an energy resolution of about 10 keV. Both were used to take spectra exactly at the time an alarm was given by the RTM 910 and to identify the alarm causing radionuclides by analysing the spectra with two different programmes. All the detected radionuclides are naturally occurring.

In addition measurements with the germanium detector were conducted in order to estimate radionuclides which cause the background.

Introduction

To detect illicit trafficking of radioactive material, radiation portal monitors are used at border crossings. The currently most widely used detector material is plastic scintillator. These plastic scintillators are sufficient for gross counting but they have disadvantages in nuclide identification due to their low energy resolution. Therefore their performance is compare to detectors with much higher resolution like e.g. sodium iodide (NaI) or high purity germanium (HPGe). This comparison helps to estimate how an appropriate use of such detections systems is possible under operational field conditions. Therefore spectra, recorded with such high resolution detectors, have been analysed regarding possible radionuclides. Furthermore measurements have been conducted to get an overview about naturally occurring radioactive materials (NORM) like e.g. potassium or the products of the uranium and thorium natural decay series which lead to an appreciable radiation background.

Material and methods

To get a first overview on the situation of cargo-control, measurements were conducted at the cargo container checkpoint of the German Customs Office at the Hamburg Harbour.

At this checkpoint a radiation portal monitor has been installed. This monitor, RTM 910 which was developed by MIRION Technologies, is capable for neutron- and gamma-detection with a low energy-resolution. To detect gamma radiation and to produce signals proportional to the intensity of the radiation, plastic scintillators are used. The signals are then collected by a central monitoring system (CeMoSys).

Thereafter the signals are analysed and compared to the radiation background. If the adjustable alarm limit is exceeded an alarm is given. The measured radiation is divided into six ranges of energy. This allows to discriminate between certain types of radionuclides (e.g. NORM or SNM: Special Nuclear Material).

The RTM 910 has two detectors (each detector 50 x 80 x 5 cm plastic scintillator) on both sides of an incoming street to the checkpoint. The distance between the two detector parts is six metres and the cargo containers are transported through this portal monitor with an average velocity of 30 km/h.

In the field experiment 30 to 40 cargo containers were controlled per hour. In this time approximately three alarms were given by the CeMoSys. To examine what kind of radionuclides caused these alarms, it was necessary to analyse spectra of the radiation when an alarm occurred.

For the identification of the radioactive substances two other detectors were used in addition to the RTM 910. These detectors were high-resolution spectrometric gamma detection systems.

One detector is called ReGeM and was produced by Canberra. This is a high purity germanium detector (coaxial germanium cristal, length: 59 mm, diameter: 60.5 mm) with an energy resolution of 0.3% at 662 keV. The other detector (Spir Ident, produced by Mirion Technologies) based on sodium iodide (40 x 10 x 5 cm) and has an energy resolution of 8% at 662 keV.

The idea was to take spectra exactly at the time an alarm was given by the RTM 910 and to discover the alarm causing radionuclides by analysing the spectra. To record the spectra simultaneously to RTM alarms it was helpful that the Spir Ident could be triggered on radiation above background level.

It was not possible to trigger the ReGeM on radiation increase in order to inspect the relevant containers. Therefore short time spectra (3- 4 seconds) had to be taken manually.

All measurements were conducted during a period of ten days. In this period approximately 320 cargo containers were inspected per day. During one hour, three to four alarms were given by the RTM 910, but due to problems with the central monitoring system only a small amount was recorded.

The second purpose was to determine the naturally occurring radionuclides which causes the radiation background. For that purpose 24 spectra had been taken with the ReGeM detector over 20 minutes each. The ReGeM detector was most suitable for this due to its high energy resolution.

Results

The results of the measurements with the Spir Ident are quite satisfying. It was possible to discover radionuclides in the spectra that were simultaneously recorded to RTM alarms. The identified radionuclides were potassium and products of the thorium and uranium decay chains. All these radionuclides are classified as NORM. The spectra were analysed with two different programmes; SMI (a product of Mirion Technologies) and Genie-2000 (a product of Canberra).

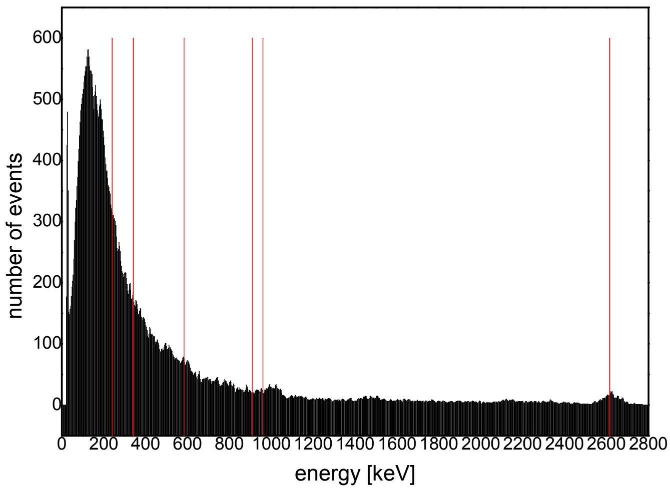

Fig. 1. Spectrum obtained with the Spir Ident due to an increase of background radiation and simultaneously recorded to an alarm given by the RTM 910. The positions of peaks related to the characteristic energetic lines of Th-228 are marked with red lines. Only at 2614 keV a peak was found, but it was sufficient to identify the presence of Th-228 with a probability of 60% by the key line of its daughter product Tl-208.

As written above all alarms can be explained with naturally occurring radioactive materials. The identification probability was 20 – 30 % in case of uranium (four times detected), 40 – 90 % in case of thorium (three times detected) and 40 – 70 % in case of potassium (ten times detected). The results of the SMI software were confirmed with the Genie 2000 Software.

The short time spectra recorded with the ReGeM detector were not usable since the measured rate of radiation was too small in order to get statistically significant information on possible radionuclides, even if several channels were aggregated.

The estimation of background causing radionuclides was analogous to the spectrum analysis before. Based on 24 spectra recorded with the ReGeM detector (each measurement time 20 minutes), the presence of several radionuclides has been determined. These radionuclides occur also naturally and were again nuclides like potassium or the products of primordial radionuclide decay chains, e.g. Bi-214 or Pb-14. Table 1 shows occurring naturally radionuclides as they were found in the recorded spectra.

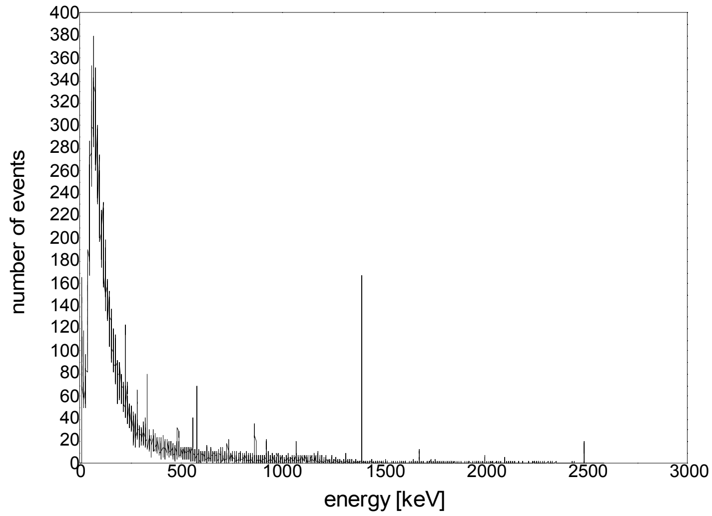

Fig. 2. Spectrum obtained with the Regem detector. The duration of measurement was 20 minutes.

Table 1. Radionuclides, discovered in background spectrum shown in figure 2 recorded with the ReGeM detector. As an example the count rate obtained from the spectrum shown in Fig. 2 is given for each emission line.

Radionuclide	Emission line [keV]	Count rate
K 40	1461	1030
Pb 214	295.224	88
Pb 214	351.932	291
Bi 214	609.312	253
Bi 214	768.356	49
Bi 214	1120.287	59
Bi 214	1238.110	35
Bi 214	1377.669	40
Bi 214	1764.494	71
Bi 214	2204.21	18
Pb 212	238.632	273
Tl 208	510.77	124
Tl 208	583.191	184
Tl 208	2614.533	155
Av 228	911.204	128
Ac 228	968.971	77

Discussion

All identified nuclides (10 x potassium, 4 x uranium, 3 x thorium), which are supposed to be the reasons for the alarms given by the RTM 910, occurred naturally. They are often contained in building materials but even they can be found in litter or K-40 fertilizer. Since such materials are often transported through the Hamburg Harbour their occurrence is not anomalous.

Conclusions

The Spir Ident detector is suitable for container inspections; every RTM910 alarm was also simultaneously accompanied by a detection of a higher radiation background by the Spir Ident and instantaneous nuclide identification with SMI.

The ReGeM detector was not suitable for container control because of the low count rate that did not allow for any detection. The detection efficiency of a germanium detector is too low for short time measurements. However the ReGeM detector was suitable to estimate natural radionuclides that occur in the measurement area permanently. Therefore 24 spectra had been analysed. It was possibly to identify the typically occurring radionuclides that are part of natural decay chains of uranium or thorium. These spectra can further be used for consistency checks of e.g. radiation background estimations.

Acknowledgements:

The measurements at the Hamburg Harbour were conducted in cooperation with MRION Technologies (RADOS) GmbH in Hamburg, the Fraunhofer Institute for Technological Trend Analysis in Euskirchen (INT) and the technical service of the German Customs Office in Hamburg.

Detection of radiation sources and assessment of measurement signals for nuclear security

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Abstract
Nuclear security is an important item at major public events and political meetings. The organizers and the law enforcement have to guarantee that no radioactive material is hidden at the venues. Portal monitoring is effective in controlling flow of people and goods. Alone, however, it is not sufficient for radiological security. Mobile measurements have to be carried out during pre-event search and during the event itself. Radionuclide detection capability is needed inside and outside the venues, and also at the major traffic nodal points. Mobile measurements are technically demanding.

The Radiation and Nuclear Safety Authority (STUK) started a project, known as VASIKKA, for in-field measurements. With EU-support another project, SNITCH, was launched for data management. Together they are intended to detect criminal use of radionuclides at the major public events and political meetings. End-users of the system are law enforcement agencies.

VASIKKA and SNITCH secure critical venues through integrated radionuclide detection capability, based on mobile monitoring, efficient data communication (in-field sensors) and data management, including automated data exchange from database to database via Internet. SNITCH transfers the alarms and the key analysis results immediately to experts or to duty officer. This gives timely response, based on assessment of the key findings, for the law enforcement against unauthorized or criminal acts related to nuclear or other radioactive materials.

Radiation measurement system VASIKKA
A backpack size measurement system called VASIKKA has been designed to be used by the field teams. The system consists of a gamma-ray spectrometer, a neutron count rate detector and a rugged data collection and management computer. $LaBr_3$ scintillation detector is used in the gamma spectrometer. The spectrometer has good energy resolution (< 3 % @ 662 keV) and performs well in different environments.

The measurement system uses a short acquisition time to enable mobile measurements with good spatial resolution even with relatively high speeds. A robust summation algorithm is the basis of the peak detection. VASIKKA has three modes of operation, fast, medium and slow:

- SRCH (4 s)
- MON1 (40 s)
- MON2 (400 s)

The user does not have to select any measuring mode; the monitoring modes run in the background, and provide alarms when the triggering level has been exceeded. The alarm is based on the concept of peak significance (Table 1).

Table 1. Confidence on nuclide identification in VASIKKA software. The initial categorization is based on peak information. In addition, nuclide-specific discard rules are implemented to avoid false identification. For definition of the peak significance *S*, see text.

Confidence level	Number of peaks	Rule	Comment
1	1	$1 \le S \le 1.5$	Small peak (H_0)
2	1	$1.5 < S \le 2$	Small but clear peak (H_0)
3	1	$S > 2$	Unequivocal peak (H_0) - no other information on nuclide ID. Typically ^{137}Cs @ 661 keV
4	2	$1 \le S_{1,2} \le 1.5$	Two small peaks (H_0)
5	2	$1.5 < S_1 \le 2$ $1 \le S_2 \le 2$	Two small peaks, at least one of them clear (H_0)
6	2	$S_1 > 2$ $S_2 \ge 1$	Two peaks, at least one of them unequivocal (H_0)
7	≥ 3	$S_1 > 2$ $S_2 > 2$ $S_3 \ge 1$	Three or more peaks, two of them unequivocal (H_0)
8	2	$S_1 > 2$ $S_2 > 2$ $0.7 < A_1/A_2 < 1.3$	The ratio of the measured peak areas is within 30 % as predicted by the decay data and the efficiency curve. No low energy line is considered.
9	≥ 3	$S_1 > 2$ $S_2 > 2$ $S_3 > 2$ $0.7 < A_i/A_j < 1.3$	The ratios of the measured peak areas of three most significant peaks are within 30 % as predicted by the decay data and the efficiency curve. No low energy line is considered.
10		Human review	

The peak significance (S) is defined as the normalized ratio of the peak area and its standard deviation. S is calculated in such away that it receives a value of 1 at the false positive risk level of 1:10^6 ; this means that the normalization factor is the abscissa $k_\alpha = 4.75$ of the Gaussian distribution.

All measurement and analysis results are stored in the local LINSSI database running in the data management computer.

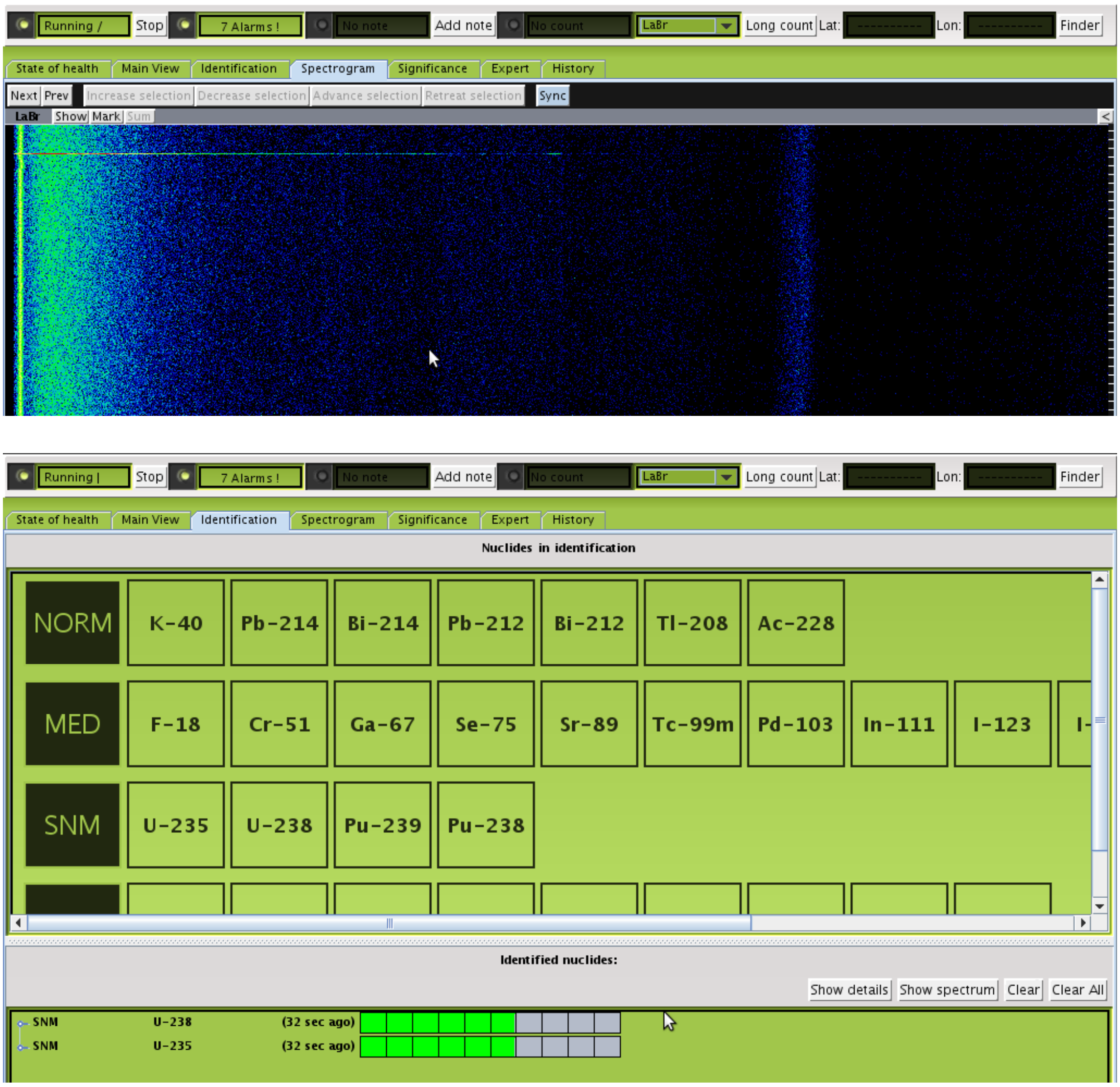

Figure 1. Screenshots from the VASIKKA user interface.

VASIKKA implements an automated connection to the SNITCH remote data management and analysis system. Several automated data transfer modes can be used to send the data to the reachback facility (e.g. all measurements, measurements with signals above the preset alarm limits, manual long measurements only) depending on the band width of the data transfer link. If the on-line data transfer is not possible, the measurements can be saved to a memory stick and sent manually to the reachback facility.

SNITCH – a data management system

An important element of integrated radionuclide detection capability is mobile monitoring. SNITCH provides efficient data communication and management, including automated data exchange from database to database via Internet. SNITCH transfers the alarms and the key analysis results immediately to Command and Control for alarm handling. This gives timely response capability for law enforcement against unauthorized or criminal acts related to nuclear or other radioactive materials. SNITCH also provides means for reachback functionality to expert organizations. Measurement results can be sent manually or automatically to an expert organization for detailed analysis and the analysis results can be sent back to the field team.

Main usage model of the SNITCH system can be described as "multiple users – single expert" model. The expert in the model can be a person or the automated analysis pipeline inside the SNITCH system. The automated pipeline can be regarded as an expert because the SNITCH system server may implement more powerful analysis tools than the simple mobile devices can.

SNITCH provides a user-friendly way to exchange measurement data and analysis results. Depending on the level of integration of the measurement device to the SNITCH system, the data exchange can even be fully automatic and no user actions are needed. However, data can be sent to the SNITCH system manually and the results can be retrieved manually also.

SNITCH is built around the LINSSI database version 2.2 and thus the native data exchange method is the exchange of LINSSI markup language files (lml-files). In addition to lml-files, four commonly used open file formats are supported: ANSI 42.42 (n42-files), IEC 61455 (iec-files), CTBTO IMS 2.0 pulse height data (phd-files) and IAEA ASCII file format recommendation for gamma spectrometers (spe-files). However, only lml-files contain analysis results.

Inside the SNITCH system the processing of the data are broken down into small sub processes that each work in "first in first out" (FIFO) fashion. This means that they will process the tasks they receive in the order that they received the tasks.

Data exchange interfaces in the SNITCH system

Currently two data exchange (upload) interfaces have been implemented: email message interface and web browser interface. Email messages are versatile enough to support SNITCH data exchange. All supported file formats are basic ASCII text files; therefore, they can be sent as message body text, but file attachments are also supported. Multiple files can be sent in single message as file attachments, where as only one file can be sent in the message body. Also the additional information files can be sent as email attachments, if other data file formats than lml-files are sent. The subject field of the email message is used for the processing instructions. Currently only the database and analysis methods are selected based on the keywords in the subject field. Sending of email messages can also be automated with scripting languages and mail sending software that has a command line interface.

Web browser interface is mainly used for manual data insertion. Web browser file upload is a well known and simple way to upload data. Web browser is also a great way to collect additional information needed when uploading files other than lml-files. Additional data can also be checked and validated before the uploaded data files are inserted to the data processing. The additional data are also saved to the server into the user profile, so that user does not have to input the same data several times. Web browser interface has intrinsic encryption feature through the https protocol. This eliminates the possibility to capture the data in transit. The web browser interface is a safe way to send classified data.

Web services interface is used for the fully automated machine to machine data transfer. Several services can be provided. For example, different service will be provided for each of the supported file formats, because they all have different additional data needs and they must be inserted into different preprocessing FIFOs. Web services is implemented with the SOAP protocol that can be transmitted over the https protocol. Thus, the inherent encryption features of the https can again be used to prevent in transit data capture and simple username and password can be used for the user authentication.

Data processing in the SNITCH system

Data processing in the SNITCH system has been broken down into small sub processes. Each of the sub processes process the data in FIFO manner. However, this does not ensure that the data flowing through the multiple FIFOs is processed in FIFO manner as a whole. Data entering the data processing first might not come out first if some branching/splitting occurs. Also all sub process steps process data simultaneously, so several incoming measurement data messages are processed simultaneously, if needed.

Data processing has the following generic sub processes

1. file format conversion to lml
2. upload lml-file to database
3. notify upload
4. run automated analysis
5. send email messages

Some of the sub processes are used several times in the processing of the incoming data. Generic flow of data is show in Figure 2. The experts can do manual analysis to the incoming measurement data or they can review the results produced by the automated analysis sub processes and add their own comments to the final results.

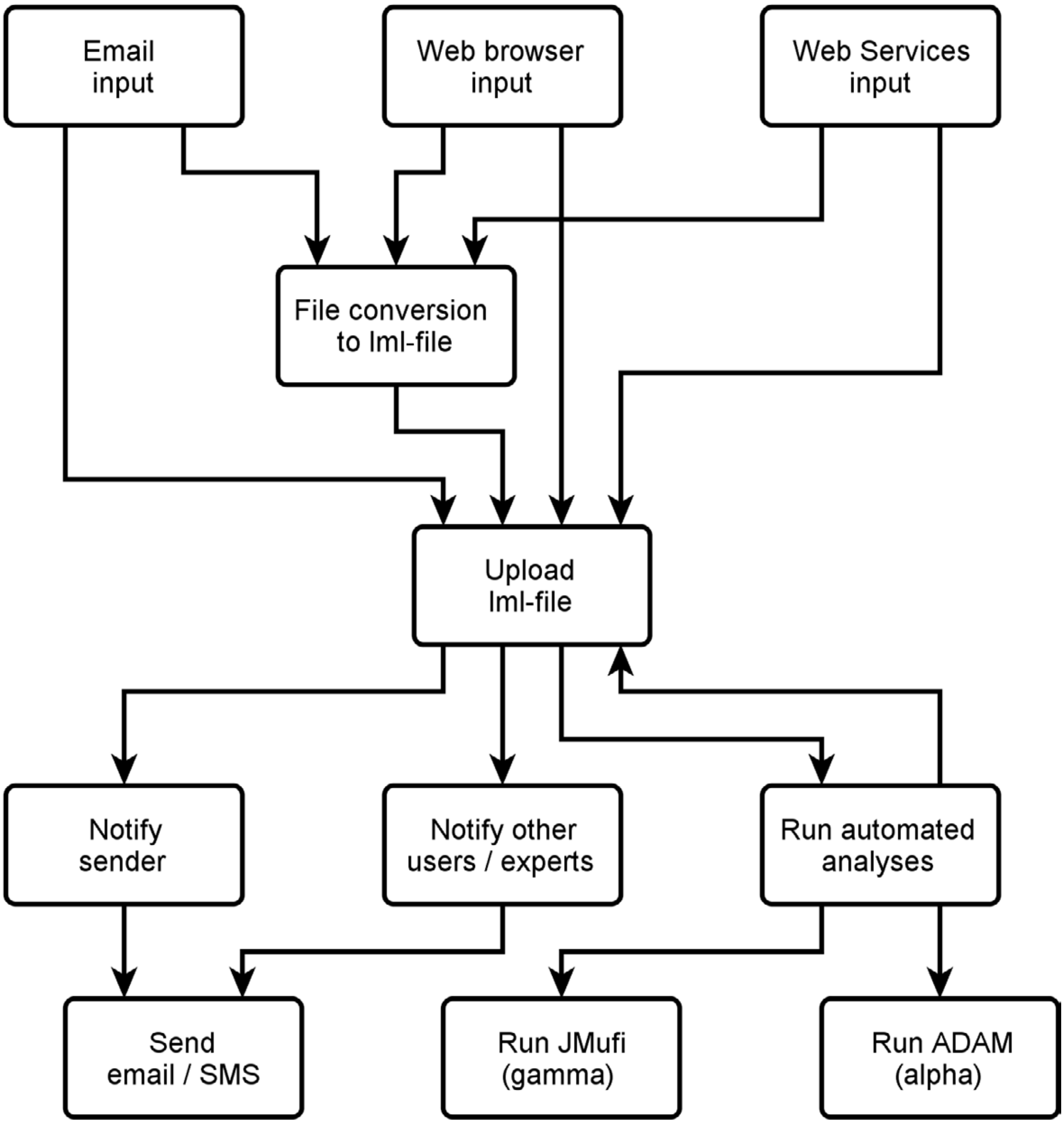

Figure 2. Generic flow of data in the SNITCH system. SNITCH can launch different analyses processes; two of them are shown, JMufi for gamma spectrometry and ADAM for alpha spectrometry.

SNITCH training package

A crucial factor in the successful deployment of the SNITCH reach back capability is the ability of the field team to make the relevant radiation measurements and to retrieve the expert analysis results and recommendations from the SNITCH system. The law enforcement officers in the field team need some additional training to operate the radiation measurement system and the SNITCH data management system. To address this issue, a training package has been composed. The training package will give the law enforcement officers the basic knowledge needed to make the radiation measurements safely and properly, so that the radiation expert in the remote location can trust the validity of the measurement data received through the SNITCH system. The training package comprises the following subjects:

1. SNITCH data management system;
2. Basic training on radiation, radioactive material and radiation protection;
3. Radiation measurement and surveillance;
4. Operational awareness in RN-situations;
5. Security screening of places, people and goods; and
6. seven different scenarios involving radioactive material.

The first three items are designed to give the basic knowledge on the SNITCH system, radiation safety and radiation measurement techniques. Operational awareness in RN-situations module will teach how to collect and process information other than radiation measurement information to support the evaluation of the situation. The Security screening module provides useful radiation measurement tactics that give reliable results when places, peoples and goods need to be screened with limited resources and timetable. In this case the reliability means that radioactive materials are found or absence of them can be proved with adequate certainty. Scenarios in the sixth module include criminal usage of RN-material with varying threat levels and amounts of material actually used.

VASIKKA - SNITCH interplay

Data flow between the field team using VASIKKA measurement system and the reachback expert facility using the SNITCH data management system is shown in Figure 3. The process is

1. Field team makes a spectrometric measurement of the suspect material or area.
2. Measurement is automatically analysed by VASIKKA software. In a simple case the measurement is analyzed correctly and the field team can jump directly to step 7.
3. However, in a complex case the measurement cannot be fully analyzed in the field and the measurement data (with the results of the automated analysis) are sent automatically to the remote expert facility.
4. Automated data handling will store the data to the LINSSI database in the SNITCH server, makes the predefined automated analyses and alerts the expert either via email or SMS. Alert to the expert can be an optional step if more powerful automated analysis tools are needed.
5. Expert on duty can look into the results of the automated analyses and make additional analyses manually. Expert on duty can insert his remarks and recommendations to the final analysis results.
6. Final analysis results with the remarks and recommendations of the expert on duty are transferred automatically back to the VASIKKA system used by the field team.
7. Field team takes appropriate actions based on the received final analysis results and/or the recommendations of the expert on duty.

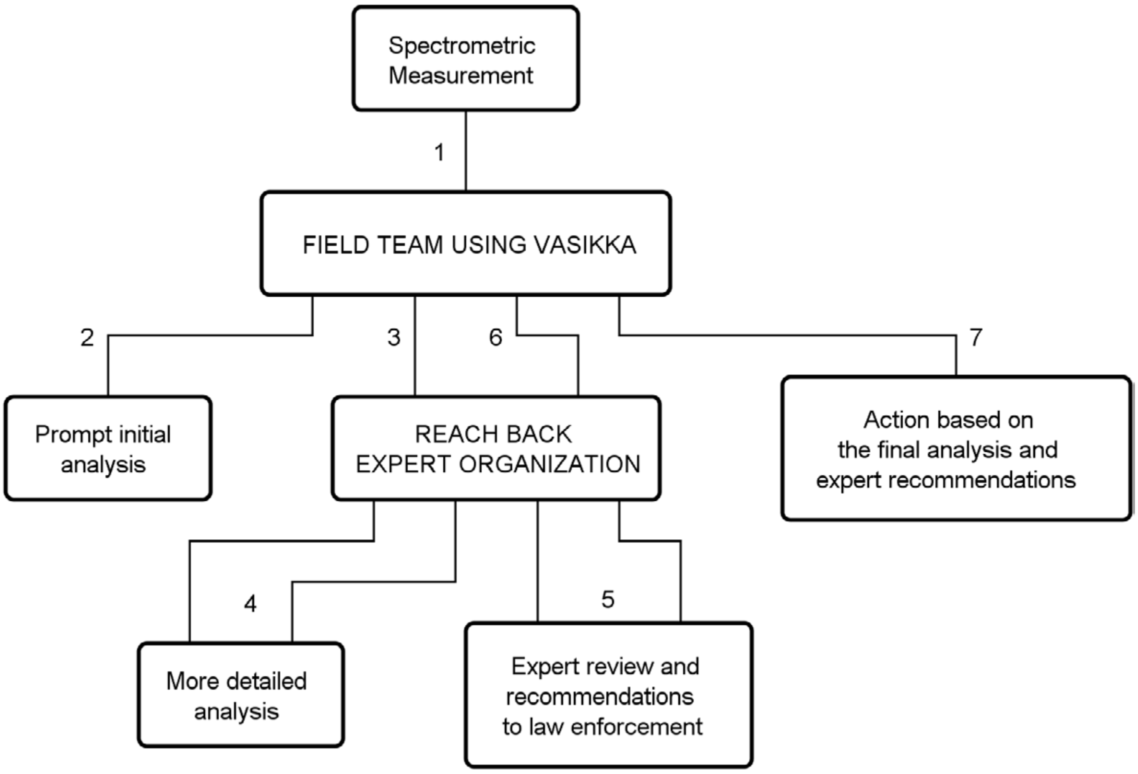

Figure 3. Integrated measurement and remote analysis concept.

Manual use of the SNTICH system is also possible. In step 3 the data can be sent via email or web page and the feedback (steps 6 and 7) can also be received via email or a web page.

Conclusions

The automated VASIKKA – SNITCH mobile measurement and remote data management system is a valuable tool in a radiation incident management. It increases the reliability of the correct interpretation of the measurement made in the field. The system has already been tested in real operational conditions by a Finnish counter terrorist unit, and the performance has been satisfactory.

Acknowlegements

SNITCH system has been developed with financial support from the European Commission - Directorate-General Justice, Freedom and Security under the Prevention of and Fight Against Crime Programme 2007.

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Indoor positioning for nuclear security

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Abstract
Mobile measurements are needed to search for nuclear material out of regulatory control at major public events and political meetings. The mobile measurement teams may have to screen hotels, living quarters and other venues before the event and during the event. Measurement and positioning information are crucial for planning the mission and for reporting the findings.

Traditionally the global satellite navigation system is used for positioning outdoors. Positioning indoors is difficult. Various indoor positioning technologies are available on the market. However, they often need a specific infrastructure installed in the building which limits their use.

Radiation and Nuclear Safety Authority (STUK) has performed indoor positioning tests with Ekahau's wireless network based system. The experiences with the field tests were encouraging. Also a novel indoor positioning system has been developed by VTI Technologies. In this system navigation is based on the measurement of the length and direction of every step of a person. It uses a chest-worn speed and distance measurement module, originally developed for the sports market, together with an instrument-grade gyroscope and a magnetometer.

Introduction
Searching for nuclear material is of utmost importance in security arrangements at major public events or political meetings. The mobile measurement teams go through hotels and event venues and search for radioactive material. STUK has developed a portable device, VASIKKA, for mobile measurements. The measurement system is based on spectrometers that write measurements and analysis results to the LINSSI database (a database for gamma-ray spectrometry). Simultaneously the navigation system writes the positioning data to the same database. The measurements and position data are linked together with time stamps. The idea of separating the radiological measurement system from the navigation system makes it possible to use various kinds of positioning systems for indoor and outdoor applications.

The spectra and measurement analysis results together with the team locations are transmitted to the command and control centre for further analysis. The results of the measurements are shown on screen, including the movement of the teams on the online digital map. In case radioactive material is found, an alarm is generated and, the mapping system indicates the place on the map. The command and control centre uses the information and gives instructions to the field teams.

Indoor positioning

Traditionally a global satellite navigation system (e.g. GPS) is used for positioning. It works well outdoors, but positioning inside a building is challenging. Navigation is difficult or impossible in areas where satellite reception is limited. Indoors navigation could be carried out manually by pointing out the current position on the digital layout of the building. In this case there is always a risk for a human error. The possibility of loosing track increases when the person doing the measurement is not familiar with the building to be searched.

There are various indoor positioning techniques available. They are usually meant for tracking goods in a warehouse or tracking people at a hospital. They need a specific infrastructure installed in the building or a time-consuming model of the building before they can be used. For authority work, the navigation system should be easy to set up and easy to use in buildings where there are no pre-installed techniques available.

Ekahau's Real-Time Location System

Ekahau is a Finnish company specialized in indoor positioning systems. One of their products, the Real-Time Location System (RTLS), has been tested together with VASIKKA in mobile measurement field tests. The Ekahau RTLS is a Wi-Fi-based positioning solution. It uses existing wireless local area network infrastructure. The Ekahau RTLS consists of the Ekahau Positioning Engine (EPE) server software, the Ekahau Location Survey (ELS) and battery powered Wi-Fi tags. Ekahau RTLS uses existing Wi-Fi standard access points as the reference devices for tag location.

Before Ekahau Wi-FI positioning is operational in a new environment, a positioning model of the building has to be made. It requires a layout of the building in digital format. The site survey is made by walking through pre-defined tracks and by registering the available wireless network access points. When the model is completed it is uploaded to the EPE server.

The Ekahau RTLS was used in field test in the STUK head office and in the Itäkeskus shopping centre. In the tests VASIKKA was used for radiological measurements and a separate Java program, IPARM (Indoor Positioning Aware Radiation Measurement), as a navigation system (Garlacz 2009). IPARM retrieves position data from the Ekahau server and writes it to the LINSSI database. The average accuracy of the Ekahau RTLS is one to three metres.

The initial test results on the Ekahau system were promising (Syrjälä 2009). The first field test was carried out in the STUK head office (Fig. 1). A Cs-137 calibration source was used in the test. The measurement team walked along the corridors and passed the table where the source was placed. The system clearly detected the source and created an alarm. The alarm is shown as a pink spot on the map. The test proved that the accuracy of the positioning is good enough to find even low-active radiation sources.

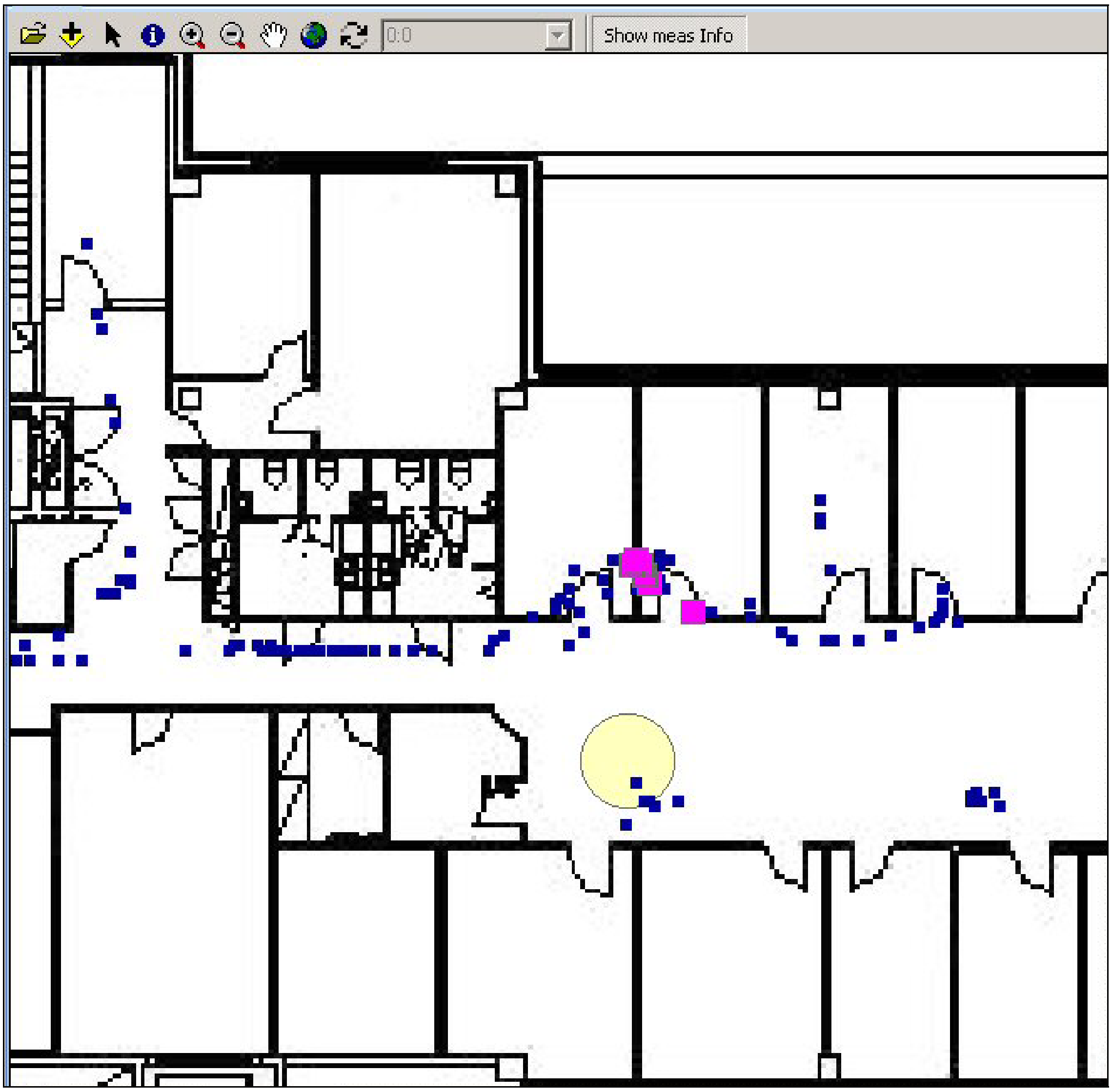

Fig. 1. Ekahau RTSL used together with VASIKKA in field test. In the test Cs-137 calibration source was placed on a table in the corridor (yellow circle).

The Ekahau positioning system has also been tested in the Itäkeskus shopping centre (Garlacz 2009). The first test was carried out in June 2009 and the second test period was in February 2010. The positioning system worked well, but the complex environment made the building of the model more problematic. The constructions in the shopping centre caused errors in the connections between the Wi-Fi tags and the positioning server. It was also noticed that the wireless network access points of the shops were not in the fixed places they were supposed to be. Some of the access points had been moved to a different place and, therefore, the model had to be rebuilt.

With the wireless network technique, building the model and defining the wireless network access points can be time-consuming. If the wireless network environment is alternating, the model may have to be rebuilt every time the model is used for navigation to ensure best positioning accuracy. Therefore, it is suitable for stable environments where there is a fixed wireless network.

Step navigation by VTI Technologies

A novel indoor positioning system has been developed by VTI Technologies. In this system the navigation is based on the measurement of the length and direction of a person's every step. The step length is measured using a MEMS (Micro Electro Mechanical System) accelerometer and a novel and robust algorithm converting acceleration to horizontal speed. The direction of each step is measured with a MEMS angular rate sensor. The initial direction could be taken, for example, from some well-defined event or using radio navigation (e.g. GPS). If an electronic map of the premises is available, active map matching and filtering can be used to get initial position and direction or improve overall accuracy.

Results from the step navigation prototype test below indicate an accuracy of a couple of meters during a 5-minute walk with a total of 2520º turns.

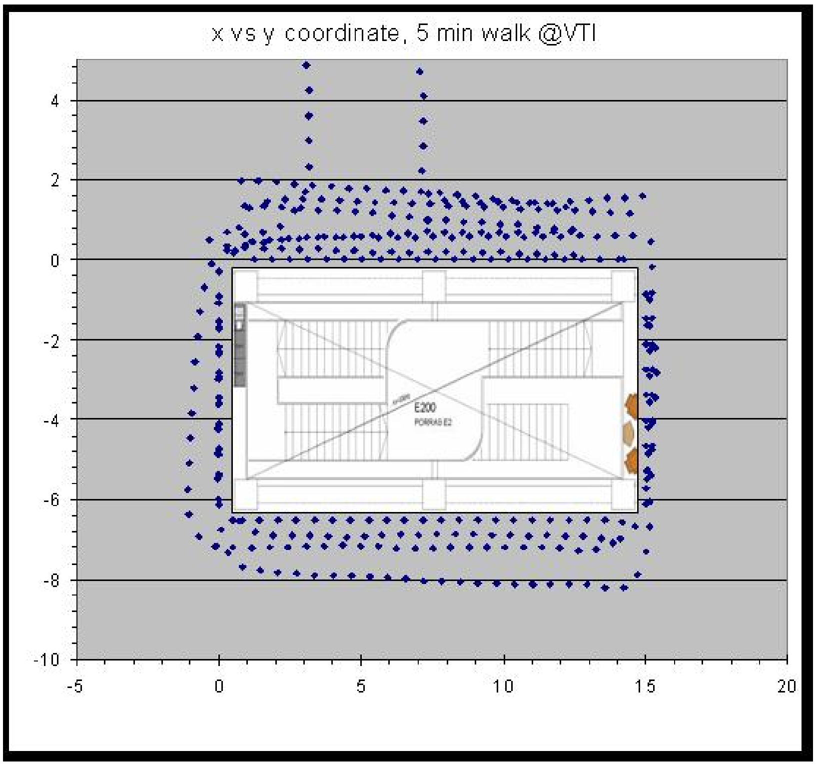

Fig. 2. Results from a short step navigation session at VTI premises using the combination of an accelerometer and an instrument grade gyro.

There is ongoing work to improve the accuracy and robustness of the step navigation system as well as to widen its usability to other motion, like e.g. crawling.

Conclusions

Although there are some indoor positioning systems available they are not technically ready for in-field use by mobile measurement and search teams.

In the wireless network based system, building the model is time-consuming and the model has to be updated every time there are changes in the wireless network. It is not suitable for ad hoc navigation. It can be used in stable environments such as hotels or conference facilities with fixed wireless network.

The step navigation system is easy to build up but it is still under development. The idea seems good but it has not yet been tested in a real time environment.

The radiological measurement should work the same way indoors and outdoors whereas only the navigation system may vary. The online mapping system should be able to detect whether the position is indoors or outdoors. It is envisaged that in the future the user does not have to know when the system is using satellite or indoor navigation system for positioning but the software behind the system performs all the necessary actions.

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Control of nuclear materials and related radiation safety

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Abstract

Nuclear materials are special fissionable materials and source materials, namely uranium, plutonium, thorium, etc. The definition of nuclear material is very often related to implementation of nuclear safeguards. Handling nuclear materials is strongly regulated by national legislations, e.g. laws regulating nuclear safety or physical protection, as well as by international agreements e.g. EURATOM Treaty from 1957, Non – Proliferation Treaty from 1970, Convention on the Physical Protection of Nuclear Material from 1979. The material can be found at different premises, namely laboratories, storages, workshops etc. When handling such material not only radiation risk should be taken into account but also other risks. A comprehensive analysis of all risks should be done and it is vital that harmonised safety measures are applied. The regulations of nuclear material are changing from the first regulations in the middle of the last century, when such material was called “a product” in the Manhattan project. Especially after the Second World War the nuclear material became a subject of very intensive investigations and as a consequence the development of regulations followed. A special attention to nuclear materials was intensified after 11 September 2001 regarding serious threats. The article gives an overview of the development of regulations related to nuclear materials taking in parallel the development of radiation safety standards. It focuses on specifics of different national and international definitions of nuclear materials as well as on a use of other terms related to nuclear materials, e.g. special nuclear materials, source material, byproduct material. An overview of relation between present standards regarding nuclear safeguards and radiation safety requirements (ICRP 103, EU BSS, IAEA BSS) is given, taking into account a control of the material from its cradle to grave, e.g. finally to its disposal as radioactive waste.

Direct Alpha Analysis for Forensic Samples (DAAFS): Techniques, applications, and results

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Abstract

The goals of the DAAFS project are to develop new methods of sample acquisition and analysis for in-situ measurement of alpha radiation. In-situ alpha tests of DAAFS have been performed using either a well-characterised swipe technique with a fluoropore membrane filter, or a vacuum sampling system and optional surface impactor. The unique components of the DAAFS system include: 1) a variety of specialized sampling techniques, 2) a Monte Carlo spectral acquisition simulation software called Advanced Alphaspectrometric SImulation (AASI) that simulates the alpha spectra by using the specific geometry and sample collection parameters, 3) an Advanced Deconvolution of Alpha Multiplets (ADAM) software package for fitting actual sample spectra, and 4) an advanced MySQL database management/telemetry subsystem called LINux System for Spectral Information (LINSSI) with alarming and notification via email and SMS.

In addition to the nuclear safeguards and security design goals, other potential uses for DAAFS are: thoron progeny identification and possibly quantification of alpha emitters in drinking water, urine analysis, decommissioning and contamination measurements in nuclear reactors and laboratories.

Introduction

Currently, analysis of alpha emitters in field samples in either a nuclear security or safeguards context requires time consuming full radioisotope chemical separation to obtain a high level of specificity. Additionally, the ability to perform high-throughput alpha analysis capability became apparent during the Litvinenko ^{210}Po (a pure alpha emitter) incident in the UK. The DAAFS system was designed to function in a mobile laboratory as a platform for rapid direct measurement of samples. The system will be fully tested through field and lab exercises by the end of the project in 2011.

Conventional alpha spectroscopy is not well suited to nuclear security applications when a timely response is desired. Traditional techniques employed in alpha spectroscopy often require radioisotope chemical separation methods – a time consuming process when rapid response time is essential. The requirement for full laboratory support to perform conventional techniques is neither amenable nor practical in field deployment, on-site analysis, or other common situations where malevolent use of alpha radiation has occurred. In the event of a Radioactive Dispersion Device (RDD) incident, rapid alpha assessment would be an ideal capability to have to detect radioactive materials that are easier to identify and quantify using alpha detection such as ^{241}Am.

The direct spectral measurement methodology of DAAFS is very different from conventional alpha spectroscopy techniques in a number of key areas. The primary difference between the DAAFS approach and conventional techniques are the acquisition and handling of samples. Samples for analysis are collected in a highly controlled and repeatable fashion to minimise sample variations. Minimising sample variability provides consistent input to the ADAM spectral deconvolution (Toivonen et al. 2009) and AASI (Siiskonen and Pöllänen 2005) simulation software. Samples are not subjected to any radiochemical treatments, making the DAAFS process a non-destructive analysis technique, resulting in relatively rapid (on the order of minutes to hours) assessment. The non-destructive nature of DAAFS is ideal as evidence is intact for criminal prosecution. Additionally, the ability to perform other radio analyses on the same sample can be very valuable as it minimises the number of samples required along with the necessary sampling equipment. Both of these are important features for incident response. Training first responders in common sample collection techniques minimises the training and knowledge level required of non-expert personnel.

The equipment for performing direct measurement of samples was designed to be field-portable. The measurement equipment used for DAAFS is shown in Figure 1. The system is compact and is easily portable in a mobile laboratory. The materials used to perform sampling vary depending on application. Figure 1 shows the largest piece of sampling equipment for DAAFS - the Lilliput vacuum sampler. All the other sampling equipment is more portable, requiring only a single person to operate and perform all procedures.

Figure 1. DAAFS spectral acquisition equipment (left) and sampling of clothing from pre-Olympic Exercise with Lilliput vacuum and nozzle (right).

DAAFS was designed for rapid assessment, and as such, it emphasizes qualitative observations over quantitative. Risks to the public and responders are known as efficiently as possible, when a positive result occurs, the quantitative results can be requested via conventional radiochemistry techniques performed by a laboratory. The

Litvinenko incident, where a pure alpha emitter, ^{210}Po, was used as a poison is a prime example where application of DAAFS technology would have been more useful than conventional techniques to identify the hazard, rapidly define and assess the crime scene, and indicate areas needing decontamination.

During field use, a single non-expert can perform the sampling and spectra acquisition with a brief training session, with minor advice coming from off-site if necessary. Once the spectrum is acquired, the DAAFS system is designed so that all sample and measurement associated data can be sent via e-mail to offsite experts for analysis. This "reachback" capability is made possible through the use of an open source database using the LINSSI database design (Aarnio et al. 2008), and computer hardware capable of wireless WLAN access.

Material and methods

DAAFS sample collection types can be broadly described as being a member of one of the following categories: swipe, air filter, and liquids. Each category has a specific methodology for sample collection to obtain optimal results in a direct alpha measurement system.

Acquiring a high quality swipe sample requires a media with the key feature of not allowing sample material to penetrate the matrix. Rather than using conventional glass fibre airfilters, a fluoropore membrane filter is used (Pöllänen and Siiskonen. Fluoropore membranes are an ideal choice as the media resists sample penetration and the resulting alpha particle energy absorption. This means superior peak resolution and allows an accurate match to the energy calibration. Swipe samples are most successful when used to sample hard surfaces.

Air filter samples are acquired using the same type of media as the swipe above, but using a vacuum either with a nozzle or without. For field use, a portable battery powered vacuum sampler called Lilliput (Senya Ltd.) is used. The vacuum provides an intake flow rate up to 12 m^3/h, and uses standard round air filters. The filters are mounted and laminated for insertion into the nozzle apparatus or direct attachment to Lilliput for aerosol sampling. A sample is collected for approximately 15 min when used in airborne collection mode. The optional nozzle is used to collect samples from textiles and other soft surfaces. Samples collected using Lilliput are acquired in triplicate for analysis using other desired techniques.

Once the sample is acquired it is measured in a standard commercial alpha spectrometer. The analyst has two novel tools at their disposal. The first tool is a spectral simulation package called AASI. The program simulates the results of the spectral acquisition process, when relevant physical parameters associated with the sample and measurement is provided. AASI allows an expert to examine the impact of parameters associated with sampling (for example particle size distribution), measurement (detection geometry), and calculation of detector efficiency and coincidence factors. More importantly, it allows an expert to determine and examine the validity of their assumptions about the sample collection and measurement process. The second and most important component is the advanced spectral fitting package, ADAM. The program performs the fitting using a Gaussian peak model with two-component exponential low-energy tail, and is capable of performing calibrations and accepts coincidence correction factors. ADAM is capable of operating in either batch or non-interactive mode, and includes a comprehensive alpha emission library based on ENSDF data.

Results

The DAAFS systems has undergone preliminary testing on many different samples and participated in one field exercise. In preparation for the 2010 Olympics in Vancouver, Canada, the DAAFS system was deployed for a simulated Olympic terrorism scenario. During the exercise, a suspect was apprehended, who had an unknown substance that was thought to be radioactive in origin on his clothes. The DAAFS system was activated to acquire a sample and perform an analysis. Lilliput acquired a sample off the suspect's clothes, which was then counted at a sample-detector distance (SDD) of 13 mm. After only 10 minutes the analyst was able to conclude that a radioactive substance was present, and that the identity of the substance was ^{241}Am. Simulations performed in AASI using 100000 decays of Am seem to reasonably approximate the observed spectra (Fig. 2).

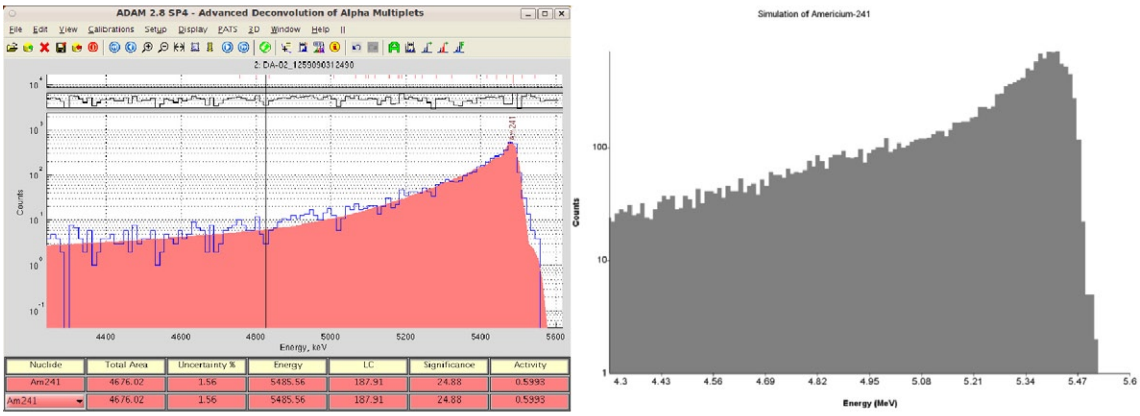

Figure 2. ADAM (left) analysis and AASI (right) simulation of Lilliput vacuum-sampled clothing from pre-Olympic Exercise showing ^{241}Am being identified.

Preliminary examinations of liquid samples were performed using an IAEA drinking water intercomparison sample that appears to have been spiked with ^{230}Th (blue). In the resulting spectra, acquired after 24 hours of direct measurement at a SDD of 13 mm, the possible presence of a ^{232}Th impurity (red) can be seen in Figure 3. The presence of the impurity is not conclusive, but is reasonable hypothesis if the thorium was separated from spent nuclear fuel.

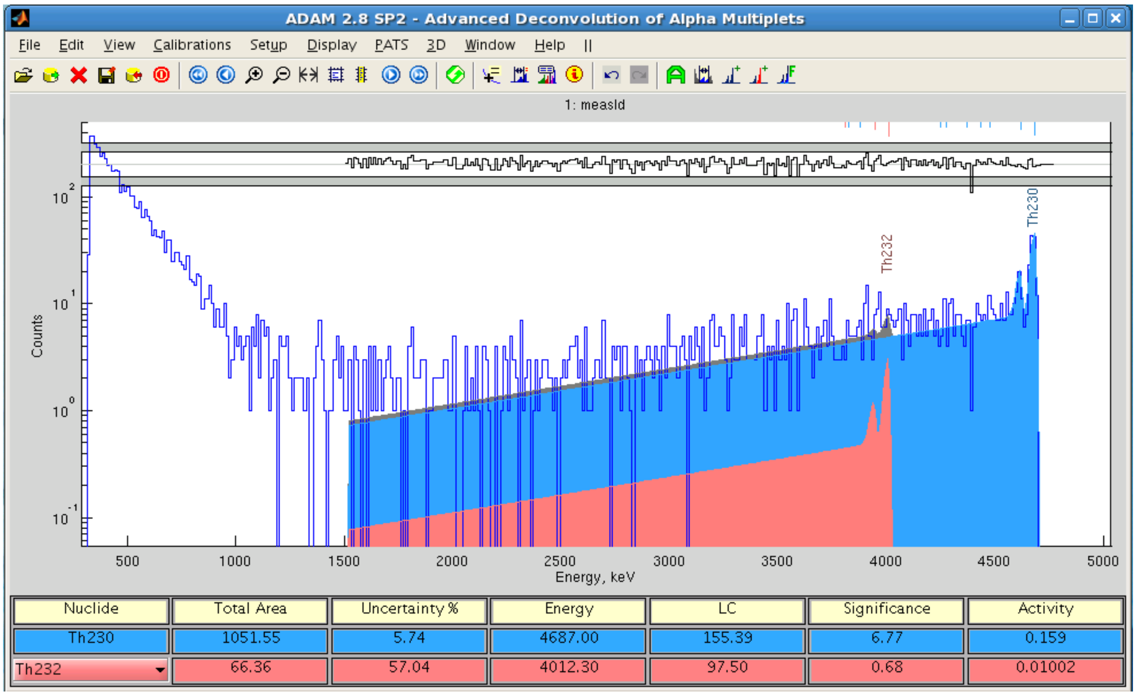

Figure 3. Analysis of an evaporated IAEA drinking water sample on planchet showing main peak Th-230 and presence of possible impurity Th-232.

The final example is an aerosol sample from a basement with high radon levels. The Lilliput vacuum sampler was used in an aerosol collection model of operation, or without using the sampling nozzle. The progeny of radon (^{212}Po – purple, ^{214}Po – yellow, ^{212}Bi – blue, ^{218}Po – red) are shown immediately after sampling with a spectral acquisition time of roughly 2 hours.

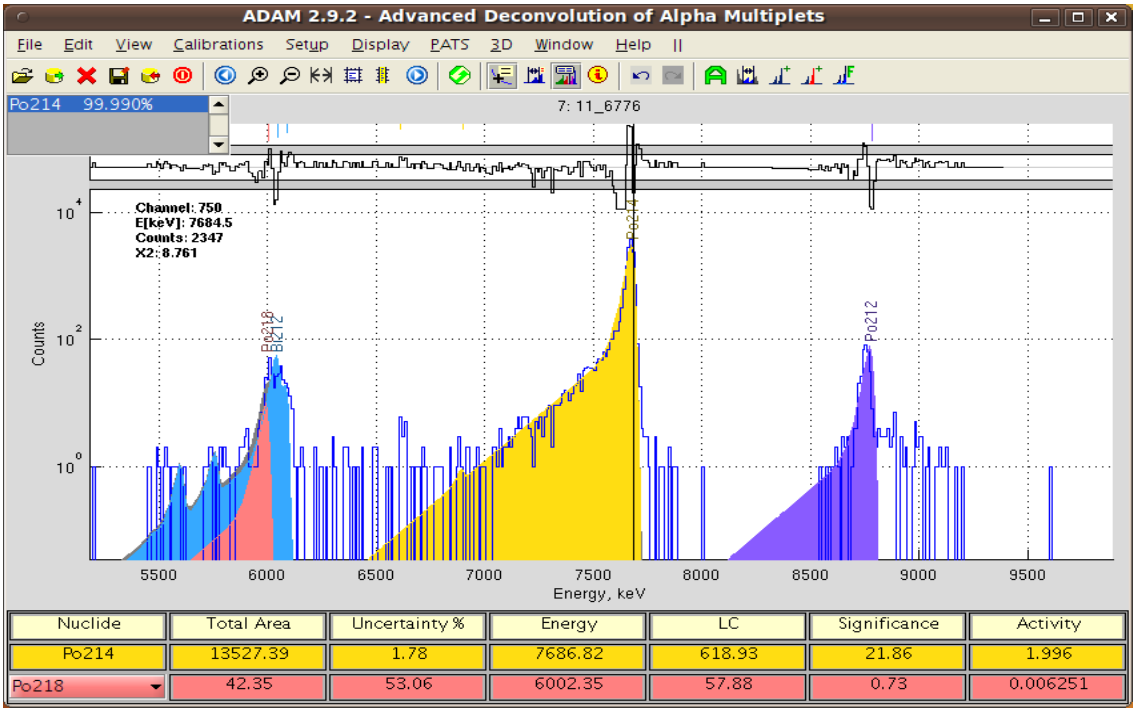

Figure 4. Analysis of aerosol sampler from a basement showing radon progeny after 2 hours acquisition.

Discussion and conclusion

DAAFS has been used on a wide variety of samples and radioisotopes to identify alpha-particle emitting isotopes. DAAFS has demonstrated success for nuclear security applications requiring qualitative assessment under specific conditions where a "thin" sample can be produced. Successful field trials illustrated the portability and off-site real-time expert support available to users of the DAAFS system. Further testing on different radioactive materials and the use of new sampling techniques such as ion specific sampling materials (3M Empore^{TM}) will be tested during the final year of the project (2010-2011). Planned trials for the DAAFS system include: depleted uranium, fresh and spent nuclear fuel, further liquid trials, and decommissioning feasibility studies.

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Explosion tests using radioactive substances

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Abstract

The results of several field tests in which the short life-time radioactive matter (RaS) was released by explosion in the free or indoor environment are presented. The primary goal of these tests was to verify the detection methods applicable for the obtaining of relevant data set – time and space distribution of the dose rate, surface and volume activities which can be used for modelling analyses of short radioactive substances dispersion by explosion.

Introduction

Potential disuse chemical, biological or radioactive substances for committing a terrorist attack have brought new dimensions into possible scenarios of terrorist attacks. Specific place belongs to so – called “dirty bomb“[1-6], i.e. radioactive substances (RaS) dispersed using a conventional explosive or any other mechanism/system.

Model analyses focused on evaluating possible consequences of a terrorist attack using a RaS are performed in a number of countries [2-6]. The National Radiation Protection Institute (SURO) in Prague in the frame of the State Office for Nuclear Safety (SUJB) grant[1] realized set of tests in which a radioactive substance (RaS) was dispersed by explosion. The main goals of these tests were:

- to verify in real conditions set methods appropriate for evaluation dispersed radioactive substance - assessment distribution dose rate, surface and volume activities, aerosols mass concentration, etc.,
- to obtain relevant set of data usable for testing and development of the mathematical codes/models fit for testing and evaluation of a propagation these substances on a short distance,
- to verify possibility realize tests and in more complex geometry (indoor environment, terrain obstacles, etc.).

The presentation is focused on the description, comparison and evaluation of the two tests carried-out in free areas (tests No. 1 and 2) and two tests in free area with

[1] Project SUJB No. 8/2008 “Methods and measures to reduce the occurrence and liquidation of consequence of terrorist abused of radioactive matters is handled by the SURO in Prague with by an extensive team of contract-bound research workers and institutions.

artificial obstacles (tests No 1P and 2P). Two tests in the small house and in the bus are shortly mentioned.

Tests characteristics

For the tests a combined controlled explosion system (industrial explosive) with the RaS dispersion in the selected space angle was chosen. As radioactive substances Tc-99m activities ≤ 1 GBq was used. Radionuclide was diluted in water coloured with potash and put (Fig. 1) in a spheric glass bottle (volume of 6 ml).

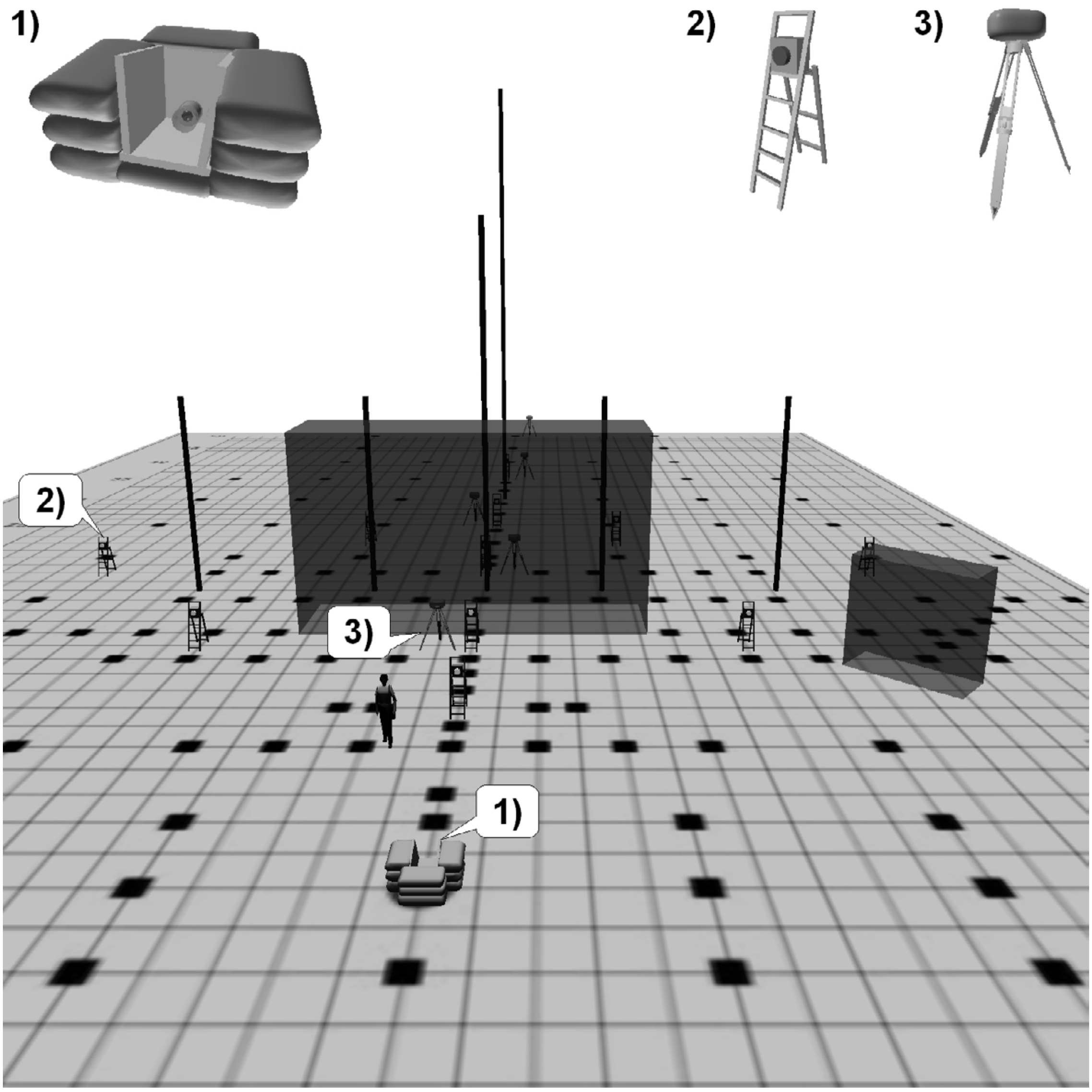

Figure 1. Location of filters, detectors and obstacles on the polygon – test 2P (table 1); the configuration of an explosive – a glass sphere with RaS is demonstrated in figure on left side above (1); No. 2 labels a localisation of aerosols collectors, and 3- DustTraks in the figure.

The survey performed and in this paper presented tests is given in the Table 1.

Tests were carried out on testing polygon of the National Institute for Nuclear, Chemical and Biological Safety (SUJCHBO) Příbram – Kamenná, based on the permit given by the SUJB and an appropriate Mining office board.

Material and methods

Optical and infrared (ThermaCAM P65 infrared imaging system) technology was used to record the time development of the scanned scene before and after a controlled explosion.

Measurement of selected meteorological values was carried out using a mobile automatic weather station with the following being measured – wind speed and direction, air pressure, temperature and humidity.

The measurement of dose rates was carried out by portable devices (GR135 miniSpec, Exploranium and NB 3201, Tesla).

Table 1. Characteristics of the tests.

Test No.	Date	Explosion time	Activity (MBq)/date, time (h)	
1	15.05.2008	11:30	1058	15.05.08, 10:10
1P	21.10.2008	12.34	900	21.10.08, 11:00
2	05.05.2009	12:22	1222	05.05.09, 12:22
2P	14.07.2009	12:42	1088	14.07.09, 11:00

The surface activities were detected using paper collection filters located densely both directly on the polygon area of app. 50x40 m^2 and in selected places on vertically placed columns (height $z \leq 12$ m). To evaluate the time distribution of the RaS dispersion, some of the filters were changed after the explosion in selected times. Up to 550 filters were located and measured in one test to evaluate the surface activities (Fig. 1). Filters activities were measured by HpGe semiconductor gamma spectrometry at 9 spectrometric chains in special shielding.

Radionuclide's volume activities (activity concentrations) in air were determined in several selected (up to 10) sites using aerosols sampling devices (SENYA - JL-150, HUNTER, DWARF 100) including a cascade impactors to determine the aerosol's size distribution.

By means of the DustTrak - DT model 8520 (TSI) laser nephelometers, a distribution of a mass concentration of an atmospheric aerosol in time with a very short (1 s) integration time was monitored - the particle masses within the size range (0.24-10) µm were effectively determined.

The more details of the tests experimental arrangements are described in [7, 8].

Results, discussion

The meteorological conditions characteristics for tests carried-out in free area with and without obstacles are summarized in Table 2.

Table 2. Summary of meteorological conditions in tests performed in free area with and without obstacles.

Test No.	1	1P	2	2P
Date	15.5.2008	21.10. 2008	5.5.2009	14.7. 2009
Explosion time	11:30	12:44	12:22	12:42
Temperature [°C]	22.2 - 22.3	14,8 - 15,05	9.7 - 10.4	23.6 - 27.9
Relative air humidity [%]	41 - 47	68 - 71	42 - 56	51-71
Condensation point [°C]	8.4 - 10.6	9,3 - 9,8	0 - 1.5	15.8 - 18.6
Wind speed [km/h]	1.2 - 6.6	0 - 3,24	1.4 - 16.2	0 - 6.5
Gusty wind speed [km/h]	0	0 - 3,24	3.2 - 25.9	0 - 17.6
Wind direction	S-SSW	SW-ENE	SW - NNE	SSE-NNW
Air pressure [hPa]	1009.1 - 1009.2	1012.9 - 1013.2	1021.2 - 1022.9	1012.5-1013.4

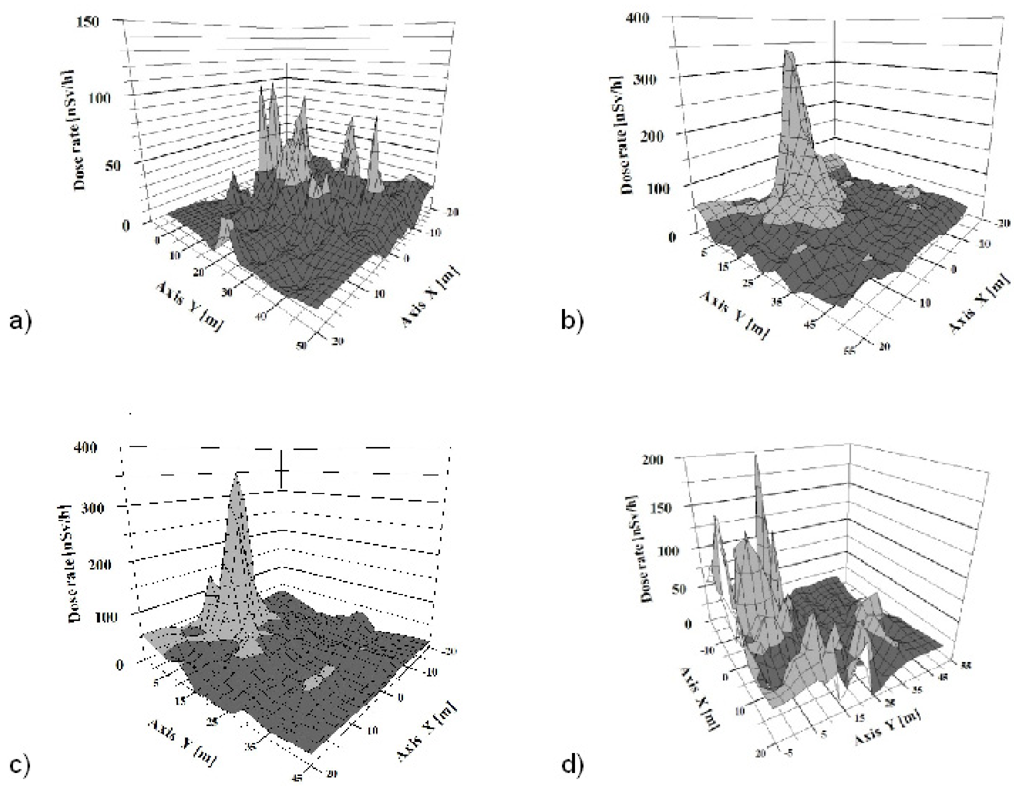

Figure 2a – 2d: Dose rate distribution [nGy/h] - direction of RaS spread – from left to right - axis y; axis x – perpendicularly to the spread axis y; a - test 1, b - test 2, c – test 1P, d – test 2P. [9].

Note:
The black area in Figs. 2a-2d represents territory where the dose rates are lower than 20 nGv/h (after subtraction of the background value in given locality), i.e. an area of the high uncertainties.

Results of the *dose rates* measurements for these 4 tests are presented on Fig. 2a – 3d. The nature of the dose rate distributions in individual tests strongly depended on meteorological conditions, e.g. stable conditions in the 1st test, high temperature and very low wind velocity without gusty evoked lower values of dose rates with less decrease in y – axis direction in the comparison to test 2.

A comparison of the ***surface activities*** distribution on the ground for 4 analysed tests is demonstrated in Fig. 3a – 3d.

Small amount of the RaS dispersed - tenths as far as percentages only was deposited on the test polygon (app. 50 x 40 m^2) in the performed tests - in the 1st test 0.8%, in the 2nd test 2.8% and in the 1P and 2P tests 0.25% and 0.18 % respectively. Differences were given different weather conditions (wind speed and direction, gusts wind, air humidity, temperature - inversion – see tab. 2) influencing the deposition at otherwise practically the same arrangements of the tests. Nevertheless, generally low values of the surface activities correspond of findings (see below), that prevalent amount of the RaS released is transferred outside polygon in the first minutes after explosion.

During 1P and 2P tests practically immediately after explosion, a wind direction gently shift from direction of the RaS propagation (y-axis). Due to this shifts maximum values of surface activities for the given distance on the y axis shifted on the right (on x-axis) in the test 1P (Figs. 3c) and to left in the test 2P (Figs. 3d,).

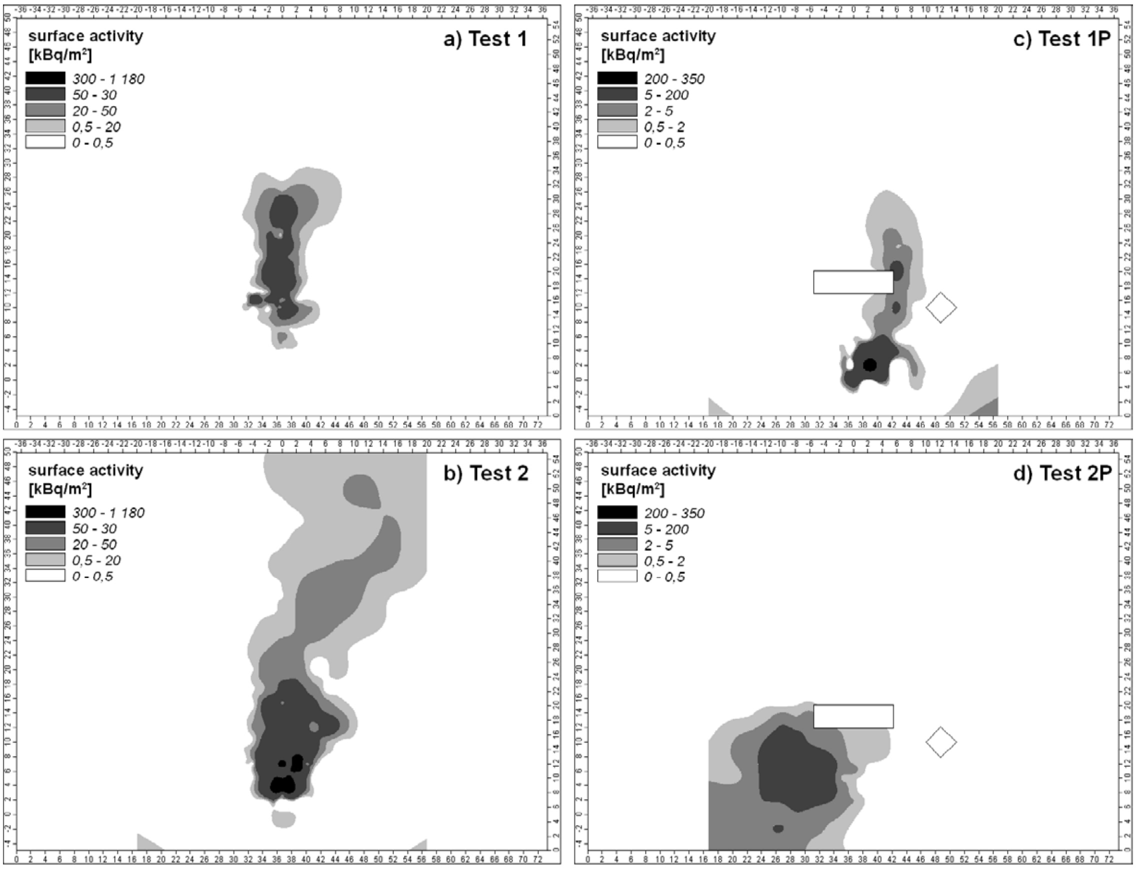

Figure 3a – 3d. Interpolation (Multilevel B-Spline) [15] distributions of surface activities [Bq/m^2] on polygon area - direction of RaS spread (axis y) – bottom-up.

Up to a distance of y < 20 m, the *horizontal surface activity* along the x axis ≤ ±5 m decreased by more than two orders of magnitudes, which indicates that the angle delimited for the RaS dispersion is relatively narrow. At distances of y ≥ 20 m, the value of the maximum surface activity for given y was shifted depending on instantaneous meteorological conditions in direction of the x-axis by more than ± 5 m. More detailed information on surface activities distribution during these tests is given in [8].

Fig. 4a shows time distributions of the surface activity average rate (Bq/m^2/min) for the exposure time of a given horizontally situated filter (test 2). Along the axis of the RaS propagation the surface activity in further sampling procedures was lower by two orders of magnitude compared to the first sampling. At higher distances perpendicularly to the propagation axis (x = ± 8 m), the decrease in the activity with time was much slower, but activities in the first sampling were lower by orders of magnitude.

This finding is also demonstrated by measurements of volume activities fig. 4b, as well by measurements of the aerosols mass concentration by laser nephelometers DustTraks [8,10].

The RaS dispersion in *vertical direction* was more uniform than along x – axis (again due to directionality of the RaS release). No marked and reproducible maxima in z – axis direction were manifested; in several cases, at a maximal height (z < 12 m), the activities were comparable with or higher than subsurface activities measured on the ground. Time distribution of vertical measured surface activities was similar as for horizontal measured activities.

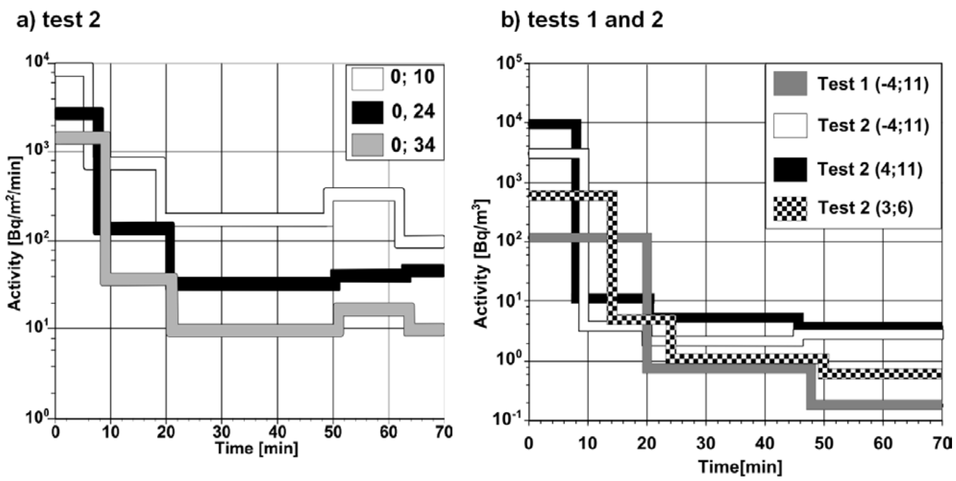

Figure 4. Time distribution of the surface activities rate - 6a (test 2) and the volume activities – 6b - (tests 1,2).

Notice: numbers in the Figs represent position [x,y] m of the collecting filters or position of the aerosol collectors.

Table 3 presents the total activities (the sum of the **volume activities** of all particle sizes), distribution (in %) of ***volume activities*** in dependence of aerosol aerodynamic diameter (AD) for test 1, 2 and 2P. High values of volume activities measured in first minutes after explosion are an explanation of the low total surface activities on collecting filters covered area – the bulk of released RaS leaves the monitored polygon in the first minutes after the explosion, even if meteorological conditions are very stable. The distributions were slightly bimodal with the boundary around 0.4 μm and so the activity median aerodynamic diameters (AMAD) and their geometric standard deviations (GSD) were estimated without taking into account the activities connected with the finest particles (AD < 0.39 μm). AMADs and GSDs are presented in the table 3 too. In the test No 1 collecting substrates from certain stages were combined and counted together and the AMADs and GSDs were not possible to estimate. The cascade impactor in the test 2P in the distances (0, 18) m and (0, 25) m were placed behind the obstacle.

The aerosol by size corresponds to the industrial aerosol (a large proportion of particles with AD > 1.3 μm) with a relatively high GSD value.

Table 3: Distribution of the volume activities in dependence of the aerosol aerodynamic diameter (AD) - tests 1,2, 2P.

Test No	1			2			2P		
Coordinates (x,y) [m]	(0,11)	(0,25)	(0,35)	(0,11)	(0,25)	(0,35)	(0,11)	(0,18)	(0,25)
Sampling time [min]	117	117	129	85	85	84	69	48	47
Total activity [Bq/m^3]	627	102	1,7	811	404	249	19 300	64	62
AD [μm]	Activity [%]								
> 10.2	10	4	18	13	7	11	37	20	21
1.3 - 10.2	47	20	47	63	58	65	37	39	39
0.39 - 1.3	15	6	15	13	9	14	10	9	17
< 0.39	28	69	21	10	26	10	16	32	23
	AMAD and GSD for aerosols with AD > 0.39 μm								
AMAD [μm]	-	-	-	2.5	1.7	2.8	8.4	5.4	4.2
GSD	-	-	-	3.3	4.8	3.8	4.3	3.5	4.2

Notices
The cascade impactor in the test 2P in the distance (0,18) m was placed behind the obstacle.

Tests in enclosed places

Two pilot tests in enclosed places were also carried out in 2008:

- Jul 22, 2008 – test in a single-storey building - "Small house";
- Sep 30, 2008 – test in a bus - "Bus".

The **Small house** test was carried out in a single-storey building with two rooms (industrial explosive, RaS - Tc-99m 302 MBq activity in glass sphere of 6 ml -similarly as in the free-area tests). Omnidirectional RaS dispersion took place in this case.

An identical method as in free-air tests used for the detection of surface activity. Filters were located (app. 300 filters were located and measured) in both rooms on floors, walls and ceiling, in a staggered arrangement in a distance of app. 1 m from each other (with an exactly defined position). Apart from filters and devices for aerosol taking, 6 phantoms simulating presence of persons in the building were located in the “Small house” – see Fig. 5a.

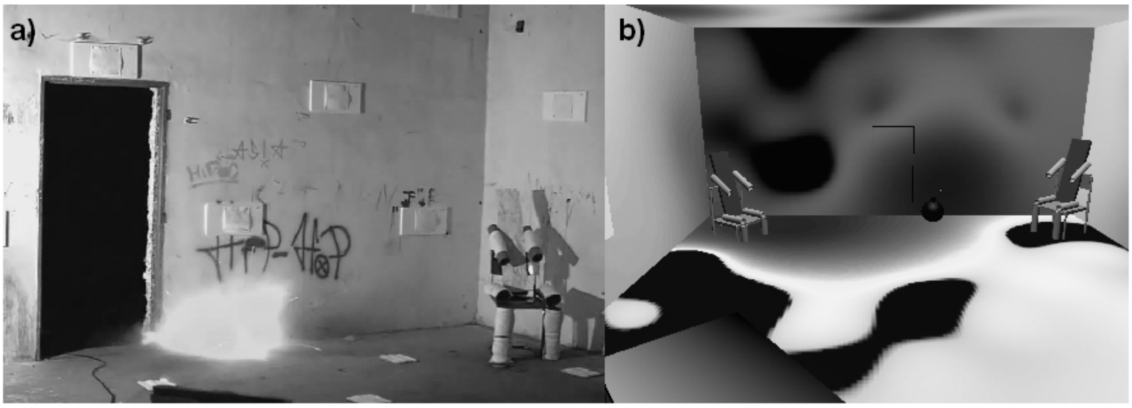

Figure 5. a) An explosion in which Ras was dispersed in “Small house” (location of collecting filters and phantoms can also be seen in the Figure); b) surface activity distributions after RaS dispersion in "Small house“ test.

The volume activities were measured by 4 sampling devices, two of which located in each room. The interpolated surface activity distribution in large room is demonstrated in Fig. 5. Table 4 presents the distribution of the volume activity in dependence of the aerosol aerodynamic diameter (AD).

Table 4. Distribution of the volume activity in dependence of the aerosol aerodynamic diameter (AD) - tests “Small house”.

AD interval [μm]	Volume activity [Bq/m3]	Volume activity [%]
> 8.85	664	50
1.13 - 8.85	391	30
0.34 - 1.13	114	9
< 0.34	149	11
Total	1318	100

Another test in enclosed places was carried out in the “Karosa” type **bus**. An identical explosive as in the “Small house“ test was used - collecting filters were located in an aisle between seats in the first and second row from the driver. 150 MBq of ^{99m}Tc solution was dispersed. The detection technique was the same – nearly 400 filters were placed on the floor, seats, walls and ceiling of the bus and 8 phantoms were put on seats. The cascade impactor was also used to measure the distribution of atmospheric aerosols. The impactor was placed on the final, back seat in the bus's direct axis with the entry towards the place of RaS dispersion. The dose rate and surface activity distribution is demonstrate in fig. 6.

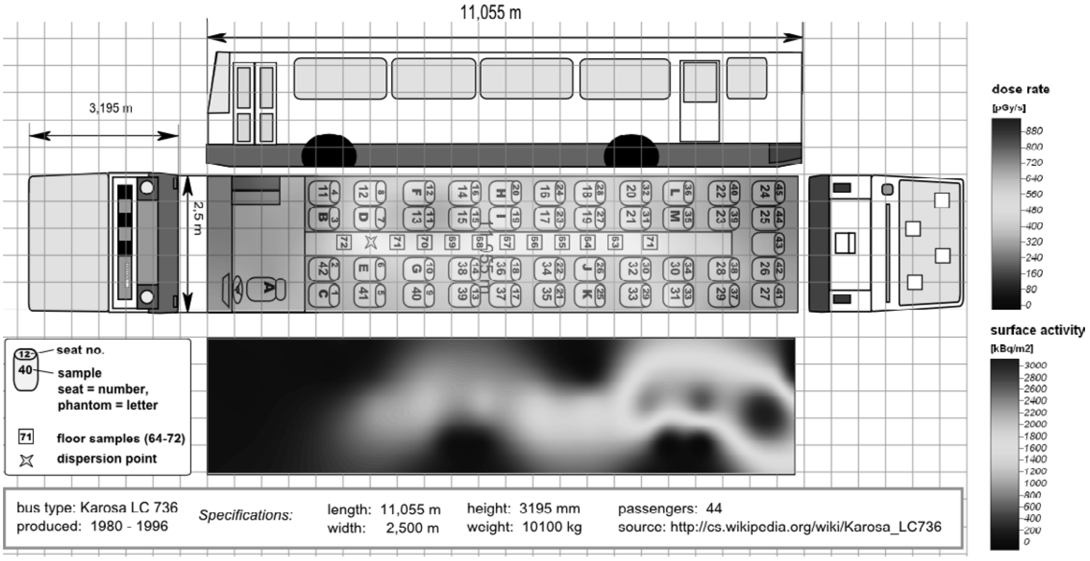

Figure 6a,b. Dose rates (a) and surface activity (b) distributions after RaS dispersion in "Bus“ test (location of collecting filters can also be seen in the Figure).

Regarding small distance between place of RaS dispersion and an entrance of the impactor in tests „small house" and „bus", majority of released RaS was captured on the great particles transferred by blast wave in the short time after explosion.

Conclusions

Presented comparison results demonstrates that the obtained set of data – dose rates, surface and volume activities, mass concentrations - is applicable for evaluation of the RaS propagation on short distances. It is easy to understand that absolute values of particular quantities will always be strongly dependent on the actual meteorological situation at the time of the RaS release under otherwise identical conditions.

The measurements of the surface and volume activities demonstrated the prevalent amounts of the released RaS are transferred across monitored area within very short time. For the vertical distributions (up to 12 m above the ground level) of surface activities the similar results were obtained. These findings confirmed as well measurements using DustTraks [8, 10], which showed, that a spread of aerosols driven by the explosion pressure wave up to a distance of 50 m during less than 1 sec, after that the distribution of surface and volume activities corresponds the propagation by the convection, depends on instantaneous meteorological conditions.

Preliminary evaluation made using different codes [11- 13] demonstrates that the obtained data/results may be used for purposes of model calculations and upgrade and development of existing models (programme IAEA EMRAS II [14].

Acknowledgements

The research was supported by the grant of the SUJB No. 2/2008 “Methods and measures to reduce the occurrence and liquidation of consequence of terrorist abused of radioactive matters“.

The authors wish express their appreciation namely in alphabetic order to S.Bradka, P.Dvorak, M. Havlova, K.Klouda, J. Pokorny, T. Pokorny and J. Santora for professional reinforcing, creation of the optimal conditions for the tests realization and encouragement throughout the work. The authors are also indebted to all the colleagues from the National Radiation Protection Institute, Prague and from the National Institute for Nuclear, Chemical and Biological Safety Pribram – Kamenna participating in realisation of field tests.

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Genomic-based biodosimetry monitoring analysis method

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Abstract
Large-scale radiologic emergency due to terrorism or large-scale accidents could result in potential radiation exposure of hundreds to thousands of people. The present guidelines for biological evaluation after such an event are still scarce. Therefore, there is a need for biomarkers of retrospective biodosimetry after radiation exposure and assessment human health risk. The frequency of chromosome translocations in individuals exposed to low to medium doses of whole-body irradiation served up till now these goals. Measurement of chromosome translocations in peripheral blood lymphocytes is presently the golden standard to quantify the effects of ionizing radiation and has been used for workers exposed to low or chronic doses. The major problem associated with the assessment of chromosomal aberrations is that it requires a considerable amount of time and labor for aberration scoring and that the sensitivity is rather low.

In this study, we used whole genome microarray expression profiling to identify genes with the potential to predict radiation dose across an exposure range relevant for dose discrimination and medical decision making in a radiologic emergency. Human peripheral blood from 10 healthy donors was irradiated ex vivo using mainly 0.1 Gy X-rays as low dose and 1 Gy as a high dose to be compared to non irradiated control cells, and global gene expression was measured at 8h after exposure identified previously as optimal time for gene expression. Data analysis revealed a clear cut in terms of the pathways modulated with the two doses. At the high dose (1 Gy) we observed mainly the induction of p53 responsive genes (MDM2, DDB2, XPC, EDA2R, SESN1, CCNG1) and pathways associated with cell death processes. In contrast, at the lower dose (0.1 Gy), we observed modulation of another set of pathways mainly associated with mitochondrial oxidative stress and chromatin remodelling.

In conclusion, our analysis method allowed us to discriminate between low and high dose exposures based on the modulated pathways, in contrast to other studies attempting to identify sets of marker genes expressed in a dose-dependent way, which might be biased by inter-individual variation.

This work is financially supported by Belspo (Belgian Science Policy)