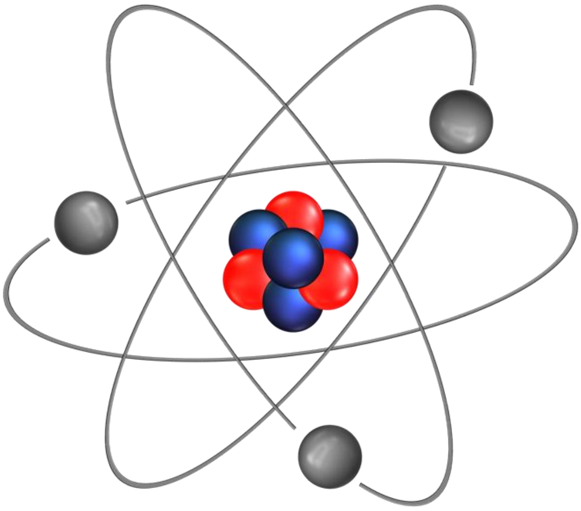
JRC TECHNICAL REPORT

Robotic equipment carrying RN detectors: requirements and capabilities for testing

ERNCIP Radiological and Nuclear Threats to Critical Infrastructure Thematic Group



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Abstract

In the last decade the European Union has faced a range of terrorist threats and CBRNE attacks. In particular, giving the potential threats to critical infrastructure involving RN materials underlines even stronger the significant potential for the use of robots in sampling and measurements in radiological incidents which may have societal consequences and/or cause wide-scale damage to the economy and environment.

This report exploits the ability of robots to carry sensors, especially in areas beyond human access, and boost the operator's situational awareness and capabilities. This, in turn, is a prerequisite for testing and training, particularly for sophisticated search strategies that can help to map and localise RN agents, but also more broadly to identification, detection, monitoring and manipulation of contaminants across various domains.

The use of robotic equipment for radioactive sources leads to maximize information gain and minimize costs, reducing human workload and radiological exposition as well.

To structure the planning and future employment of robots in this context, it is helpful to understand the possible fields and types of application where robots – with different grade of automation and autonomy – could be of use for radiation protection in case of nuclear security events occur, including combination of multiple unmanned systems in air-, land-, sea-based applications and benchmarking. Furthermore, the future possibilities for using robots are assessed as well as improvements and additional needs, potentially expanded to all CBRNE materials.

The role of technical, scientific and operational expert support is analysed through case studies and simulated scenarios for the successful handling of a nuclear security event, including radiological crime scene management.

In particular, this document results from a collection of reports, developed by multiple sub-groups of experts falling into the Radiological and Nuclear Threats to Critical Infrastructures (RN) Thematic Group of the ERNCIP framework.

1. General Introduction

The European Reference Network for Critical Infrastructure Protection (ERNCIP) has been established to improve the protection of critical infrastructures in the EU. The project is sub-classified by different thematic groups. One of them is the "Radiological and Nuclear Threats to Critical Infrastructures (RN) Thematic Group"[1] which has the goal to promote common technology standards and harmonized processes for the improvement of detection of radioactive substances in Europe.

Recently, this Thematic Group has carried out its work on the requirements and capabilities needed for testing of robotic equipment carrying measurement devices for the detection of RN threats in an authentic environment whose findings have been reported within this document.

1.1 Context

In the last decade the European Union has faced a range of terrorist threats and attacks of a violent nature. Radicalised groups have carried out attacks in the EU with the aim of maximising both the number of victims and the psychological and economic impact on society. In this context, the potential of CBRNE materials is daunting. Among these sources, radiological and nuclear (RN) agents are not only a health hazard, but may involve higher threats and have societal consequences and/or cause wide-scale damage to the economy and environment.

In particular, giving the potential threats to critical infrastructure involving RN materials, the first responders to any emergency and or terrorist threat need to be aware of eventual hazard material on site. Expert support from radiation protection professionals and radiological assessors are necessary in order to detect presence of any radioactive source.

First comes the safety of the deployed forces in an all-hazard approach. In this regard, Hazardous Materials Incident Response Operations (HAZOPER) pose a huge risk to life and limb under normal circumstances like accidents. The additional involvement of malicious intentions underlines even stronger the significant potential for the use of robots in this field of operations.
To structure the planning and future employment of robots in this context, it is helpful to understand the possible fields and types of application where robots – with different grade of automation and autonomy – could be of use for radiation protection in case of nuclear security events occur, including combination of multiple unmanned systems in air-, land-, sea-based applications and benchmarking.

The ability of robots to carry sensors, gather information and perform sampling, especially in areas beyond human access, boosts the operator's situational awareness and capabilities. This in turn is a prerequisite for testing and training, particularly for sophisticated search strategies that can help to map and localise RN agents, but also more broadly to identification, detection, monitoring and manipulation of CB contaminants and explosive materials across various domains.
Moreover, the use of robotic equipment for radioactive sources leads to maximize information gain and minimize costs, reducing human workload and radiological exposition as well.
Further, in case of a crime scene, the quality of evidence, including the chain of custody considerations and preventing cross-contamination, is of highest importance.

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[1] https://erncip-project.jrc.ec.europa.eu/networks/tgs/nuclear

However, there are no standards regarding the training and testing of such unmanned vehicles, which makes it difficult to compare the state-of-the-art. Common standards would simplify the use of remote-controlled vehicles in an emergency scenario, including novel equipment and techniques - such as the use of artificial intelligence and virtual reality in connection with the use of robots -, being innovation technologies intended to pave the way for future possibilities of using robots to enhance critical infrastructure protection and resilience against CBRNE threats.

1.2 Purpose, content and structure of this document

There is significant potential in the use of unmanned remote-controlled vehicles in sampling and measurements in radiological incidents.
To this purpose, this document summarizes the need for and the possible use of robots carrying RN measurement equipment, by defining the minimum required capabilities of radiological detection systems that use robots in a set of scenarios in real environments.

The document also specifies test methods and facilities to verify that robotic equipment, components and complete systems comply with the minimum required capabilities, pointing out standardization needs for Member States and regulatory limitations on the use of radioactive material for testing, including radiological crime scenes. Furthermore, the future possibilities for using robots are assessed as well as improvements and additional needs, potentially expanded to all CBRNE materials.

The role of technical, scientific and operational expert support is analysed through case studies and simulated scenarios for the successful handling of a nuclear security event both nationally and internationally. In particular, this document results from a collection of reports, developed by multiple sub-groups of experts falling into the Radiological and Nuclear Threats to Critical Infrastructures (RN) Thematic Group.

Diversified experts' judgement and support is a crucial cross-cutting element of a nuclear security detection architecture. Therefore, this joint document attempts to identify the basic elements and capabilities of a national expert support system.

This document is structured according to four reports corresponding to the chapter described below:

Chapter 2 — RN regulatory requirements for testing of robotic equipment

Chapter 3 — Robotic equipment in RN missions

Chapter 4 — Simulations for searching RN sources by robotic equipment

Chapter 5 — Use of robotic equipment at RN crime scenes

Each chapter is designed to be "independent and autonomous" so it can be considered complementary in the fields of operation. Chapters narrative has a modular structure which can adapt to different operational and technical needs as well as task objectives.

Finally, the **Annexes** (directly accessible via hyperlinks) comprise more detailed material and use-cases for assessing and managing various sub-tasks, including civil-military synergies and EU projects to tackle CBRNE threats more broadly.

2. RN regulatory requirements for testing of robotic equipment

By Renate Czarwinski[1], Jens-Tarek Eisheh[2], Emily Kröger[2]

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Abstract

The regulatory requirements for radiation protection during testing and training with robotic equipment carrying RN measurement equipment should be considered in advance. The use of radioactive sources has advantages for testing the technical requirements of robotic equipment designed to measure radiological and nuclear threats, in particular if the radioactive sources can be deployed in a testing environment that simulates an authentic environment for emergency management. However, the advantages must be weighed against the principle that the received radiation dose to personnel must be kept As Low As Reasonably Achievable (ALARA). The use of radioactive sources for training and testing must be justified and without any alternative technologies to reach the planned targets. This report sets out general considerations, as well as examining the radiation protection requirements in the European Union for the testing and training with robotic equipment carrying radiological and nuclear measurement equipment. In conclusion, specific recommendations for a potential testing and training facility in the EU are presented with a focus on radiological safety issues.

2.1 Introduction

The fundamental safety objective is to protect people and environment from harmful effects of ionizing radiation. To reach this safety goal, the International Atomic Energy Agency (IAEA) states in its first principle for safety that "the prime responsibility for safety must rest with the person or organization which is responsible for facilities and activities that give rise to radiation risk" (IAEA 2006).
The responsibility for nuclear and radiological security rests with the State for meeting the objective in establishing, implementing, maintaining, and sustaining a nuclear security regime.

Already at the planning phase for testing robotic equipment, the purpose and the goal of the test must be stated and assessed, for example information collection capability on the threat object or the prevailing radiation field, timeliness, material durability, hardening against radiation, feasibility of decontamination, behaviour in radiation field.

The initial behaviour of some technical systems can be tested in simulated radiation fields. For this reason, the use of actual radioactive material for tests must be justified. In particular, three approaches for testing in a radiation field or a contaminated environment are possible:

1. Bringing the robotic equipment to a facility where radioactive material can already be used (facility with pre-existing license);
2. Bringing the radioactive material to a facility where the robotic equipment is already in use (licenses for transport and mobile use);
3. Bringing robotic equipment in a pre-existing contaminated area (without license for operating with radioactive substances before, an entry permit may be required).

In addition, the creation of a designated test facility for robotic equipment with radioactive material could be considered. This approach is essentially a variation of the first bullet above.

2.2 Underlying international recommendations and directives

The current international framework for radiation safety is summarized in Figure 1 and provides an overview on the development of the current regime in radiation protection from science to practice (Council of the European Union 2013; IAEA 2014b; ICRP 2007; NORMLEX 1960; ONU 2019; UNSCEAR 2021).

The establishment of the radiation protection principles (ICRP 2007) is based on scientific key findings published by (UNSCEAR 2021). The radiation protection principles relevant for the regulations in radiation protection are "Justification", "Optimization" and "Limitation" applied to dose limits. In particular, (ICRP 2007) makes clear how they apply to radiation sources delivering exposure and to individuals receiving exposure. It also includes an approach for developing a framework to demonstrate radiological protection of the environment.

Based on (ICRP 2007), the IAEA revised the International Basic Safety Standards (IAEA 2014b), and the European Commission overhauled the Directive on Basic Safety Standards for the health protection of the general public and workers against the dangers of ionizing radiation and replaced further legislation (Council of the European Union 2013).

The regulatory requirements for use of radioactive material in EU Member States are derived from IAEA recommendations, both for transport of radioactive material and use of sealed sources or non-sealed radioactive material and defined by the Council Directive (Council of the European Union 2013) whose legislative requirements must be implemented by the Member States.

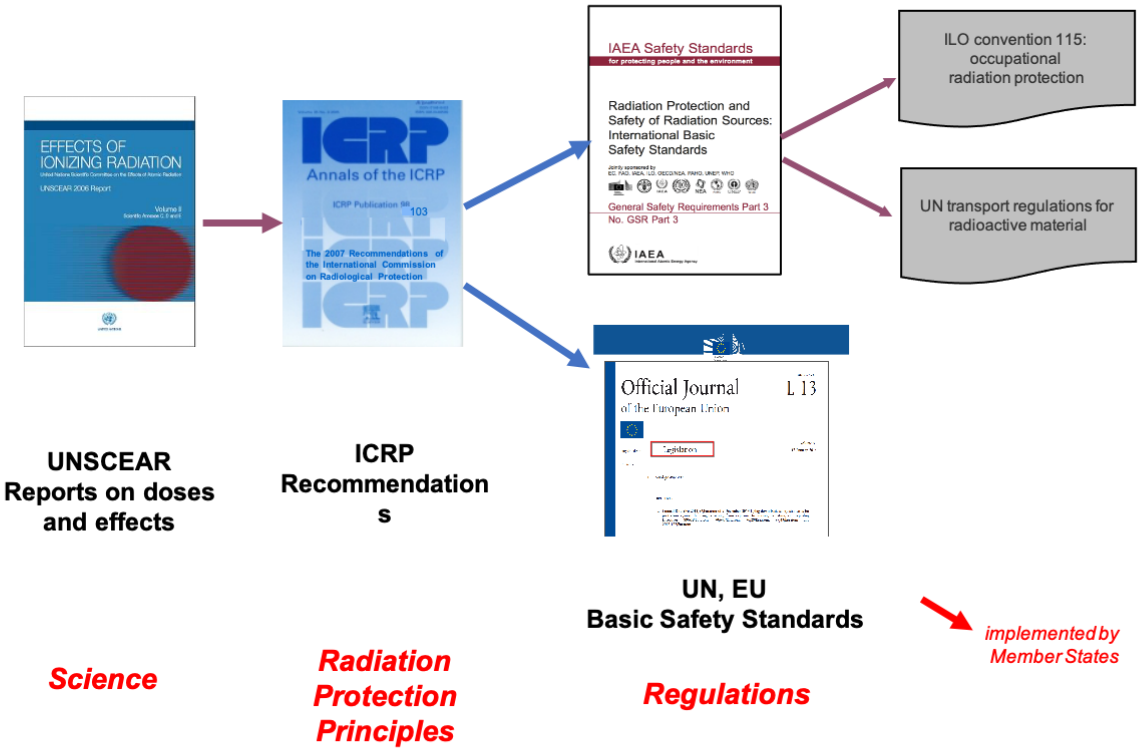

Figure 1. Radiation Safety Framework

2.2.1 IAEA System of International Safety Standards

Based on its statute the IAEA is authorized "to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards" (IAEA 1989).

The IAEA Safety Standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. In particular, the IAEA Safety Standards Series are graded in three sets with different level of obligation: the Safety Fundamentals, the Safety Requirements, and the Safety Guides (see Figure 2). The Safety Fundamentals establish the fundamental safety objective and the principles of protection and safety. Furthermore, essential for the robot testing project are the Safety Requirements which put together the necessary requirements to ensure protection of people and environment; while the Safety Guides provide guidance for the implementation of the requirements.

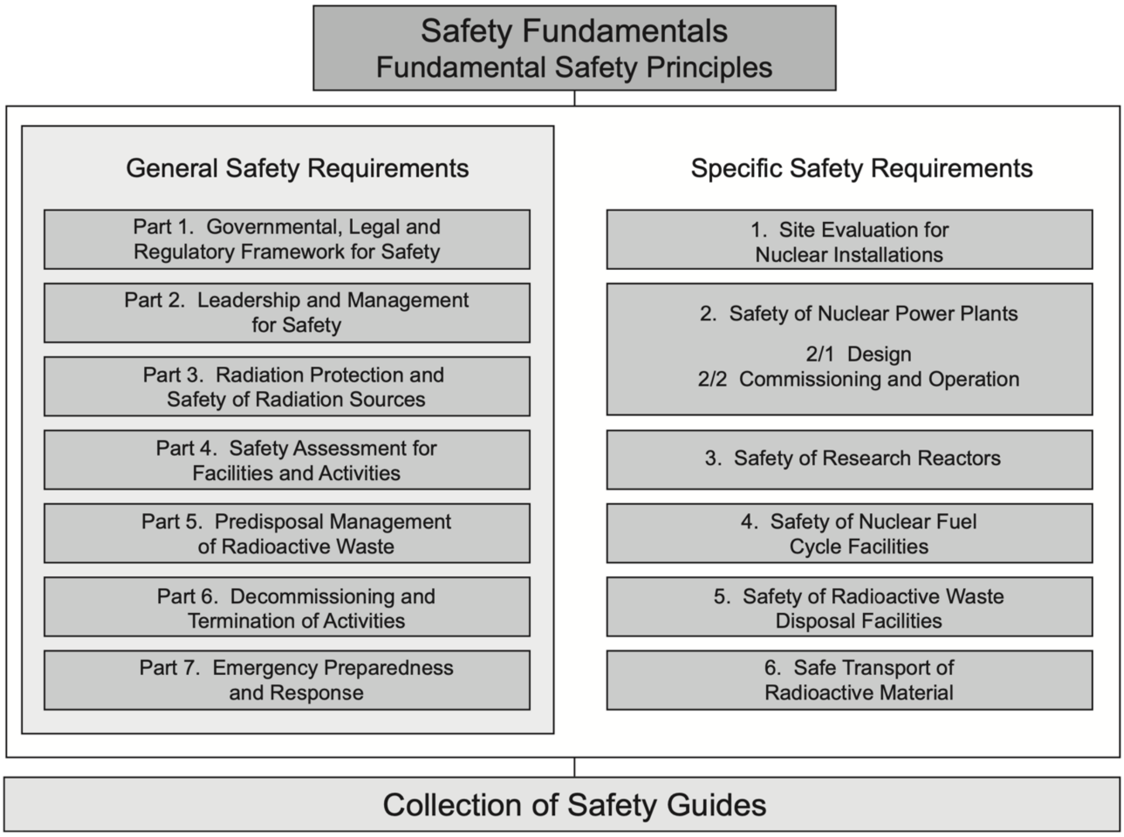

Figure 2. The long-term structure of the IAEA Safety Standards Series (source: IAEA 2016)

IAEA General Safety Requirements (Part 3) – Radiation Protection and Safety of Radiation Sources

The IAEA Basic Safety Standards (BSS) General Requirements Part 3 (see Figure 2) focus on the exposure of workers and the public and additionally on the impact on the environment caused by work with radioactive material at a given location. Dose constraints are given for regulatory requirements. It forms the basis for the European and national legislation which implements the BSS in a Member State.

Particular consideration has to be given to work with high radioactive sealed sources because there are additional requirements for safety and security, which usually lead to more personnel and time being needed to fulfil the requirements. This also leads to a significantly higher costs, both for transport and use. For most radioactive sources additional security requirements are necessary when two-digit GBq activities are reached (e.g., 30 GBq for Co-60).

IAEA Specific Safety Requirements (Part 6) - Safe Transport of Radioactive Material

Objectives of the specific safety requirements SSR-6 (IAEA 2018) are in Figure 2:

a) Containment of the radioactive contents;
b) Control of external dose rate;
c) Prevention of criticality;
d) Prevention of damage caused by heat.

(c) and (d) are relevant only for special nuclear material (SNM), which should not be considered for the purpose of this document. Therefore, only the objectives (a) and (b) are considered for the test procedures of robots. The provisions in SSR-6 contain recommendations for limits of exposure of personnel, public and environmental impact under routine transport conditions, normal transport conditions and accident conditions. With increasing activity, the requirements for the transport container, vehicle, security, and training of personnel also increase.

2.2.2 International transport regulations and agreements

Regarding activity, two values are introduced in the international transport regulations: A_1[2] and A_2[3] (IAEA 2018). The A_1 value is valid only for certified (usually ISO) encapsulated material ("special form material"). The A_2 value is relevant for radioactive material that is "not special form material". Safety and security requirements are developed relative to the A_1- or A_2-value of the radionuclide to be transported. A management programme which includes dosimetry, contamination checks, quality assurance is required, including trainings for transports with dose limits of 1 mSv/a or 6 mSv/a for the personnel involved. Those values are the starting points for a monitoring programme or individual dose monitoring.

For each mode of transportation, international agreements exist. Transport by sea is regulated worldwide by the international maritime dangerous goods (IMDG) code. There are no uniform international agreements for the transport by road or rail. At the European level (and in some associated countries) agreements are in place to standardize transport. These agreements are "ADR" for transport by road and "RID" for rail transport. National regulations implement ADR and RID for transport of all dangerous goods and mostly add some national exceptions. Besides the implementation of ADR and RID, therefore further national regulations are of minor importance for the transport of radioactive material in EU Member States. All agreements provide some procedures for multimodal transportation (e.g. land and sea transport of a shipping container).

For the purpose of this document, it seems reasonable to focus only on transport by road. RID and IMDG are similar in their provisions and can be used when rail transport or shipping is advantageous. Air transport should be avoided whenever possible because it is time consuming and expensive and most likely requires external specialists. Nevertheless, each airline has its IATA specialists who will enforce regulations. To facilitate this, most airlines have guiding pages for dangerous goods.

Several national (e.g., DIN for Germany) and international norms (e.g., ISO or IEC) support the safety and security implementation with practical recommendations.
In contrast to the transport agreements, the national legislation for the use of radioactive sources is a direct implementation of the relevant requirements in the BSS.

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[2] A_1 refers to the activity value of "special form radioactive material".
[3] A_2 refers to the activity value of "radioactive material", other than special form radioactive material.

2.2.3 Relevant European regulatory requirements for radiation protection

Most of the safety requirements are derived from the same international recommendations and implemented in national legislation. The national requirements on safety in the EU Member States shall be similar, as they are based on the relevant European Directives whose implementation is obligatory for the Member States of the European Union. Mainly, (Council of the European Union 2013) is laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing (Council of the European Union 1989, 1990, 1996, 1997, 2003).

In particular, the dose limits are valid for all EU Member States. The definition of the dose limit is: "dose limit means the value of the effective dose (where applicable, committed effective dose) or the equivalent dose in a specified period which shall not be exceeded for an individual". The European Directive (Council of the European Union 2013) sets the **dose limits for occupational exposure**:

1. Member States shall ensure that dose limits for occupational exposure apply to the sum of annual occupational exposures of a worker from all authorized practices.

2. The limit on the effective dose for occupational exposure shall be 20 mSv in any single year. However, in special circumstances or for certain exposure situations specified in national legislation, a higher effective dose of up to 50 mSv may be authorized by the competent authority in a single year, provided that the average annual dose over any five consecutive years, including the years for which the limit has been exceeded, does not exceed 20 mSv.

3. The following limits on equivalent dose shall apply:
   (a) the limit on the equivalent dose for the lens of the eye shall be 20 mSv in a single year or 100 mSv in any five consecutive years subject to a maximum dose of 50 mSv in a single year, as specified in national legislation (e.g., StrlSchV 2018).
   (b) the limit on the equivalent dose for the skin shall be 500 mSv in a year, this limit shall apply to the dose averaged over any area of 1 cm2, regardless of the area exposed.
   (c) the limit on the equivalent dose for the extremities shall be 500 mSv in a year.

Further importance during the planning of the tests should be given to the **dose limits of the public** which are given in the same Directive (Council of the European Union 2013):

1. Member States shall ensure that the dose limits for public exposure shall apply to the sum of annual exposures of a member of the public resulting from all authorized practices.

2. Member States shall set the limit on the effective dose for public exposure at 1 mSv in a year.

3. The following limits on the equivalent dose shall apply:
   (a) the limit on the equivalent dose for the lens of the eye shall be 15 mSv in a year.
   (b) the limit on the equivalent dose for the skin shall be 50 mSv in a year, averaged over any 1 cm2 area of skin, regardless of the area exposed.

Finally, particular consideration should be given on justification and regulatory control of practices (Council of the European Union 2013).

2.2.4 National example of testing and training using manned and unmanned vehicles equipped with RN measurement devices (use-case Germany)

Germany has implemented the European Directive into its legislation for radiological safety. For the first time, a separate law on radiation protection was enacted (StrlSchG, 2018). At the same time, the existing Radiation Protection Ordinance was revised intensively (StrlSchV 2018).

The Franco-German ANCHORS project[4] (2012 – 2015) used a ~2 TBq radioactive source (originally licensed for non-destructive materials testing) to create a radiation field in which the Unmanned Aerial Vehicles (UAVs) developed in the project could be tested. The demonstration was carried out in an industrial area in Dortmund with about 200 visitors including the press. For the demonstration, a special one-off license was issued.
The project also tested their UAVs against failures in a strong radiation field. This was carried out in an irradiation lab of the Fraunhofer Institute (Fraunhofer-INT[5]) with a Co-60 source (activity ~150 GBq).
The sensors for the UAVs developed during the project were validated in high dose rate fields (by Fraunhofer-INT) and low dose rate fields (by the German Federal Office for Radiation Protection (BfS[6])).
German specialists of the Federal Criminal Police Office[7] and BfS carry out regular exercises with radioactive material. Activities used for these exercises are usually some MBq of gamma emitters and neutron sources.
For international AEROGAMMA exercises[8] (helicopter-based detection) BfS has used GBq sources. The sources were detected from a helicopter (~100m over ground) while in transit on a highway.

2.3 Conclusions

If a facility already has a safety and security regime for the use of radioactive material, it is unlikely that the use-case "testing of robotic equipment" is included in their current license. This means that the existing license must be changed to include "testing of robotic equipment", or a new license should be applied for, leading to significant differences in the licensing requirements. Nevertheless, it is unlikely that these differences would result in higher (possible) exposition of workers.
Universal regulatory requirements mean that in every facility with a comparable radioactive inventory there should be regulatory controls of (roughly) the same level. Therefore, creating a facility for the testing of robotic equipment in a radiation field or in a contaminated environment will lead to the creation of a designated regulatory regime for this facility. This will always be a bigger effort than the use of existing licenses. To maintain regulatory control of radioactive sources and their licensed use, a dosimetry regime including regular checks of the health fitness of the occupational exposed workers are required. This is especially important if higher activities of radioactive material are to be used.
Therefore, the use of radioactive material, especially high activity sealed sources, must be justified.

If a goal can only be achieved by the use of radioactive material, then the use of sources for testing must follow the ALARA ("As Low As Reasonably Achievable") principle.
One other main reason not to use or to minimise the use of radioactive material, besides background checks and dosimetry, are the additional costs (for specialists, for licensing, for transport, for containers, etc.).

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[4] https://www.dortmund.de/de/leben_in_dortmund/sicherheit_und_recht/feuerwehr/forschung_fw/abgeschlossene_projekte_fw/index~3.html
[5] https://www.int.fraunhofer.de/en.html
[6] https://www.bfs.de/EN/home/home_node.html
[7] https://www.bmi.bund.de/EN/topics/security/federal-criminal-police-office/federal-criminal-police-office-node.html
[8] https://www.bfs.de/EN/topics/ion/accident-management/exercises/air/airborne-exercises/airborne.html;jsessionid=25876B8CCCBB0685F5B298CFC9BEA1B6.2_cid391

If a license for the robotic equipment testing must be requested (as the use of radioactive sources is justified and necessary), quite a lot of additional issues with respect to radiological safety must be considered and defined, e.g.:

- duration for conducting the testing;
- applicant has the necessary number of competent personnel (proof of education, knowledge about radiation protection);
- applicant must give information on the reliability of the involved experts (background check done by intelligence agency);
- applicant has the necessary equipment for the safe handling of the material;
- applicant has the necessary equipment for the monitoring of personnel and workplace and registration of measuring values;
- sufficient emergency precautions are taken and exercise regularly;
- applicant needs an appropriate insurance;
- dose limits for personnel and public and environment will be monitored with appropriate techniques (including storage of personnel data and the necessary protection of the data);
- solid waste, wastewater, and the release of material from controlled areas;
- are handled according to regulations (checks required through a competent authority) including the wastewater analysis for trace amounts of radionuclides (µBq-level) by an accredited laboratory;
- separate licenses for use and transport could be necessary;
- use of radioactive material above the threshold is forbidden unless a responsible authority grants a license.

Finally, the precise planning of the work is essential. Indeed, the aim of the test, the content and volume of the test, the goal of test and a strong justification of the reasons why the test cannot be conducted without radioactive material are essential to be considered at the planning stage. It is recommendable to contact the relevant regulatory bodies well in advance to discuss the necessary and requested measures for a smooth testing procedure.

3. Robotic equipment in RN missions

By Frank E. Schneider[1], Jan Paepen[2], Juha Röning[3]

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Abstract

To structure the planning and future employment of robots in RN operations, it is helpful to understand the possible fields and types of application where robots could be of use. This report elaborates how Hazardous Materials Incident Response Operations (HAZOPER) can be supported and enhanced by robots.
The ability of robots to gather sensor information and perform sampling, especially in areas beyond human access, boosts the operator's situational awareness and capabilities. The report looks into acquiring and representing the sensor information. Once the operator has found the object of potential interest and gathered enough situational awareness, the robot might also be used to take a sample or manipulate the object.
To enhance the capabilities and reduce the workload of the operator it is also necessary to consider the type and grade of the robot's automation or autonomy desired. The report presents potential definitions for the classes of autonomous operations. These classes have been elaborated with a set of possible applications in the RN domain.
Afterwards, a short excursion to the very relevant field of benchmarking for robots is given (Annex A) as well as to which extent the aspect of Civil-Military Cooperation (CIMIC) in CBRNE incidents can apply on a larger scale beyond national (Annex B).
Finally, it is shown that standardisation does not only fertilise national data exchange (between different national players, like civilian agencies or military entities) but also on an international level (EU, NATO, IAEA or UN) (Annex C).

3.1 Introduction

Reconnaissance and surveillance of theatres suspected to contain RN threats is currently dominated by manned missions. These missions expose humans to severe health risks and also rely on deficient human observations.

The overall objective of a Manned Site Assessment (MSA) mission usually is to conduct reconnaissance and surveillance in order to facilitate an actionable decision regarding future exploitation, surveillance, destruction, or abandonment of a theatre. Mission tasks might include identifying hazards, determining the theatre's purpose, and characterizing the physical environment of the site with augmented sensor information.

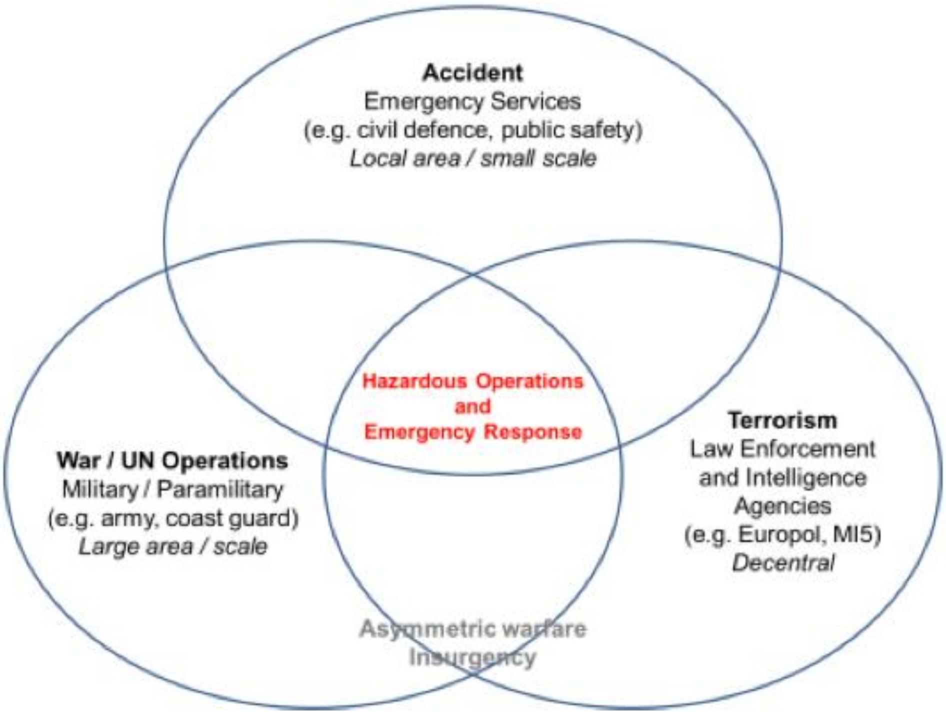

Figure 3. Hazardous operation and emergency response in the intersection between emergency services, (para-)military and law enforcement

Figure 3 shows the diversity of possible HAZOPER. Given this range, all further considerations must be based on the assumption that the mission will take place in an a-priori unknown, unstructured and not necessarily cooperative dynamic environment.

Sites involving RN threats present special challenges for MSA missions because of the potential for severe injury to or death of mission personnel due to the lack of practical personal protective equipment. Additionally, RN-based theatres bare also the difficulty in isolating, classifying, and identifying substances encountered in such HAZOPER. Despite the demanding tasks and environments, there is significant potential for the use of Unmanned Systems[9] (UMS) in sampling and measuring radiological events (Schneider et al. 2015).

This report focuses on robotic aspects of unmanned systems in RN missions rather than on detector or regulatory limitations (see Robotic equipment in RN missions). It is meant to give some structure to the planning and future use of robots in this field of operations. This will be helpful to understand the possible fields and types of application where robots could be of use.

The first part focuses on the ability of robots to gather sensor information and perform sampling, especially in areas beyond human access. The report looks into acquiring and representing the sensor information. Once the operator has found the object of potential interest and gathered enough situational awareness, the robot might also be used to take a sample or manipulate the object.

The next section examines the possibilities to enhance capabilities and reduce the workload of the operator with respect to the type and grade of the robot's automation or autonomy. The report gives potential definitions for the classes of autonomous operations. These classes have been elaborated with a set of possible applications in the RN domain.

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[9] The terms unmanned system and robot will be used synonymously.

3.2 Typical tasks for unmanned systems in HAZOPER

With respect to the UMS action planning, three major tasks have been extracted from a past survey initiative, carried out by the TG, on the use of robots for radiation measurements (Schneider and Gaspers 2015):

Table 1. Major tasks on the use of robots for RN measurements

1.	spatial mapping of RN sensor data	exploration, change detection etc.
2.	searching for RN sources	active sensing, hotspots, isocurves etc.
3.	sampling	manipulation, sweep and material sampling, cleaning etc.

The following sections amplifies on the details of the above-mentioned tasks.

3.2.1 Spatial mapping of RN sensor data

In general, spatial mapping (also called 2/3D reconstruction or world modelling) is the process of creating a 2/3D map of the environment based on sensor data. It allows a UMS and the user to understand, interpret and interact with the real world. Spatial mapping is useful for collision avoidance, motion planning, and realistic blending of the real and measured world. The resulting representation is usually usable by the machine as well as by the operator.

Typically, this process is done on the fly while the robot is moving. If the movements of the robot are driven by the goal to map a designated area the process is called "Exploration". It is possible to combine multiple UMS from the same domain (air, land and sea) as well as from different domains.

This robotic topic is a very well-established and active research field with many effective solutions for single-robot-single-domain applications. In multi-robot-multi-domain applications ground and air-based exploration is a currently extremely active research topic.

In a typical 2D mapping process the world is segmented into square cells (like a chess board), often called grid. This grid contains not only the geometric position but also all the corresponding sensor measurements at the location as well as the exact time when taken. It is somewhat similar to a pixel in 2D or a voxel in 3D, except that it contains more than just one piece of information. Simple grids contain only the last measurement, others accumulate the measurements through a Bayesian or Dempster-Shafer process working with probabilities. With increasing memory and CPU power newer approaches store the whole measurement history in a time line per grid cell. This is giving the opportunity to do retrodiction on estimation and fusion in advanced sensor networks.

Following, some examples taken at the EnRicH 2019[10] in Zwentendorf NPP[11] by an unmanned robotic exploration system[12].

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[10] https://www.fkie.fraunhofer.de/en/press-releases/enrich_2019_announcement.html

[11] https://www.zwentendorf.com/en/

[12] Source: Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE), https://www.fkie.fraunhofer.de/en.html

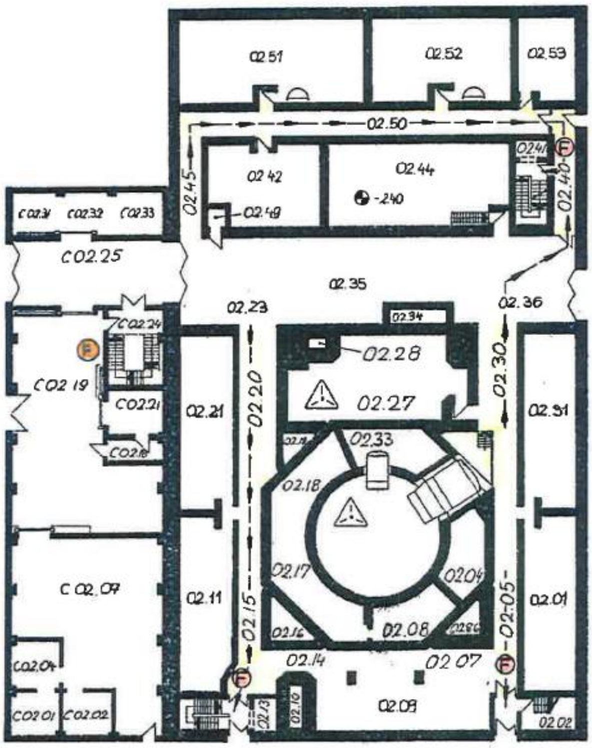

Figure 4. Original floor plan of Zwentendorf NPP

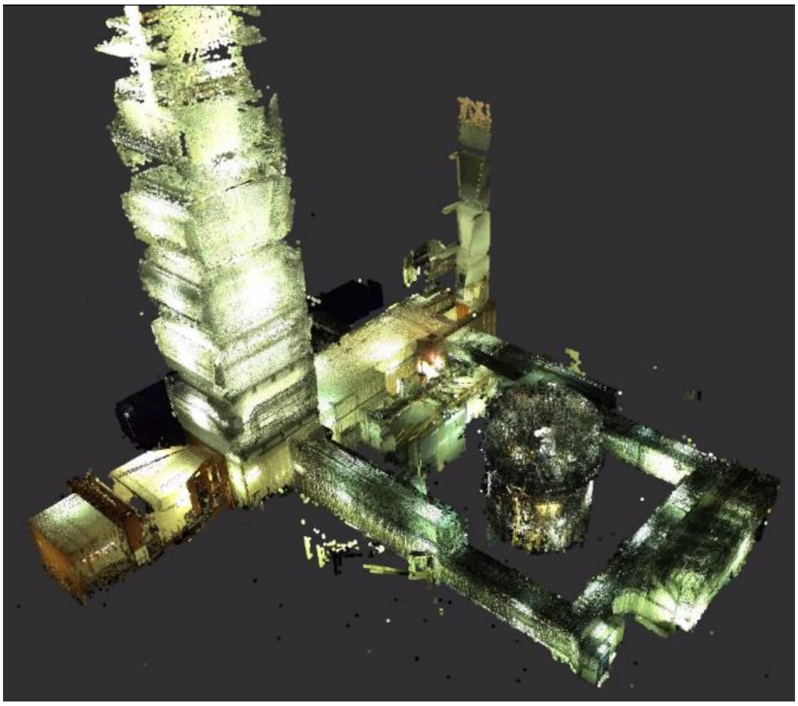

Figure 5. 3D model of the facility generated in real time by laser scanner and video camera

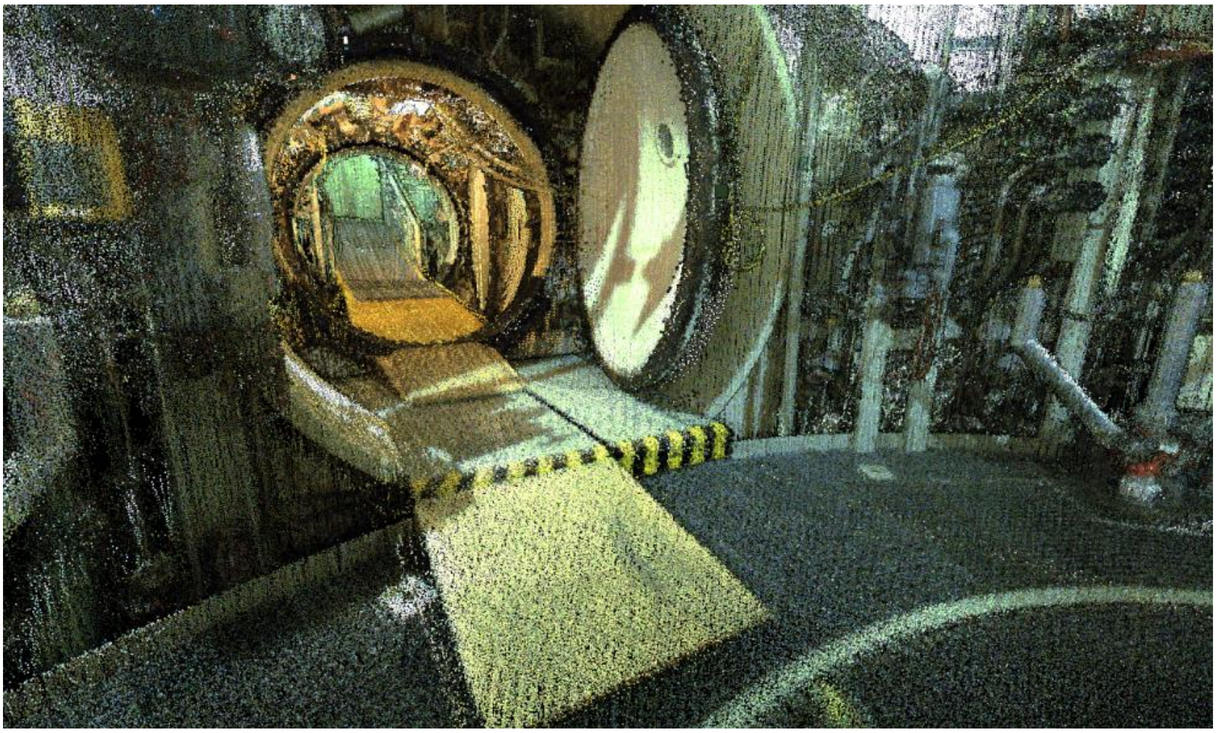

Figure 6. 3D model of the facility generated in real time by laser scanner and video camera

Figure 7. FKIE robot used for Zwentendorf NPP exploration

3.2.2 Searching for RN sources

If the main task is not to completely map a whole area but rather to actively search for a single or multiple hot spots in a designated location, typically “Active Sensing” is used. Active sensing in robotics incorporates the aspects of where to position the robot carrying the sensors, and how to make decisions for next actions, both in order to maximize information gain and minimize costs. In other words: Where should the robot move to get the highest/best sensor reading without travelling too far.

Efficiently this can only be solved in combination with mapping due to the required overall planning. Typically, a greedy exploration process is used to cover the area with a maximum of information gain and then extract the global maxima. However, there are also quite effective approaches to model this problem as a reactive process which then is often either behaviour or potential field-based. These methods lead to some problems with multiple global maxima or local minima, depending on the method used. The movements of the robot depend on the sensor coverage. The higher the coverage of unvisited or better unswept cells, the less the robot has to travel overall. If the number of sources is unknown the robot has to do a complete search of the area.

It is possible to combine multiple UMS from the same domain (air, land and sea) as well as from different domains. This later is easier in the map-based approach than in the behaviour-based or reactive approach. When involving multiple searching robots, the problem is figuratively called the "Paparazzi Problem".

Currently, this topic is not a focus of research especially when involving multiple robots. In multi-robot-multi-domain applications the field is somewhat unpopular due to the high burden in maintaining and operating several heterogeneous real robotic systems.

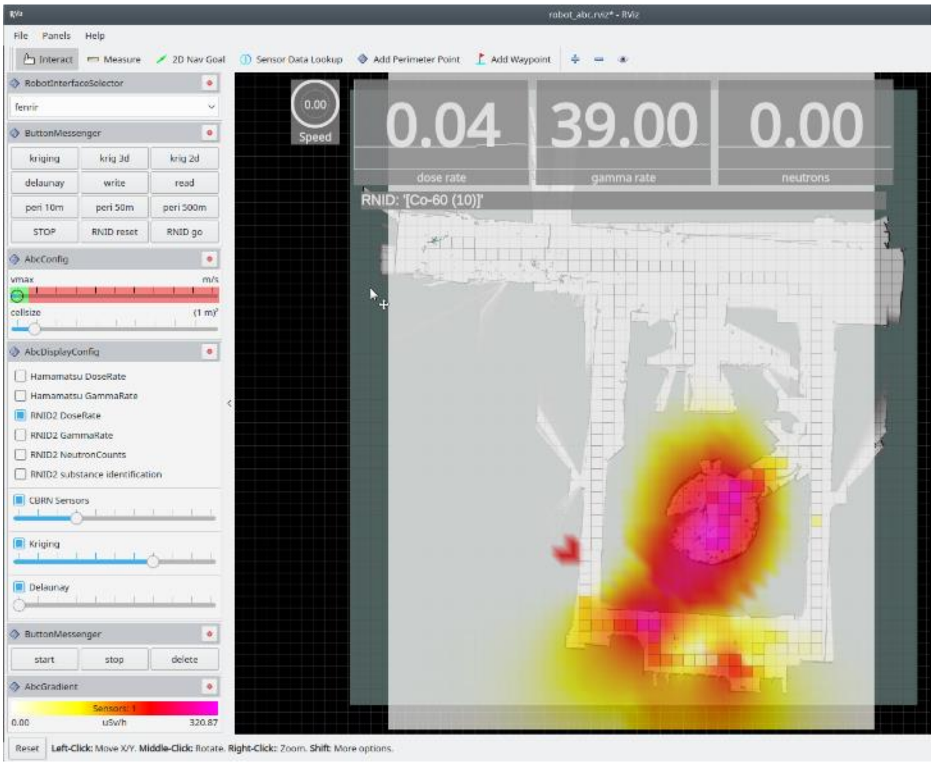

Figure 8. Screenshot of radiation measurement map (done at the EnRicH 2019[13])

3.2.3 Sampling

The field of sampling involves not only a moving robot chassis but additionally some sort of actuator (e.g., a manipulator arm) that will move the device / tool used for sweeping,

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[13] https://www.fkie.fraunhofer.de/en/press-releases/enrich_2019_announcement.html

digging, scooping or grasping. Additionally, a mobile manipulation system allows to hold and move a RN sensor into (almost) any desired position. The combined motion planning for chassis and manipulator is called "Mobile Manipulation".

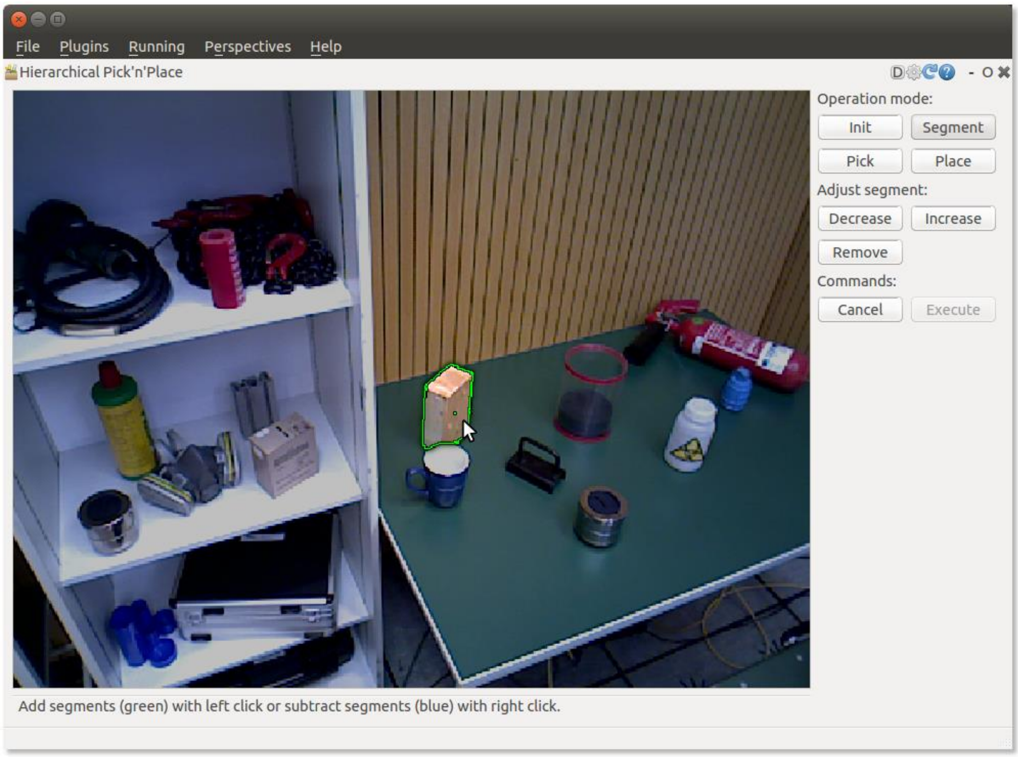
There are several combinations of planning possible, first plan the movement of the chassis and then the movement of the manipulator or visa-versa or even plan both independently. The actual realisation depends on various factors like sensors, computing power and actuator capabilities.

If it is desired to plan and execute the movement of the chassis and the manipulator at the same time in parallel, it can be one of the most complex and challenging processes in robotics since it involves all aspects of planning in a high dimensional configuration space.

Typically, this process involves highly accurate sensors for obstacle avoidance and map building in 3D. This sensor data is used to generate a 3D environmental model, which allows collision-free motion planning for chassis and manipulator. While motion planning for the vehicle can be done in real-time, the planning for the manipulator is only near real-time.

This robotic topic is a rather new and rare research field with a lot of room for future research grants. There are effective solutions for single-robot-single-domain applications with no parallel chassis-manipulator movement. The concurrent movement of chassis and manipulator is ongoing research as well as dual-arm manipulation. Multi-robot-single-domain cooperative manipulation is a rare research topic.

There are however already interesting combinations of autonomous vehicle planning in combination with intelligent user assistance functions for moving the manipulator semi-autonomously. These range from augmented reality-based pick-and-place of objects to human mounted sensors that map the human arm movement to a movement of the manipulator.



Add segments (green) with left click or subtract segments (blue) with right click.

Figure 9. Example of pick-and-place; click on object to be picked up by manipulator (wooden block)

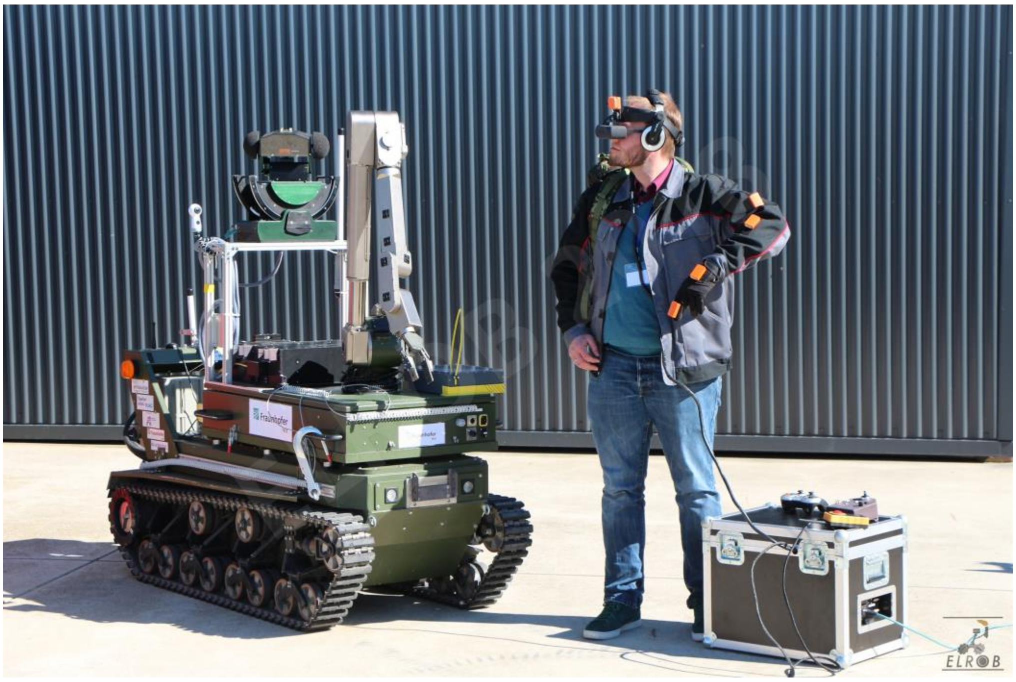


Figure 10. Mapping of human arm movement to a movement of the manipulator; stereoscopic vision and tracking of head movement

Figure 11. Human-arm to robot-arm mapping but with VR/AR assistance using 3D model of the facility generated by laser scanner and video camera (in Zwentendorf NPP)

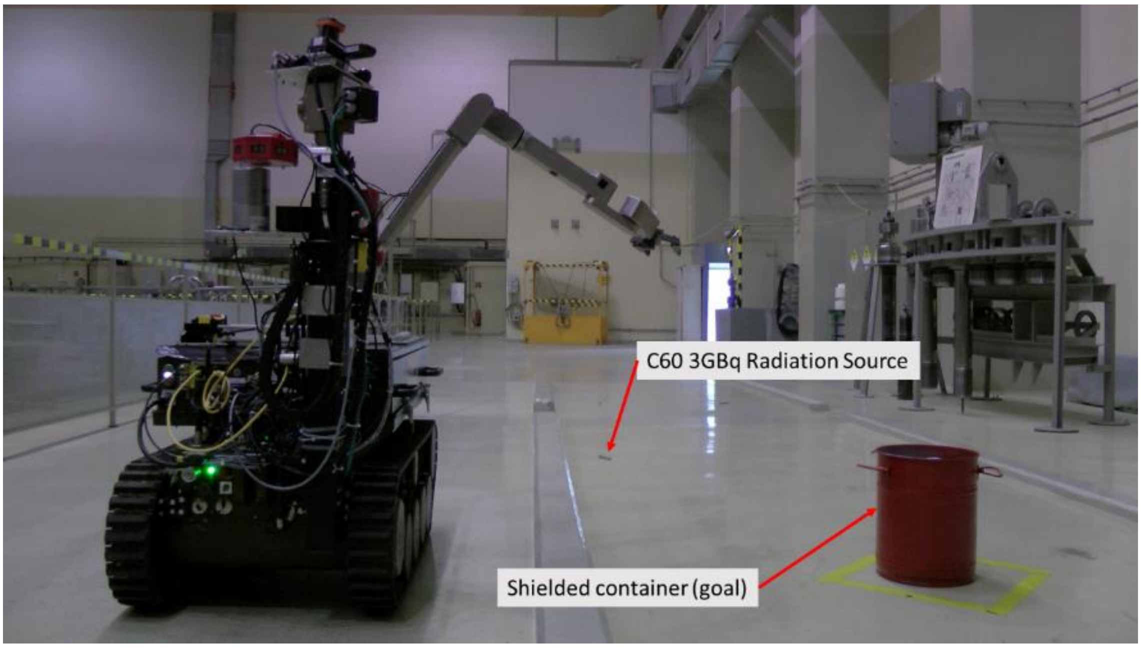


Figure 12. Robot with manipulator (in Zwentendorf NPP)

3.3 Levels of autonomy for unmanned systems

From the robotics perspective there is one key element with a major influence on the feasibility, performance and usability of UMS in HAZOPER: the desired / required level of autonomy for the UMS.

An autonomous robot is a robot that performs behaviours or tasks with a high degree of autonomy without permanent or direct influence of an operator. An autonomous robot may also learn or gain new knowledge like adjusting for new methods of accomplishing its tasks or adapting to changing surroundings.

3.3.1 Classes of robotic operations

Based on the desired / required level of autonomy we can identify four classes of robotic operations in RN missions:

I. Teleoperated. This means that all actions of the robot are controlled by the operator manually.

II. Automated / autonomous driving without RN-sensor input to the navigation and planning. The actions of the robot are pre-programmed (automated) or sensor based (no RN-sensors); all without direct or limited operator intervention.

III. Automated / autonomous driving with RN-sensor input to the navigation and action planning. The actions of the robot are pre-programmed or sensor (including RN-sensors) based; all without direct or limited operator intervention.

IV. Autonomous driving with RN-sensor input to the navigation and action planning facilitated by some kind of radiation model. The actions of the robot are sensor (including RN-sensors) driven and aided by appropriate sensor and environmental models; all without direct or limited operator intervention.

At least the systems belonging to classes III and IV are highly cognitive robotic systems which are typically AI-based. These UMS are very complex due to the underlying structures and methods used. But only these systems will deliver the highest level of adaptivity in dynamic and diverse environments.

3.3.2 Example application

Assume that a given area has to be mapped in order to declare this area free of RN radiation. In a standard MSA a person with a detector would have to visit each square meter of the area and do a measurement for a given period of time. This measurement has to be documented in combination with the precise position and time. Depending on the class of autonomy, a UMS would tackle this task differently.

Class I

With a teleoperated robot, the vehicle can carry the detector relieving the burden of carrying the device manually or pushing a trolley. But most important, the personnel will not be exposed to dangerous levels of radiation. Still an operator has to manually drive the robot from square to square by joystick. Depending on the computing equipment of the robot the actual RN mapping can be done on the robot or in the Operator Control Unit (OCU). Each cell of the RN map will contain the measurement, the position (GNSS) and the time (coming from GNSS also). The raw data from the detector, the RN map and the position might also be transmitted by a radio link or recorded on something like a USB flash-drive.

Class II

The unmanned system with the mounted detector is given the boundaries of the area that has to be mapped. The robot is also equipped with appropriate sensors to do obstacle avoidance. The vehicle will then visit automatically or autonomously each square meter of the given area and do the desired measurements. It has no "knowledge" about the RN sensor readings, meaning it does not change the mapping process depending on the readings. If the system gets stuck it will alert the operator. The actual RN mapping is usually done on the robot (which might be different on air-based systems due to the reduced payload). Each cell of the RN map will contain the measurement, the position (GNSS) and the time (coming from GNSS also). The raw data from the detector, the map and the position might also be transmitted by a radio link or recorded on something like a USB flash-drive.

Class III

Class III is comparable to class II, but in this case the navigation and action planning has not only the obstacle avoidance information but also the live input from the RN sensors. With this additional information extra rules and actions can be implemented. For example:

- follow the increasing RN sensors measurements;
- visit each cell with a threshold above XYZ twice;
- avoid cells with a threshold above XYZ;
- send an alarm if reading exceeds value XYZ;
- drop a warning beacon; or
- if dose rate exceeds XYZ additionally record an energy spectrum.

This UMS must already have a sophisticated navigation and reasoning component. Current state-of-the-art robots in this class mostly rely on an advanced environmental mapping process giving not only the robot but also the operator a sensor-based model of the perceived world. Also, systems of this class would have the capability to efficiently co-operate with other robots of the same or higher classes.

Class IV

Additionally to the capabilities of class III, systems in this category make extended use of models. A model for the robot usually includes most of its capabilities and limitations like a physical model and navigational aspects. The same is applicable for the sensors. The sensor interpretation process makes use of a sophisticated model of how the device operates (e.g., sensor measurement cone), what the device measures and how it can be interpreted. For RN measurements the physical characteristics and specialities of radiation will be used in this model for example, scattering and attenuation of gamma radiation. Due to this additional information the UMS might e.g., estimate the likelihood of sensor values even for areas that have not been visited yet.

3.4 Conclusions

The presented report summarises the main tasks for robots and classes of robotic operations in RN missions. This highlights that unmanned systems, like ground robots, can help to reduce the health and safety risks to the action forces. Robots are on their way to revolutionise the process of information gathering and enable unprecedented possibilities of supporting the situational awareness. Together with the ability of remote mobile manipulation this will boost the prospects of telepresence in HAZOPER.

In order to reduce the operator workload and extend the current capabilities of remotely operated robotics beyond known frontiers, the use of AI-based automatic and autonomous assistance functions is of paramount importance. The report briefly explains different levels of autonomy and illustrates them in intuitive examples.

Furthermore, robotics systems that could also be used in the broader domain of CBRNE incidents are described (in Annexes A-C). The progress in deployable CBRNE robotics is currently rather limited through a lack of standardisation. To fertilise the R&D process the EU must channel the various tangled initiatives by providing clear structures for CBRNE robotics. There are currently no established and mandatory guidelines, best practices, norms or standards that will enable a coalescence of all past and current EU CBRNE activities, not to mention the correlated CBRNE activities by the European Defence Agency (EDA). In the end most, if not all, initiatives come up with some sort of proprietary standard, interface or benchmark for their proposed system.

Concluding, the Annexes A-C visualise the benefits of Open Access and Open Source with established standards and norms through an example in the field of Civil-Military Cooperation (CIMIC). In a multi-national CIMIC context, interoperability is ensured on multiple levels by using existing and established standards. This example proves the need for a guiding EU initiative to consolidate the efforts in the field of CBRNE robotics.

4. Simulations for searching RN sources by robotic equipment

By Harri Toivonen[1]

[1]HT Nuclear Ltd, Finland

Abstract

Simulations are carried out to test the capabilities of radiological detection systems in an open area. The analyses are intended to define test conditions for robots in searching and characterising nuclear and other radioactive Materials Out of Regulatory Control (MORC). The basic idea is to define test setups in such a way that the capability tests can be carried out in any safe and secure open free space. Some tests can be implemented outside in a fixed radiation field (1 μSv/h) using different sources at a suitable source-detector distance. This arrangement provides flexibility allowing test facilities to use sources at their disposal (> 5 GBq) without any need to purchase specific test sources and building dedicated infrastructure for the tests.

4.1 Introduction

Search of a radiation source is a basic in-field capability of the competent authorities. In the past, these operations have been carried out by field teams using backpacks, vehicles or airborne systems (Nordisk Kernesikkerhedsforskning 1997). Since 2001, the mobile use of the radiation detection instruments for nuclear security has been widely acknowledged (IAEA 2011, 2014a) Nowadays, efficient in-field detection capability can be built for the robots.

The operational conditions set several constraints for the in-field operations, such as time available, health hazard or minimum allowed distance to the target. The information needs of the competent authorities regarding nuclear and other radioactive MORC are the following:

1. Detection of MORC - gamma and neutron radiation;
2. Safety assessment - dose rate evaluation and presence of contamination;
3. Localization of unknown sources - coordinates of the sources (one or more), source-detector distance estimation;
4. Identification of nuclides involved;
5. Activity estimates - calculation of emission rate (1/s) or apparent activity (Bq) of the sources (assuming no shield);
6. Reports - real time data transfer and immediate summary of the findings.

Substituting robots for human beings in the operation of the detection instruments provides great advantages but also challenges. Of particular importance, before the operational use of robots, is the testing of the unmanned ground systems (UGS) and unmanned aerial systems (UAS), including their radiation detection capability, manoeuvrability, reliability in the field conditions and timely reporting of the findings. The present report focuses on identifying field tests for the robots in an open area and developing test requirements for their operational use.

4.2 Testing robots in open area

For testing radiation detection capabilities, baseline radiological conditions[14] should be defined (see Table 2**Table *1***). In addition, different test arrangements should be designed, for example, by using several sources in several locations having partial or directional shielding or by introducing obstacles preventing the movement of the robots. Objects, such as vehicles and cargo containers, could be brought to the testing site to make the manoeuvres more complex.

All tests must be carried out in safe radiological conditions. The ALARA principle has to be used in selecting the sources and their activities. The radiation exposure should be as low as possible, but not lower, so as to have an effective test fulfilling scientific, technical or operational needs. Testing with radioactive materials will inevitably be regulated by the national authorities. The radiation dose to the people must be minimized.

A remote small air field is an ideal test site for unmanned detection systems, assuming all safety and security arrangements can be implemented (see Figure 13):

Figure 13. A remote airfield for capability testing of UGS and UAS

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[14] Baseline radiological condition**:** a controlled test environment where radiological tests can be carried out in a systematic and repeatable manner. Useful for R&D, system comparisons and certification of robots for in-field operations.

Table 2. Baseline radiological conditions for testing in-field robotic systems carrying radiation detection instruments

	Infrastructure for the tests
Site	• Dimension 200m x 200m (UGS), 1000m x 1000m (UAS), • Sources in open free space, • Flat terrain with a hard surface, • Possibility to add obstacles or objects on the field to provide uneven radiation field (asymmetrical flux).
Environment	• Weather: dry weather, no snow, temperature 10 - 25 ^{o}C. Lighting conditions: daylight.
Nuclides	• Industrial sealed sources (Co-60, Se-75, Cs-137, Ir-192, Am-241), • Medical non-sealed sources (F-18, Tc-99m, I-131), • Neutron sources (Am/Be, Cf-252), • NORM (uranium and thorium), • Special sources (DU)[15].
Activity	• Sealed sources: 10^9 - 10^{13} Bq, • Non-sealed sources 10^8 - 10^{10} Bq.
Radiation field	• Source passing tests are performed in a radiation field where maximum doserate is fixed, say to 1 μSv/h ± 30%. This procedure gives flexibility to carry out the test with the sources available at the site. The aim is to have almost the same maximum radiation field in all test arrangements. • In wide-area search no doserate limitation is set.

The test methods should answer the question whether the equipment is deployment-ready. The quality of information acquired should be quantified: source localization capability, source characterization capability, timeliness of information, communication capability (real-time data transfer), usability of detection systems such as battery life and weather proofing, etc.

The detectors used in the robots have to be characterized. The operating teams themselves should perform in advance the required calibrations for a fixed geometry (see Table 3). The efficiency calibration can be performed by measurements or Monte Carlo simulations. However, also the testing site should provide a possibility to verify the detector response for certain radionuclides (e.g., Am-241, Cs-137 and Co-60) having certified activities. These calibration measurements should be carried out at a certain source-detector distance "r_0" giving good counting statistics in 10 min for the sources involved (10,000 counts in a peak of interest or total counts of 10,000 above background). The detector calibrations should be made at a large-enough source-detector distances, typically r_0 = 5 m or more, for determining the counting efficiency (see Table 3). Calibrations of the spectrometers at shorter distances may lead to errors in field operations because the beam of arriving primary photons is not parallel as it is in large source-detector distances. When the efficiency is known at the distance r_0, it can be calculated (efficiency transfer modelling) for any source-detector distance by taking into account the photon absorption in the air.

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[15] DU, depleted uranium, is a common radiation shield and seen often by the spectrometers during a field mission; Pu and HEU should be handled only at specific institutes licensed to have access to such materials.

Table 3. Detector properties. A data sheet should be filled at the test side to document the properties of the instruments used

<table>
<tr><th colspan="6">Detector name</th></tr>
<tr><td>Detector material and type</td><td colspan="5">NaI(Tl) or CsI scintillator, HPGe semiconductor, GM tube, ionisation chamber, …</td></tr>
<tr><td>Detector shape
Detector dimensions and volume (cm^3)
Drawings
Cladding materials</td><td colspan="5">Cylindrical/rectangular</td></tr>
<tr><td rowspan="5">Application and data type</td><td></td><td>alpha</td><td>beta</td><td>gamma/X</td><td>neutron</td></tr>
<tr><td>count rate</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>dose rate</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>energy spectrum</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>nuclide identification capabilities</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>Efficiency of the spectrometer
• Intrinsic
• Point source at 5m

(cps / photon emitted)</td><td colspan="5">Energy (keV) Peak efficiency Total efficiency
▪ 59.5
▪ 661
▪ 1332

(complete efficiency curve covering the region of interest)</td></tr>
<tr><td>Standards to which the detector complies</td><td colspan="5">IEC, ANSI, national</td></tr>
</table>

4.3 Simulations of in-field operations

HT Nuclear Ltd[16] has developed simulation software for training purposes concerning radiation hazards and operational in-field missions for the detection and characterization of MORC. The software, known as SIMO - simulation of MORC - creates a radiation field for the sources involved and then allows moving in that field with various detectors. SIMO has been used successfully in domestic and international training courses and exercises.

During the software development process, new algorithms were invented to solve the problem of source localization and characterization. The basic idea is hypothesis testing: "assume a source in a certain location and then show if the claim is wrong or correct". Then repeat the process for the whole area of interest. A patrol, such as a robot, is allowed to move in the radiation field gathering information on the source or sources. This information is used for the analyses of the potential sources which have produced the radiation field.

In the present study SIMO is applied to understand the problems related to the testing of the robots and to develop solid requirements for the capability testing[17].
Typically, SIMO creates a likelihood map, an area of interest for the source location, and then the emission rate (1/s) or apparent activity (Bq) of the source is estimated, including

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[16] http://htnuclear.fi/About-us.php

[17] Video on Electronic Table Top Exercise: https://www.dropbox.com/s/zthrbhd69m0gmxe/simo-RN-threat-simulation.mov?dl=0

its uncertainty, for the most probable location of the source. Immediate reports (results on a map in kml format) are generated for the transfer to the competent authorities.

4.4 Design of tests

Defining test infrastructure requirements is a complex task if the goal is to cover radiological scenarios in general for the robots. However, a search on an open area requires consideration of a few specific items only, such as the safe use of testing materials. The capability tests of robots can be simulated to understand how the tests should be implemented in the field conditions.

The tests in an open area can be divided in three categories. In all of them, the specific task is to find one or more hidden gamma sources and report their properties:

1. Unshielded sources;
2. Shielded sources (Pb, concrete, water):
   - Shield symmetrical
   - Shield asymmetrical
3. Obstacles on the field to prevent UGS movements.

The analysis below deals with case 1 only. The typical test arrangement could be as follows:

A. Open area where all measurements can be carried out safely. A field of 200m x 200m is large enough for UGS; 1000m x 1000m for UAS.

B. Hard surface, no obstacles; good weather conditions, no rain, no fog, 10 - 25 °C.

C. Defining a straight line where some of the measurements are carried out (See Figure 14).

D. Choosing a gamma emitter, such as Cs-137, not revealing its properties (for R&D, the source properties should be revealed in advance).

E. Placing the gamma emitter somewhere on the field (the measurement team does not know the source location).

F. Implementing different measurement tactics. Measurements could be repeated several times for collecting statistics (found: yes/no, average positional displacement, etc) (see Searching for radioactive sources by UGS - open area simulations).

For a specific <u>source passing test</u>:

- Set the source at a distance D somewhere along the road at a suitable distance of 10m - 100m (See Figure 14).
- Define distance D for the source available at the test site: D is a distance where the doserate DR = 1.0 ± 0.3 μSv/h at the nearest point to the source.
- Measure and record accurately DR and D.
- Increase distance D to find out the maximum performance capability of the detection system of the UGS.

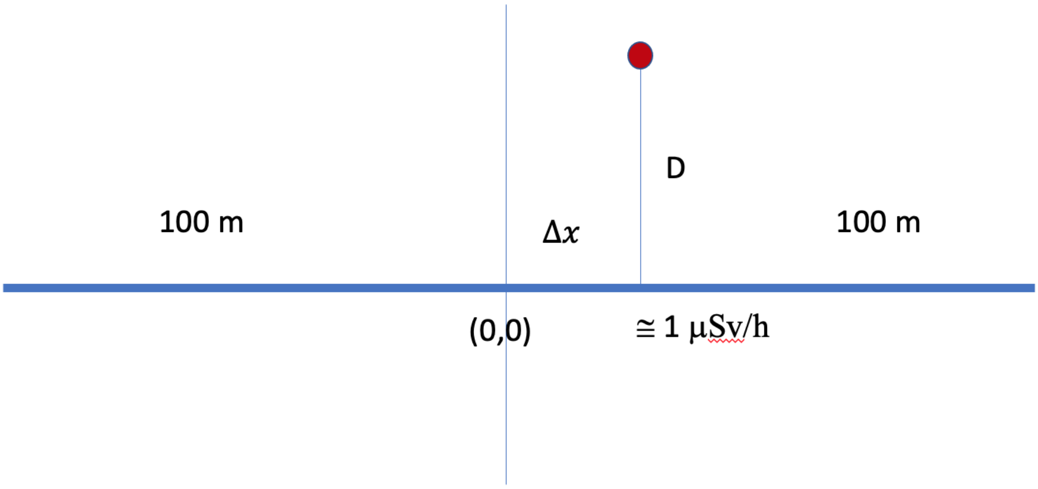

Figure 14. Test geometry for source passing on a road. The distance D can be varied, but it should always be longer than 10m

4.5 Searching for radioactive sources by UGS - open area simulations

Several simulations were designed for different test conditions to illustrate that the testing of robots can be carried out in safe and secure manner on a large open field without any complex infrastructure.

4.5.1 Source localization by moving on a straight line

Simulations were carried out for the following setup:

1.	Source	Cs-137 with activity of 50 GBq
2.	Location of source	65 m away from the road (D)
3.	Speed of UGS	1.2 m/s
4.	Detector	LaBr3, 1.5″ x 1.5″
5.	Efficiency (5 m, 661 keV)	9.4×10^{-7}
6.	Doserate	Calculated from spectrum in every location of the robot
7.	Background	Environmental doserate 0.05 - 0.15 µSv/h (random)
8.	Measurement height	1 m

The following tasks were given to the UGS:

1. Move on a straight road for source finding with speed v = 1.2 m/s (can be varied up to 10 m/s).

2. Report the position on the road where the maximum reading (doserate or peak cps) is observed, preferably in map coordinates (Long, Lat)[18]; the result should be available within 10 seconds after passing the source.

3. Report the location of the source: most probable location (Long, Lat) and area of interest containing location uncertainties - notify the symmetry of the geometry (in principle the measurement cannot reveal on which side of the road the source is located).

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[18] Longitude and Latitude should be given with the accuracy of 5 decimals.

4. Report the emission rate or apparent activity of the source (assuming no shielding) and its uncertainty.

5. Record the time interval between source passing and providing a complete report on the findings.

For the results, see Figure 15-Figure 17.

Figure 15. UGS passing a source and marking the nearest point to source on the road. The coordinates (Long, Lat) at the measurement point of the maximum doserate should be reported immediately after passing the source (< 10 s)

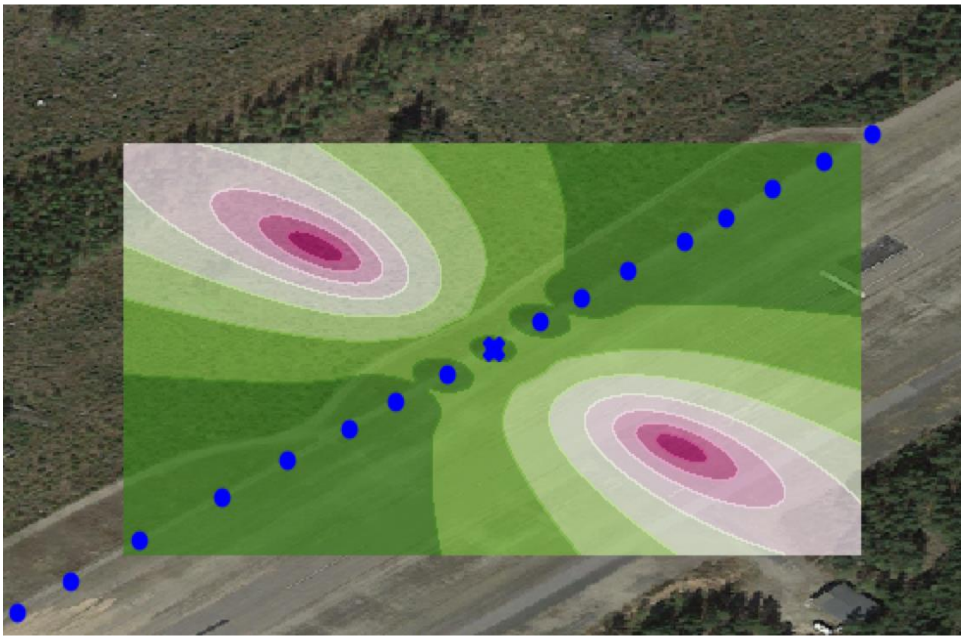

Figure 16. Likelihood map of possible source locations near the path of the UGS. The image was produced from UGS spectrometric data

Figure 17. Most likely source location X and related activity calculation (symmetry issues omitted, see Figure 16). Activity estimation using spectrometric data was performed simultaneously with the source localization analysis giving 5 x 10^{10} Bq ± 23% for Cs-137. The measured doserate is marked on the road (μSv/h) passed by the UGS

4.5.2 Cordoning of radiation field by isocurve techniques

Isocurves are a powerful method to understand the extent of the radiation hazard and to localize a source or sources. When creating isocurves there is no need to go near the source (which may be an operational constraint in certain security scenarios[19]). The isocurves reveal the possible asymmetry of the radiation field thus providing information on the shielding around the source or presence of several sources. In addition, often for response the authorities have to cordon the area of interest. The criterion could be 30m away from the source (no explosives) or 300m from the source (explosives cannot be excluded) or a radiological requirement such as 100 μSv/h or any value decided by the competent authority involved.

The results of isocurve simulations are shown for one source (see Figure 18) and for two sources (see Figure 19), including cordoning of the location of interest.

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[19] Scenario: Unknown radiological condition with specific sequence of events, including in-field missions for searching radiation sources.

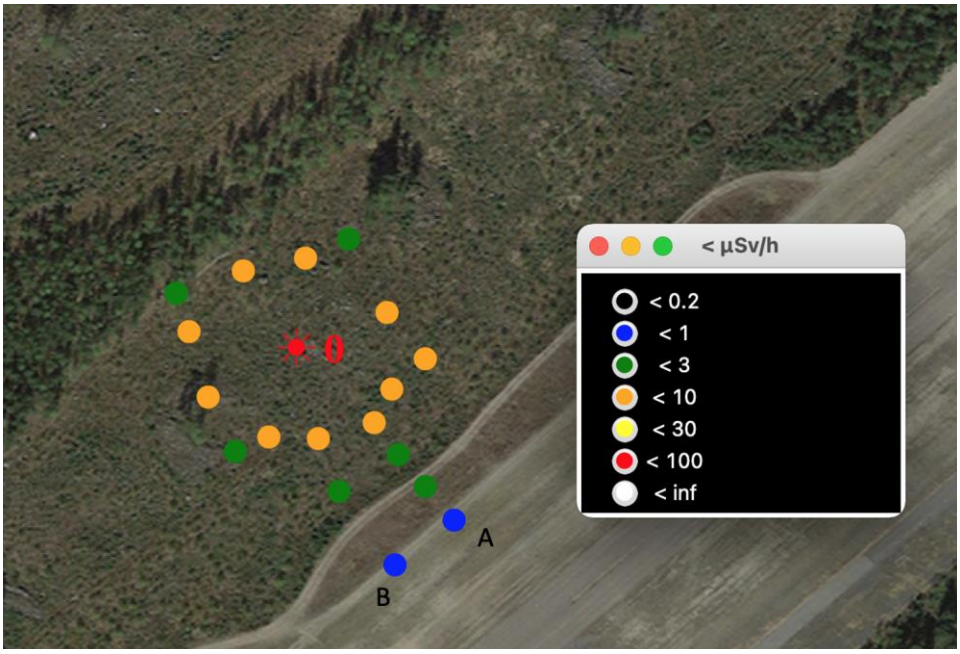

Figure 18. Isocurve around a point source with constant doserate of about 5 µSv/h. The robot was sent towards the area of interest and then it moved around the source keeping the doserate constant (not allowed to enter to a higher radiation field). The yellow points (3 - 10 µSv/h) form a circle with a diameter of 60m. Conclusion: a point source in the centre of the circle at a distance of 30m from the perimeter

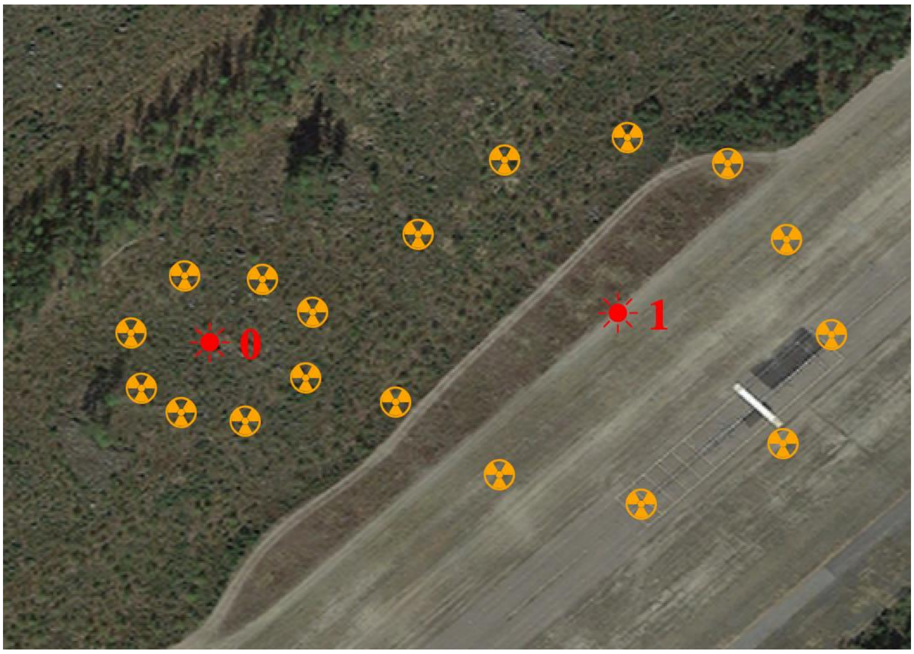

Figure 19. Isocurve in an unknown radiation field; the markers dropped by a robot refer to a doserate of about 10 µSv/h (isocurve criterion). The markers form an asymmetrical pattern. Conclusion: the area of interest seems to contain two sources. In fact, this scenario contained a Cs-137 source with activity of 5 x 10^{10} Bq and a Co-60 source with activity of 1 x 10^{11} Bq

4.5.3 Source localization by two or more UGS

A Co-60 source with activity of $3.7x10^{10}$Bq (1 Ci), unknown to the test team, was placed somewhere on the field. Two robots should find the source and report its activity. The robots can take any path. However, the simulations were performed on movements on the roads perpendicular to each other. This choice was made to demonstrate simple measurement tactics which reveal the location of the source without sophisticated data processing (see Figure 20).

Figure 20. Doserate measured by two robots moving perpendicular to each other. The location of the source can be estimated from the maxim reading on both axes (see Figure 21)

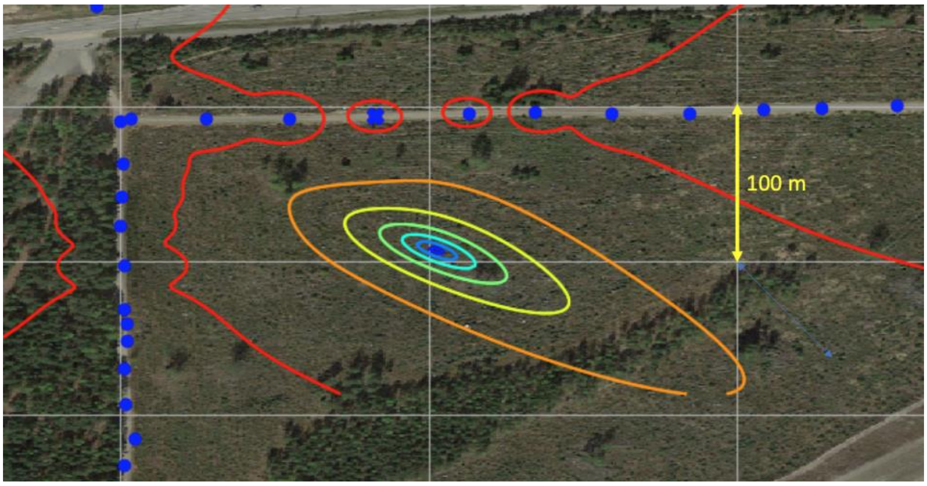

Figure 21. Isocurve analysis of spectrometric data produced by two robots. Activity estimation for the most probable location (Long, Lat) of the identified Co-60 source: $3.6\text{x}10^{10}$ Bq ± 20 %

4.5.4 Source localization by one UGS using data on its own track

An unknown source can be characterized by one UGS moving in the neighbourhood of the source. The best response is achieved if data are available from different directions relative to the source. Figure 22 shows the result of a simulation for a Se-75 source with activity of $1 \text{ x } 10^{11}$ Bq. The robot was moving around the source. At 180 degrees a reliable result became available; however, sometimes only three measurements may be enough for source localization, depending on statistics and location relative to the source. The reliability of the analysis requires more data points. A report generated for the authorities is shown in Figure 23.

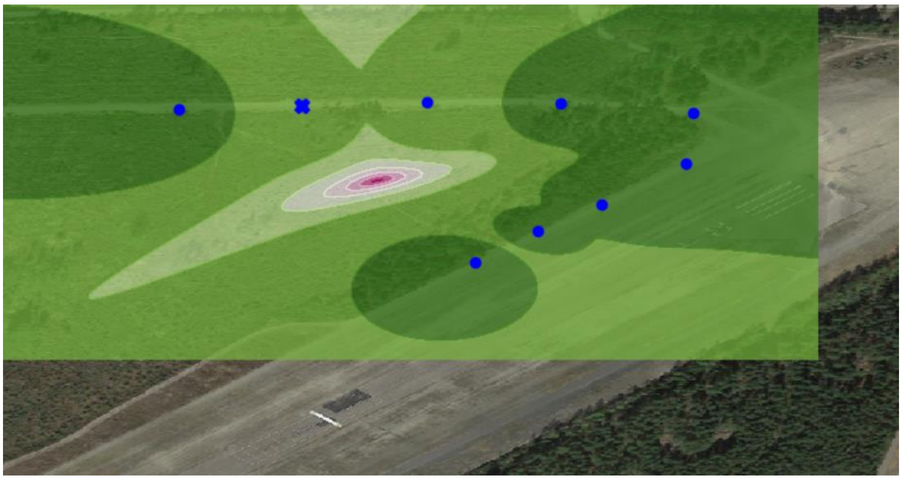

Figure 22. Source localization by one UGS using spectrometric data. The area of interest is correctly localized and the nuclide identified as Se-75 with estimated activity 9.1 x 10^{10} Bq ± 28%

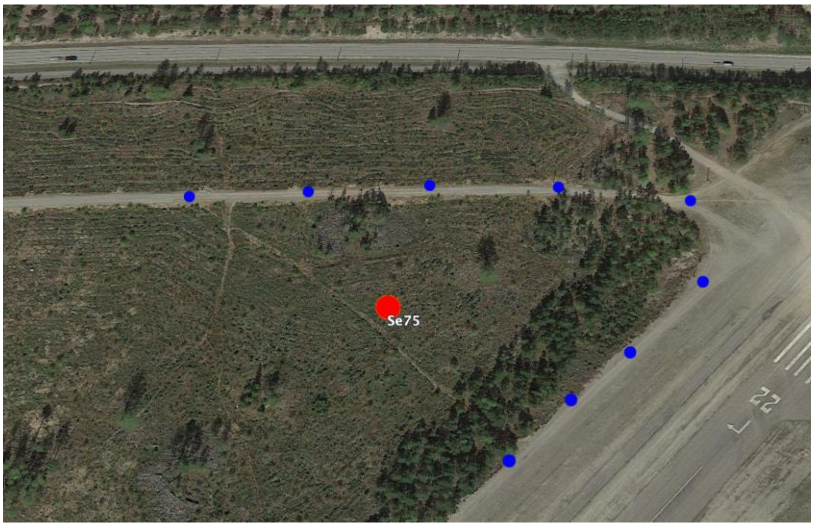

Figure 23. Report in kml-format (source: Google Earth[20])

4.6 Searching for radioactive sources by UAS - simulations for area mapping

Airborne detection systems require a large test site, preferably 1000m x 1000m. To demonstrate the search capability of an UAS, simulations were carried out for a 50 GBq Cs-137 source using the same parameters as with the UGS (see Searching for radioactive sources by UGS - open area simulations), except:

Speed of UAS	10 m/s
Flight altitude	50 m

4.6.1 Area scanning

Before the implementation of an area search, the flight parameters and the data acquisition parameters have to be optimized. In principle, an even distribution of the data points on the area of interest may be a good criterion, at least when no a-priori information is available on the expected location of the source. Arrival to the site and departure back to

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[20] https://earth.google.com/web/

the base take some time, and time is also lost at the end of every flight line. Therefore, the time spent on the area of interest is always smaller than the total mission time. The flight parameters of the present simulations were optimized by SIMO (see Table 4).

Table 4. Parameters for UAS for a search operation of radiation sources on an area of interest

Size of search area (m x m)	530 x 460
Flight altitude (m)	50
Speed of UAS (m/s)	10
Mission time (s)	1000
Data acquisition time (s)	4
Giving:	
Time spent on the search area (s)	672
Measurement points total	180
Flight lines	12
Measurement points per line	15
Distance between points (m)	40
Grid width (m)	42

The search results are in Figure 24 and Figure 25. The detection sensitivity, based on the dose rate measurements, was estimated by varying the activity of the source (see Figure 26).

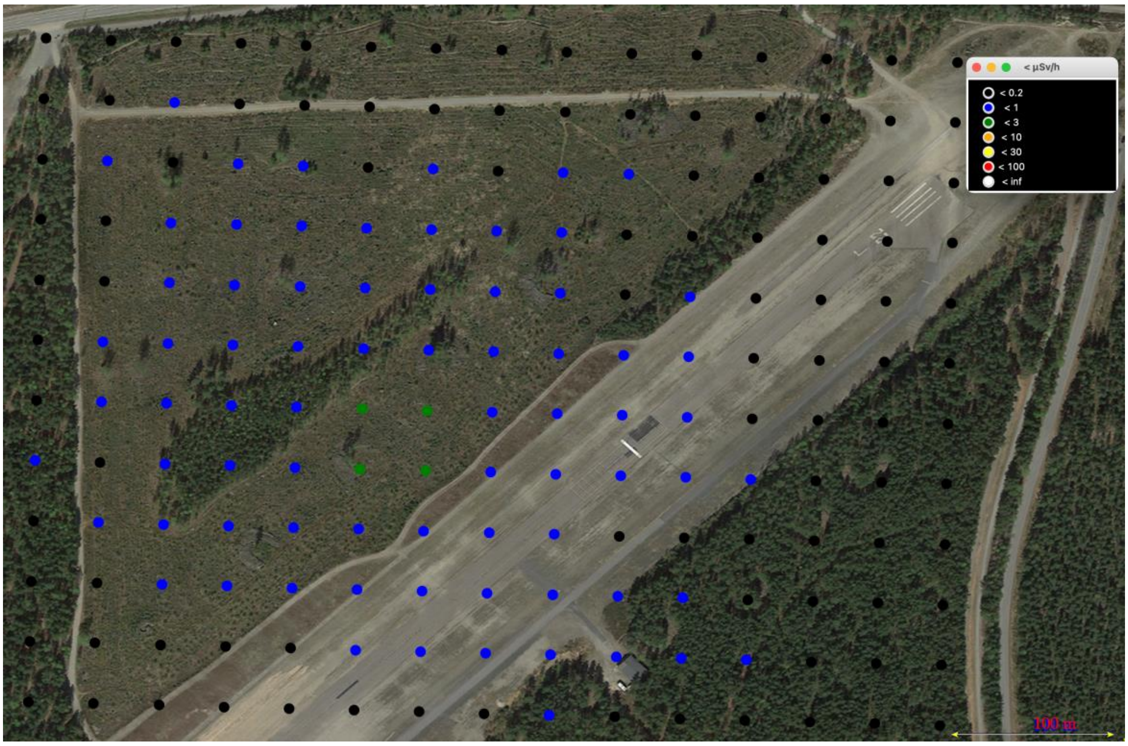

Figure 24. Doserate on the area of interest screened by an UAS at the altitude of 50 m (50 GBq of Cs-137). The blue and green dots refer to doserate above background, 0.2 - 1 µSv/h and 1 - 3 µSv/h, respectively; raw data, 180 points

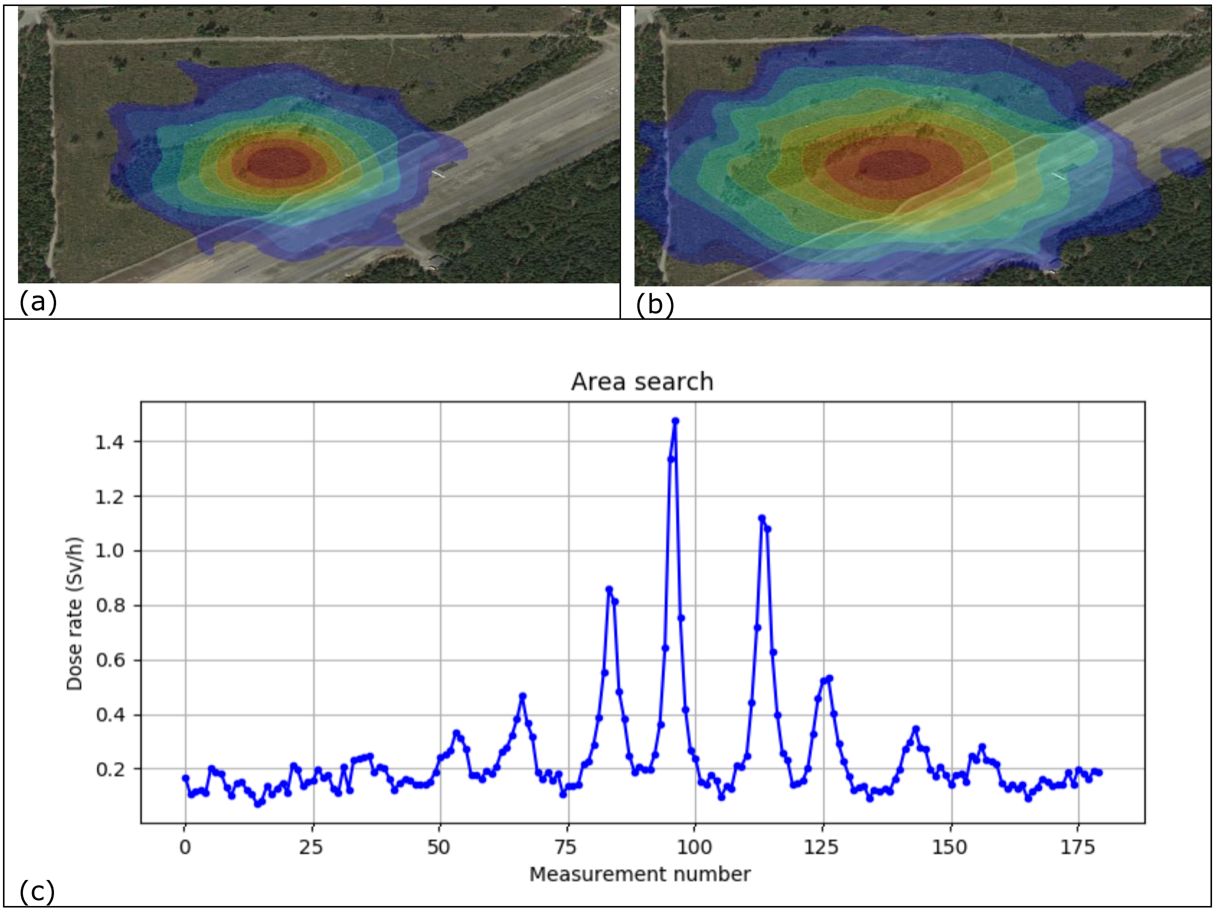

Figure 25. Capability testing of UAS using 50 GBq of Cs-137. (a) Isocurves of doserate (outer boundary 0.25 μSv/h). (b) Spectrometric isocurves for Cs-137 cps at 661 keV. (c) Doserate on each measurement point; the flight lines near the source are clearly seen

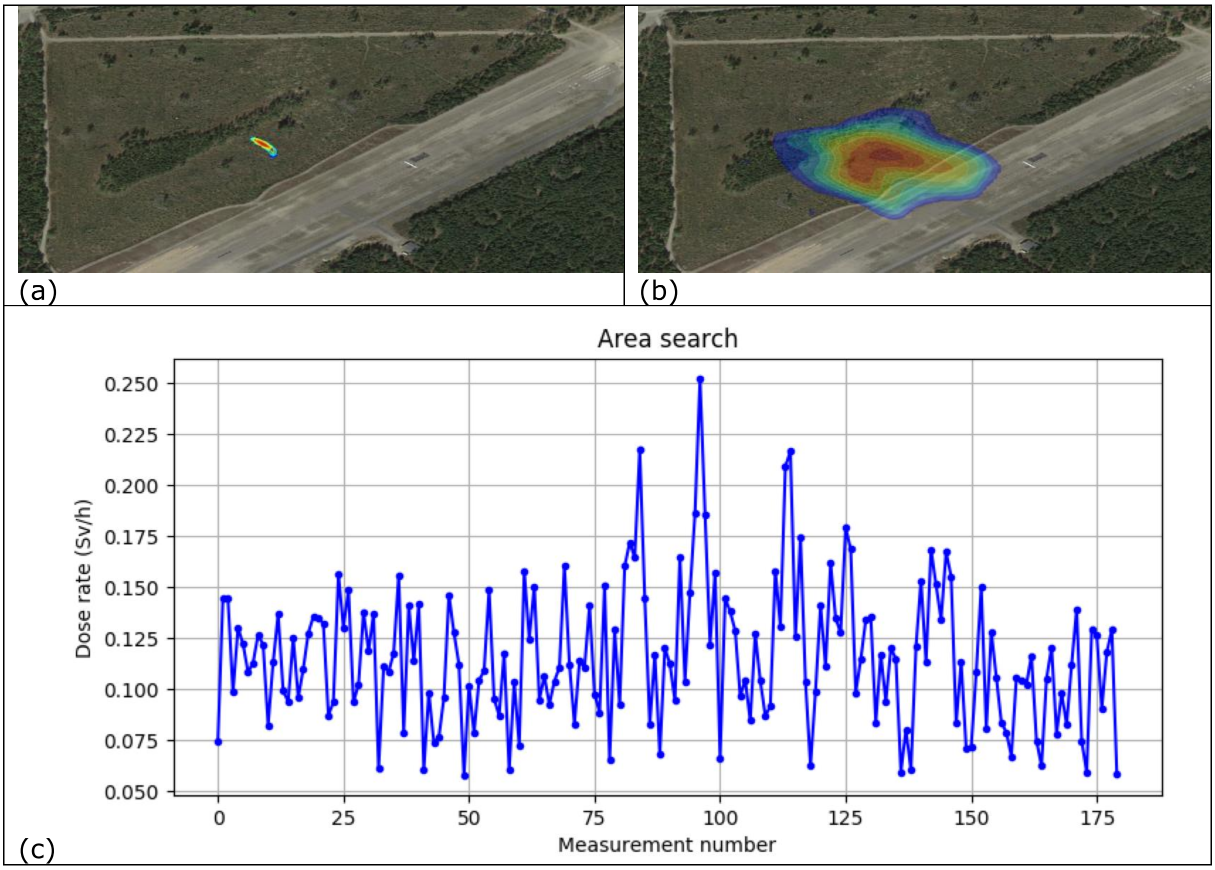

Figure 26. Sensitivity analysis of an UAS for 1 GBq Cs-137 source. Measurement geometry is the same as in Figure 6.2. (c)Three flight lines are still visible. (a) Doserate measurements are on the brink of the sensitivity whereas (b) spectrometric results are reliable

Finally, geofencing is the ideal solution to define the forbidden area virtually by (Long, Lat) points. For an example, see Figure 27.

Figure 27. Example of an exclusion zone around a source (no entrance)

4.7 Conclusions

The simulations show that basic capability testing of the robots can be performed on any large open area which is safe and secure. The movement of the robots can be made more difficult by exclusion zones (fencing, flagging) which are not allowed to be entered. Complex scenarios can also be designed by attenuating the emitted gamma radiation with a shield or shields which could be of complex shape giving asymmetrical radiation field.

Some tests, such as source passing, could be implemented in a fixed radiation field using different sources at a suitable source-detector distance. In these tests, the sources should be placed at critical (unknown) locations giving the agreed total maximum exposure about 1 μSv/h (0.7-1.3 μSv/h); in repeated tests, variability of activity and source-detector distance should be adopted. Different and more complex source finding and characterization tests can be designed for the end-users who do not know the precise properties of the sources.

Standardizing or restricting the radiation field to a certain interval, rather than using standard radiation sources with fixed well-defined properties, provides flexibility allowing the test facilities to use sources at their disposal (> 5 GBq) without any need to purchase specific test sources.

The simulation results show that some capability tests of robots can be implemented with minimum infrastructure in every EU Member State. There are infinite possibilities to create the radiation field. Similarly, setting up constraints to the robot movements can be implemented freely. Therefore, consistent and repeatable capability tests in different sites, as well as EU Member States, require a formalized approach which defines the specifications of these tests. In the long run, an international standard would be the solution.

Tests in an open area are part of the overall capability tests of the robots. The simulations show that these tests can be performed without any need for establishing a dedicated testing facility. However, urban security manoeuvres and crime scene management require test capabilities in “a city” or a building with complex infrastructure, including constraints set by the authorities for their security missions and crime scene management. Simulations of these scenarios are essentially more complex, albeit not impossible.

5. Use of robotic equipment at RN crime scenes

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Abstract

This report covers the "crime scene" part of the broader analysis of the requirements and capabilities needed for the use of autonomous robotic equipment carrying measurement devices for the detection of RN threats in a hostile/real life environment. The focus is on Radioactive and Nuclear (RN) materials, although the ideas could be expanded to all CBRNE materials.
The report sets a basic scenario for a crime scene where RN materials are present, this is then used to determine the requirements for and limitations of the use of robots at a crime scene. Furthermore, the future possibilities for managing a radiological crime scene using robots are assessed.

5.1 Introduction

The European Union has faced a range of terrorist threats and attacks of a violent nature. Radicalised groups have carried out attacks in the EU with the aim of maximising both the number of victims and the psychological and economic impact on society. In this context, the potential of radioactive materials is daunting. Radiological and Nuclear (RN) agents, such as polonium in the Litvinenko case (Owen et al. 2016), are not only a health hazard, but may also involve higher threats and have societal consequences and/or cause wide-scale damage to the economy and environment.

The first responders to any emergency and or terrorist threat need to be aware of eventual RN material on site. Support from radiation protection experts and radiological assessors is necessary. First comes the safety of the deployed forces in an all-hazard approach. Further, in case of a crime scene the quality of evidence, including the chain of custody considerations and preventing cross-contamination, are of highest importance.

This report covers the "crime scene" part of the broader analysis of the requirements and capabilities needed for testing of autonomous robotic equipment carrying measurement devices for the detection of RN threats in a hostile/real life environment.
To approach the problem, the report first defines what is a "radiological crime scene", and continues by establishing a basic scenario in order to assess the needs of the crime scene investigators for support by robots. The report discusses what can a robot assist with at the crime scene, which are the requirements on the robot, which are the limitations when using a robot.

The need for training and testing with the novel techniques are discussed and also, the use of artificial intelligence and virtual reality in connection with the use of robots is mentioned. The need to standardize the crime scene management and use of novel equipment, and finally, the legal aspects when using these techniques at the crime scene is discussed.

Finally, more detailed investigation into the problem can be found in the Annexes D-F, where also the different European projects dealing with CBRNE materials more broadly, are summarized.

5.2 Radiological Crime Scene Management

The primary goal in RCSM is enabling a police investigation where open or sealed radioactive sources or nuclear material are present. At such a scene expert support from radiation protection experts and radiological assessors are necessary.

First comes the safety of the deployed forces in an all-hazard approach, following the ALARA principle (the radiation dose must be kept "As Low As Reasonably Achievable"), secondly the quality of the evidence, including the chain of custody considerations and preventing cross-contamination, are imperative.

In addition, the police investigation may be under time pressure due to evolving threats.

Important considerations are the prevention of spread of radioactive material into the environment, via air or water, or via the spread of contamination by the deployed forces leaving the scene.

5.2.1 Basic scenario of RN crime scene

To set the scene for the discussion we establish a basic scenario. Setting this scenario, we assume that during a police investigation, the competent police authority needs to investigate an enclosed room within a larger crime scene. There are information alerts / measurement alarms which indicate that RN material could be present in the enclosed room. The room is the kitchen of a residential house with two windows and one door, area 16m^2. The house has been evacuated and the site has been cordoned off by the police.

The necessary steps include:

- Establish the hazard control area, considering background dose rate;
- Initiate the assessment of hazards present at the crime scene. All-hazard approach, to identify eventual chemical, biological and radiological dangers, while also checking for the presence of explosives, or other kinds of dangers, such as the structural integrity of the building;
- Body search;
- Check for airborne or surface contamination of RN material;
- Situation assessment and briefing for deployed forces, creating a forensic examination plan;
- Implementation of health and safety measures, including radiation protection measures, for deployed forces (Personal Protective Equipment (PPE), dosimetry, calculation of time that can be spent at the hazard control area, necessity of shielding, decontamination facilities, medical support, safe and secured temporary storage for collected RN materials, etc.);
- In the case of open contamination, the entrance / exit to the scene should be sealed, ideally with a mobile air lock with a filtered air pumping system;
- Further search and removal / shielding of sealed sources with radiation fields that prevent work from being carried out at the scene (these sources should also be considered as evidence in the police investigation);
- Carrying out crime scene work, including documentation of the scene, viewing the evidence, documentation of evidence and securing evidence. The crime scene work must be accompanied by continuous hazard assessment;
- Removal of evidence (non-contaminated evidence, evidence contaminated with RN material and RN material and/or sources) from the scene for further investigation (for example in a mobile glove box or in a suitable laboratory);
- Special transport of evidence to a suitable laboratory (e.g., dedicated nuclear forensics laboratory), holding or other nuclear facility or waste disposal site;
- Decision to end the crime scene work and seal of the scene;

- Inventory of waste materials produced during the crime scene work; at the scene and at the decontamination facilities;
- Decontamination or disposal of contaminated equipment;
- Decontamination of scene / disposal of contaminated items from the scene;
- Release the scene to the appropriate authorities or to the owner / public.

Several of these steps to be performed are looking into unknown territory and can be dangerous to the person deployed to do the job, this risk has to be reduced.

5.2.2 Background on the use of robots at RN crime scene

The use of modern robots or other unmanned vehicles at a crime scene can ensure the safety of crime scene investigators, by reducing the need to enter dangerous scenes to gather evidence. This will help to protect human life, reduce threats, and ensure that the crime scene is processed in an efficient manner. However, there are many technical as well as juridical aspects to consider when and how to use robots at a crime scene that will be discussed in the following.

The deployment of robotic equipment to RN crime scene has to be agreed to and approved by the crime scene management. Procedures have to be protocolled and approved before deployment in order to make sure that the continuity of evidence is preserved and documented. This contributes to maintaining the chain of custody. For example, a ground-based robot could potentially destroy radiation contamination patterns, which should be considered as nuclear forensic evidence, and also traditional evidence (e.g., footprints) on the floor.

Robots can support in:

- Initial safety assessment and threat neutralization;
- Situational awareness;
- Recording/filming the scene and actions taken;
- Collecting evidence;
- Performing further measurements and monitoring;
- Remove/shield RN material.

General **limitations** for the use of robots in a crime scene include the following:

- It may be the case that radio communication is not possible (e.g. NATO Guidelines recommend not to operate radio devices in the vicinity of suspect packages (NATO Civil Emergency Planning 2014)). For this reason, other communication links or evaluation of data at a fixed point outside the crime scene should be available as an option;
- It may be the case that no Global Positioning System (GPS) signal is received. In this case, motion without GPS is necessary;
- The risk of destroying evidence via the use of robotic systems, in particular autonomous systems. The potential for cross-contamination of evidence is an additional limitation;
- An Unmanned Aerial Vehicle (UAV) could stir up or cause radioactive contamination, resulting in an additional hazard for deployed forces and the environment;
- An Unmanned Ground Vehicle (UGV) could spread radioactive contamination within while moving around and outside when leaving the crime scene;
- Caterpillar tyres cannot be used before contamination mapping and other evidence (e.g., footprints) have been secured from the floor of the crime scene. This means that ideally the initial survey should be carried out by a specialised robot with a smaller contact point with the floor (e.g., "spider type");
- In order to preserve chain of custody and preserve evidence, only semi-autonomous robots can be deployed that do not perform steps without explicit authorisation of the crime scene investigators.

General **requirements** for the use of robots in a crime scene include the following:

- Radiation hardened electronics is essential for robots that are to enter RN contaminated area, as well as to be equipped with RN detectors. Especially if the robot is designed to manipulate radioactive sources and/or shielding material, as in this case they could be exposed to large radiation fields (e.g., potential dose rates greater than 100 Sv/h within a few centimetres of a highly active sealed gamma source);
- UAV should be able to complete radiation mapping outside of a crime scene (for instance, outside a building);
- Parallel function of robots is required, i.e., one robot is the "eyes" recording while the other carries out measurement or manipulations at the scene;
- Radiation mapping and 3D scanning should be combined (for instance first a geo-map is constructed and then radiation mapping is added on top);
- Level of airborne radioactivity should be monitored in real-time (including alpha and beta);
- Swipe samples should be collected via robot;
- One robot should be capable of collecting urgent evidence and manipulating shielding and containers.

5.2.3 Advanced applications and challenges of robotic equipment at RN crime scene

This section gathers further technical details, in bullet form, based on discussions with first responders at the crime scene and crime scene investigators.

Potential dangers, problems can be caused by using a robot at a crime scene:

- contamination of the robot itself and (further) contamination of the crime scene;
- cross contamination of evidence/samples collected;
- destruction of evidence;
- the robot can transport contamination to the outside area.

Possible **applications:**

- 3D laser scanning and photogrammetry of the scene, full-digital, visual mapping and recording, video-reporting;
- detection of the presence of hazardous materials (CBRN and explosives);
- detection and monitoring of high doses and air contamination;
- build shielding or other safety tools at the scene;
- collection of hazardous materials and/or swipe samples for further analysis;
- collection of evidence under continuous on-line control of the crime scene manager/scene commander;
- collection of evidence or trace-recording if the exploitation of certain/additional areas of the scene requires the passage of traces/evidence;
- collection of evidence with high priority in urgent cases (e.g., in the prevention of a secondary event);
- primary trace-recording on dead bodies (photo of the face and maybe collection of fingerprints for "fast" identification);
- preliminary analysis of evidence with high priority in urgent cases at the crime scene (e.g., in a glove-bag);
- decontamination of the scene or reduction of any risk at the scene.

Technical **requirements:**

Robot legs: track system (caterpillar) is not useful (destroying evidence, can contaminate the scene and difficult to decontaminate it). E.g., spider type robots would be good:

- small surfaces of legs will touch contaminated areas;
- less chance to destroy trace evidences;

- the detector on the abdomen can move close to the surface (e.g. for surface contamination measurement: alpha-beta-gamma contamination);
- capable of different heights: it can lift its abdomen over objects.

Visual recording:
- 3D laser with immediate distance measurement (during robot movements the distance of each object relative to the robot can be seen – online image processing);
- height-adjustable photo angle (“craning”);
- special camera can be applicable for trace and evidence recording;
- using extra light (assist illuminator in the range of infrared to UV).

Evidence/trace and latent evidence search – equipment for the robot platform:
- application of special forensics light (forenscope, handsope, etc.) for optical evidence search;
- high quality picture sending system to the crime scene manager/operational; commander to help to decide whether the evidence can be collected by a robot;
- use fibreoptic camera.

Trace evidence collection:
- development of special fast tests and special, disposable, simple, cheap kits for sampling;
- using a small air sampling system with special filter for collection of micro-traces and smell remains;
- swipe/swab sampling kit;
- Dead body search equipment using air sampling and measurement.

Technical **challenges:**

- how long can work a robot in extreme radiation dose environment (what is the limitation in dose)?
- Physical size, how big/high can the robot be? (searches on surfaces on high lying, like ceiling – and: search in deep, hidden places, like under a couch, or search on the walls);
- carrying capacity;
- using of artificial intelligence can be used for latent trace evidence search;
- manipulation via the robots: remote control (operator/investigator using remote control to manipulate with the robots at the scene – like in the reality: the robot is his/her hands);
- robots and devices should be decontaminated (self-decontamination?).

5.2.4 Support via robots carrying measurement devices and other equipment for RN crime scene

In the case of RN threats present at the crime scene, probably the most likely situations when robots would be required are related to high gamma-ray activity, source fragments or spread contamination that causes significant external radiation hazard for investigators. Another situation where the use of robots could be advantageous is related to airborne activity levels (e.g. alpha activity). The use of robots could significantly reduce the risk of incorporation (primarily via inhalation) of alpha activity for the deployed forces.
Generally, robotics should be deployed in order to reduce the total radiation dose (internal and external) to deployed forces. In addition, due to health and safety considerations, robotics should be deployed to reduce the time spent by deployed forces.

Actions that would contribute to improving the crime scene work are e.g., the use of remote manipulators to support the radiation protection of deployed forces. More precisely a robot is used to collect a dangerous source or high activity fragments of it and place them inside a proper radiation shielding. While doing such work, a capability for at least robot-based dose-rate measurements would be important.

Furthermore, methods should be employed that improve the speed and simplicity of secure data transfer from the scene to the crime scene management, to the incident commander, and to the reachback capacity (also known as "expert support"). Methods should be used to improve documentation and to reduce the volume of evidence that must be removed from the scene for transport to the laboratory.

Different types of RN measurement and monitoring payloads should be developed for robots. During the early phase of an incident, while other threats have not yet been excluded, robots could also be used for the collection of initial RN information. In case of inadequately shielded dangerous gamma-ray sources, spectrometric measurements could be conducted from stand-off distances. These measurements could be used for nuclide identification, source localization, analysis of source shielding and activity estimation. Such information is very important when planning the next steps. While moving the robot near the source, dose rate measurements are enough. A surface contamination meter that can be used with the manipulator may also be considered, also swipe (smear) tests may be needed in order to confirm contamination (depending on other external radiation fields). A swipe test must be agreed to by the police investigators, as swipe tests have the potential to destroy other evidence.

Notice that, if the situation is still unclear after the initial radio-assay and the presence of surface contamination cannot be excluded, very careful robot manoeuvres are required, for instance if the robot is directly driven next to the leaking source, it can become heavily contaminated. Due to this self-contamination, the robot cannot be used for RN mapping anymore and has to be decontaminated. Also, while moving around, the robot might be spreading the contamination. Notice that most sensors are quite easy to protect from contamination, so it is mainly the robot that needs to be decontaminated before further measurements can be performed.

5.3 Requirements for testing of robotic equipment to be used in radiological crime scene management (RCSM)

The main requirement for testing is the ability to run through the specific task that the robot is to carry out in a suitable environment. For the basic radiological crime scene scenario this would be an enclosed room with open and sealed radioactive sources positioned within it. The use of open sources requires careful consideration, as for some tests non-radioactive material can be used as a replacement (for example contamination replacement products - e.g., UV fluorescent powder or paint, X-ray sources). While planning the following test requirements the potential presence of other than RN-threats was excluded.

5.3.1 Robotic tasks for basic scenarios

In a typical robot-scenario, the room should contain at least one dangerous gamma-ray source that prevents the human intervention (causing external radiation fields that would prevent or restrict the deployment of personnel). The decision to use a robot is based on the high dose rate measured previously outside the room. To minimize the radiation dose received by the deployed persons, a robot will be employed for the collection of further RN information using a spectrometric detection instrument (**first robotic task**). In case other threats in the room would not have been excluded, this robot-based radiation surveillance operation would be even more justified. The goal of these measurements performed outside the room are to identify the main radioactive nuclides in the room, provide some position information related to them, analyse potential radiation shields around them, and estimate associated activities. Here the key components influencing the quality of the analysis results are the spectra collected and the associated position information. This will depend upon the type of detection instrument used; spectrum statistics and overall quality: the measurements should not be made too far or not too close, optimal count rate range depends on the characteristics of the specific instrument used.

The **second robotic task** takes place in the room. The robot needs to enter the room in order to localize and image the irradiating objects without touching them. Analysis results from the first task can and should be used while planning the actions during the second task. After completing the second task, the real sources could be replaced with surrogate ones.

The **third robotic task** would be to collect the surrogate objects and move them into transport containers without breaking them. Task three actions should be documented. Notice that the shielding containers required may also be transported by the robot.

The ALARA principle should be implemented in order to find the lowest activity possible that still would give suitable results for the specific task to be tested.
The number and position of the sources could be varied to obtain data on the limits of the equipment. Notice also that one high activity source effectively masks several lower activity sources. Therefore, above tasks may need to be repeated multiple times. Time constraints would be introduced incrementally in order to test the response times.

From a regulatory point of view this would mean that, if the location of the testing site was fixed, the site operator would need to have access to a selection of suitable alpha, beta, gamma and neutron sources. The use of open sources requires careful consideration. The site operator should hold the relevant permits and perform the necessary quality assurance for the sources to use them for testing purposes (see RN regulatory requirements for testing of robotic equipment).

5.3.2 Testing in advanced scenarios

The basic scenario can be expanded in several ways that would change the requirements for robots carrying measurement devices and change the testing conditions.
An example of a possible expansion of the basic scenario is given in Annex E in the form of information injects and open questions. Annex E itself can be expanded upon and adapted to a Member State’s threat assessment, as necessary.

Some further examples are:

- Crime scene in the open, perhaps spread over a wide area;
- Crime scene in a larger enclosed space (e.g. warehouse, flat);
- Crime scene in a room with blast damage / other structural damage, e.g., partly open and the structural integrity must be assessed;
- Sources are placed into more difficult locations in the room, for example, into closets with other objects, making radioactive object identification and documentation in the second task more difficult and also requiring more advanced robotic manipulations in the third task.

5.4 Emerging technologies for RN threats

At the present time, autonomous robotic equipment carrying RN measurement devices are generally not routinely deployed during crime scene work within the EU.
In this section we consider the tasks during RCSM that could be supported by robotic equipment carrying measurement devices for RN threats and the technology required to meet these goals. Research and development in these fields should also consider the end users of the technology (police, firefighters and CBRN expert support), in order to develop robust systems that can be used during real-life deployments.

Although the technology is in wide parts already available, technology transfer for operational use may still be necessary.
Specific tasks during RCSM that could be supported by robotic equipment carrying measurement devices for RN threats include:

- Robotic systems could provide 3D radiation mapping in order to support the crime scene management and the incident commander (e.g., digital site visualisation via online data);
- Robots equipped with stand-off detection techniques could localize and/or image radiation hot-spots without the need for swipe samples (e.g., alpha stand-off detection utilising UV-radiation);
- Robots could work on time consuming tasks (e.g., creating 3D photo documentation) in a hazardous environment and perform multiple tasks at the same time (e.g., 3D laser-scan with a simultaneous check for airborne contamination). This may be necessary due to operational time constraints;
- Artificial Intelligence (AI) combined with robotics could take over the automatic analysis of gamma spectra and of airborne contamination samples, among other automated analysis tasks (however, this cannot replace an analysis thorough a human expert);
- Robotic systems could be used for the removal and manipulation of radioactive sources, fragments of sources or high activity nuclear materials such as spent fuel within the crime scene. Manipulator robots can position shielding to reduce the radiation dose to the deployed forces;
- Robotic systems could also be used for immediate on scene collection of fingerprints and DNA samples from the high activity objects. Among other things, a robotic arm capable for fine mechanical manipulations would be needed. Collecting DNA samples with minimal amount of RN contamination is a preference;
- Virtual Reality (VR) could be combined with a robotic arm for the remote manipulation of evidence in a highly contaminated crime scene or in a mobile glove box. Also, the remote manipulation of radioactive sources could be possible with suitable radiation-hardening of robotic equipment.

The **technology** required to meet the goals of deploying robots during RCSM includes:

- Robotic systems that can be decontaminated and are radiation-hardened (especially cameras) with interchangeable sensors with well-defined data interfaces and open data formats;
- VR systems for controlling manipulators equipped with RN detectors that can also select and move pieces of evidence and support their analysis;
- Specialised sensors: measuring the radiation dose, gamma spectrometry (including high-energy gamma detection for neutron-gamma reactions), imaging detectors to assess contamination patterns in a non-destructive manner and locate radiation sources, monitoring air contamination, measuring distance, 3D laser scanning, etc.;
- Data transfer over a standard interface to enable remote situation visualisation with 3D mapping combined with radiation mapping in real-time for the continuous hazard assessment.

Research and development in these fields should consider the end-users of the technology (police and CBRN experts), in order to develop robust systems that can be used during real-life deployments. One should aim for functional/modular robot structures where modular equipment can be changed based on the purpose of the activity, i.e., different modules can be used and changed on the robot platform (e.g., only detectors or evidence collection kits or evidence transport outside, etc.). It may be necessary for the modules to be replaced at the scene. Another possibility is a second assistant unit/robot which can transport and replace the modules on the main robot platform.

5.5 Standardization needs in the Member States

Robots in CSM are used to different degrees in different EU Member States (MS). There is a clear need for unification of standards for crime scene management and of equipment to be employed. Therefore, it is a need for demonstration and training facilities in which organizations from the MS can test and train with their equipment, exchange views and share best practices in a non-competitive environment. This could lead to a faster and wider spread of the usage of novel technology. One or more central testing and training facilities should be made available for this purpose, using the approach described in this report. There is also a clear need to raise awareness of the very existence of such facilities. In particular, the need for support through robots in radiological crime scenes has been confirmed by Member States.

From the experience of the joint exercises carried out in Germany (Kroeger 2019) on the topic of RCSM, further specific tasks during RCSM that could be supported by robotic equipment were identified. These tasks do not necessarily require autonomous equipment carrying RN measurement equipment, but are listed here for completeness. Tasks that robotic equipment could carry out include:

- radiation checks and dosimetry, e.g., collecting data, informing or warning deployed forces about received doses;
- support the health and safety of the deployed forces by monitoring air supply, pumps and PPE use, controlling deployment time;
- document the distance and location of equipment and provide an inventory overview;
- check for contamination during crime scene work (e.g., using a manipulator for taking 100cm² swipes);
- Automated double-bagging and labelling of collected evidence and the decontamination of the outside of the evidence bags;
- support the automatic removal of evidence over an air lock;
- AI systems could be used for information and knowledge management and for training purposes;
- 3D scanning and remote printing of pieces of evidence could be carried out by manipulator robots, especially in situations where humans cannot be deployed (the effective 3D scanning of shiny objects is still a technological challenge);
- Robotic systems could support the radiological and conventional survey with infrastructure support (power, data transfer, function as a platform for heavy equipment like gamma spectrometers, neutron detectors etc.).

Robot test requirements need to be developed in detail and documented so that they can be adopted in all EU Member States. This may require the production of an international standard (IEC). However, before this is possible, pre-normative research should be carried out to identify the best test protocols.

5.6 Potential legal/technical obstacles

The major concern regarding the use of autonomous robots during RCSM is that evidence is preserved and not destroyed and/or lost. For example, a ground-based robot could potentially destroy radiation contamination patterns, which should be considered as nuclear forensic evidence, and also traditional evidence (e.g., footprints) on the floor.

A further concern is the documentation of evidence by autonomous robots. For example, before allowing autonomous robots to document a crime scene, the use of the data in court has to be considered, in particular if AI is used to select the search area. In addition, the integrity of the data and the data security are essential considerations before such data collection can be accepted for use during RCSM, as this is part of the chain of custody for evidence.

Autonomous action by the robots in the crime scene has to be balanced by the need to preserve evidence in the crime scene. Autonomous action could also impact documentation of the scene, as an exact record of actions and their impact at the scene may be required.

This is particularly relevant for AI, as the decision-making process is not always transparent and cannot always be reconstructed. For these reasons, some fully autonomous actions will not be possible during RCSM. However, semi-autonomous motion for the completion of separate set tasks could be considered.

It is clear that the impact of introducing these novel techniques at the crime scene need further discussion and one should aim towards a EU standard of best practice at the crime scene.

5.7 Conclusions

This report summarizes the need for and the possible use of robots, and technological systems, in radiological crime scenes in order to assure, in first instance, the safety of personnel employed at the scene, but also to aid in the decision making by gathering important information: site 3D mapping with overlayed RN information is crucial for an efficient RCSM.
Furthermore, the report paves the way for future possibilities to manage a radiological crime scene using robots and to assess the requirements and limitations for testing.

The basic scenarios and testing conditions for a crime scene where RN materials are present is described, and potentially expanded to all CBRNE materials, as elaborated in the Annexes.
The need for unification within the MS of standards for crime scene management and of equipment to be employed at the scene is recommended.

Crime scene investigators and experts should continue to integrate novel measurement equipment, especially for RN detection, into existing robotic systems for crime scene management. It is important to consider the ease of decontamination and radiation-hardening of new or existing robotic systems.

Research and development in these fields should consider the end-users of the technology in order to develop robust systems that can be used during real-life deployments.
The capability developed should be tested at suitable sites, including the need for training and testing with the emerging technologies such as artificial intelligence and virtual reality in connection with the use of robots that mirrors the conditions of a real deployment, for example the one based on the basic scenario set out in this report.

Finally, the potential legal obstacles when using robots and/or AI at a crime scene have to be discussed and procedures that will be accepted in court needs to be defined.

6. Concluding remarks

This document exploited the ability of robots to carry sensors, especially in areas beyond human access, and boosted the operator’s situational awareness and capabilities. This, in turn, is a prerequisite for testing and training, particularly for sophisticated search strategies that can help to map and localise RN agents, but also more broadly to identification, detection, monitoring and manipulation of contaminants across various domains.

The first report started investigating the regulatory requirements in every facility with a comparable radioactive inventory where there should be regulatory controls of (roughly) the same level. Therefore, creating a facility for the testing of robotic equipment in a radiation field or in a contaminated environment would lead to the creation of a designated regulatory regime for this facility, including regular checks of the health fitness of the occupational exposed workers. This is especially important if higher activities of radioactive material are to be used.

Furthermore, the second report pointed out the main tasks for robots and classes of robotic operations in RN missions where unmanned systems can help to reduce the health and safety risks to the action forces. Robots are on their way to revolutionize the process of information gathering and enable unprecedented possibilities of supporting the situational awareness and remote mobile manipulation. In order to reduce the operator workload and extend the current capabilities of remotely operated robotics beyond known frontiers, the use of AI-based automatic and autonomous assistance functions would be of paramount importance.

In addition, simulations for searching RN sources by robotic equipment showed - in the third report - that basic capability testing of the robots can be performed on any large open area which is safe and secure. The simulation results illustrated that some capability tests of robots can be implemented with minimum infrastructure in every EU Member State. These tests can be performed without any need for establishing a dedicated testing facility, providing room for improvement for different and more complex source finding and characterization tests based on end-users’ needs.

Finally, the last report described the need for and the possible use of robots, and technological systems, in radiological crime scenes in order to assure, in first instance, the safety of personnel employed at the scene, but also to aid in the decision making by gathering important information. It paves the way for future possibilities to manage a radiological crime scene using robots and to assess the requirements and limitations for testing, including potential legal obstacles.

To complement the document, robotics systems that could also be used in the broader domain of CBRNE incidents as well as in the field of Civil-Military Cooperation are described in the Annexes, including benchmarking, EU projects and testing initiatives and state-of-art of nuclear forensics.

7. References

Council of the European Union. 1989. "Council Directive 89/618/EURATOM. Official Journal of the European Communities. L 357 (27-11-1989) 31-34." (L):31–34.

Council of the European Union. 1990. "Council Directive 90/641 /Euratom on the Operational Protection of Outside Workers Exposed to the Risk of Ionizing Radiation during Their Activities in Controlled Areas." 1990(L):21–25.

Council of the European Union. 1996. "Council Directive 96/29/Euratom." (L):L159/1-159/114.

Council of the European Union. 1997. "Council Directive 97/43/ Euratom." L(180):22–27.

Council of the European Union. 2003. "COUNCIL DIRECTIVE 2003/122/EURATOM of 22 December 2003 on the Control of High-Activity Sealed Radioactive Sources and Orphan Sources." 8.

Council of the European Union. 2013. "Council Directive 2013/59/Euratom of 5 December 2013 Laying down Basic Safety Standards for Protection against the Dangers Arising from Exposure to Ionising Radiation, and Repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom A." *Off J Eur Commun L13* (December 2003):1–73.

Guerin, Frank and Lauriane Rat-Fischer. 2020. "Benchmarking in Developmental Robotics BT - Metrics of Sensory Motor Coordination and Integration in Robots and Animals: How to Measure the Success of Bioinspired Solutions with Respect to Their Natural Models, and Against More 'Artificial' Solutions?" Pp. 73–86 in, edited by F. Bonsignorio, E. Messina, A. P. del Pobil, and J. Hallam. Cham: Springer International Publishing.

IAEA. 1989. "The Statute of the International Atomic Energy Agency (IAEA)."

IAEA. 2006. "Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1."

IAEA. 2011. "Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control." *IAEA Nuclear Security Series* (15):7.

IAEA. 2014a. "IAEA Nuclear Security Series No. 22-G Implementing Guide Radiological Crime Scene Management." (22).

IAEA. 2014b. "Radiation Protection and Safety of Radiation Sources : International Basic Safety Standards General Safety Requirements Part 3."

IAEA. 2015. "Nuclear Forensics in Support of Investigations." *IAEA Nuclear Security Series* (2-G):1–80.

IAEA. 2016. *Governmental, Legal and Regulatory Framework for Safety*. Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY.

IAEA. 2018. "SSR-6 (Rev.1) - Regulations for the Safe Transport of Radioactive Material." 6.

IAEA. 2019. "Developing a National Framework for Managing the Response to Nuclear Security Events."

ICRP. 2007. *The 2007 Recommendations of the International Commission on Radiological Protection*.

Kroeger, E. A. 2019. "The 11th Joint Annual Crime Scene Exercise,." *ITWG Nuclear Forensics Update* (13):1, 6, 7.

Müller, Vincent. 2019. "Measuring Progress in Robotics: Benchmarking and the 'Measure-Target Confusion.'" Pp. 169–79 in *Cognitive Systems Monographs*.

NATO Civil Emergency Planning. 2014. "Project on Minimum Standards and Non-Binding

Guidelines for First Responders Regarding Planning, Training, Procedure and Equipment for Chemical, Biological, Radiological and Nuclear (CBRN) Incidents: Guidelines for First Responders to a CBRN Incident." (August):1–16.

Nordisk Kernesikkerhedsforskning, Roskilde (Denmark). 1997. *RESUME 95 Rapid Environmental Surveying Using Mobile Equipment*. Denmark.

NORMLEX. 1960. "C115 - Radiation Protection Convention, 1960 (No. 115)."

ONU. 2019. *UN Model Reg Vol 1 - Recommendations on the Transport of Dangerous Goods – Model Regulations Volume I*. Vol. Volume I.

Owen, Robert, Great Britain, Parliament, and House of Commons. 2016. *The Litvineneko Inquiry: Report into the Death of Alexander Litvinenko*.

Schneider, Frank E. and Bastian Gaspers. 2015. *Survey on the Use of Robots / Unmanned Systems in Scenarios Involving Radiological or Nuclear Threats ERNCIP Thematic Group for Radiological and Systems in Scenarios Involving Radiological or Nuclear Threats*.

Schneider, Frank E., Bastian Gaspers, Kari Peräjärvi, and Magnus Gårdestig. 2015. *Current State of the Art of Unmanned Systems with Potential to Be Usedfor Radiation Measurements and Sampling: ERNCIP Thematic Group Radiological and Nuclear Threats to Critical Infrastructure Task 3 Deliverable 1*.

Strahlenschutzgesetz - StrlSchG. 2018. "Act on the Protection against the Harmful Effect of Ionising Radiation (Strahlenschutzgesetz - StrlSchG)." 1–195.

StrlSchV, Strahlenschutzverordnung-. 2018. "The Amended Radiation Protection Ordinance (StrlSchV)." *TU Technische Ueberwachung* 43(1–2):38–41.

UNSCEAR. 2021. *UNSCEAR – Report 2020 on Sources, Effects and Risks of Ionizing Radiation*.

List of abbreviations and definitions

2/3D	2/3 Dimensional
ADR	European Agreement on Carriage of Dangerous Goods by Road
AI	Artificial Intelligence
ALARA	As Low as Reasonably Achievable
ANSI	American National Standards Institute
AR	Augmented Reality
BfS	Federal Office for Radiation Protection
BSS	Basic Safety Standards
C	Celsius
C3I	Command, Control and Communications Interface
CB	Chemical and Biological
CBRN	Chemical, Biological, Radiological, Nuclear
CBRNE	Chemical, Biological, Radiological, Nuclear and Explosives
CIMIC	Civil-Military Cooperation
Cps	Counts per second
CPU	Central Processing Unit
CsI	Caesium Iodide
CSM	Crime Scene Management
D	Distance
DARPA	Defense Advanced Research Projects Agency
DIN	Deutsches Institut für Normung
DNA	Deoxyribonucleic acid
DR	Doserate
DU	Depleted Uranium
EC	European Commission
EDA	European Defence Agency
EnRicH	The European Robotics Hackathon
EOD	Explosive Ordnance Disposal
ERNCIP	European Reference Network for Critical Infrastructure Protection
EU	European Union
EURON	European Robotics Network
FKIE	The Fraunhofer Institute for Communication, Information Processing and
GEM	Good Experimental Methodology
GM	Geiger Müller
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GSR	General Safety Requirements
HASS	High-Activity Sealed Radioactive Sources
HAZOPER	Hazardous Materials Incident Response Operations
HEU	Highly Enriched Uranium
HPGe	High-Purity Germanium
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICRA	International Conference on Robotics and Automation
ICRP	International Commission on Radiological Protection
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMDG	International Maritime Dangerous Goods Code
IOP	Interoperability Profile
IRIX	International Radiological Information Exchange Format
IROS	Intelligent Robots and Systems
ISO	International Organization for Standardization
IST	Information Systems Technology
JRC	Joint Research Centre

kml	Keyhole Markup Language
LAN	Local Area Network
Lat	Latitude
Long	Longitude
MORC	Material Out of Regulatory Control
MS	Member States
MSA	Manned Site Assessment
NaI	Sodium Iodide
NATO	North Atlantic Treaty Organisation
NIST	National Institute of Standards and Technology
NORM	Naturally Occurring Radioactive Material
NPP	Nuclear Power Plant
OCU	Operator Control Unit
PPE	Personal Protective Equipment
R&D	Research and Development
RAS	Robotics and Automation Society
RAV	Robotic Aerial Vehicle
RCSM	Radiological Crime Scene Management
RDD	Radiological Dispersal Device
RED	Radiological Exposure Device
RID	Regulations on the International Carriage of Dangerous Goods by Rail
RN	Radiological and Nuclear
ROS	Robot Operating System
RSS	Robotics Science and Systems
RTG	Research Task Group
RGV	Robotic Ground Vehicles
SIG	Special Interest Group
SIMO	Software simulation
SME	Small and Medium-sized Enterprises
SNM	Special Nuclear Material
SSR	Specific Safety Requirements
STANAG	Standardization Agreement
TC	Technical Committee
TG	Thematic Group
US	United States
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UCS	Unmanned Control System
UGS	Unmanned Ground System
UGV	Unmanned Ground Vehicle
UK	United Kingdom
UMS	Unmanned Mobile System
UN	United Nations
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USB	Universal Serial Bus
UV	Ultra Violet
VR	Virtual Reality
WiFi	Family of wireless network protocols
YCB	Yale-CMU-Berkeley

Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE) Material is used as an umbrella term for chemical, biological, radiological, nuclear and explosive agents in any physical state and form, which can cause hazards to the populations, territory or forces. It also refers to the chemical weapons precursors, and facilities, equipment or compounds that can be used for development or deployment of CBRNE weapons or CBRNE devices.

CBRNE Threat refers to the threat of CBRNE weapons, CBRNE devices or release of CBRNE materials.

CBRNE Event refers to any realisation of a CBRNE threat.

CBRNE Reachback is defined as a process by which deployed forces may be provided with timely, coordinated, authoritative and detailed advice on CBRNE hazards and defensive countermeasures, drawing upon remote expert sources of information. Effective CBRNE reach back should support the whole spectrum of response to proliferation, protection and recovering.

Radiological crime scene is a crime scene is any place connected to a police investigation where police need to secure relevant evidence that could be used in a court of law. A radiological crime scene is a crime scene in which a criminal act or intentional unauthorized act involving nuclear or other radioactive material has taken place or is suspected.

Radiological crime scene management (RCSM) is the process used to ensure safe, secure, effective and efficient operations at a crime scene where nuclear or other radioactive material are known, or suspected, to be present.

Dose limitation: in planned exposure situations, the sum of doses to an individual shall not exceed the dose limits laid down for occupational exposure or public exposure. Dose limits shall not apply to medical exposures.

Absorbed dose: denotes the dose averaged over a tissue or an organ. The unit for absorbed dose is the gray (Gy) where one gray is equal to one joule per kilogram: 1 Gy = 1 J kg-1.

"**becquerel**" (Bq): is the special name of the unit of activity. One becquerel is equivalent to one nuclear transition per second: 1 Bq = 1 s-1.

"**sievert**" (Sv): the special name of the unit of equivalent or effective dose. One sievert is equivalent to one joule per kilogram: 1 Sv = 1 J kg-1.

A_1: activity limit for the use of Type A packaging when shipping special form radioactive material.

A_2: activity limit for the use of Type A packaging when shipping radioactive material in open form (not special form).

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Annexes

The Annexes provide more comprehensive test methods and criteria for assessing capabilities, performances and operational aspects of robotic equipment, including more advanced airborne contamination scenarios for CBRNE applications.

Annex A - Benchmarking for robotics

There are many competitions in robotics where their performance and skills are evaluated and compared with each other (e.g., RoboCup leagues) and challenges (e.g., the multiple DARPA or euRathlon challenges). However, there is nearly any accepted standards on how the benchmarking should be done. ISO/TC299 has six working groups to investigate this but their work is not finished[21]. Also, NIST has been active and launched their proposal for standardized metrics of mobile robot operations.

The US National Institute of Standards and Technology (NIST) is developing a comprehensive set of standard test methods and associated performance metrics to quantify key capabilities of emergency response robots[22]. The focus is on urban search and rescue operations. There are no special test criteria list for EOD robots. NIST is acknowledging importance of international competitions in developing standard test metrics. In particularly the RoboCup Rescue Robot League has played a critical role[23]. More recently NIST has also been active on UAV side where their interest was mainly on lifting capacity versus duration of flight[24].

Benchmarking is recognized to be essential to guarantee quality of scientific robotic papers. A very long series of workshops (more than 20) at various IROS, ICRA and RSS has debated the related issues and proposed examples of reproducible experiments and measurable results. In 2008 the European Robotics Network (EURON) started a Special Interest Group on Good Experimental Methodology and Benchmarking, the following year within IEEE RAS the TC Pebras was started. In 2012 the EUROM GEM SIG led to the establishment by euRobotics aisbl of the Topic Group on Replicable Robotics Research, Benchmarking and Competitions[25].

Yale University[26] has proposed a suite of task-based benchmarks for robotic manipulation. The test suite contains of 77 objects and can fit in a suitcase. The idea is that the objects are incorporated into several benchmarking tasks and a robot's performance is measured depending on which tasks it can successfully complete.

Also, robot benchmark[27] offers a series of robot programming challenges that address various topics across a wide range of difficulty levels. These benchmarks are provided for free as online simulations[28].

Another kind of approach is from the Robotics and Autonomous Systems Group in collaboration with the Queensland University of Technology who has created a benchmark

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[21] https://committee.iso.org/home/tc299

[22] https://www.nist.gov/el/intelligent-systems-division-73500/standard-test-methods-response-robots

[23] https://rrl.robocup.org

[24] https://www.nist.gov/el/intelligent-systems-division-73500/standard-test-methods-response-robots/robot-competitions-1

[25] http://www.heronrobots.com/EuronGEMSig/gem-sig-events

[26] https://phys.org/news/2016-11-standard-robotics.html

[27] https://robotbenchmark.net/

[28] http://robobench.net

for simulated manipulation[29]. The benchmark allows comparison of simulators to the real world. (Müller 2019) argues that a focus on benchmarking can be a hindrance for progress in robotics. His conclusion is that we need a balanced approach with sophisticated benchmarks, plus real-life testing and qualitative judgment.

The EUROBENCH project[30] aims to create the first unified benchmarking framework for robotic systems in Europe. This framework will allow companies and/or researchers to test the performance of their robots at any stage of development. The project is mainly focused on bipedal machines, i.e., exoskeletons, prosthetics and humanoids, but aims to be also extended to other robotic technologies.

Finally, the solution (Guerin and Rat-Fischer 2020) has proposed is to benchmark developmental robotics efforts against human infant capabilities at various ages.

Annex B - Civil-Military cooperation, robotics and standards in CBRNE domain

Traditionally in complex emergencies, military forces have been involved in HAZOPER, including provision of relief and services to the local population. At the same time, due to the changing nature of modern complex CBRNE incidents, the civil emergency services have faced increased operational challenges as well as greater risks and threats for their personnel in this field. These developments, together with cases of military HAZOPER interventions, have – in some countries – also led to a relaxation of the separation between the civil and the military CBRNE domains. These developments necessitate increased communication, coordination and understanding between civil agencies and military bodies.

Intelligence and information sharing, including the furnishing of CBRNE Reachback capabilities, are absolutely crucial in these scenarios. Comprehensive information gathering and consistent assessment is an essential aspect of HAZOPER intelligence and CBRNE Reachback. It encompasses operational or tactical detection and characterisation of CBRNE threats, characterisation of the theatres and forensic attribution.

The seamless real-time data exchange between all involved entities is the core exigency. It is essential for the success of these missions and ensuring health and safety for every engaged body. This can only be achieved by thorough standardisation through all organisations, levels and assets.

In the military domain there are a number of well-established standards with regards to CBRNE reporting and payload integration. The most widely used two standards come from the NATO:

1. Stanag 2103: Warning and Reporting and Hazard Prediction of Chemical, Biological, Radiological and Nuclear Incidents[31];
2. Stanag 4586: Standard Interfaces of UAV Control System (UCS) for NATO UAV Interoperability[32].

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[29] https://research.csiro.au/robotics/manipulation-benchmark/

[30] http://eurobench2020.eu/

[31] https://standards.globalspec.com/std/14352759/STANAG%202103

[32] https://www.lockheedmartin.com/en-us/products/cdl-systems/stanag-4586.html

In the civil domain there are only a few CBRNE standards which are mostly not well established and only applicable to one of the CBRNE segments. The RN sector has, by far, the most accepted standards from CBRNE. Typically used and implemented are:

3. IEC 63047: Nuclear instrumentation - Data format for list mode digital data acquisition used in radiation detection and measurement[33];
4. IEC 62755: Radiation protection instrumentation - Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials[34];
5. IRIX: International Radiological Information Exchange (IRIX) Format[35].

With regards to mobile robotics or unmanned systems the number of available standards in this field are even more limited. The following two standards are towards interoperability rather than CBRNE and therefore focusing more on the civil-military cooperation (CIMIC) aspect:

6. Stanag 4818: Unmanned Ground Vehicle Interoperability Profiles, IOP[36];
7. ROS: Robot Operating System[37].

These seven standards build the foundations for a CBRNE robotics system that could be used in a multi-national CIMIC context, ensuring interoperability on multiple levels.

Annex C - European Robotics Hackathon: robotics standards for testing in RN domain

To facilitate R&D and standardisation of robotic equipment in RN domain, the FKIE[38] (as part of the ERNCIP RN TG) together with the Austrian Armed forces[39] have created the European Robotics Hackathon (EnRicH)[40]. EnRicH is the world's first and only robotics trial that provides pure and unspoiled real-world scenarios for testing. It provides a full-blown Hazardous Materials Incident Response Operations (HAZOPER) including finding real radiation sources, mapping challenging environments and manipulating radioactive material.
Designed and guided by practitioners, made for the users, the industry and the R&D sector. As a true European event it is fully devoted to open-sciences and open-research and as such compliant with the EU policies.

For the ERNCIP RN TG this event is the perfect opportunity to test and promulgate the findings and developments of the group. In order to illustrate the CIMIC aspect, a NATO Research Task Group concerned with interoperability was invited to support the experiment. The NATO IST/RTG-179 on "Interoperability for Semi-Autonomous Unmanned Ground Vehicles"[41] was the perfect match since it makes heavy use of the identified military standards in conjunction with unmanned ground systems for CBRNE missions.

To show the potential in using the beforehand mentioned standards (see Annex B), the JRC site in Geel developed a RN demonstration device from off-the-shelf components. Goal

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[33] https://webstore.iec.ch/publication/28999
[34] https://webstore.iec.ch/publication/65526
[35] https://www.iaea.org/publications/12257/international-radiological-information-exchange-irix-format
[36] https://apps.dtic.mil/sti/pdfs/ADA554246.pdf
[37] https://www.ros.org/
[38] https://www.fkie.fraunhofer.de/en.html
[39] https://www.bundesheer.at/english/index.shtml
[40] https://enrich.european-robotics.eu/
[41] https://www.sto.nato.int/Lists/test1/activitydetails.aspx?ID=16750&Source=https%3A%2F%2Fwww%2Esto%2Enato%2Eint%2FPages%2Factivitieslisting%2Easpx&IsDlg=1

was to provide and test an open-source solution for encoding and decoding binary IEC 63047[42] messages. The RN demonstration device consists of a single-board computer, a spectrometric radiation detector and a Global Navigation Satellite System (GNSS) receiver (see Figure 28).

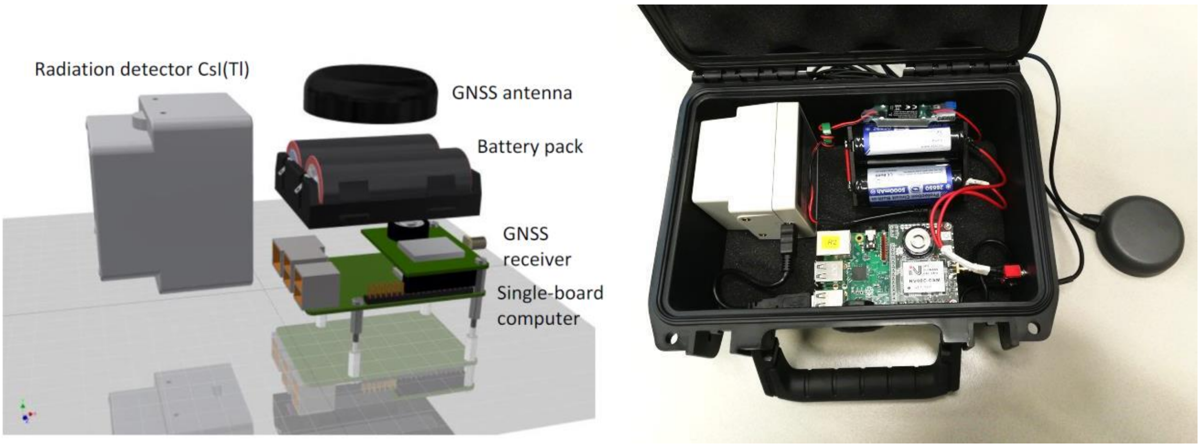

Figure 28. Components of the IEC 63047 (demonstration device)

The FKIE, as part of the ERNCIP RN Robotics subgroup, developed a comprehensive software interface between IEC 63047[43], Stanag 2103[44], Stanag 4818[45] and the Robot Operating System[46]. Tests performed at the JRC site in Geel assessed the performance of the demonstration device in laboratory and under simple field conditions. The FKIE then successfully integrated the demonstration device and the software interfaces on one of their land robot systems.

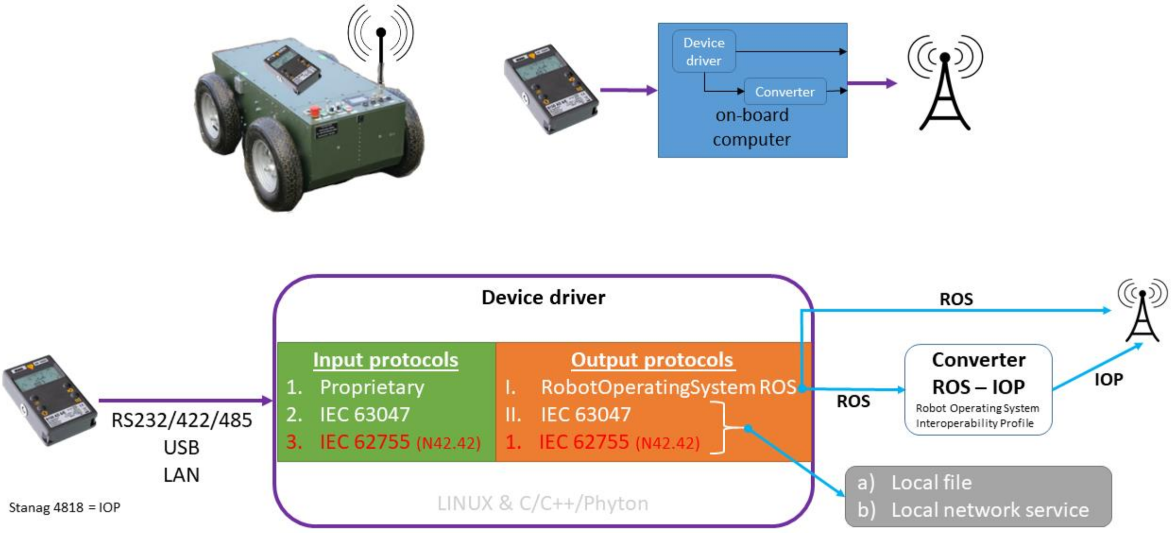

Figure 29. Robot based set-up and implemented communication standards

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[42] https://webstore.iec.ch/publication/28999
[43] https://webstore.iec.ch/publication/28999
[44] https://standards.globalspec.com/std/14352759/STANAG%202103
[45] https://apps.dtic.mil/sti/pdfs/ADA554246.pdf
[46] https://www.ros.org/

The RN detector, in this case the JRC demonstration device, is connected through its hardware interface to the local computer on the robot. All data from the device to the computer is transmitted using IEC 63047. The local device driver encapsulates the data into either ROS or Stanag 4818 (IOP) and transmits it over a radio link to the robot control centre or handheld operator control units (OCU) (see Figure 29). In the robot control centre, there is the possibility to provide the received data in the formats IEC 63047 and Stanag 2103. The interfaces for IEC 62755, Stanag 4586 and IRIX are subject to future development. All data streams are distributed thorough LAN, WiFi or USB (see Figure 30).

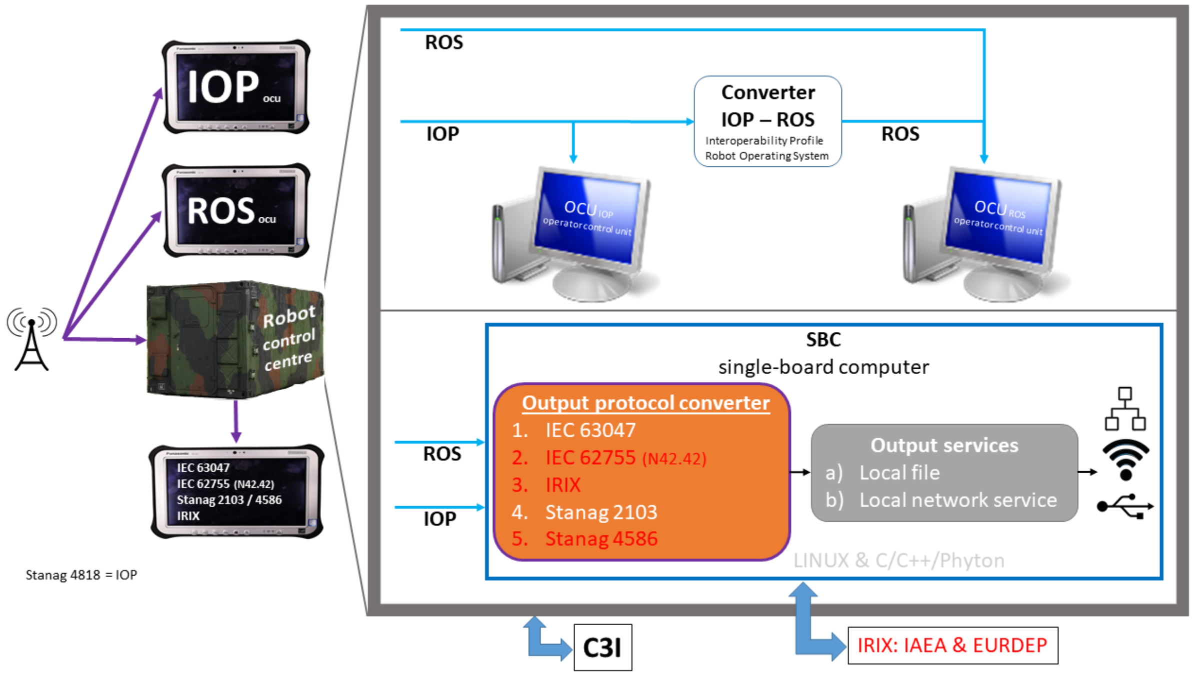

Figure 30. Control station-based set-up and implemented communication standards

The whole system took part in the European Robotics Hackathon 2019 in Zwentendorf, Austria. While the robot was autonomously exploring the NPP on the search for unknown radiation sources the detector data coming from the robot mounted devices was streamed over the radio link to the operator control unit. The streams were also transmitted over the Internet to three additional OUCs, one located in the U.S., one in Poland and one in Norway. Examples of the trial can be found on Flickr[47] and YouTube[48] (including Sections 3.2.1, 3.2.2, 3.2.3). At the OCU the incoming data was recorded on two separate USB flash drives. One receiving the IEC 63047 stream for the JRC-Geel / ERNCIP RN TG and second receiving the Stanag 2103 stream for the NATO RTG-179. After the trial both groups verified the conformity and consistency of the recorded data streams. The capability concept demonstrator delivered accurate results, showing that the demonstration device as well as the chosen standards and implementation for data transmission are a feasible approach for radiological and nuclear robotics CIMIC applications on a multi-national level.

Annex D - State-of-the-art RCSM

Since years, the International Atomic Energy Agency (IAEA) have back taken several actions in order to define and structure safe handling of RN material in all situations. There are several documents (IAEA 2014a, 2015, 2019) where one tries to foresee different scenarios where RN material can be released to the environment. Intentional release, like

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[47] https://www.flickr.com/photos/europeanrobotics/sets/72157711886365193/

[48] https://youtu.be/Q2vBS354iJo

sabotage, theft or terror actions or other criminal actions, one has also to deal with radiological crime scene management. In this Annex a short summary of what is more related to the main reference report (see Use of robotic equipment at RN crime scenes) is presented.

Following the definition of the International Atomic Energy Agency (IAEA) a radiological crime scene is a specific crime scene in which a criminal act or intentional unauthorized act involving nuclear or other radioactive material (RN material[49]) has taken place or is suspected. In this context, radiological crime scene management (RCSM) is the process used to ensure safe, secure, effective and efficient operations at a crime scene where RN material are known, or suspected, to be present (IAEA 2014a). However, the scene can be more complex by other factors such as the detonation of explosives with dispersing nuclear or other radioactive material in the environment or presence of chemicals. The radiological crime scene should be managed in a way that considers the possible presence of multiple hazards. Therefore, a common risk assessment including all hazards is required, drawn up by a hazardous materials operation's specialist, a safety specialist in cooperation with the radiological assessor.

The primary goals of a crime scene investigation are to collect and examine evidence in a timely manner in order to develop investigative leads to prevent potential additional crimes, and to identify and prosecute those involved or suspected. Key elements are the careful documentation of the scene and recognition of all relevant physical evidence.

Operating procedures are similar to those used to manage a conventional crime scene but also differ at the same time because of the presence of RN material. Processes should follow the main rules of radiation protection with control of the following elements (IAEA 2014a):

- Time spent in the hazard control areas: personnel at a radiological crime scene may need to limit the time spent within designated areas to protect the health and safety of all on-scene personnel;
- Distance between the evidence contaminated with radionuclides and the individual collecting the evidence in order to limit personnel exposure to radiation;
- Necessity of radiation shielding between the evidence and the individual collecting the evidence. Such shielding may affect personnel's view of items to be sketched, photographed, collected or inventoried, and may restrict personnel's mobility;
- Radionuclide surface and air contamination: to avoid radionuclide incorporation, cross-contamination of samples and to minimize the dispersal (or further dispersal) of radioactive material. It needs access control and decontamination lines, as well as continuous instrumental checking (monitoring of personnel, equipment, evidence collected, etc.);
- Monitoring of individual radiation exposure;
- Crime Scene personnel should be specially trained.

A key and unique factor of RCSM is the need for specialist knowledge of RN materials. Such special expertise could be found at nuclear regulatory bodies, universities, research institutes, and nuclear facilities. The expertise helps to response a radiological crime scene on the proper and safe way, besides might help investigators to formulate questions for prospective witnesses, and understand the relevance of the responses that are received. Specialists can assist law enforcement personnel with information of signs of the presence of RN material (e.g. radiation symbols), how-to-use hand-held detectors and understand measurement data, level, type and proper use of protective equipment, details for transport and specialized storage containers, unusual occurrences of illness or injury suggestive of radiation exposure etc. These kinds of experts can be: nuclear physicists, radiochemists, radiation protection experts and nuclear forensics experts, calling at RCSM

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[49] "RN material" form is not used at IAEA documents. Official definition is: nuclear or other radioactive material. It is used in this document to shorten the text.

procedures radiological assessor. Involving of the expert into the RCSM process is highly essential.
There are interfaces between nuclear security, radiation safety and nuclear or radiological emergency response that need to be considered for the management of a radiological crime scene. In particular, law enforcement operations, radiation protection procedures and emergency response activities should be applied simultaneously and in a coordinated manner at a radiological crime scene. Although during response of a hazardous situation safety (i.e., protection of human life) has priority, in this case it should also be considered that management of a crime scene includes the process of ensuring the orderly, accurate and effective collection and preservation of evidence so that it may be used in the context of legal proceedings (IAEA 2014a).

If a nuclear security event is declared, scene control procedures should immediately be established by first responders and, as applicable, by other competent authorities (see Figure 31).

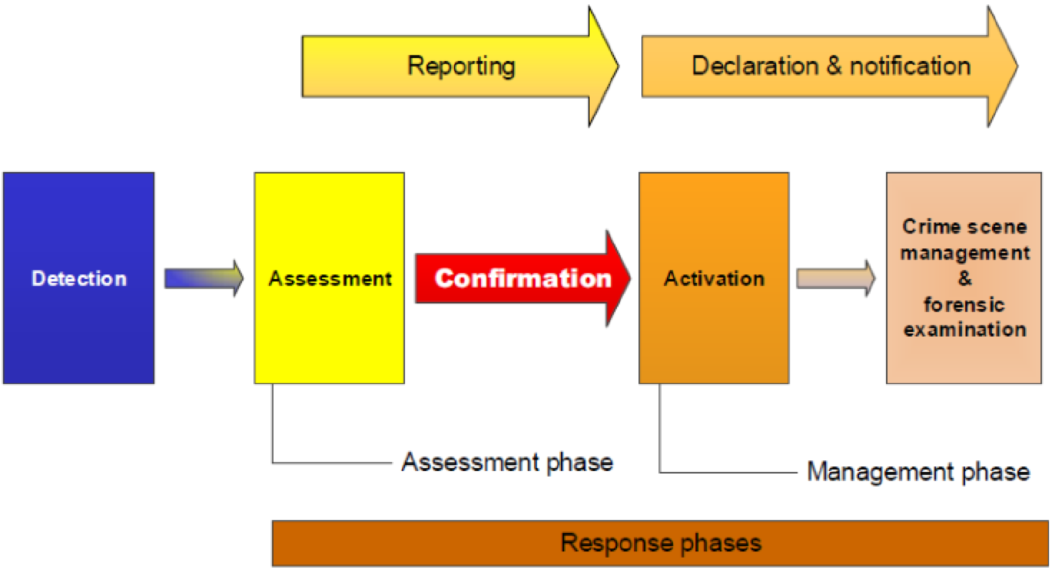

Figure 31. Flow of actions in response to a nuclear security event (source: IAEA, 2014a)

In Figure 32 is schematically shown the coordinated actions to be conducted from the identification and notification of a nuclear security event, to the submission of evidence and subsequent release of the scene.

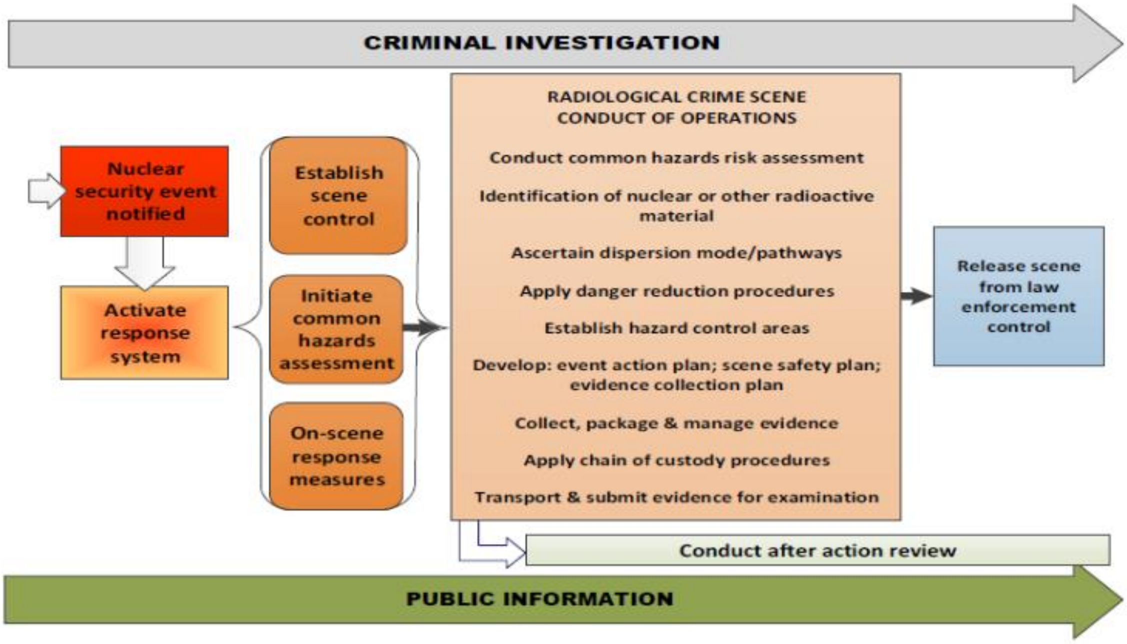

Figure 32. Radiological crime scene conducts of operations (source: IAEA, 2014a)

The initial phase of operations at a radiological crime scene should include an assessment of the risks associated with hazards that might be encountered at the scene. The Scene safety plan contains the following elements:

- Minimizing the number of personnel operating;
- Avoiding physical contact with RN materials or limiting such contact;
- Avoiding or otherwise limiting human passage through areas where nuclear or other radioactive material is present;
- Avoiding radionuclide contamination of persons and equipment;
- Using the ALARA principle: minimizing time, maximizing distance and employing shielding to reduce exposure to radiation;
- Maintaining radio communications among the entry team, backup team and the safety specialist.

In this phase the use of ancillary equipment, like robots can effectively support operations at a radiological crime scene.

Necessary main tools for RCSM:
Radiation detection instruments and dose meters, personal protective equipment (PPE) and ancillary equipment like manipulators, shielding, communication and decontamination tools, equipment for evidence packaging, etc.

Initial entry to the scene:
Initial entry is conducted by personnel whose actions are coordinated with the hazardous materials operation’s specialist, safety specialist and radiological assessor, and such personnel need to wear suitable personal dosimeters and PPE.

Tasks:
- Measuring oxygen and contaminant levels in the air;
- Detecting the presence of airborne and surface contamination to help determine suitable protective measures;
- Measuring levels of gases and vapours;
- Measuring external dose rates to help determine permissible stay times for team personnel as well as to identify locations with high radiation levels;

- Identifying the radioactive material in order to evaluate the risks associated with the specific material;
- Obtaining spectral data to identify isotopic composition.

Radiation search:
It is important to have a scene diagram (sketch) prepared by the scene modeller with indicated exact location of all RN materials with dose and isotope identified, as well as any items of evidence that are recovered.

Forensics evidence management:
RN material present at the scene should be collected to contribute both to evidence gathering and to risk reduction. All evidence should be checked for contamination with radionuclides.

Release of scene:
Once collection of evidence has been completed, the scene may be released from law enforcement control.

Equipment:
The acquisition of equipment for use at a radiological crime scene should be guided by technical specifications that reflect the concepts of operations at such scenes. These specifications should adhere to national or international standards. In determining the technical specifications, account should be taken of the nature of the scenes and types of radiation that are expected to be encountered, as well as functional requirements such as:

- Ability to withstand exposure to environmental factors, such as a suitable range of temperatures, humidity and adverse weather conditions;
- Ease of installation, use, decontamination and removal under expected conditions of deployment;
- Ease of training personnel in use, calibration and maintenance;
- Ability to be sustained (e.g., ease of maintenance, availability of consumables and spare parts).

Periodic exercises should imitate a real situation as closely as possible and should be conducted with all items of equipment intended for radiological crime scene operations.

Use of remotely operated vehicles (robots):
Manipulators and remotely operated vehicles afford a means of limiting the time spent by personnel in the hazard control area and maximizing the distance between individuals and radiation hazards. Remotely operated vehicles can effectively replace human involvement in radiological crime scene operations to, for example, safely conduct the initial entry to a scene, perform radiation surveys and provide surveillance.

Nuclear Forensics:
Nuclear forensics is the examination of nuclear or other radioactive material (RN materials), or of evidence that is contaminated with radionuclides, in the context of legal proceedings under international or national law related to nuclear security. Nuclear forensics is a subdiscipline of forensic science and as such, it is the examination of evidence in the context of international or national law to discover linkages among RN material and people, places, things and events (IAEA 2015).

In the case of nuclear forensics, the RN material collected at the scene is the physical evidence which needs to be examined using different techniques. Due to the fact that also conventional forensic evidences, can be radioactively contaminated, evidence preservation and integrity is highly essential to ensure proper collection, packaging, transport and chain of custody.

It is also highly important to avoid cross-contamination of the samples during collection and packaging. The contamination of evidence with radionuclides may affect the manner and timeliness with which the evidence should be examined. Cross-contamination with radionuclides may alter the radionuclide signature that is the goal of the forensic examination (IAEA 2015). It is important to mention that any decontamination procedures at the crime scene may result in the loss of evidence (also radionuclides) that is important to the nuclear forensic examination. Traces of radionuclides from contaminated surfaces can be collected using different techniques like collection of swipe or swab samples before decontamination of the area for safe response.

Possible sample types and their potential forensic value could be collected during an investigation of a nuclear security event or radiological crime scene management as in Table 5.

Table 5. Sample types that can be collected at a radiological crime scene that could support nuclear forensic examination (source: IAEA, 2015)

Sample Type	**Potential forensic value**
Bulk nuclear or other radioactive material	• Determine unauthorized possession; • Identify possible material origins; • Identify material process history; • Connect cases where the same material was discovered.
Items contaminated with radionuclides	• Identify places where nuclear or other radioactive material has been handled or processed; • Identify additional RN material that may have been previously handled at a location where bulk material was found; • Link those involved or suspected to the material.
Biological samples (i.e., urine, blood, hair and tissue)	• Identify individuals who have handled nuclear or other radioactive material; • Identify individuals who have received an external radiation dose; • Connect individuals to events involving nuclear or other radioactive material.
Environmental or geological samples associated with the nuclear or other radioactive material	• Determine possible smuggling routes or pathways through which the nuclear or other radioactive material was transported.

Analysis and categorization of RN materials is essential already at the crime scene that is part of nuclear forensics examination. Information about the material collected at the crime scene is required in order to determine their proper, safe and secured temporary storage and transport. Besides, it will serve essential information to the nuclear forensics laboratory to be prepared to receive the sample and plan the examination in consultation. First information from the scene is especially important when the analysis is urgent, in order to prevent a secondary event (e.g., a second terrorist attack).

It means radiological crime scene management should provide nuclear forensics starting at the scene already. Proper radiological crime scene management contributes to the success of a nuclear forensic examination. In addition, on-site handling and collection of certain materials (especially nuclear materials, like plutonium) definitely requires the help of a nuclear forensics' expert at the scene.

Type of a Nuclear Security Event:

Potential consequences of a nuclear security event will depend on factors such as the nature of the criminal or intentional unauthorized act involved, the situation at the time the nuclear security event is detected and the nature of the RN material involved. At all times, the main aim should be to prevent any type of nuclear security event from escalating.

There are typical scenarios which can represent generally possible categories of nuclear security event:

Scenario 1: A criminal or intentional unauthorized act leading to dispersal of nuclear or other radioactive material, harmful energy release from a nuclear reaction, or harmful exposure of people to radiation from nuclear or other radioactive material.

There are sub-categories:

- Sabotage of a nuclear facility or nuclear material resulting in a release of energy and/or dispersal of radioactive material.
- Sabotage of an associated facility using or storage of radioactive material or an associated activity (e.g., transport of radioactive material) resulting in dispersal of radioactive material.
- Operation of a radiation exposure device (RED), exposing people in its vicinity to radiation.
- Operation of a radiological dispersal device (RDD) resulting in dispersal of radioactive material by means of explosives or other means of dispersal (e.g., an aerosol generator, via a building ventilation system, manually).
- Dispersal of nuclear material or energy release (and dispersal of radioactive material) from a detonation caused by a fission chain reaction in nuclear material.
- Introduction of radioactive contamination at or into one of the following:
    - A strategic location, such as the venue of a major public event;
    - The food chain;
    - The water supply network;
    - Cosmetic, pharmaceutical or other products used by the public;
    - To cause radioactive contamination or irradiation of a targeted individual in such a way that the impact may be more widespread;
    - Detection of radioactive material out of regulatory control (MORC): at designated and undesignated points of entry and exit or within a State's interior.

Scenario 2: Information alerts are assessed to indicate a credible possibility of a criminal or intentional unauthorized act, but the location of the nuclear or other radioactive material or sabotage, or any planned target, might not be known.

This scenario of a nuclear security event may have moderate to significant consequences for persons, property, society and the environment, but if an information alert concerns, for example, the theft of high enriched uranium or a Category 1 source, it becomes serious.

Sub-categories can be:

- Information indicating planned or attempted unauthorized removal of nuclear or other radioactive material;
- The report of the theft or loss of or missing radioactive material, where the whereabouts of that material have not been established;
- Information indicating planned or attempted sabotage of nuclear or other radioactive material or associated facilities and activities (e.g., transport of radioactive material);
- Information that there is a RED, RDD or fission detonation device in a place where it could cause harm to persons, property, society or the environment and/or disruption;
- Operational information from intelligence services, such as an illicit trafficking warning or information on a known adversary;
- Information on regulatory non-compliance, such as missing material, discrepancies in accounting for nuclear material or in a register of radioactive material, or other unauthorized acts.

The management of a radiological crime scene needs an integrated command structure with clear responsibilities for decision making at different levels. Managing radiological crime scenes is complex, involves multiple competent authorities and may extend across local and national jurisdictions. For well-working and effective, successful response activity is needed to have periodically exercised procedures based on cooperation and involving of multiple competent authorities. It should ensure that all parties understand their roles and responsibilities and can help the preparedness to be ready for effective mobilization of resources. Harmonized work between different agencies and crime scene investigation team is essential for safe and proper RCSM.

Annex E - Expanded scenario on crime scene

The aim of this Annex is to expand the basic scenario on "crime scene", in order have specific details of the scene and to focus on possible challenges.
The text is structured with information along with open questions, allowing first responders or crime scene investigators to imagine the situation. The information injects are designed to be added once the open questions to the last information have been discussed.
The scenario described in this Annex is fictional.

Information Inject 1
An internationally organized criminal group dealing with weapons - explosives and chemical, biological, radiological and nuclear materials - over the so-called darknet, is suspected of having built a radiological dispersal device (RDD) or "dirty bomb". The competent police authority has identified one member of the group. This person lives in a house in a suburb of a large city. There have been information alerts which indicate that the RDD may have been built in the kitchen of the house. The location of the RDD is not yet known.

Open Questions 1
- Which authorities are involved?
- How is a hazard control area and cordon established?
- What health and safety provisions are available for the deployed forces?
- How are robotic systems used to support establishing a hazard control area at present?
- How could robotic systems support and establish a hazard control area in future?
- What problems do you associate with deploying robotic systems for establishing a hazard control area?

Information Inject 2
The house has a ground floor of 100 square metres. The kitchen, on the ground floor, has two windows and one door with an area of 16 square metres. At the preliminary cordon, which is the same as the garden perimeter (between 6 and 20 metres from the outside walls of the house), there is no elevated neutron or gamma dose rate.

Open Questions 2
- How is the initial assessment of the hazards present at the crime scene performed?
- What kind of personal protective equipment (PPE) is used and how is the decision made?
- Is the dose rate of the deployed forces monitored?
- What equipment is deployed during the initial assessment?
- Are decontamination facilities available? Where are they situated?
- How does robotic equipment support the initial assessment at present?
- What ways could robotic equipment be further deployed to support the initial assessment in future?

- Could measurement data (video feed, radiation mapping, etc.) from robotic systems help support the situation assessment and the briefing for deployed forces?
- What problems do you associate with deploying robotic equipment in a crime scene?
- Would the deployment of autonomous robotic systems in a crime scene be possible?

Information Inject 3
The initial hazard assessment shows that there is no RDD present in the kitchen. However, the presence of CBRNE materials cannot be ruled out. The structural integrity of the building is assessed as low risk. Contamination checks on deployed forces / equipment indicate open (non-fixed) alpha contamination. In addition, within the kitchen a maximum gamma dose rate of 200 microSievert per hour was measured close to a closed kitchen cupboard at floor height.

Open Questions 3

- Who is responsible for the decontamination of the deployed forces (in the event that a crime scene investigator comes into contact with open RN materials)?
- Who is responsible for assessing the radiation dose received by the deployed forces?
- How are hazards in the crime scene monitored?
- Are robotic systems used to support the continuous monitoring of radiation and other hazards at present? Could this be possible in principle?
- How is airborne contamination at a radiological crime scene measured at present?
- Is the measurement of airborne contamination performed by a robotic system at present? Would it be possible in principle?
- How is the spread of contamination into the environment prevented?
- Could robotic systems be used to help support the measurement of surface contamination?
- Can forces be deployed in an area with 200 microSievert per hour gamma dose rate?
- Are robotic systems used to position shielding within the crime scene at present?
- What problems do you associate with deploying robotic systems to remove radioactive sources from a crime scene or to position shielding in a crime scene (in particular cross-contamination and the inadvertent destruction of evidence)?

Information Inject 4
In this scenario, the suspect has made written notes and has sent text messages about the RDD planning (e.g., through mobile phones and note books). These devices could contain information about the location of the RDD which can be retrieved. It is unknown if the mobile phones and note books are contaminated with RN material. All the evidence in the police investigation so far indicates that the RDD has been built in the crime scene and transported to a further location. For this reason, finding the location of the RDD is the priority of the police investigation.

Open Questions 4

- Are forces deployed to investigate the mobile phones and notebooks? Could robots assist the collection of this evidence from the scene?
- Are robotic systems deployed to support viewing, documenting and securing the evidence at present? Could robotic systems (for instance remote manipulators) be deployed in principle?
- Are robotic systems used to remove hazardous material that is also evidence, for instance radioactive sources, from the scene at present? Could this be done in principle?
- What challenges do you associate with the use of robotic systems to support crime scene work in a radiological crime scene (in particular cross-contamination of evidence and the inadvertent destruction of evidence)?

Annex F - EU projects and ongoing CBRNE actions

The European Commission has funded several actions to deal with the assessment of different CBRNE safety events that can occur. In this Annex, some of these European projects have been listed as well as their findings and approaches that are more related to radiological crime scene management.

ROCSAFE (2016 – 2019)

Remotely **O**perated **C**BRNe **S**cene **A**ssessment & **F**orensic **E**xamination

ROCSAFE's overall goal was to fundamentally change how CBRNe events are assessed, and ensure the safety of crime scene investigators, by reducing the needs to enter dangerous scenes to gather evidence. Ensure that CBRNe scenes are assessed rapidly and thoroughly, and that forensic evidence is collected in a manner that stands up in court, without putting personnel at risk. Understanding the balance between securing forensic evidence and gaining actionable intelligence is crucial in devising the detail of the remote technology.

End-users highlighted specific issues:

- A piece of evidence, including a sample intended for evidence, needs to be collected by a known person, from a known position at a known time and date, and be identified by a unique identifier;
- It also requires context, meaning where that piece of potential evidence sits in the overall crime scene.

Steps to be taken when introducing remote operation are:

- Make use of cost-effective remotely-controlled robotic air and ground vehicles (RAVs/RGVs) to assess the scene;
- To reduce the crime scene manager's cognitive load, ROCSAFE anticipates a Central Decision Management software and a Command, Control and Communications Interface (C3I);
- When the scene is assessed, RGVs will be dispatched;
- Forensic material will be collected, bagged, tagged, documented, and stored by the RGV.

Images and data should be streamed to C3I, in order to be analysed and displayed on a sophisticated and intuitive interface with maps and video, showing results of analytics and giving readings geographical context.

Hardware needs: Robotic Ground Vehicles (RGV) for Remote Evidence Collection in combination with Robotic Aerial Vehicle (RAV) platform is required to automatically survey the scene and assist the scene commander.

- Lab-on-a-Chip Analyzer;
- Lightweight Chemical Sensor for Robotic Aerial Vehicles;
- Portable and rugged C sensor for RGVs, based on fast Gas-Chromatography;
- Radiation Detector Module integrated with the ground and aerial vehicles. It detects increased levels of gamma radiation and identifies radionuclides.

Software needs: Central Decision Management: Communications, Artificial Intelligence, and Decision Support.

- Propose route planning for teams of robotic aerial and ground vehicles;
- Support the scene commander by coordinating: RAVs and RGVs with cameras and sensors;

- Provide context-aware decision support for assessing the crime scene in an optimal fashion, dispatching coordinated RAVs with appropriate sensor loads;
- Provide innovative artificial intelligence algorithms for data analytics, including deep learning analysis of images, and probabilistic reasoning over time about most likely threats based on evidence.

Virtual Environment for Testing Scenarios:

- built simulations of critical incidents with a 3D physics-based game engine;
- System Integration and Validation;
- The system integration procedure follows a series of steps for every sub-system and assembly: assemble - test - pre-validate - next.

ENCIRCLE (2017 – 2021)

European **C**brn **I**nnovation for the ma**R**ket **CL**uster

To improve its resilience to new CBRN attacks and threats, the EU needs a specialized, competitive, efficient and sustainable industry.

The ENCIRCLE project has developed an innovative approach to reach this goal in a short to long term perspective. It allowed SMEs and large industries to deliver and invest in the best innovations on the market. ENCIRCLE had five key objectives aimed at promoting innovation and business development to fill market gaps in the project.

The main expected impact from ENCIRCLE was the enhancement of the EU CBRN industry's competitiveness. This allowed it to enlarge its market share while increasing the benefits of the EU research and innovation to improve CBRN preparedness, response, resilience and recovery efficiency. ENCIRCLE ran as part of building the cluster, and developed with the ENCIRCLE Dynamic Catalogue a community of 224 registered organisations including 211 Practitioner organisations.

CBRN Gaps and Needs (Over 300) have been identified and reviewed with the practitioner community and a selection of these form the topics for the Part B H2020 SME CBRN calls. The project has identified a considerable number of CBRN-related projects, and 31 of the projects can be found in the catalogue, which also contains 266 tools and innovations.

Key activities for the project have included practitioner workshops, market analysis and investigations into the challenges with integration and interoperability. Networks have been built with the Practitioner networks (e.g. eNOTICE, FIRE-IN, NO-FEAR) as well as standards and procurement initiatives (Stair4Security and iProcureNet).

The project has also addressed sustainability requirements for the project and the cluster. A key objective of the project was to support and facilitate the SME led Part B projects and tools have been implemented such as Business Maturity models so the projects can be monitored and gaps where assistance is required identified.

TERRIFFIC (2018 – 2021)

Tools for early and **E**ffective **R**econnaissance in cb**R**Ne **I**ncidents providing **F**irst responders **F**aster **I**nformation and enabling better management of the **C**ontrol zone

The TERRIFFIC project brought together 10 European organisations, working to deliver an important change in the effectiveness of first responders during the first hours of a Radiological, Nuclear, explosive (RNe) incident.

This leads to reduced response times, less health and safety risks for the response teams, and less human intervention in the operation due to a higher number of automated processes and extended mobile detection capabilities.

After discussion with the end-user community the project started to define the specifications of the TERRIFFIC system, as well as those of each of its components in terms of robustness, endurance, performance, but also the maintenance of operational capability.

The first TERRIFFIC Trial was conducted in April 2019 in Chambéry, France. During the three-day assessment and training field trial, several radiation scenarios were used to challenge the components in both indoor and outdoor environments.

The technical teams will continue to develop and evolve their technologies – both independently and as an integrated system. Subsequent trials, with the ongoing involvement of practitioners, will help to ensure that TERRIFFIC can really make a difference to first responders involved in the initial response to a Radiological, Nuclear, explosive (RNe) incident.

INCLUDING (2019 – 2024)

Innovative **Clu**ster for Radiological and Nuclear Emergencies

INCLUDING connects 15 Partners from 10 EU Member States, bringing together infrastructure, equipment and experts coming from Medical Organizations, Fire Corps, Government Department, Municipalities, Law Enforcement Agencies, Ministries, Governmental and Civilian Research Institutes and Industries operating in the field of radiological and nuclear emergencies.

INCLUDING pursues to develop a Federation in which individual Members will cooperate together to provide a common framework to standardize access to their respective facilities, enhance interoperability and share equipment among users.

The operative tool to manage the Federation will be a web-based platform with a sophisticated architecture and proven functionality. At the same time the project aims to enhance practical know-how and to boost a European sustainable training and development framework for practitioners in the Radiological and Nuclear Security sector.

The INCLUDING project aims to become flexible in order to include new facilities and innovation in technology, organizations and procedures. The plurality of facilities and expertise in the INCLUDING Federation reflects the complex and intertwined structure of the prevention and response phases of RN threats and will provide to the practitioners a set of real or emulated scenarios where to test concept of operations in a controlled environment.

The Joint Actions will be the focal points of the project. They are multidisciplinary field exercises, tabletop exercises, training, serious gaming and simulation organized at their premises by the project partners and with the objective of demonstrating the added value of the Federated scheme and of the use of an innovative tool like the INCLUDING web-based Platform to manage a pan-European network of training facilities and resources.

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