European Commission

Survey on the use of robots/unmanned systems in scenarios involving radiological or nuclear threats

ERNCIP thematic group for radiological and nuclear threats to critical infrastructure
Task 3 deliverable 3

Frank E. Schneider, FKIE
Bastian Gaspers, FKIE

October 2015

The research leading to these results has received funding from the European Union as part of the European Reference Network for Critical Infrastructure Protection project.

Report EUR 27766 EN

Joint Research Centre

Survey on the use of robots/unmanned systems in scenarios involving radiological or nuclear threats

JRC Science Hub
https://ec.europa.eu/jrc

JRC100475

EUR 27766 EN

ISBN 978-92-79-56877-0

ISSN 1831-9424

doi:10.2788/112402

ERNCIP thematic group for radiological and nuclear threats to critical infrastructure

Survey on the use of robots/unmanned systems in scenarios involving radiological or nuclear threats

October 2015

Kari Peräjärvi	STUK	Finland	Coordinator of the thematic group
Frank E. Schneider	FKIE	Germany	Lead scientist for the development of this report

Other main contributors to the report

Bastian Gaspers	Fraunhofer FKIE	Germany

RN thematic group members who also attended the meetings

Per Reppenhagen Grim	DEMA	Denmark
Olof Tengblad	CSIC	Spain
John Keightley	NPL	United Kingdom
Jan Paepen	JRC	EC
Hubert Schoech	CEA	France
Peter Gattinesi	JRC — ERNCIP Office	European Commission
Carl-Johan Forsberg	JRC — ERNCIP Office	European Commission
Harri Toivonen	HT Nuclear Ltd	Finland
Juha Röning	University of Oulu	Finland
Agnieszka Spronska	PIAP	Poland

Related Erncip documents

1. List-mode data acquisition based on digital electronics (EUR 26715)
2. Critical parameters and performance tests for the evaluation of digital data acquisition hardware (EUR 26976)
3. Remote expert support of field teams — Reachback services for nuclear security (EUR 27099)
4. Current state of the art of unmanned systems with potential to be used for radiation measurements and sampling (EUR 27224)
5. Possible scenarios for radiation measurements and sampling using unmanned systems (EUR 27225)

Executive summary

This is the third deliverable of task three of our European reference network for critical infrastructure protection (ERNCIP) thematic group for radiological and nuclear threats to critical infrastructure. This is the only report for this year in this task about remote-controlled radiation measurements and sampling using unmanned systems. We designed questions for a survey with experts from the radioactive and nuclear materials (RN) and robotics communities that we circulated through different channels, such as mailing lists and professional social media groups.
In this report, we present the questionnaire and then discuss the outcome of the survey that we conducted this year to raise public interest in this topic and to get more insight and additional views from experts in this field and related subjects. One further aim was to obtain information from the experts and to bring the different communities of roboticists and RN experts together. We succeeded in getting information from scientists, especially from the robotics community, as they are well represented in the answers, but we lack answers from industries and end-user communities.
Most of the respondents agreed on the scenarios that we identified in 'Possible scenarios for radiation measurements and sampling using unmanned systems' ([1]). About additional sensors, most people suggested including position and time to radiation measurements. The answers on bottlenecks and future topics point to robots' manoeuvrability, autonomy and communication as well as decontamination and human–robot interaction.

([1]) Schneider, F. E., *Possible scenarios for radiation measurements and sampling using unmanned systems*, Luxembourg: Publications Office of the European Union, 2014

Contents

Acronyms

3D	3-dimensional
ANS	American Nuclear Society (United States)
BfS	Bundesamt für Strahlenschutz, (German Federal Office for Radiation Protection)
CBRNE	chemical, biological, radiological, nuclear and explosive
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (French Alternative Energies and Atomic Energy Commission)
CEN	Comité européen de normalisation (European Committee for Standardisation)
Cenelec	Comité européen de normalisation électrotechnique (European Committee for Electrotechnical Standardisation)
CERN	Conseil Européen pour la Recherche Nucléaire (European Council for Nuclear Research)
CSIC	Consejo Superior de Investigaciones Científicas (Spanish National Research Council)
DARPA	Defense Advanced Research Projects Agency (United States)
DEMA	Danish Emergency Management Agency
DIN	Deutsches Institut für Normung (German Standardisation Institute)
DKE	Deutsche Kommission Elektrotechnik Elektronik und Informationstechnik (German Commission for Electrical, Electronic & Information Technologies)
DOVO	Dienst voor de opruiming en vernietiging van ontploffingstuigen (Belgian Bomb disposal unit)
EDA	European Defence Agency
EDEN	End-user driven Demo for cbrNe (PIAP Project)
ELROB	The European Land Robot Trial
EOD	Explosive Ordnance Disposal
ERNCIP	European reference network for critical infrastructure protection (European Commission)
Eurados	The European Radiation Dosimetry Group
Eurathlon	An outdoor robotics challenge for land, sea and air
FKIE	Fraunhofer-Institut für Kommunikation, Informationsverarbeitung und Ergonomie (German Fraunhofer Institute for Communication, Information Processing and Ergonomics)
GIE INTRA	groupement d'intérêt économique INTervention Robotique sur Accidents (French Economic Interest Group for robotics intervention on accidents)
Hazmat	Hazardous materials and items
Hazoper	Hazardous Materials Incident Response Operations
ICRC	International Committee of the Red Cross
IEDD	Improvised Explosive Device Disposal
INFN	Istituto Nazionale di Fisica Nucleare (Italian National Institute for Nuclear Physics)
IRID	International Research Institute for Nuclear Decommissioning
JRC	Joint Research Centre, the European Commission's in-house science service
KHG	Kerntechnische Hilfsdienst GmbH (German nuclear power plant emergency response authority)
LHC	large hadron collider
LiDAR	Light detection and ranging
NERIS	European Platform on preparedness for nuclear and radiological emergency

	response and recovery
NIST	National Institute of Standards and Technology (United States)
NKS	Nordic nuclear safety research
NORM	naturally occurring radioactive material
NPL	National physical laboratory (United Kingdom)
NPP	Nuclear power plant
PIAP	Przemysłowy Instytut Automatyki i Pomiarów (Polish Industrial Research Institute for Automation and Measurements)
RCV	Remotely controlled vehicle
RN	radioactive and nuclear materials
RPAS	Remotely Piloted Aircraft System
RUAG	Swiss defence industry
SAR	Search and rescue
SCK	Studiecentrum voor Kernenergie (Belgian nuclear research centre)
STUK	Säteilyturvakeskus, Radiation and Nuclear Safety Authority (Finland)
TNO	Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)
UAS/UAV	Unmanned aerial vehicle/system
UGV	Unmanned groud vehicle
VDE	Verband der Elektrotechnik Elektronik Informationstechnik (German Association for Electrical, Electronic & Information Technologies)
WMD	Weapon of mass destruction
ZHAW	Zürcher Hochschule für Angewandte Wissenschaften (Swiss University)

1 Introduction

There are several measurement and sampling scenarios that are too risky for humans to carry out. For these scenarios, remote-controlled radiation measurements and sampling using robots need to be developed. The use of remote-controlled devices, such as unmanned ground vehicles (UGV), small size unmanned planes (UAV), unmanned surface vehicles (USV) and unmanned underwater vehicles (UUV), may be more cost effective than the use of manned vehicles or planes. Decontamination of the measurement system and related costs should be taken into account. Situations envisaged for the use of remote-controlled measurement and sampling devices are:

- reactor supervision and related accidents, such as Chernobyl and Fukushima;
- dirty bombs before or after an explosion;
- searching for sources out of regulatory control; as well as
- long-term measurements.

Lessons learned from incidents such as Fukushima and Chernobyl, as well as the decommissioning of old nuclear power plants, show that robots have some advantages. Robots can operate in areas with high radiation or danger of explosives, for example boiling liquid expanding vapour explosions (BLEVEs), collapsing structures, improvised explosive devices (IEDs), booby traps and heat. Additionally, they have the ability to manipulate the environment and to take potentially heavy samples, as they usually have a high payload. Robots can also be used for long-time surveillance of contaminated areas and monitoring the movements of a threat with real-time data from multiple mobile sensors.

Despite the huge potential presented by the use of remotely controlled robots, no standards for sampling or taking measurements have been developed for these systems. The development of such methods could prove to be very beneficial for critical infrastructure protection (CIP). For example, the use of unmanned aerial vehicles to perform standardised measurements of the radioactive plume from a nuclear reactor incident or dirty bomb explosion is of tremendous importance to emergency response personnel. This type of information could be used in atmospheric transport modelling calculations, which are important parts of the decision support systems. This topic therefore contributes to CIP by enhancing in-field operation capability.

The ERNCIP office ([2]) has established a thematic group on the protection of critical infrastructure from radiological and nuclear threats (RN thematic group). The group looks at issues such as certification of radiation detectors, standardisation of deployment protocols, response procedures and communication to the public, for example in the event of criminal or unauthorised acts involving nuclear or other radioactive material out of regulatory control. In short, the focus of the RN thematic group is to advise the European Committee for Standardisation (CEN) and the European Committee for Electrotechnical Standardisation (Cenelec) on standardising formats and protocols used in sending the collected data to enable further analysis. The issue is closely related to the opportunity, opened up by current developments in technology, to utilise remote support of field teams (reachback) for radiation detection.

([2]) The ERNCIP Office operates within the organisational framework of the Institute for the Protection and Security of the Citizen (IPSC) of the European Commission's Joint Research Centre. The institute provides scientific and technological support to European Union policies in different areas, including global stability and security, crisis management, maritime and fisheries policies and the protection of critical infrastructures. The IPSC works in close collaboration with research centres, universities, private companies and international organisations in a concerted effort to develop research-based solutions for the security and protection of citizens. The ERNCIP mission is to foster the emergence of innovative, qualified, efficient and competitive security solutions through the networking of European experimental capabilities. The ERNCIP Office was mandated by the Directorate-General for Migration and Home Affairs of the European Commission.

The RN thematic group works in the following three issues:

1. **List-mode data acquisition based on digital electronics**. The time-stamped list-mode data format produces significant benefits compared to the more conventional spectrum data format. It improves source localisation and allows signal-to-noise optimisation and noise filtering, with some new gamma and neutron detectors actually requiring list-mode data to function. The list-mode approach also allows precise time synchronisation of multiple detectors, enabling simultaneous singles and coincidence spectrometry such as singles gamma and UV-gated gamma spectrometry.

2. **Expert support of field teams**, i.e. data moves instead of people and samples. A fast and high-quality response can be achieved with fewer people. Optimal formats and protocols are needed for efficient communication between frontline officers and reachback centres.

3. **Remote-controlled radiation measurements and sampling using unmanned systems**. There are several measurement and sampling scenarios that are too risky for humans to carry out. Applications envisaged are: reactor and other accidents, dirty bombs before and after explosion and searching for nuclear and other radioactive material out of regulatory control.

This is the third report that deals with item 3, remote-controlled radiation measurements and sampling using unmanned systems. The first two reports on this topic are about the state of the art and about possible scenarios. This year we conducted a survey on this topic, asking stakeholders from the robotics and radiological/nuclear measurements domains for their opinions.

The remainder of this report is organised as follows. First we present the questionnaire itself, along with the letter of intent we used to contact out target group. Then we show the results of the answers we received. Finally, we discuss the results in a conclusion.

2 Questionnaire

The questionnaire was planned for checking (and if necessary raising) awareness of the topic of 'remote-controlled radiation measurements and sampling using unmanned systems' in the RN community as well as the robotics community. Furthermore, we wanted to give interested people from both of these communities the opportunity to get involved, share ideas and give their opinions on some of our ideas. The first part of the survey was about the participants themselves, so that we could sort their answers accordingly. Additionally, we wanted the participants to specify the needs and best practices in their country, if they knew and wanted to share them. Next, we gave them the opportunity to rate and comment on the importance of robots in the scenarios we identified in our report 'Possible scenarios for radiation measurements and sampling using unmanned systems' (3). One important question was on their views on future bottlenecks in this topic.

2.1 Questions and structure

Survey on the use of robots/unmanned systems in scenarios involving radiological or nuclear threats

Fields marked with * are mandatory.

*1 Name
[Free Text]

*2 Email
[Free Text]

Dear Responder,
The European Reference Network for Critical Infrastructure Protection (ERNCIP) is a project run by the Institute for the Security and the Protection of the Citizen, part of the Joint Research Centre of the European Commission. ERNCIP's mission is to foster the emergence of innovative, qualified, efficient and competitive security solutions, through the networking of European experimental capabilities.

(3) Schneider, F. E., *Possible scenarios for radiation measurements and sampling using unmanned systems*, Luxembourg: Publications Office of the European Union, 2014

One of the ERNCIP thematic groups focuses on 'radiological and nuclear threats to critical infrastructure'. To facilitate the work of the group, we are surveying the opinions of key stakeholders concerning the use of robots/unmanned systems in scenarios that involve possible radiological or nuclear threats. The scope of this questionnaire is to survey the current state of the use of robots/unmanned systems, as well as possible future prospects regarding this field.

All information provided will be treated in confidence and will remain anonymous. Data will be processed in bulk and only aggregated data (e.g. in statistics) will be reported. Upon request, we will make the results of this research available to you (please select this option in the relevant question below). Besides, you will find the email address of a contact person should you have any questions regarding the completion of this survey.

All questions are optional. If you do not want to answer a question, please feel free to leave it out.

1. About you

1.1. Which country are you from?
[List of countries to choose from.]

1.2. Which organisation are you from? [(Multiple answers possible.]

	Governmental
	Industry
	Research and development
	End-user
	Other

1.3. Please specify your organisation.
[Free Text]

1.4. What is your field of expertise? [Multiple answers possible.]

	CBRNE
	Robotics/unmanned systems
	Other

1.5. Please specify your field of expertise.
[Free Text]

2. Using robots/unmanned systems in RN scenarios in your country

2.1. Is your country using robots/unmanned systems in RN scenarios?

	Yes
	Yes, but in another organisation
	No, but we are interested
	No (please specify why not)
	Other
	I do not know

2.2. Please specify.
[Free Text]

2.3. Does your country cooperate with other countries regarding using robots/unmanned systems in RN scenarios?

	Yes

	No, but we are interested
	Other
	I do not know

2.4. Please specify.
[Free Text]

2.5. Who in your country could be another valuable point of contact in the field?
[Free Text]

3. Using robots/unmanned systems in RN scenarios in general

3.1. How do you rank the use of robots/unmanned systems in the following scenarios?

	1 (Robots are mandatory)	2	3	4	5	6 (Robots are useless)	no ranking
Spatial mapping of RN sensor data (exploration, change detection, etc.)							
Searching for RN sources (active sensing, isocurves, hotspots, etc.)							
Sampling (air sampling, sweep sampling, material sampling)							

3.2. This PDF describes the abovementioned scenarios for the relevance ranking.
[Link to scenario descriptions as PDF in Annex A:]

3.3. In what RN scenarios would you consider using robots/unmanned systems?

4. Other

4.1. What other data you would like to record/map other than RN sensor data? (i.e. GPS, temperature, 3D-laser, wind, etc.)
[Free Text]

4.2. What are, in your opinion, the hot topics and/or bottlenecks in the next 3 years?
[Free Text]

4.3. Would you be interested in human–robot team competitions/exercises (person(s) working together with robots)?

	Yes, as participant
	Yes, as observer
	No

5. Keep me informed

5.1. Would you like to receive the results of the questionnaire? Then leave your email address here.
[Free Text]

2.2 Recipients

We had different sources for mail addresses and ways of distributing the letter of invitation we used to offer people from the robotics and RN communities the opportunity to fill in the survey forms:

- 50 LinkedIn groups
  mainly robotics (see Annex B:);
- EOD/IED and Hazemat/Hazoper;
- robotics-worldwide mailing list
  world's largest robotics-related mailing list; subscribers: 10 000;
- euRobotics mailing list
  'the' European Commission/European Union robotics mailing list; subscribers: 4 442;
- NERIS network;
- European Reference Network for Critical Infrastructural Protection Inventory
  addresses (manually) extracted from the website above;
- personal contacts connected with robotics;
- Eurados voting members (http://www.eurados.org/en/About/Voting_members);
- DKE German Commission for Electrical, Electronic and Information Technologies of DIN and VDE;
- all persons given in the free text field of question 2.5 'Who in your country could be another valuable point of contact in the field?'.

2.3 Letter of invitation

Dear Sir or Madam,
This email is sent by the European Commission project /European Reference Network for Critical Infrastructure Protection (ERNCIP). For more information about ERNCIP, please see https://erncip-project.jrc.ec.europa.eu. ERNCIP is running a number of so-called thematic groups of experts addressing standardisation and harmonisation of testing in the area of critical infrastructure protection. One of these thematic groups is the radiological and nuclear threats to critical infrastructure thematic group. This group focuses on the following three current issues: (1) list-mode data acquisition based on digital electronics, (2) remote expert support of field teams and (3) remote-controlled radiation measurements and sampling using unmanned vehicles.
We would be very grateful if you could set aside 5 minutes of your time for a survey on the use of robots/unmanned systems in scenarios involving radiological or nuclear threats as soon as possible, and by 16 August 2015 at the very latest please.
Please find further instructions and the survey itself in your language of choice.
Thank you for your support! If you have any questions about this request, please don't hesitate to contact me.

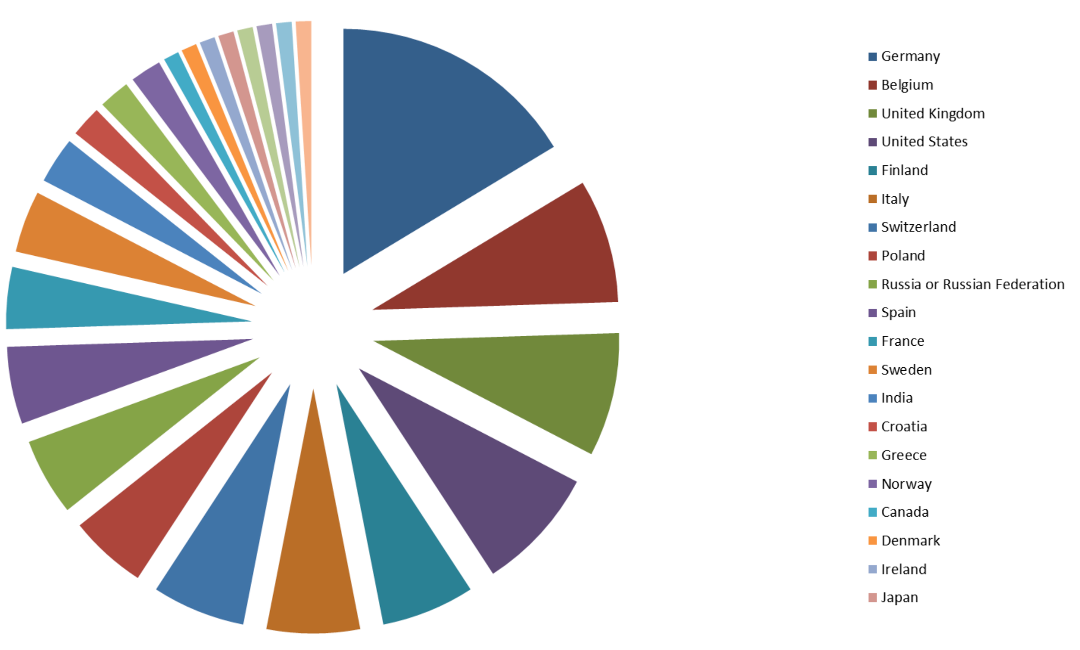
English version:
https://ec.europa.eu/eusurvey/runner/UseOfRobotsInRNThreatsSurvey2015
French version:
https://ec.europa.eu/eusurvey/runner /UseOfRobotsInRNThreatsSurvey2015?surveylanguage=FR
German version:
https://ec.europa.eu/eusurvey/runner /UseOfRobotsInRNThreatsSurvey2015?surveylanguage=DE
Russian version:
https://ec.europa.eu/eusurvey/runner /UseOfRobotsInRNThreatsSurvey2015?surveylanguage=RU

Sincerely Yours
The ERNCIP Office through
Carl-Johan Forsberg

Yes/no and selection answers

Which country are you from?

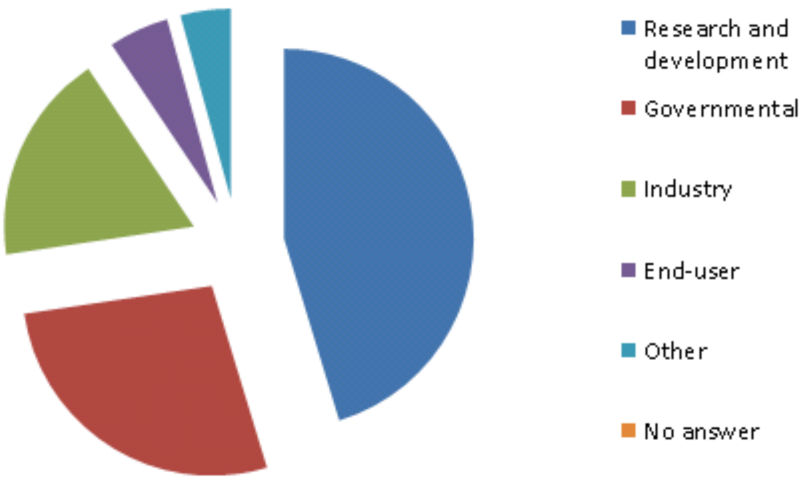
Country	**Answers**	**Ratio**
Germany	16	16.327 %
Belgium	8	8.163 %
United Kingdom	8	8.163 %
United States	8	8.163 %
Finland	6	6.122 %
Italy	6	6.122 %
Switzerland	6	6.122 %
Poland	5	5.102 %
Russia or Russian Federation	5	5.102 %
Spain	5	5.102 %
France	4	4.082 %
Sweden	4	4.082 %
India	3	3.061 %
Croatia	2	2.041 %
Greece	2	2.041 %
Norway	2	2.041 %
Canada	1	1.020 %
Denmark	1	1.020 %
Ireland	1	1.020 %
Japan	1	1.020 %
Portugal	1	1.020 %
Serbia	1	1.020 %
Taiwan or Republic of China	1	1.020 %
No answer	1	1.020 %
Total	**98**	**100.000 %**



Even though France and Russia are countries with a very strong usage of nuclear facilities, the number of returns is disappointingly low given the fact that the questionnaire was translated into French and Russian.

Which organisation are you from? (Multiple answers were possible.)

Organisation	Answers	Ratio
Research and development	53	54.082 %
Governmental	32	32.653 %
Industry	21	21.429 %
End-user	6	6.122 %
Other	5	5.102 %
No answer	0	0.000 %
Total (multiple answers possible)	**117**	**119.388 %**

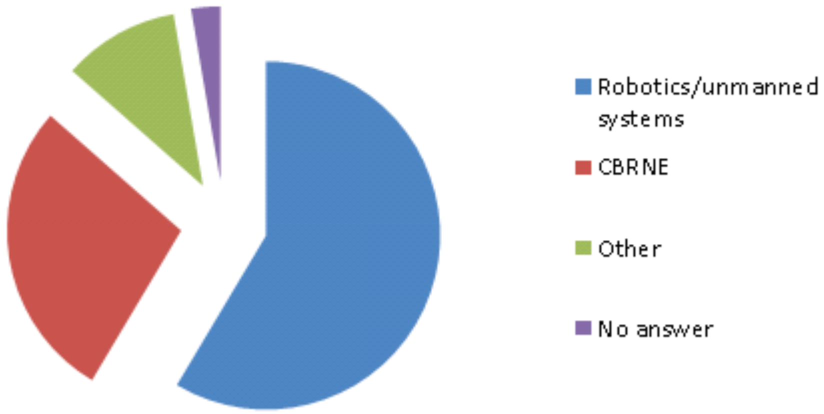


Around half of the participants have a research and development (R & D) background. Due to the overrepresentation of the robotics community, the amount of R & D individuals is higher than the rest. That is why we added an additional short discussion on end-user answers at the end of section 2.4.3 of this report.

The questionnaire obviously reveals that the group failed to address the end-user community.
It seems that posting the call in the LinkedIn groups did not have the desired effect. This also holds true (but less so) for the industrial part. More answers from both groups would have added more value.

What is your field of expertise? (Multiple answers were possible.)

Expertise	Answers	Ratio
Robotics/unmanned systems	65	66.327 %
CBRNE	31	31.633 %
Other	12	12.245 %
No answer	3	3.061 %
Total (multiple answers possible)	**111**	**113.265 %**



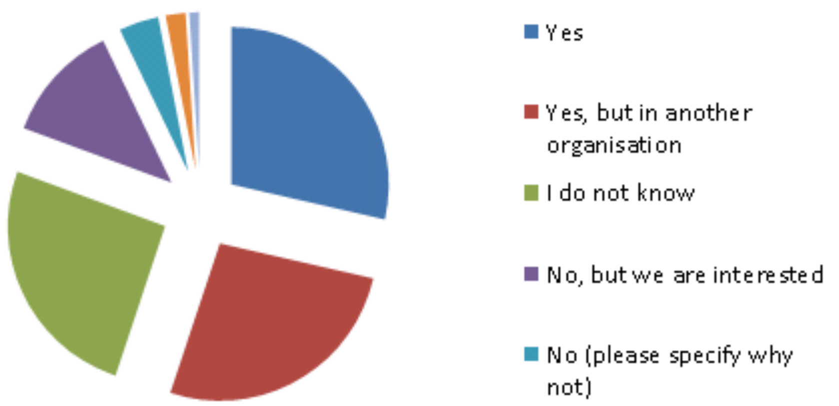
As can be seen in the answers to question 2.2, the robotics community is highly overrepresented, and therefore all the following answers are biased by their views.

Entries for others:

- Control engineering.
- Renewable energies, safety, environment management.
- Geology, remote sensing.
- Civil defence.
- Engineering for particle accelerators (CERN).
- Nuclear power plant protection.
- Radiation protection, defence against nuclear hazards.
- Dosimetry.
- Radiation safety.

Is your country using robots/unmanned systems in RN scenarios?

Using robots?	**Answers**	**Ratio**
Yes	28	28.571 %
Yes, but in another organisation	26	26.531 %
I do not know	25	25.510 %
No, but we are interested	12	12.245 %
No (please specify why not)	4	4.082 %
Other	2	2.041 %
No answer	1	1.020 %
Total	**98**	**100.000 %**



A surprisingly high number of 55 % answered that robots are already being used in their country. It is somewhat awkward that 26 % answered 'I do not know', since we tried to address the experts in the field. On the other hand, even in Germany there are many different official organisations that are uncoordinated. Therefore the number of people not knowing about robot usage in RN scenarios is not really surprising.

Text answers:
No:

- There is no special plan of use, but if needed we are ready to use if there are available resources.
- Not yet deployed, undergoing R & D.
- Assistive robots can be used in dexterous situations.
- We are in the development process of multipurpose CBRNE robotic systems.
- They are not used by defence or Hazmat teams, yet.
- Our organisation uses a robot platform in laboratory experiments for transportation of our detector SENNA (detection of explosives and radioactive sources) to suspicious objects. See http://www.apstecsystems.com
- We are experienced in operating in a BC-E environment. RN is a little more complex and we are just started to look into those problems.

- The need is recognised, but readiness is not established on a firm base.
- Transport Canada restrains this possibility.
- Under development, some feasibility trials made.
- The subject is under investigation — we do not yet have operational equipment.
- Cost, lack of awareness.
- Because French installations are assumed to be safe and with zero risk.

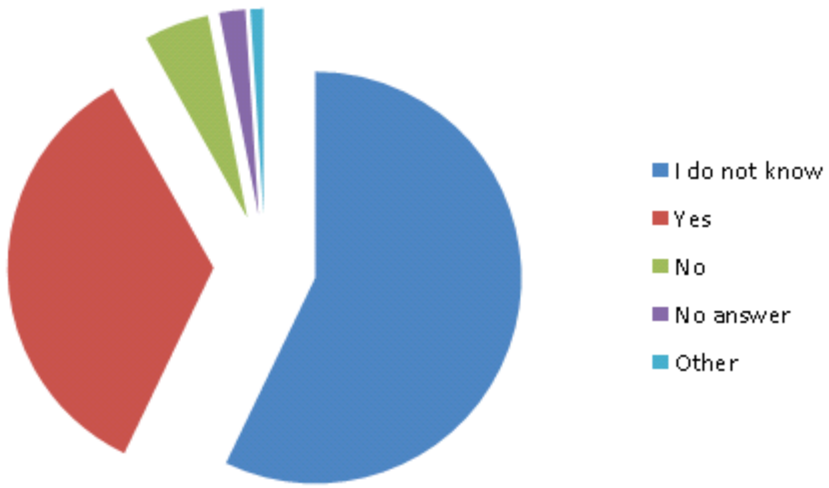
Other:
- The country is investing in robotic solutions. In our organisation we do research in EU-projects such as Eurathlon.
- Urban search and rescue.

Yes:
- SCK: https://www.sckcen.be/
- CERN — European Organisation for Nuclear Research.
- Academic research.
- Various national security organisations (IEDD robot users).
- Federal Office for Radiation Protection (Bundesamt für Strahlenschutz (BfS)).
- There are a number of specialised robotic systems for work in conditions of radioactive contamination. Most of them are remotely operated vehicles on tracks.
- Military forces and police.
- INFN.
- KHG (Kerntechnische Hilfsdienst GmbH).
- Bomb disposal robots teleoperated platforms (at DOVO), may/would probably also be used in RN scenarios, to some extent.
- UGV, UAV.
- Defence forces.
- CEA.
- Fire-fighters' crisis response exercises, Central Forensic Laboratory of Police training — no real RN crisis occurred so far.
- Research projects ongoing.
- Radiation & Robotic s.r.l.
- Also in other organisations. In our institute, we are trying to develop a UAV platform with a RN sensor (originally for border management but fully deployable to CI).
- NCCR-Robotics is a Swiss nationwide organisation funded by the Swiss National Science Foundation pulling together top researchers from all over the country with the objective of developing new, human oriented robotic technology for improving our quality of life. It counts with a budget of CHF 35 425 700 (2010-2014), with a second phase starting this year. The centre was opened on 1 December 2010, and binds together experts from four world-class research institutions; École Polytechnique Fédérale de Lausanne (EPFL) (leading house), Eidgenössige Technische Hochschule Zurich (ETHZ) (co-leading house), Universität Zurich (UZH) and Istituto Dalle Molle di Studi sull'Intelligenza Artificiale (IDSIA) Lugano. NCCR Robotics promotes three main strands of research in which the one that bring us here is the rescue robots. We develop new types of flying, walking, and swimming robots that are portable and safe for humans, and could be used for disaster areas or in normal life for exploration and transportation. So far there has not been any formal deployment of our robots in a disaster or RN scenarios. However, we are leading state-of-the-art research on this topic, and keeping constant collaboration with stakeholders in the field, improving the readiness of our technology.

- Yes, there are several forces using robotics for CBRN/CBRNE intervention, the most relevant are Guardia Civil and UME (Military Emergency Unit).
- Radiological monitoring and control, characterisation of contaminated areas, decommissioning and dismantlement of contaminated buildings/structures.
- The GIE INTRA bases on the Chinon nuclear production centre. It uses this kind of robots for Mapping and Exploration. Additionally, they use teleoperated systems for interventions.
- Reconnaissance and mapping of disaster zones with a team of mobile robots.
- Use in nuclear facilities.
- Military EOD robots have been considered and exercised for carrying hand-held detectors.
- Development of UGV and UAV for inspection of waste deposits.
- Multicopter with sensors.
- Civil Protection uses UAS and UGV for CBRN detection.
- Various DARPA-sponsored activities.
- Emergency response for nuclear facilities.
- Disposal and processing of nuclear waste.
- Fukushima-Daiichi NPP decommissioning, nuclear accident response.
- QinetiQ Operate Project 'GHOST' a service to support United Kingdom emergency services by using RCVs.
- Ground based platforms with sensors.
- Unmanned interventions in radioactive areas of CERN particle accelerators.
- Packbots.
- We are preparing robots for support work in nuclear waste disposal.
- Handling consequences of CBRNE incidents.
- RPAS as mobile sensor platforms.

Does your country cooperate with other countries regarding using robots/unmanned systems in RN scenarios?

Cooperations?	Answers	Ratio
I do not know	56	57.143 %
Yes	34	34.694 %
No	5	5.102 %
No answer	2	2.041 %
Other	1	1.020 %
Total	**98**	**100.000 %**



Again, the number of 35 % answering 'yes' is surprisingly high. The obvious follow-up question would be of what nature the 'cooperation' is. Since cooperation in this field is mostly at governmental level (only 33 % of the participants), the number of 'I do not know' answers (57 %) is understandable.

Text additions:
No:

- There is no organised way to cooperate at the moment. Possibly in the case of an accident robots can be arranged on an ad-hoc manner.
- Because French installations are assumed to be safe and with zero risk.

Other:

- We aim for a full collaboration with stakeholders like the ICRC among other international organisations, opening the way for other countries' cooperation. In the technology side, Prof. Robin Murphy from Texas A&M (world leader in Robotics Search and Rescue), is part of the steering committee of the NCCR-Robotics programme. Moreover, we started collaborations with Prof. Satoshi Tadokoro, from Tohoku University, whose work is leading international joint efforts for the recognition of Robotics as an enabling technology for these disaster activities including RN scenarios. An international committee on these matters which speaks

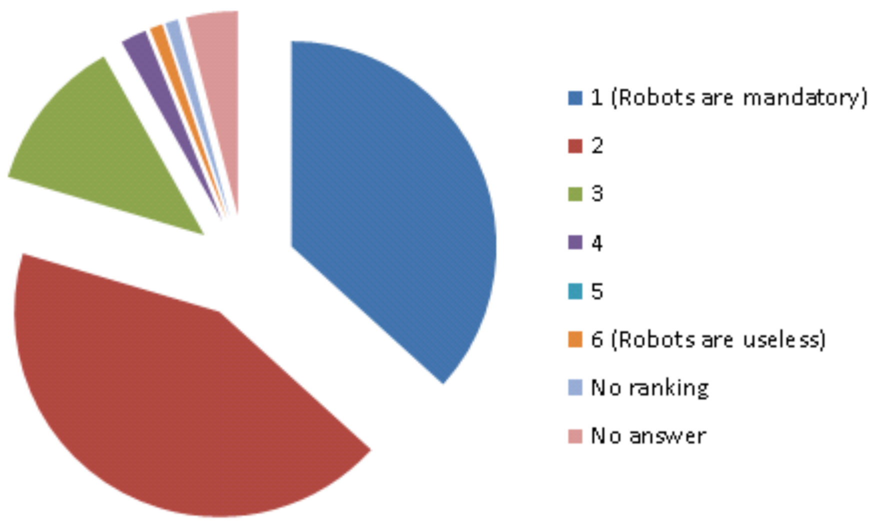
directly to the United Nations was established by Prof. Tadokoro to promote the robotics use in disasters. There is one member of the NCCR-Robotics in that committee.

Yes:

- We have a cooperation with NASA related to this domain: http://valkyrie.inf.ed.ac.uk
- Royal military academy.
- RUAG, ZHAW, fkie.fraunhofer.de
- R & D collaboration.
- Russia, Singapore, United States, United Kingdom, Germany.
- R & D programmes in course and CBRN equipment initiatives.
- We cooperate with TNO (Netherlands).
- Nordic collaboration.
- We participated in an NKS programme (seminars) in the subject area. No operational cooperation.
- Different EU projects.
- In the EU FP7 project called Eurathlon. Collaboration between United Kingdom, Spain, Italy, Finland and Germany. We have also collaborated with DARPA and NIST from the United States.
- We are involved in various projects in robotics and teleoperation — space, nuclear, crisis.
- France, Sweden and most other European countries.
- Japan, Russia.
- France.
- Japan.
- EDA and FP7 projects.
- Yes, Spain has agreements with special forces in many countries (some in south and central America) and as far as I know there is a kind of cooperation in this area.
- A few foreign companies provide technology solutions and equipment for decommissioning and environmental remediation purposes.
- I think that concerning RN operations the GIE Intra cooperates with the German KHG (Kerntechnischer Hilfsdienst GmbH).
- In research projects.
- There is a contract for collaboration with French task forces.
- IRID is collaborating with other countries.
- We take part in the Eurathlon and ELROB real world robotics events.
- In research projects, e.g. EDEN.
- Sweden.

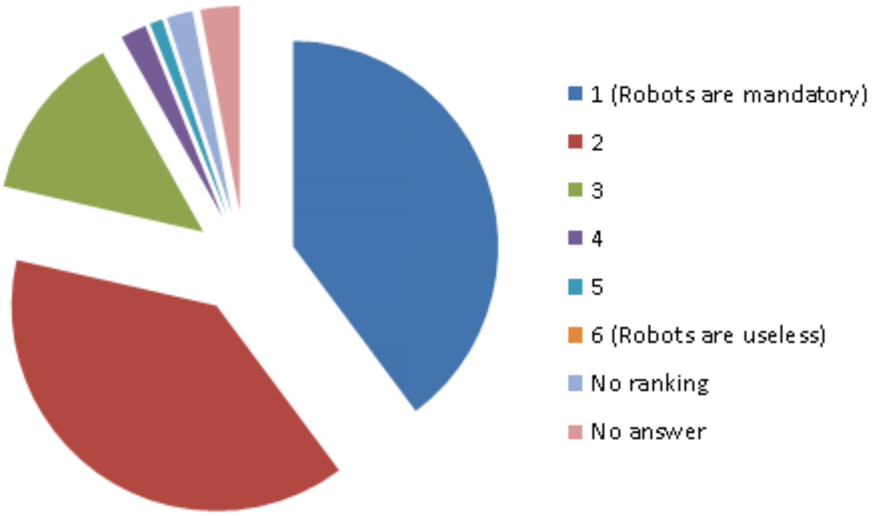
Spatial mapping of RN sensor data (exploration, change detection, etc.)

Rank use of robots	Answers	Ratio
1 (Robots are mandatory)	36	36.735 %
2	42	42.857 %
3	12	12.245 %
4	2	2.041 %
5	0	0.000 %
6 (Robots are useless)	1	1.020 %
No ranking	1	1.020 %
No answer	4	4.082 %
Total	**98**	**100.000 %**



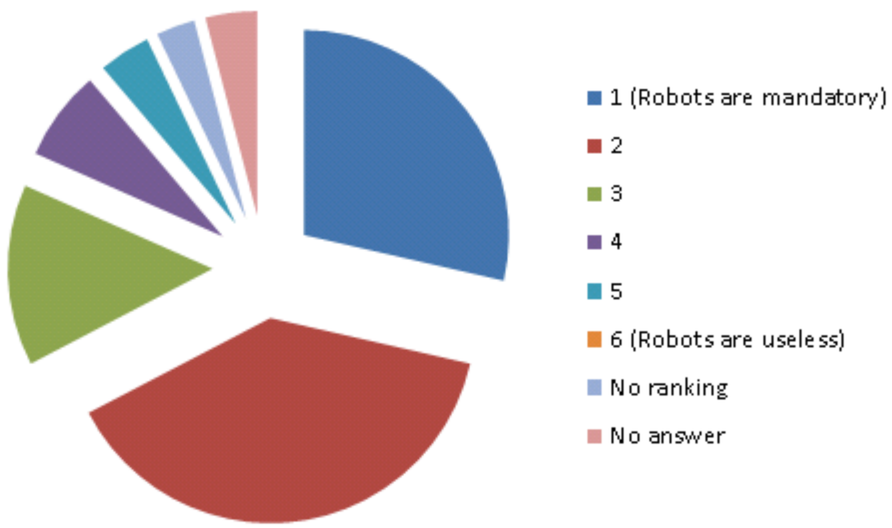
Searching for RN sources (active sensing, isocurves, hotspots, etc.)

Rank use of robots	Answers	Ratio
1 (Robots are mandatory)	39	39.796 %
2	38	38.776 %
3	13	13.265 %
4	2	2.041 %
5	1	1.020 %
6 (Robots are useless)	0	0.000 %
No ranking	2	2.041 %
No answer	3	3.061 %
Total	**98**	**100.000 %**



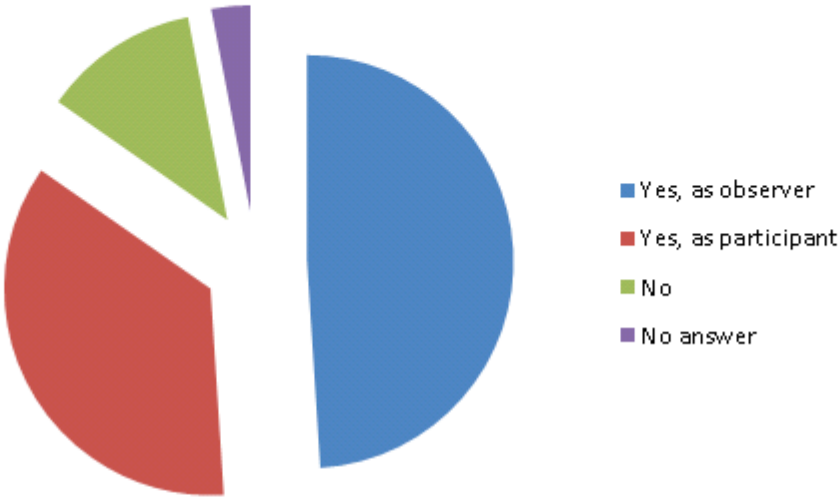
Sampling (air sampling, sweep sampling, material sampling)

Rank use of robots	Answers	Ratio
1 (Robots are mandatory)	28	28.571 %
2	38	38.776 %
3	14	14.286 %
4	7	7.143 %
5	4	4.082 %
6 (Robots are useless)	0	0.000 %
No ranking	3	3.061 %
No answer	4	4.082 %
Total	**98**	**100.000 %**



Would you be interested in human–robot team competitions/exercises (person(s) working together with robots)?

Competitions?	Answers	Ratio
Yes, as observer	48	48.980 %
Yes, as participant	35	35.714 %
No	12	12.245 %
No answer	3	3.061 %
Total	**98**	**100.000 %**



As head of the ELROB robot trials, Frank Schneider will contact the 85 % of the participants that answered 'yes' and keep them informed about future trials, giving them the chance to observe or participate.

2.4 Free text answers

2.4.1 In what RN scenarios would you consider using robots/unmanned systems?

List of all answers:

- Spatial Mapping in scenarios with large storage areas and border control, sampling in response scenarios (with leakages) and long-time monitoring (intermediate and end storage of RN-products/waste).
- Suspicious object, scrap metal.
- Mapping of dirty bomb sites to reduce the exclusion zone; survey of suspicious packages or vehicles.
- Any scenario where the operator could undergo severe risks in doing the same tasks that the robots can execute.
- Although there is no industrial tool to deal with all the abovementioned scenarios, there are some solutions for partial problems that can be improved. I think that the situation in all scenarios could be improved using robots now or in the future.
- Radioactive dump retrieval (e.g. in Asse, Germany) — Disaster first responder aids (situation awareness) — Disaster monitoring (mid and long term supervision of events)
- RN accident/threat.
- Inspection of waste deposits.
- Accidental release of radioactive material. Criminal/terroristic release of radioactive material.
- In all three scenarios.
- All the scenarios are possible to use robots/unmanned systems.
- RN incidents or accidents where high level of radiation or contamination is present or long presence working time is required.
- Spatial mapping & reactor tasks.
- Mostly all of them. Robotic technology is a tool that facilitates different stages of the human work in RN scenarios. We are not aiming only to disaster stages. We also think that our technology will serve in other stages as prevention, preparedness, as well as in inspection and maintenance of infrastructure related to RN and other scenarios.
- More or less the same as those that was mentioned in quest-scenarios.
- Detection of hotspot in a RN/EOD scenario where there is a strong likelihood of explosives being collocated.
- Monitoring actual plume shape, size, direction and isocurves as part of incident management and remediation planning.
- RN scenarios: recce. and survey, detection and decontamination, sample collection, product control, Hazmat.
- Disposal warehouses of RN-related material and factories dealing with RN material.
- Tracing and mapping seaborne radiation to find sources such as dumped material and outflow from industrial waste pipes into the sea.
- Interaction and manipulation with the environment with robots.
- Radiological monitoring and control, characterisation of contaminated areas, decommissioning and dismantlement of contaminated buildings/structures, physical protection of restricted contaminated areas, etc.
- All mentioned in the pdf. Robots are useful, but in rare cases mandatory. Also legislation hinders the use of robots in some scenarios.
- N/R source detection and classification, localisation and mapping, autonomous search and coverage.

- Disasters/earthquake in RN sites, visual inspection and radiation mapping in high radiation/risk areas, handling of radioactive wastes/objects.
- All: exploration, patrolling (search for source, change detection, major public event), and all the response scenarios.
- All prevention and intervention scenarios mentioned in the document. Other nuclear industrial facilities surveillance scenarios.
- Scenarios mentioned above.
- Large storage areas (customs, harbours). Accident areas (e.g. airplane crashing sites, submarine wrecking sites, bombing sites, military target areas). Wastelands. Critical industrial sites (nuclear power plants, steel factories, sawmills working imported wood, chemical plants). Critical infrastructures deserving continuous monitoring (dams, major bridges, railways, airports).
- Animal rescue in radioactive areas deserted by humans.
- a. Spatial mapping of RN sensor data (exploration, change detection). b. Searching for RN sources (active sensing, isocurves, hotspots). Prevention scenarios: exploration (esp. illicit trafficking, container area). Response: in dangerous areas, mapping. Identification of nuclides with remote-controlled high resolution detectors.
- Hazardous for human intervention, use of robots could speed up intervention.
- Technology is mature for exploration and mapping particularly in semi-structured environments like ports, etc.
- Interoperability of robots/machines in contaminated areas, surveillance and monitoring of areas at risk of nuclear attacks, decontamination and disposal of radioactive waste, evacuation from contaminated areas.
- Search of orphan sources; to find secure passages in a deposition field; mapping a deposition pattern; high altitude sampling of radioactive particles; dose rate measurements in a radioactive cloud.
- Harbour area, waste disposal area.
- Transportation to the place of discovery and manipulation of CBRNE detection equipment.
- RN identification by remotely piloted aircraft systems (RPAS) and unmanned ground vehicles (UGV) equipped with dosimeter/spectrometer. To detect possible radiological/nuclear materials RPAS carrying a dosimeter/spectrometer will fly to the site, hover over it in suspicious places and read the radiological dose level during the process. Short range measurements over the suspicious area may be acquired also by the UGV with the dosimeter/spectrometer devices mounted on the UGV arm. The exact dose rate level data, nuclide identity, timestamp and location stamp will be transmitted via a the ground communication network nodes back to the Command Centre where they will be stored in the forensic evidence repository keeping the data in strict adherence to the chain of custody requirements.
- In some/many situations it may well be more appropriate to use unmanned drones (which are flying robots).
- If there is a threat of high radiation doses for the forces or an open contamination through an alpha source.
- All of them. Either aerial or land robots depending on scenario.
- All of them. The use of robot/unmanned systems in those scenarios will be useful and helpful for humans.
- Yes, robots and unmanned systems are apparently useful in the whole scenarios.
- Our robots can be fitted with radiation monitors and can patrol a controlled area, they have undertaken operations inside our nuclear establishments. We are the only group that has a certificated sealed ‘Body Bag’ to contain a contaminated robot post operation in a hot zone. Our robots could open ISO container doors and pick and carry suspect items.

- NPP-accidents, sea accidents, overland transports with critical infrastructure.
- (1) Recovery of high activities for example, after an attack on a transport, a laboratory, etc. (2) Determining the distribution of contamination in a building or area. (3) Matching of radioactive measurements to people or objects (vehicles, containers). (4) Airborne intelligence-gathering on ships or areas. (5) Identification of suspect sources in gatherings of people (railway stations, airports, etc.).
- As a EOD unit only first response to known object or specific threats as support to DEMA (Danish Emergency Management Agency) maybe recce and sampling.
- Container Inspection. Only for 'unshielded' Gamma sources. Common sensors do not detect shielded gamma sources (e.g. hidden in heavy metal scrap) when passing through the detector. Likewise Beta and Alpha sources cannot be detected this way. The only things that work are minimum detection distance and long measurement times during the travel time of containers or by directly placing the detectors on top of a radiation source in the field. Therefore, living biological systems (e.g. bacteria) are suggested as detectors for biological damage from radiation.
- 1.3.1-6 all are potential for use of robots.
- UAVs that could execute such work safely are mostly very expensive like the Predator. Dr Jon Stevenson has demonstrated that small UAVs cannot be used in security applications above ports, in nuclear reactors, pipelines, power lines because we do not yet know how to control them at security breakdowns. In addition, there are no methods of 'sense-and-avoid' worthy of the name, yet, even though there are people working on the subject. We must develop methods with new paradigms associated with ACAS units or even ADSB as radars cannot be carried by small or medium UAVs currently due to their excessive weight.
- There are no RN scenarios in which I would not give serious consideration to using robots/unmanned systems.
- The exploration and the patrolling.
- Prevention scenarios, response scenarios.
- Search and rescue. Active detection of NR sources.
- RN accident/threat.
- Every scenario has a robotics application.
- Bomb disposal. Hazardous waste matters.
- Dismantling obsolete nuclear plants. Handling and long-term monitoring of nuclear waste storage facilities.
- Explosions with unknown origin. Accidents of vehicles with potential radiation.
- Robots are being operated for — radiation mapping in LHC tunnel before granting access — removal of some very radioactive elements using robots with screwing tools <100 Nm/15kg — visual inspections working on heavier equipment.
- (1) Geo-mapping. (2) Maritime security. (3) Fisheries/whale detecting services. (4) Anti-poaching in forests. (5) Border surveillance. (6) Oil & gas pipeline surveillance/monitoring. (7) Pipeline leakage detection. (8) Anti-terrorism control/monitoring. (9) And many more …
- Discovery of highly active radiation sources, situations with dirty bombs.
- Especially when there is suspicion of further hazardous material. Mapping after an incident.
- Corner incidents.
- 1.2.1; 1.3.4; 1.3.5; 1.3.1; 1.3.6 (for those scenarios search is more important than full mapping in my opinion).
- I guess most of them. If well used in close collaboration with human operators, they can become a great asset when dealing with RN scenarios.
- Spatial mapping, precise searching of the source, environmental sampling.
- Generally when the risk is high for human activity.

- Exploration, surveillance, inspection, long periods, dirty and difficult areas, dull, dirty, dangerous work; scenario 1 and 2: long-term scenarios; scenario 3: dangerous work.
- All possible or unknown RN scenarios where human life would be at risk.
- Crisis/accident response, forensics, RN infrastructures inspection and monitoring.
- Transporting radioactive sources; gathering radioactive material and its transportation to the place of disposal; decontamination of buildings and equipment.
- In all the stated scenarios. Robots would be beneficial in all 3D tasks.
- I would consider to use robots/unmanned systems in all the main tasks: a. Spatial mapping of RN sensor data (exploration, change detection, etc.) b. Searching for RN sources (active sensing, isocurves, hotspots, etc.) c. Sampling (air sampling, sweep sampling, material sampling).
- Dirty bomb scenarios.
- (1) Searching of hot spots in some critical field (i.e. NORM industries, landfill, contaminated areas, etc.) also for mapping of areas. (2) Automatic scan and identification of radioactive sources in scrap metals. (3) Automatic exploration and identification of radioactive sources in seaport containers with ‘spiders’ robots during 24 hours.

These scenarios were named to be the most important ones:
- mapping
- exploration
- inspection

This matches our indication. In our last report on scenarios for unmanned systems, we added some specialised scenarios as well, to make each scenario more specific.

There were additional scenarios mentioned in the answers. One scenario does not really fit into the CIP category, but is about using unmanned systems in RN scenarios. It concerns robots for the long-time monitoring of RN products and waste in intermediate or end storage and the retrieval of radioactive waste (from intermediate storage).
Our group does not currently cover unmanned systems on or in the sea, but one of the answers pointed out an interesting scenario of tracing and mapping seaborne radiation to find sources such as dumped material and outflow from industrial waste pipes into the sea. But this only alters the domain that we did not explicitly limit to land or air robots. So this is a specialised case of one of the scenarios already mentioned.

2.4.2 What other data you would like to record/map other than RN sensor data?

Some examples were given with the question (GPS, temperature, 3D-laser, wind).
List of all answers:
- GPS, Photo/video material from a relevant irradiance/dose.
- GPS, 3D-laser, wind.
- GPS; gamma spectrum.
- GPS, odometry, visual sensors, temperature, wind, pressure.
- Any data that is of interest.
- Distance measurements and weather data like temperature, wind and humidity.
- ‘Dryness’ (inflammability of forests and plants) — radioactivity — reflectivity.
- GPS, temperature, wind.
- GPS, temperature, 3D-laser, wind, humidity, visual data.
- GPS, gas (CO_2, etc.).
- Hazardous chemical substances. Wi-Fi coverage.
- Intelispeed.

- 3D-laser.
- Weather-related data, temperature, humidity, etc. and photos.
- GPS, surface meteo data, sampling and image.
- GPS and temperature.
- All general 'localisation' data will be important for both, the robot navigation as well as the mapping of the inspected areas. In this case, world perception based data is essential to be acquired. This includes video, depth images, temperature, pressure, humidity, water level, pollution, air quality, GPS (if possible) and robot odometry data, particularly robot's proprioceptive sensors (this last one is important as this robot status uses part of the bandwidth of the control communication channel).
- Time, GPS, film/video.
- Wind, precipitation, temperature, air pressure, location, water and drainage run-off.
- GPS, temperature, TIC, RN sensor, video data transfer.
- Localisation data (GPS, 3D-laser, 2D-laser, tags …), temperature (it's cheap and can be interesting), humidity (same reason) and wind.
- Obviously, when a source has been detected, we need to know where, so GPS is minimal. Other data always useful…
- Temperature.
- At least GPS, wind and rain in almost all cases.
- GPS, odometry, IMU, 3D laser, wind.
- GPS/position, 3D-structure, wireless signal coverage, thermal/heatmap, harmful gases (such as He), oxygen level, etc.
- GPS or (robot localisation estimation indoors), PTU pressure, temperature and humidity, indoor/outdoor environment point cloud, video streams, etc.
- GPS, meteorological data, all mission related video/audio streams, 2d/3d laser/rgbd data, etc.
- Location (x,y,z), time, atmospheric data (wind speed, direction, rain/no rain, temperature, etc.).
- 3D-laser.
- Of course GPS. Also chemicals?
- Meteorology, infrastructure data, population data, building inventory.
- GPS, temperature, 3D laser, wind, water temperature.
- GPS, wind, 3D-laser.
- Place, wind direction and speed.
- GPS, 3D-laser, images (visual data is important when human follow up is involved).
- 3D maps, dynamic plume spread maps with weather conditions, identification of different sources, direction of radiation.
- GPS, altitude, wind moisture.
- GPS, Image, 3D scan.
- Our task — detect explosives inside an object without disturbing its integrity. SENNA is sufficient for these purposes.
- Dose rate level data, nuclide identity, timestamp and location stamp.
- All of those, obviously.
- Indoor: 3D-laser, video and IR/thermographic images; outdoor: meteorology (wind, rain/humidity, stability), GPS.
- GPS, wind, topography, access routes, hazards, population centres around. Geolocation of potential targets.
- Localisation of objects, temperature, etc.
- Sampling of dust, 3D shapes, temperature, humidity, RN emission data as well as spatial dose rate, gas, O2, lighting conditions, road conditions, debris, water pool, sound.

- Our robots have GPS and thermal imagers, they can be adapted to provide full 3D mapping and SLAM images if required. Please see the Eurathlon website for RCV generated map images.
- Wind direction, air layers, turbulences.
- Date, time, GPS position, dose rate, nuclide, air pressure, relative humidity, temperature, wind speed and direction, predominant vegetation (optical), urban structure.
- GPS coordinates, temperature, wind, humidity, pressure, rainfall, atmospheric stability.
- Laser based explosive detection.
- No RN sensor data. For scanning large search areas from the air they would only be available for gamma radiation. Instead, I recommend fluorescent alarms in genetically modified radiation-hard bacteria and yeasts. This could be detected and georeferenced quickly from the air over large areas or along discharged search profiles and also from the air. In radiological gene damaging exposure they react with fluorescence phenomena, which are excited from the air and detected/georeferenced.
- Robots have to be mobile. They need a navigation system, which include GPS (Galileo), 3D-laser and a gyro. Temperature is interesting in most of the cases. Also sound may be interesting to detect remotely the running engines or other sources of noise.
- Distances, localisation GPS.
- Wind, GPS, vibrations, sound.
- Location, measure of clutter, temperature, humidity, water-on-surface, subsurface moisture, air flow, lighting, air chemistry, particulates in air, bio-matter.
- GPS data: coordinates, height.
- GPS, temperature (thermal data layer over the 3D-model created with the 3D-laser), 3D-laser.
- GPS connected with a timestamp, weather data (for spread analysis), nuclide identity (e.g. dirty bomb scenario or discovery in a container,..) data for mapping.
- Accurate 3D localisation, temperature.
- GPS, temperature, wind.
- Wind is important because of the possible spread direction.
- Various topics too complex for such a form.
- All of them.
- GPS, wind.
- 3D laser.
- Minerals & detonation detection.
- As many as possible, but especially geometrical data that can be used for navigation, for change detection and to increase situational awareness. In addition, optical data, e.g. for people detection and identification (depending on the scenario). For situation assessment additionally wind is interesting.
- Weather.
- GPS, wind (for spread analysis).
- GPS.
- 3D-Laser.
- GPS, temp — they are very cost-effective 3D-laser — it will make final robot.
- My opinion is that robots can probably acquire most of the available sensor data, if well equipped and designed for such tasks.
- GPS and time stamps and accompanying weather conditions.
- Air data, GPS, others.
- GPS/IMU, temperature, IR images, LiDAR, video, scanner.
- Temperature, wind, humidity, etc. (factors that affect dispersion of RN).
- GPS, weather, other depending on the scenario (e.g. camera images in forensics).
- Position is important for assessments. Wind, speed and air flow when air sampling.

- GPS, wind.
- Location (GPS), weather (temperature, wind), terrain/object characteristics (their rough location).
- Position; temperature, humidity, wind (force and direction), topography.
- GPS, date, time.

In addition to dose rate/radiation, the participants suggested sensors for gathering the following data with robots:

- GPS, position.
- Picture/video.
- Temperature.
- Humidity.
- Pressure.
- Wind.
- Pollution.
- 3D environment map/depth images.

There are a significant number of different data sets that seem interesting to monitor in an RN scenario. These may vary depending on the specific situation, application and system in use.

2.4.3 What are, in your opinion, the hot-topics and/or bottlenecks in the next 3 years?

List of all answers:

- Research/development to maturity of an autonomous robotic system.
- Limited interfacing between detector, robot and control system. We cannot feed data over the robot control link.
- Interoperability.
- Autonomous exploration, sensor data acquisition and interpretation, human–robot interaction.
- Wireless communication, data transfer, real-time processing inside and outside. Localisation in buildings. Data shared between different users, common standards for communication with the unmanned systems, sensors, etc.
- Limited communication bandwidth for pushing all the sensor data in real time to a base station — robot mobility on rough terrain — integration of RN sensors on small UAS which can fly indoors.
- Cheap light and sensitive radiation sensors.
- Reliable mobility of the robots in typical RN scenarios/terrains.
- Fully autonomous exploration of GPS-denied environments.
- Price and use of flying systems.
- Operational integration of RN sensors and platforms (UGV and drones).
- Robotics, haptics & virtual reality.
- Robustness and sturdiness of platforms in different aspects. Hardware: this includes waterproofing, explosion proofing in combination with lightweight and power storage/autonomy. The tether/tetherless dilemma. Software: perception processing, control. Communication: channel used (cable or wireless), signal quality, range.
- Limitation to fly in terms of safety and security rules. For example, one must have permitted from the Civil Aviation Authority and other authorities for filming or flying over certain heights.
- Remote detection of low dose at significant distance from source.
- Hot topics: absence of clear legislation regarding usage of UGVs in RN threat scenario; absence of classification among UGVs (size, weight, way of using); low knowledge of potential users in UGV application for RN scenarios. Inadequate coordination between

responsible law enforcement agencies vs. highly increased number of deliberate terrorist attacks on critical infrastructure.

- Working in large areas requires battery management strategies and combination of methods (energy scavenging, grids, energy-aware planning algorithms …).
- Robots are not always unmanned — there is an important difference here! Completely autonomous systems have much more serious implications than robots with human overseers. It would have been sensible to have separated this questionnaire into autonomous and non-autonomous robots, as the answers will be different.
- Semi-autonomous manipulation in degraded human environments, including with radiation.
- Decommissioning and restoration of highly-contaminated areas and structures.
- Robot operation in unstructured and unknown environments, e.g., for WMD consequence management.
- Wireless communication with the robots, speed and manoeuvrability of the robots, energy limitations.
- Reliable and high bandwidth communication infrastructure, decontamination capabilities, reliability and usability.
- Robotic technology reliability and price. Autonomy of UAV solutions.
- Combining robotic intelligence and dexterity with human expertise to quickly analyse complex scenarios and multiple streams of data. Efficient human–robot interaction to avoid brute-force spatial mapping of RN data and enable fast but focused intervention in emergency situations.
- Lightweight sensors, data fusion of sensors and models, faster & high resolution dispersion models.
- System integration, efficient deployment, usability, autonomy (esp. improving robustness in case of connectivity problems).
- Maintaining competence, use nuclide measuring instruments, development of robots for use in highly polluted areas.
- Reliably determine whether RN was involved in events (attacks).
- Communication, greater deployment of autonomous solutions in the field (or at recreated scenarios) to speed up learning.
- Grasping and manipulation of various pieces in unstructured environment like in the scrap metal sorting scenario.
- Autonomy, protection and durability of sensors.
- To develop high resolution gamma spectrometry detectors with low payload; to translate measurement results to e.g. deposition; density or air concentration; to develop algorithms for search UAVs to position e.g. point sources by repeated radioactivity measurements in xyz.
- Cost reduction, Lighter RN sensors.
- Remote identification of unattended suspicious items.
- RPAS.
- Investigating uses of drones.
- a) Secure communications of unmanned systems to the control station and to the swarm. b) Adequate radiation resistance the systems in use. c) ‘Operator assistance’ for decisions in non-autonomous systems.
- Developing suitable concepts of operations. Integration of suitable RN sensors on test platforms.
- Communications (losing signal), radiation exposure of electronics. Residues treatment, as some of the robots will suffer from radiation contamination.
- Surveillance of narrow space, hidden space, jungle of pipes of plants.

- Money. Robots are expensive and require much training to be fully productive. 30 years ago no bomb disposal robots existed today the first call is use a robot this is starting to happen in Hazmat incidents.
- Certification and qualification of UAVs/UGVs and their operators in the civil sector.
- (1) Energy supply. (2) Data transfer/communication/control. (3) Miniaturisation.
- The most important: mapping ambient dosimetry and atmospheric contamination outdoors and indoors (buildings).
- The physical law of quadratic distance for the detection of radiation is an insurmountable obstacle of large-scale examination from the distance.
- Development of practical SAR robots with good mobility, long enough operation time and tele-existence capability. Operational readiness of such a robot fleet needs trained operators which might be a bottleneck. This could be solved best in connection with already existing fire brigades by extending their equipment.
- Designing a small UAV sufficiently reliable. Realise intrusion detection methods to achieve an adequate proof by applying the principle of 'sense-and-avoid'. UAVs to fly in difficult conditions.
- Communication reliability, man-machine interfaces able to support human decisions and making manipulation easier.
- Robot mechanisms and algorithmic autonomy that raises confidence that robots operating in RN environments won't get stuck. Additionally or alternatively, disposable robots.
- The biggest bottleneck is the lack of community-thinking in the area of robotics development: most of the robotic engineers, researchers, etc. are working in their small groups and re-inventing things over and over again. Great results could be achieved if there would be more open society around European robotics and critical areas like robots in RN scenarios.
- Financial resources, autonomous sampling, range.
- Autonomous navigation, teleoperation and augmented reality.
- Beyond-Line-of-Sight operations, platform decontamination, integration of unmanned systems in standard operating procedures.
- Include UGV/UAV in emergency response plans.
- Human-automation interaction and human-robot interaction in time critical scenarios.
- Swarm control of groups of robots working on a single job.
- Robotic platforms radioactivity hardening (electronics), decontamination after usage, tethered fewer platforms in enclosed environments.
- Reduce cost for force feedback manipulator systems — 2 arm system.
- Bottlenecks: financial resources; important issues: increasing the situational awareness for operators (as completely autonomous mission fulfilment in the coming years for use in more complex environment will probably not be possible). Methods for estimating the threats.
- Highly sensitive sensors with low weight for UAVs.
- In this setting, the level of awareness is too low.
- Making cost effective robots for real use. Fukushima showed that there is no reliable solution in that field.
- Safety — robustness — cost of design and production — autonomy — smart systems.
- Hot topics: UV sampling, bottlenecks: R-resistance and decontamination of the equipment.
- For RN scenarios, the mass of the sensors. As matter of fact it would be useful to use small unmanned air vehicles, but the payload constraint is significant.
- Large areas to be inspected; many threats/radiological sources; threats with many variables; problem of contamination of water, air, a quick scattering vector.
- Autonomous navigation systems (ANS).
- Robotics for CBRN forensics — hot topic robots fully resistant to RN contamination — bottleneck.

- Dealing with the consequences of terrorist acts using CBRN materials.
- Regulations, user friendliness.
- Bottlenecks: air: limited operation time; weather sensitivity ground: movement capability on rough terrains.
- There is a need for a legal foundation for the use of RPAS.
- Battery life.

The answers to the question for future topics and/or bottlenecks in next 3 years pointed towards the following topics:

- Robot platforms.
- Weight, speed, mobility of robots.
- Autonomy of unmanned systems.
- Stable communication/bandwidth.
- Human-robot interaction.
- Decontamination of systems (robot platforms and sensors).
- Price of the whole systems.

As we can see, weight and mobility are hot topics. Given the number of sensors that may have to be carried and the possible payload of some small unmanned aircrafts, manufacturers should keep in mind the possibility of using standardised connectors and hot-pluggable sensors and sensor mounts/modules in order to allow different sensors to be changed rapidly without exceeding weight limits. This would make the life of field operators much easier, if they had to change a robot's sensors.

We had the impression that end-user answers could be most interesting, as their experience might give them a special perspective. So we had a closer look at their answers concerning:

- autonomy of unmanned system;
- limited bandwidth between robot and control station;
- low-dose detection at significant distance.

Autonomy and bandwidth have generated considerable interest in the robotics community for quite some time, and they influence each other. The more autonomous the unmanned system is, the less bandwidth is needed for controlling the robot and the less information (i.e. lower video resolution or frame rate) the operator needs. Only higher-level commands have to be given and more bandwidth can be used for sending other online sensor readings. In addition to that, the less exhausted the robot's operator is, the more autonomous the unmanned system is. Low dose rate detection at significant distance aims at sensor sensibility.

3 Conclusions

Overall, we gained quite a lot of information from all the answers we received. There was a wide range of backgrounds reflecting all of the groups whose opinions we were interested in receiving, although we were hoping for a more homogeneous distribution. Nevertheless, the respondents agreed with us on the importance of the scenarios that we identified and added some new views. The answers to the question on sensors indicated that time and position would be the most important additions to radiation measurements. The bottlenecks and future topics that were mentioned most often included robots' manoeuvrability, autonomy and communication, as well as decontamination and human-robot interaction.

Given the amount of sensors that may have to be carried and the possible payload of some small unmanned aircrafts, manufacturers should keep in mind to use standardized connectors and hot-pluggable sensors, sensor mounts/modules in order to allow fast interchangeability of different sensors while holding weight bounds. This would make life of field operators much easier, if they had to change a robot's sensors. Thus, as one future work item, we see the support of existing and future standards for field robots and their payloads. We see that we need further standard test methods for manoeuvrability, autonomy, communication, mapping, exploration, and inspection. Manoeuvrability and communication are already addressed in several of the ASTM test methods. See: http://www.astm.org/COMMIT/SUBCOMMIT/E5408.htm. The others still have a need for standardized test methods.

Another future work item that arises from this survey is to bring the communities of RN and robotics experts as well as end-users closer together. For that, we want to support European exercises, trials and/or competitions where robots are used for RN measurements.

Furthermore, as future work item, we see the improvement and standardization of robotic RN scenarios as mentioned in the report "Possible scenarios for radiation measurements and sampling using unmanned systems".

Concerning surveys in general, we have some insight that we would like to share. During our meetings, a question about the copyright of the ideas and answers came up. We have not had any problems concerning the questionnaire so far, but we thought about having a disclaimer at the start of the survey. This disclaimer should mention that participants hand over all rights over the answers that they give to the authority analysing the questionnaire.

As we were using so many different channels (i.e. LinkedIn, direct email and worldwide mailing lists) to distribute our survey, we were uncertain whether they all worked well and how they reached the participants. In future, we would include a question that covers how the respondent got the link to the survey. This could help when doing additional surveys. Without that question, we can only deduce some things from the total number of responses. It seems that even worldwide mailing lists with many members are not suitable for reaching large numbers of people, at least for our topic. Obviously, we had a very low response rate on that.

Annex A: Scenario descriptions

Scenario descriptions for the “Questionnaire about the use of robots / unmanned systems in scenarios involving radiological or nuclear threats”

ERNCIP Thematic Group on Radiological and Nuclear Threats to Critical Infrastructure

Main authors:
Frank E. Schneider
Bastian Gaspers
Harri Toivonen

Main contact: bastian.gaspers@fkie.fraunhofer.de

2015

1.1 Types of incidents and scenarios

Looking at incidents that involve radioactivity or radiation measurement, we can easily see that there is quite a difference in dispersed radioactivity and non-dispersed radioactivity. When dealing with dispersed radioactivity, information has to be gathered on fallout, radiation plume and the level of dispersion. When dealing with non-dispersed radioactive material, the source has to be found and identified and potential explosive materials have to be located and removed. As the action or reaction differs significantly depending on the situation, three different types of incidents involving radioactivity have been identified:

1. radioactivity confirmed – dispersed
2. radioactivity confirmed – no dispersal
3. no radioactivity (possible threat)

These types of incidents are used to categorise scenarios covering radiological incidents. These kinds of scenarios can be found as response scenarios in section 1.3. Prevention scenarios do not handle incidents and thus are not categorised in this way.

Three different major tasks have been found for radiation measurements with unmanned systems. The main tasks in the scenarios below can be related to one of these major tasks:

a. Spatial Mapping of RN sensor data (exploration, change detection etc.)
b. Searching for RN sources (active sensing, isocurves, hotspots etc.)
c. Sampling (air sampling, sweep sampling, material sampling)

1.2 Prevention scenarios

In the scenarios presented here, a radiation task force has been deployed to prevent a radiation incident or to deter people from bringing radioactive sources to a specific location. These scenarios focus on periodical inspection

1.2.1 Exploration (harbour, re-locatable, illicit trafficking)

In this scenario, a specific area has been determined to possibly contain a radioactive source. For example, a container harbour with the possibility of illicit trafficking of potentially dangerous radioactive material. This is a spatial mapping task (a).

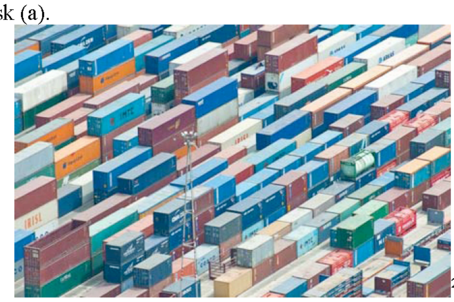
 [1]  [2]

Figure 1 Two images of container terminals: Hamburg (left) and Barcelona (right).

[1] "Hamburg Hafen Containerterminal" by Raimond Spekking
[2] "Puertobarcelona2" by OneLoneClone - http://www.flickr.com

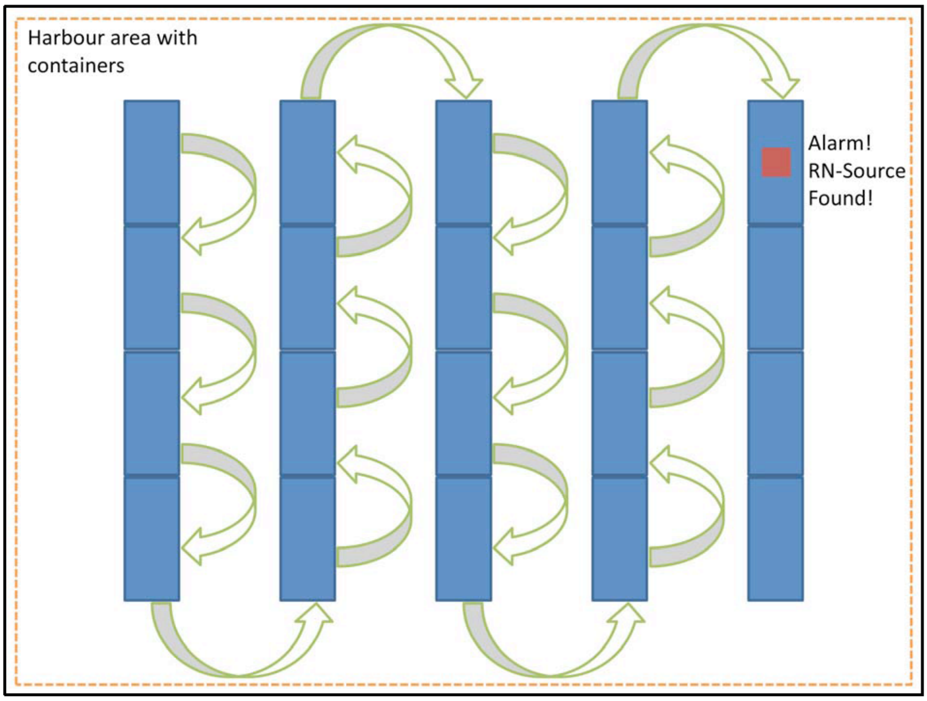


Figure 2 This figure shows a drawing of a container inspection example for scenario "Exploration". There are several containers shown in blue that should be inspected one by one.

Unmanned systems should provide real-time sensor readings to the radiation task force at any time. The aerial or ground vehicle should inspect bigger objects one by one (e.g. containers or cars). If suspicious radiation is found, the location of the measurement must be reported to the operator. After that, the real-time measurements of the unmanned system should enable the radiation experts in the safety zone or at any distant analysis centre to identify the nuclide or nuclides. After the localisation and confirmation of the source, the vehicle should map the surrounding area to determine the radiation field from the radioactive source.

1.2.2 Patrolling / search for source / change detection / major public event

In this scenario, a continuous search for radiation sources in a predefined area or on a specified route has to be performed. As this scenario requires mapping, the task which needs to be completed is of type (a).
At any moment the unmanned system should provide real-time sensor readings to the radiation task force. The vehicle has to perform a survey of a predefined area or a specified route. The system should be able to compare current measurement results to old ones from the same location/area/route in order to reduce false positives. If a suspected radioactive source is found, an alarm with measurement results and the location of those measurements must be sent to the operator. Unmanned ground systems can be used to carry very heavy devices, and to operate in dangerous terrain. Unmanned aerial vehicles can operate over the area, by parallel and/or crossed trajectories, in order to provide gamma mapping or simple detection localisation, with an embedded gamma detector or spectrometer.

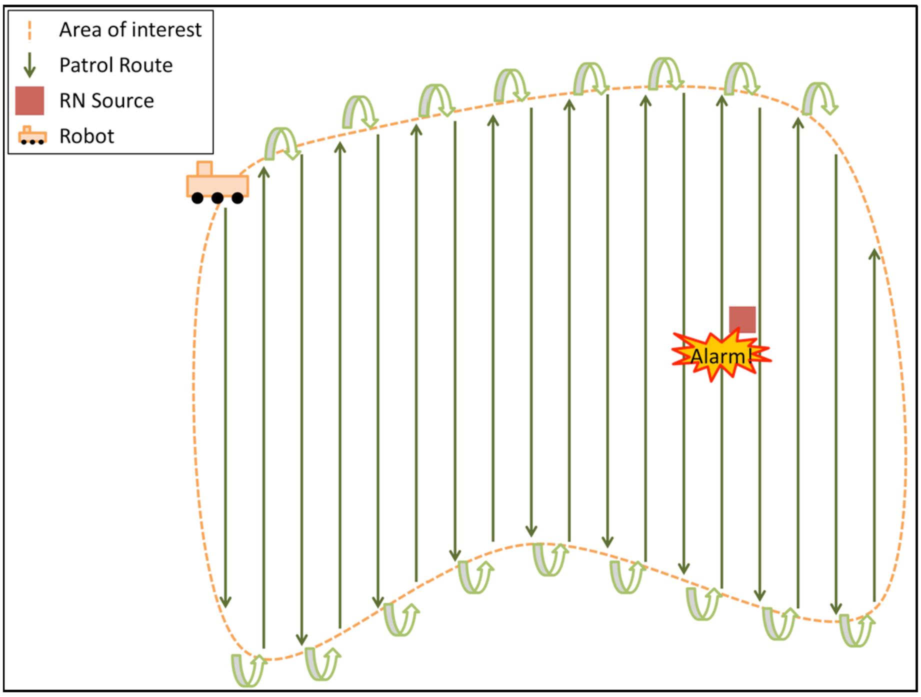


Figure 3 This is a sample of a patrolling scenario. The unmanned system sweeps a given area of interest and sends an alarm if something suspicious is found.

1.2.3 Background mapping, change detection

In this scenario, there is a predefined area that has to be checked for radiation continuously or periodically for a longer period of time. Thus, a map of the background radiation has to be made first. After that, inspection runs have to be performed and the previously mapped background radiation measurements have to be compared with current measurements. This scenario requires the completion of a type (a) task.

At any moment the unmanned system should provide real-time sensor readings to the radiation task force. The vehicle has to perform an inspection of the previously mapped area. The system should be able to compare current measurement results to old ones from the same location/area/route. If a suspected radioactive source is found, an alarm with measurement results and the location of those measurements must be sent to the operator.

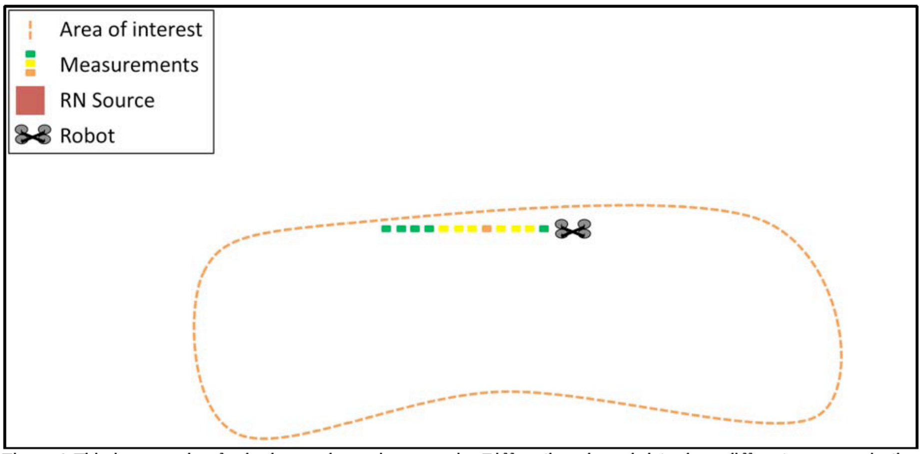


Figure 4 This is a sample of a background mapping scenario. Differently coloured dots show different measures in the background radiation map.

1.3 Response scenarios

This type of scenario involves the release of significant amounts of radioactive materials in the surrounding area or high dose rate radiation fields from unshielded or partially shielded point source.

1.3.1 Suspicious Object

In this scenario a possibly dangerous radioactive source is believed to be located in a specific area. We assume that a radiation task force is already on site, has closed down the area and established a safety zone from where it can operate. The main task for the radiation task force is to prevent any further disturbances of the environment, get accurate situation awareness and to determine the location and characteristics of the radioactive object. Thus, this is a category 2 scenario, as described above. The location of the object is roughly known but it is unclear if explosives are involved. Furthermore, the activity of the source is unknown. The main task in this scenario is the mapping of the environment (type (a) task).

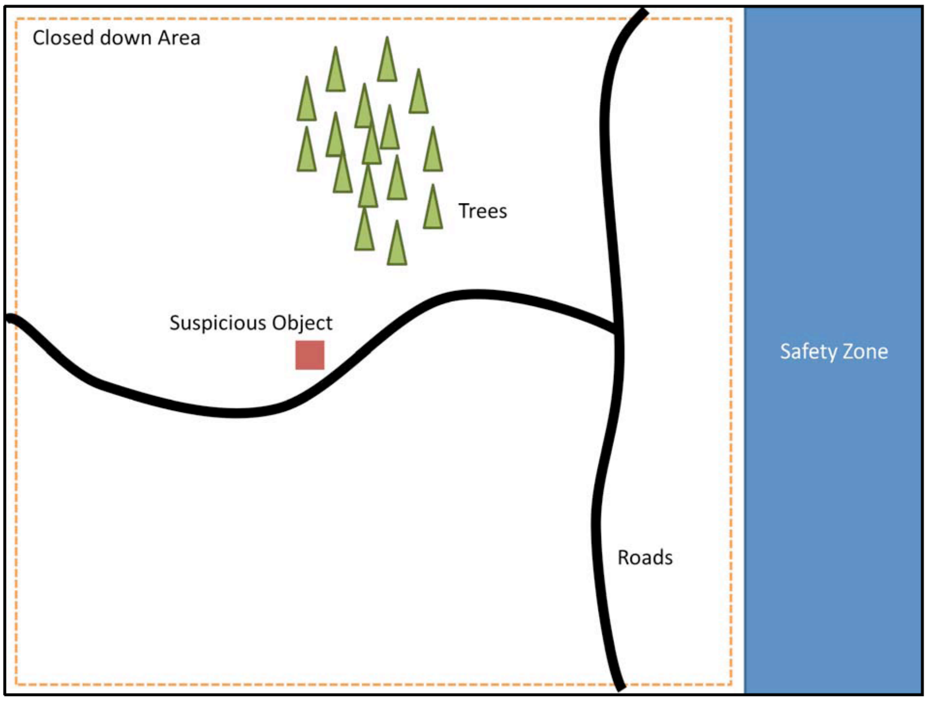


Figure 5 Drawing of an example for the scenario "Suspicious Object". There is the suspicious object in the middle of the closed down area. The radiation task force is operating from a safety zone nearby.

The unmanned system should provide real-time sensor readings to the radiation task force at all times. The unmanned system should approach the suspicious object from the deployment safe zone, where the operator of the unmanned system is located. The objective of the unmanned system would be to find the approximate or exact location of the source. Using the instruments in the vehicle, real-time measurements should enable the radiation experts in the safety zone or at any distant analysis centre to identify the nuclide or nuclides. This would be followed by mapping the radiation field of the source in the area near to the source in order to determine collimation and shielding of the source.

1.3.2 Isocurves (contour mapping)

If the location of a point source or contaminated area is roughly known, the radiation task forces will be tasked with creating iso dose rate curves (i.e. curves around the source where the dose rate is constant). This type of scenario could be of category one or two. Location, activity and dispersion of the source are unknown. It is further unknown, if explosives are involved. The main task in this scenario is the active search of the RN source (type (b) task).

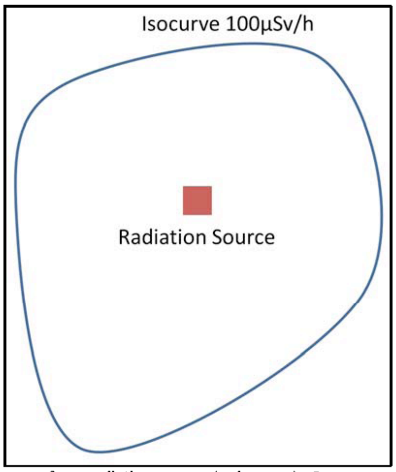


Figure 6 This is a sketch of an isocurve for a radiation source (red square). On every point of the blue curve, the radiation level is e.g. 100µSv/h.

The unmanned system should provide real-time sensor readings to the radiation task force at all times. The vehicle should identify the boundaries (create iso-curves) of the contaminated area with a given criteria (e.g. 100µSv/h). This should be followed by a survey to more precisely determine the location of the source.

1.3.3 Terror lab, Mapping

In this scenario, a workspace or laboratory has been located that contains radioactive sources, which are intended for illicit use. The radiation task force is called in to investigate the scene. This is a category one or two scenario. Activity, location and dispersion of the source are unknown. It is further unknown, if explosives are involved. The main task is the mapping of the environment (type (a) task). The unmanned system should provide real-time sensor readings to the radiation task force at all times. The task of the vehicle would be to map the radiation field in the area, starting outside and proceeding inside of the lab. If a suspected radioactive source is found, an alarm containing measurements and location of those measurements must be transmitted to the operator. This should be followed by identification of the nuclides present as well as a survey of the nearby area.

1.3.4 Scrap metal (sort out piece by piece)

In this scenario, an elevated radiation field has been found to originate from a large collection of scrap metal (e.g. a container or a large pile at a scrap metal yard). Due to the high density of metal, which collimates the source, and the difficulty of separating radioactive scrap metal from non radioactive scrap metal by visual means, every piece of metal has to be separated and checked. This is typically a category 2 scenario. Activity and location of the source might be roughly known and dispersion is unlikely. It is unknown, if any explosives are involved. The main task of this scenario is the mapping of the source.

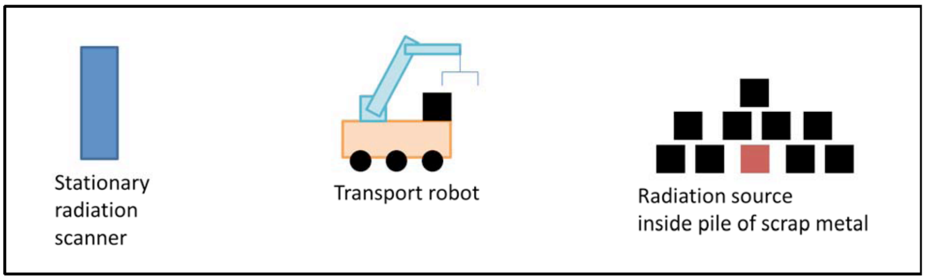


Figure 7 Sketch of a possible "Scrap metal" Scenario. On the right side, there is a pile of scrap metal with a radioactive source. The robot has to bring the pieces one by one to the stationary scanner for inspection and radiation measurement.

The task for the unmanned system is to scan the pile piece by piece and gather non-radioactive material at a safe place and to raise an alarm for active material and separate this from the non-active pieces. The unmanned system has to repeat this task until every piece has been scanned and all radioactive sources have been found and removed.

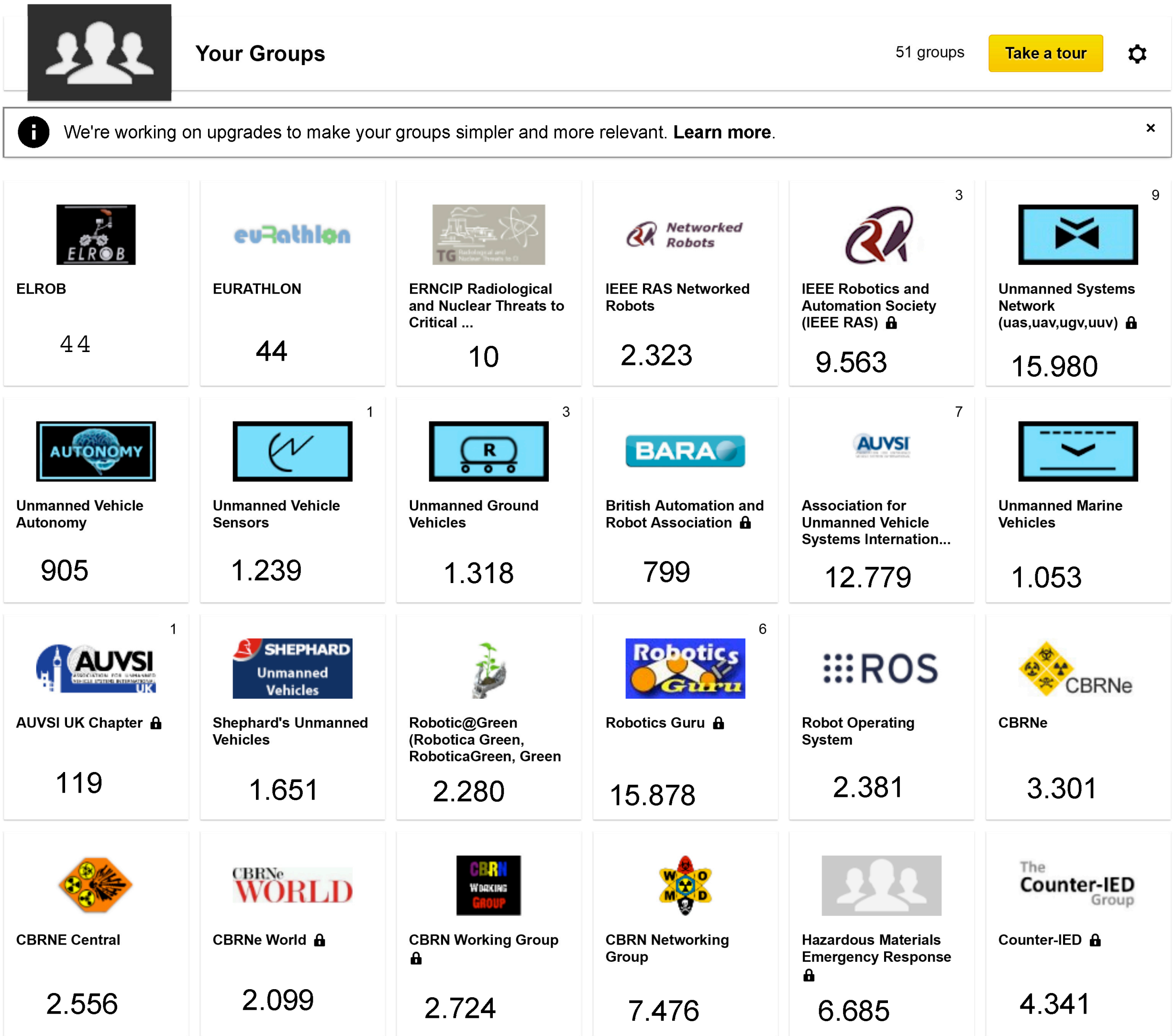
1.3.5 Sampling

In this scenario the dispersion of a radioactive source has not been confirmed. Sampling has to be performed to determine possible dispersion of the source and the extent of this dispersion. The radiation task force has already established a safety zone at a safe distance to the source. This is a category one or two scenario. Activity and location of the source are unknown. Dispersion is possible but not confirmed. The main task of this scenario is the sampling of a source (type (c) task).
The task for an unmanned system is to gather samples and bring them out of the area containing the suspected radioactivity. There could be different kinds of samples to gather including air samples and dust that could be gathered by sweeping with a tissue. At all times, the unmanned system must provide real-time sensor readings to the radiation task force. Additional constraints may apply, as gathering of evidence is highly regulated.

1.3.6 Map and search radioactivity, map and search hotspots and do identification of nuclides

In this scenario the radiation task force need a map of a given area. In this map, hotspots and radioactivity sources have to be tagged and nuclides have to be identified. The main task of this scenario is a spatial mapping (type (a) task) of the environment. This is a category one or two scenario. Activity and location of the source are unknown. Dispersion is possible but not confirmed.
The task for an unmanned system is to gather geo-referenced RN-sensor readings and put the information together in a map. At all times, the unmanned system must provide real-time sensor readings to the radiation task force.

Annex B: LinkedIn groups



Group	Members	Corner number
Defense Industry Network	15.699	8
European Community Grants, Calls and Projects	29.764	4
European Research Interests	7.277	
Horizon 2020, Framework Programme for Research and I...	103.051	10
Rheinische Friedrich-Wilhelms-Universitaet Bonn Alumni	2.608	
EOD Operators / Organizations	2.462	
IDGA - The Network for Military Personnel and Defens...	5.402	
RoCKIn	13	
Unmanned Air Vehicles	3.140	2
" HORIZON 2020 " Framework Programme for Research & ...	174.818	15
"H2020 SECURITY Research" Defense R&D Projects, Emer...	4.664	
EOD Technicians	3.968	
European Defence {Agency}	1.819	
Explosive Ordnance Disposal	5.215	
Explosive Ordnance Disposal (EOD)	3.054	
Independent UXO Risk Management Professionals	1.013	
Landmine and Unexploded Ordnance Clearance	1.278	
Mine Detection and Demining	1.790	
ROBOTICS	3.488	3
Unmanned Systems for Emergency Services	255	
Autonomous Unmanned Systems & Robotics	283	2
Coalition Battle Management Language (C-BML)	30	
Market Info Group	2.146	
Robotics Consultants	1.430	
The Future of Unmanned Systems: Markets and	1.517	
Unmanned Systems Technology (UAV | UGV | Marine | Ro...	1.447	2
Unmanned Vehicles Research Group	463	

You may be interested in **Industrial Robotics**.

industrial robotics

13247 members

View group page

Don't see what you're looking for?

Find a group

Create a group

View Less

Europe Direct is a service to help you find answers to your questions about the European Union
Free phone number (*): 00 800 6 7 8 9 10 11
(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server http://europa.eu

How to obtain EU publications

Our publications are available from EU Bookshop (http://bookshop.europa.eu),
where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents.
You can obtain their contact details by sending a fax to (352) 29 29-42758.

LB-NA-27766-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy directorates-general, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

Publications Office

doi:10.2788/112402

ISBN 978-92-79-56877-0