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SemUnaRS –
Seminar on Unmanned Radiometric Systems

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Abstract

There are several scenarios related to ionizing radiation or the release of radioactive materials where the use of unmanned vehicles certainly reduce the risk of receiving high doses to the personnel performing measurements. Other advantages are low costs of the equipment, operation, maintenance and services.
The seminar on unmanned radiometric systems was held in October 2014. The seminar was dedicated to presentations on the status of unmanned mobile measurement capacities in the Nordic countries.
An introduction to the topic of unmanned measurements covered some examples on systems of unmanned aerial, rotary and fixed wing, systems as well as ground based systems. A short description was given on the work of ERNCIP.
Linköping University presented their considerations on their ongoing development of unmanned gamma-ray spectrometry systems and presented their rotary wing and fixed wing platforms developed by Claes Meijer.
STUK presented their experience to develop radiation monitoring instrumentation to unmanned aerial vehicles. A set of radiation detectors and a sampling unit was mounted to a mid-size Ranger military UAV. A lightweight sampler and a gamma-ray detector was installed to a small-size fixed-wing UAV. Extensive tests were done for both set of instruments.
On the second day of the seminar there was time scheduled for open discussions on the way forward for Nordic collaborations regarding unmanned mobile measurements.
The seminar revealed that the Nordic capacities of unmanned mobile measurements are diverse, but no country has a system operating today. Each country have different strategies on how to meet this demand; university research, military collaboration or procuring turn-key systems.
There is a need for continued and concerted activities to strengthen the Nordic knowledge and capacities in the field of unmanned mobile measurements.

Key words

Unmanned mobile measurements, UAS, UAV, air sampling, emergency preparedness

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Final Report from the NKS-B SemUnaRS (Contract: AFT/B(14)9)

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Introduction

There are several scenarios related to ionizing radiation or the release of radioactive materials that may cause severe consequences to individuals or to the environment. Among these are for example severe nuclear reactor accidents, such as happened in Chernobyl and Fukushima, the use of radiological dispersal devices, RDDs, to throw off radioactive materials into the environment or searching highly radioactive materials out of regulatory control, MORC. In these cases the use of unmanned (aerial) vehicles certainly reduce the risk of receiving high doses to the personnel performing the measurements. Other advantages are low costs of the equipment, operation, maintenance and services.

Radioactive plume tracking, sampling of airborne materials, fallout mapping, location and manipulation of highly-radioactive point sources (MORC or RDD) on the ground, underwater source finding etc. are the areas in which unmanned vehicles may provide substantial benefits compared to manned vehicles. During recent years there has been a substantial development especially in unmanned aerial vehicles. The possibility of using miniaturized equipment and development of aviation legislation have led to a variety of platforms. In addition, modern data transfer technologies will open up novel possibilities in radiation surveillance.

The seminar

The seminar on unmanned radiometric systems was held at Vårdnäs stiftsgård in Linköping, Sweden, October 2nd and 3rd of 2014. The seminar was dedicated to presentations on the status of unmanned mobile measurement capacities in the Nordic countries. Unmanned mobile measurements is still in research state and there is little published in scientific literature beyond feasibility studies.

The seminar was the start-up and an inventory of the capacities for unmanned mobile measurements in the Nordic countries. The seminar hosted discussions on different approaches to utilize unmanned platforms, aircraft regulations and the collaborations between universities and the authorities.

An introduction to the topic of unmanned measurements was held by Magnus Gårdestig, Linköping University, Sweden, covering some examples on systems of unmanned aerial, rotary and fixed wing, systems as well as ground based systems. A short description was given on the work of the thematic group on Radiological and Nuclear threats to critical infrastructure under the European Reference Network for Critical Infrastructure Protection, ERNCIP.

Linköping University presented their considerations on their ongoing development of unmanned gamma-ray spectrometry systems and presented their rotary wing and fixed wing platforms developed by Claes Meijer. Claes Meijer presented a review of the concept of unmanned aircraft systems.

Radiation and Nuclear Safety Authority of Finland (STUK) presented their experience to develop radiation monitoring instrumentation to unmanned aerial vehicles, UAVs. Two types of platforms were used for the payload: A set of radiation detectors and a sampling unit was mounted to a mid-size Ranger military UAV. A lightweight sampler and a gamma-ray detector was installed to a small-size fixed-wing UAV. Extensive tests were done for both set of instruments.

Peder Kock, SSM, Sweden presented an exercise on mobile measurements of a simulated nuclear fall-out held outside Lund, Sweden 29th of September to 2nd of October 2014.
Two fields were contaminated with ^{18}F and ^{99m}Tc, the activity concentration being in the order of 1 MBq/m^2. The surface activities were assessed by eight field teams with HPGe-spectrometers calibrated for in-situ measurements. Combined, the teams used three different calibrations. Assessments within 30% were acceptable. The in-situ measurements were compared to grass and soil samples.
Mobile measurements were performed with cars on large simulated fall-out areas.

The abstracts are in Appendix 2.

Discussions
On the second day of the seminar there was time scheduled for open discussions on the way forward for Nordic collaborations regarding unmanned mobile measurements.

There is a funding opportunity from the European Commission in the Horizon 2020 programme, section Fight against crime and Terrorism, topic FCT-3-2015: Forensics topic 3: Mobile, remotely controlled technologies to examine a crime scene in case of an accident or a terrorist attack involving CBRNE materials (Horizon 2020, 2015), that is applicable for the topic. The participants of the seminar find this interesting, but concluded that, at this stage, there is no possibility to make any contribution to a call in this context.

The purpose of the SemUnaRS activity is to stimulate the planning process for the Nordic countries' development of unmanned aircraft radiometric systems, UARS. Future activities and proposals to NKS were discussed and the seminar concluded to propose to NKS the next step in the Nordic activities on unmanned mobile radiometric systems.

The seminar strongly agreed on the need of ongoing collaboration to facilitate development of unmanned capacities in the Nordic countries. The seminar therefore assigned Magnus Gårdestig, Linköping University, Sweden, as a coordinator to write the NKS-B proposal RUN – Roadmap for Unmanned Aircraft Radiometric Systems in the Nordic countries.

The aim is that the roadmap will assist Nordic Radiation Protection Authorities in their long-term strategy planning.

The questions to be resolved and reach consensus about is e.g.:

- Which RN scenarios would be solved with Unmanned Aircraft Radiometric Systems, UARS? Why is this needed?
- What is the expected impact on existing organizations?
- Which are the critical parameters to be met?
- Which platforms, detection systems and personnel competencies are necessary to provide these capacities?
- How will these capacities be tested?
- Who will develop, use and maintain these capacities?
- When could these capacities be available?
- Which aircraft regulations needs to be considered?
- Which standards are adequate? Data formats. Integration to reachback systems (remote expert support).

- How could cross border assistance be arranged?
- What sampling requirements need to be met? E.g. gaseous or particulates, real-time monitoring of the sample.
- Beside gamma-ray spectrometry, is there a need to measure n- and β-fields?
- Other possible detection technologies?
- What planning, presentation and analysis software need to be developed?

The outcome of the activity is the roadmap which could be implemented by the Nordic countries in concerted actions according to their resources. The continuation of the Nordic collaboration is a joint exercise of these implementations.
The end goal of all these activities is a strengthened Nordic RN preparedness with the capacities of unmanned measurements and sampling.

The development of the roadmap

The roadmap development will be divided into editing sessions with an intermediate open seminar with possible demonstrations. The proposers represent university, authority and contingency agency. The workgroup will also invite the Nordic defense forces, police and other important stakeholders. All of these categories from the Nordic countries will be invited to the open seminar.
Stakeholders will be invited to the seminar where the outline of the roadmap will be presented and discussed. The roadmap draft will be sent to the authorities in the Nordic countries for comments. The outcome of the activity is the roadmap document which each Nordic country, or in collaboration, could implement in practice according to their resources.
Building an informal network of stakeholders, scientists, authorities and young scientists in the area of interest is of importance for the Nordic radiation protection community.

Conclusions

The SemUnaRS seminar revealed that the Nordic capacities of unmanned mobile measurements are diverse among the Nordic countries, but no country has an operating system today. Each country have different strategies on how to meet this demand; university research, military collaboration or procuring turn-key systems.

There is a need for continued and concerted activities to strengthen the Nordic knowledge and capacities in the field of unmanned mobile measurements.

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Horizon 2020, (2015): Forensics topic 3: Mobile, remotely controlled technologies to examine a crime scene in case of an accident or a terrorist attack involving CBRNE materials. R. a. Innovation. European Commission, European Commission. H2020-FCT-2015.

Appendix 1 Seminar programme

Day 1 Thursday 2nd October

Time	Title of presentation	Presenter
12-	**Registration**	
12:00-13:00	**Lunch**	
13:00-13:15	**Opening of the seminar**	Magnus Gårdestig
	Tour de Table, introduction of participants/institutions	All
	Scope and Agenda of the Meeting	Magnus Gårdestig
	NKS introduction	Kasper Andersen
14:00-14:30	*Introduction to the field and information on the ERNCIP thematic group on Radiological Threats to Critical Infrastructure*	Magnus Gårdestig
14:30-15:00	*Development of radiation surveillance equipment in STUK for unmanned aerial vehicles*	Roy Pöllänen
	Coffee break	
15:30	*Considerations in the development of small UARS – Unmanned Aircraft Radiometric Systems*	Magnus Gårdestig
16:00	*Unmanned Aircraft Systems*	Claes Meijer

Day 2 Friday 3rd October

Time	Title of presentation	Presenter
07:00-	**Breakfast**	
09:00	*Operational considerations regarding the use of unmanned vehicles for radiation surveillance in Finland*	Petri Smolander
	Preliminary conclusions from the LÄRMÄT -14 exercise	Peder Kock
10:00	**Coffee break**	
	Open discussions	All
	Future NKS Proposals	
	Horizon 2020, FCT-3-2015: Forensics topic 3: Mobile, remotely controlled technologies to examine a crime scene in case of an accident or a terrorist attack involving CBRNE materials	
12:00-12:30	**Closing of the seminar**	Magnus Gårdestig
12:30	Lunch	
	Departures	

Appendix 2 Abstracts

Introduction to the field and information on the ERNCIP thematic group on RN Threats to Critical Infrastructure

Magnus Gårdestig
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Introduction

RN preparedness and measurements capacities have evolved based on the major incidents that have occurred; Three Mile Island 1979 emphasized the preparedness around the NPPs, Chernobyl 1986 gave new insights that it could grow to a global concern quite rapidly, the attack on World Trade Center 2001 increased the preparedness for malevolent actions while Fukushima-Daiichi 2011 once again set the focus on nuclear emissions. Over the years, incidents with orphan sources, so called MORC, radioactive Material out of Regulatory Control, have occurred and placed great demands on measurements capacities. The RN preparedness appears to be incident-driven.

Unmanned measurements

There are several measurement and sampling scenarios that may constitute very high risks for humans to carry out, e.g. reactor accidents, such as Chernobyl and Fukushima, RDDs (radiological dispersal devices) before and after explosion, search of MORC, or search inside buildings that are under the threat of collapsing. Other scenarios call for dull and time consuming measurements like ground dispersion mapping. For these scenarios remote controlled radiation measurements and sampling using unmanned aircraft systems need to be developed.

When forensic considerations are necessary, unmanned measurements could have less risk of cross contamination. Cover materials of the vehicle need to be easily decontaminated or replaced.

General considerations related to unmanned measurements depend on which quantity is measured (dose rate, cps, energy spectra), and if the data is transmitted or only stored locally. Gain stabilization of spectrometer is important, since conditions may change rapidly during the flight (thermal insulation of detector module could be considered). The nature of the mission decides on the optimal detector size, or multiple sizes and/or multiple types of detectors. Hence, limitations in payload set the preferred tasks for the systems.

The system's tolerance to weather conditions sets how many days per year it is usable. There could be a need for operation in darkness.

Automatic analysis of data, e.g. source localization, assessment of activity or surface concentration or autonomous tracking of release plume or nuclide specific activity concentrations in air etc. could be done onboard or by the control station when having two-way communication.

In the last years, several light weight (50-500 g) spectrometers have been developed and offered to the market. CZT and CsI seem to be the detection materials of choice in this category. When using scintillation spectrometers, NaI, LaBr e.g., when able to carry a payload over 1000 g, several PMT base MCA are offered. They have a different set of features, e.g. list mode acquisition and weight. A 100 g lighter MCA give room for more battery power and hence operating time.

Wireless communication between the RW and the ground station is crucial and the range could be increased by using other RWs as relays in a mesh network (Hening, Baumgartner et al. 2013). Sampling using RW could be done with the use of manipulators[1] (Hooper 2014, Hunt, Mitzalis et al. 2014) and air or dust sampling could be done to track and map release plumes (Kosmatka, Hong et al. 2011).

The precision in position determination, in particular the altitude, is crucial in the calculation of the source activities or surface activities. Therefore any precision enhancement system is welcome. Differential GPS or RTK, Real Time Kinematics, have been used and has developed to affordable systems with redundancy. Precision down to inch level is possible.

MDA obsession

There have been a trend for the measurements systems in the hunt for low MDA, Minimum Detectable Activity, requiring large detectors. But in the high dose rate scenarios large detectors tend to overflow the electronics and thus require longer distances, whilst smaller detectors could operate in higher dose rate conditions. Given unmanned carriers the detectors could come closer for lower MDA if necessary.

Unmanned Aircraft Systems

Unmanned Aircraft System, UAS, an expansion of UAV, Unmanned Aerial Vehicle, is a common concept for remotely piloted or autonomous operated aircraft including control system, whilst the term drone is more common for armed and military unmanned aircraft. Recently, the concept RPAS, remotely piloted aerial systems, have, mainly in the hobbyist community, complemented UAS and emphasizes less on the autonomy.

Rotary wing

Rotary wing UAS (RW) is different from Fixed wing UAS (FW) in the following aspects:

- RW operates more directly in 3D (3 dimensions).
- RW can hover.
- RW have the ability to descend closer to the source and reduce the distance and extend the measurement time and hence reduce the MDA (Minimum Detectable Activity).
- RW are more complicated to use as air samplers since the air flow is more fluctuating.
- RW has relatively shorter operating endurance and payload capacities.
- RW is relatively more sensitive to weather conditions.

RW can be separated in two main categories; heavy, petrol driven, helicopters that are under stricter regulations and lighter, electrically driven, tri-, quad-, hexa- or octocopters that are easier accessible.

The variety of innovative RW platforms is infinite and opens the possibilities to find an ultimate RW for any application. An overview of 132 different UAS and research on the platform can be found in Cai, Dias et al. 2014.

There are several examples of feasibility studies that a light enough detector-battery combination could be carried by a RW and perform measurements (Bogatov, Mazny et al. 2013, Bristol 2013, MacFarlane, Payton et al. 2014) and illustrate the usability of RW as

[1] http://youtu.be/DyAvbq8o7xI

radiation measurement platform (Okuyama, Torii et al. 2005, 2008, Gårdestig and Pettersson 2011, 2012, Reavis 2011, Towler, Krawiec et al. 2012, Han, Xu et al. 2013).

Fixed wing

Unmanned aerial fixed wing vehicles range from micro-UAVs with a 15 cm wingspan and a payload capacity of a few grams to wingspan of 35 m and a payload capacity of 2000 kg. Endurance, operational range and flight altitude comparable to, or even better than, conventional aircraft are available. Many manufacturers offer payloads for NBC (nuclear, biological, chemical) reconnaissance. Information about these payloads is, however, very limited and usually not published.

RN-payloads include capabilities for sampling and radiation spectrometry. Real-time link to operation control is important.

Air sampling

Air contamination can be gaseous or aerosol particles which decide your air sampling method. Particulate sampling should be isokinetic. This should be valid throughout the relevant air speed range. The optimal sample volume depends on the activity concentration.
In many cases on-line monitoring of sampling would be useful. Ability to link the results from the on-line spectrometry and the off-line analysis of samples would be important.
Capability to start and stop sampling during the flight would also be useful.

STUK has developed an air sampler for mounting on a mini-UAV and it collects airborne radioactive particles (Perajarvi, Lehtinen et al. 2008). The minimum detectable concentrations of several transuranium nuclides are ~ 0.3 Bq/m^3 or less using direct alpha spectrometry. This information can be obtained within 2 h from the beginning of the sampling.

Unmanned Ground Systems

Unmanned ground systems can operate in areas with high radiation or danger of explosives (e.g. BLEVE: boiling liquid expanding vapor explosion or IED, improvised explosive device), in collapsing structures, booby trap, heat etc.

Unmanned ground systems have the ability to take samples by swiping and to manipulate the environment on long-time surveys in contaminated areas, probing i n problematic environments and conditions, monitor the movements of a threat and provide real-time data from multiple mobile sensor sources. (Rohling, Bruggemann et al. 2009, Schneider and Wildermuth 2011, Schneider, Welle et al. 2012)

For actuation and navigation there are laser systems for scanning the environment with a laser scanner to plan collision free trajectories.

ERNCIP

The ERNCIP Office (European Reference Network for Critical Infrastructure Protection) has established a thematic group on Radiological and Nuclear Threats to critical infrastructure (RN Thematic Group) (ERNCIP) which looks at issues such as certification of radiation detectors, standardization of deployment protocols, response procedures and communication to the public, e.g. in the event of criminal or unauthorized acts involving nuclear or other radioactive material out of regulatory control.

The RN Thematic Group works with the following three issues:

1. List-mode data acquisition based on digital electronics. Time-stamped list-mode data format produces significant added value compared to the more conventional spectrum data format. It improves source localization, allows signal-to-noise optimization, noise filtering, with some new gamma and neutron detectors actually requiring list-mode data to function. The list-mode approach also allows precise time synchronization 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. Fast and high quality response can be achieved with less people. Optimal formats and protocols are needed for efficient communication between frontline officers and reachback center.

3. Remotely controlled radiation measurements and sampling using unmanned vehicles. 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, search of nuclear and other radioactive material out of regulatory control.

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Development of radiation surveillance equipment in STUK for unmanned aerial vehicles

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Introduction

Unmanned Aerial Vehicles (UAVs) can be equipped with a number of different instruments, which enables their use in various applications especially when manned platforms are not appropriate. They can be safely applied for example in a severe nuclear accident to monitor radioactive releases or to take samples from airborne materials. In the present paper we briefly go through the work done in STUK during the past fifteen year period to develop/mount radiation detection instrumentation to UAVs.

UAV platforms

In STUK, two types of platforms (Fig. 1) were equipped with radiation detection instrumentation. 1) Mid-sized Ranger UAV is operated by the Finnish Defence Forces and is mainly designed for electro-optical surveillance in military missions. Operation of Ranger is autonomous or remotely piloted. The maximum operation distance is 150 km, maximum operation height 4.5 km and maximum endurance 5 h. Flight speed is 100–220 km/h. Take-off is done by catapult and landing is on skids. Wing span is 5.7 m and maximum take-off mass 270 kg. Mass of the payload is 40 kg. 2) Another type of radiation surveillance equipment was mounted in a fixed-wing UAV known as Patria MASS mini-UAV. Mass of the battery-driven UAV is 3 kg and payload capacity 0.5 kg. Maximum operation time is 1 h, operating range 10–20 km and optimal cruise speed 60 km/h. MASS flies fully autonomously but manual control is also possible. Both UAV systems can send the measurement data in real-time to the ground station.

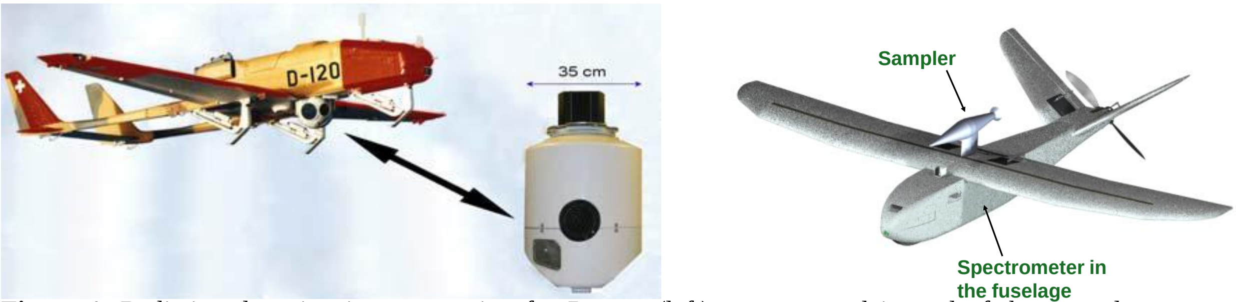

Figure 1. Radiation detection instrumentation for Ranger (left) was mounted instead of the normal camera equipment whereas no changes for the platform were necessary for the Patria MASS mini-UAV (right). See http://www.stuk.fi/julkaisut_maaraykset/en_GB/stuk-ttl-flyers/_files/88555484220687337/default/Flyer_008_Radiation_surveillance_and_UAVs.pdf

Radiation surveillance equipment

Three types of radiation detectors were mounted in Ranger. A GM counter was selected for monitoring the external dose rate. The counter covers the dose rate range of 0.01 µSv/h – 10 Sv/h. A 6″×4″ NaI(Tl) scintillation detector was for the radioactive plume localization. Large scintillation detectors may be saturated in an active plume and to overcome this situation a 5×5×5 mm^3 CZT detector was mounted inside the sampling unit. The filter cartridge contains a paper/glass-fibre filter and a charcoal filter. Air flow through the filters is generated by the dynamic air pressure.

A CsI detector was mounted in the fuselage of the MASS mini-UAV for gamma-ray detection. A light-weight sampler with flow rate of 0.2 m^3/h (generated by dynamic air pressure and using a membrane filter) was designed for radioactive particle sampling.

Testing the equipment

STUK performed laboratory tests as well as field and flight tests for the equipment. All the detectors were tested in a laboratory to find out their performance in controlled conditions. In the case of the equipment of Ranger, flight measurements were done with target drones and small manned aeroplanes.

More thorough tests were performed for the equipment mounted in MASS mini-UAV. The sampler was tested in a laboratory using a wind tunnel. Field tests were performed using a car as a platform and by the aid of radon progeny (Fig. 2). Flight tests were successfully done with MASS to verify operation of the sampler. For alpha-particle emitting radionuclides the detection limits may be considerably less than 1 Bq/m^3.

Laboratory tests, field tests and flight tests were also done for the CsI detector of the mini-UAV. Unshielded ^{137}Cs and ^{60}Co point sources were used in the testing. Detection limits were approximately 1 GBq or larger depending on the flying altitude.

Reporting

The work described above was supported by the Advisory Board of Defence (MATINE). During 1999–2003 in total 18 (internal) reports/papers, 18 presentations and 5 posters were done in which the equipment installed in Ranger were described (Kurvinen et al., 2008). Scientific reporting was done later (Kurvinen et al., 2005). The work done for MASS was reported in a large set of (internal) technical reports, presentations and scientific papers. Published papers are in the reference list below.

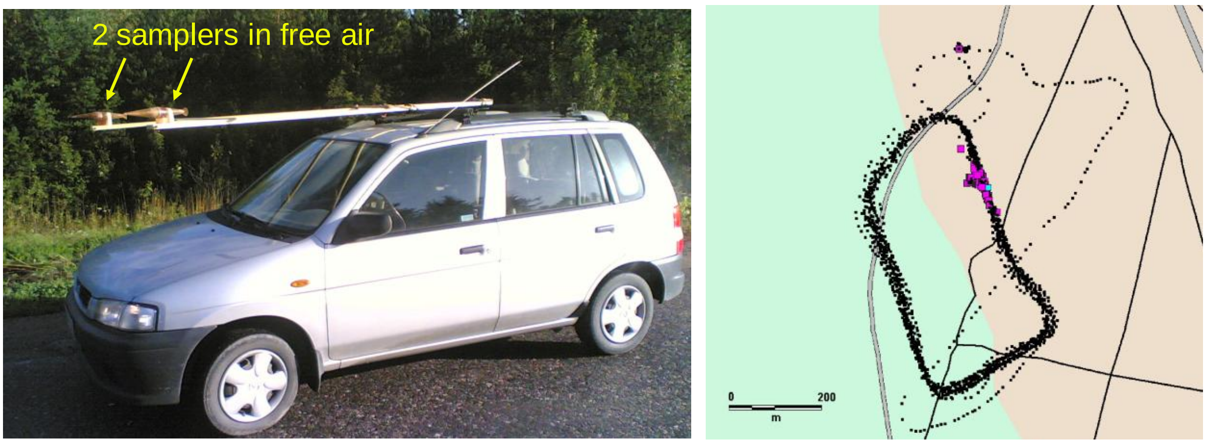

Figure 2. *Testing operation of the MASS mini-UAV samplers using a car (left). Colored points in the right show the estimated location of the detected point source on the ground when the CsI detector is mounted in the mini-UAV. Black points refer to the route of the UAV during the flight test.*

Conclusions

The goals set by STUK to develop radiation detection instrumentation for UAVs was to investigate and introduce novel means to perform mapping of a radioactive plume, sampling from the plume, fallout mapping and locating point sources. All these tasks can be performed using the equipment described above.

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Considerations in the development of small UARS – Unmanned Aircraft Radiometric Systems

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Introduction

Linköping University is part of the Swedish radiological and nuclear emergency expert organization led by the Swedish Radiation Safety Authority. The organization utilizes AGS (Airborne Gamma Spectrometry), CGS (Carborne Gamma Spectrometry) and FAT (Field Assistance Team) in the data collection efforts. In an attempt to complement these capabilities, we develop unmanned radiometric systems. We are in the progress of developing gamma spectrometry systems onboard unmanned aircraft systems, UAS, using a multirotor (Gårdestig and Pettersson 2011, 2012) and a fixed wing as well as air sampling on these platforms.

Envisaged missions

Any measurement scenario where unmanned aircraft can be used offer operation from safety distance in respect to irradiation as well as personal safety and forensic considerations. The envisaged main mission for the rotary wing system is localization and identification of individual radioactive sources. With a fixed wing, with longer endurance, mapping of ground area of fallout is possible. Both systems are intended for mapping of fallout plume by dose rate and assessment of air concentration by air sampling.

Aerial platform

Since we are mostly interested in the measurement itself and the analysis of the resulting data, the aerial platform itself is secondary, but to prove the concept, we had the following criteria:

- cost; several systems should use the same set of equipment,
- size; transportable in a standard car and portable,
- complexity; limited training,
- endurance; mission time and
- safety.

The measuring system is independent of the aerial platform, but we have chosen to cooperate with a vehicle developer to have a suitable platform in regards of speed and other critical parameters.

Detectors

The aerial platforms set limitations in payload. During recent years, commercial detectors have been developed towards rugged, lightweight and affordable detectors. CZT spectrometers lighter than 100 g is readily available. Light CsI(Tl) spectrometers are available and open source PMT-base multichannel analyzers are available for NaI or LaBr scintillators.

Communications

For online data presentation, communication with the aerial platform is critical. The communication link should be independent since communications tend to be congested in emergency situations. Communication by WiFi, analog radio, GSM, UMTS, LTE, TETRA or Zigbee were considered.

Data acquisition and presentation
The spectral and position data needs to be presented and analyzed for detection, localization, identification and quantification. This is achieved by dose rate color coded position marker in an on-line map, spectral data in waterfall display, full spectral view or by chosen ROI. Assessment of source activity or surface concentration is made by calibrated peak count coefficients. The data should be stored in the XML-file format according to N42.42 (ANSI 2012).

Position accuracy
When assessing the activity the distance to the source is a key factor. GPS systems needs to be enhanced by RTK or dGPS technology to achieve desired accuracy and precision. Other altitude sensors are barometers, ultra sound transmitter/receiver or lasers.

Conclusions
Linköping University is in the progress of developing a spectrometry system to be carried by a small rotary wing quadcopter and a fixed wing airplane. Both operated under the Swedish Transport Agency license category 1B for UAS below 7 kg (Transportstyrelsen 2009, 2013).

The system will be used in the Swedish RN preparedness organization and is intended to fill a gap between man-portable measurement systems and full-sized airborne systems, complementing car-driven.

The system will provide footage and measurements.

The current setup is the Kromek GR-1, a CZT (10x10x10 mm) with 2% FWHM% (^{137}Cs), 60 g and a 2” NaI(Tl) scintillator on a Bridgeport tube base MCA, approx. 900 g. The data acquisition is made by the small Linux-computer Raspberry Pi and communication by ZigBee 868 MHz. GPS position is acquired from the APM autopilot. The data is presented and analyzed by a developed program and the data is stored in XML-files compatible with N42.42.

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Unmanned Aircraft Systems
Claes Meijer, Scandicraft AB, Sweden

Notes from the presentation taken by Marie Carlsson and Magnus Gårdestig

Claes Meijer is a skilled and awarded pilot and developer and customizer of unmanned aircraft systems. He has long experience in various aspects of the world of unmanned systems.

His presentation gave an overview of different unmanned systems in various sizes and forms. Everything from small helicopters for fun, quadcopters used by the fire brigade, up to military drones.

Claes has his own company in developing unmanned systems. His presentation covered the VTOL vehicle Transformer that can switch between rotary wing and fixed wing operation in flight. He has also developed a jet driven target for air defense training.

The rotary wing system used by Linköping University is the quadcopter SAFE that is designed by Claes with an integrated outer rail to protect the rotors on impact as well as material or persons from the rotors.

Figur 1. Unmanned aircraft platforms used by Linköping University. The rotary wing vehicle SAFE to the left and the fixed wing prototype to the right. Photos by Marie Carlsson and Claes Meijer.

The fixed wing system used by Linköping University is a 2.5 m wingspan plane that is designed by Claes to carry as much payload as possible (up to 2 kg) and be able to fly slowly (5-10 m/s).

Operational considerations regarding the use of unmanned vehicles for radiation surveillance in Finland

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UAV platforms in use of under consideration in Finland

UAV platform users can be divided in commercial operators and public sector operators. Brief market survey did not reveal any potential commercial operators that could be used to provide a UAV platform for radiation surveillance.

On the public sector currently only the Finnish Defense Forces (FDF) has two UAV systems that could be used as a platform for radiation surveillance: Ranger tactical-UAV and Orbiter II mini-UAV. Pertinent characteristics of both systems are presented in table 1.

Table 1: Pertinent features of the FDF UAV platforms

Feature	Ranger tactical-UAV	Orbiter II mini-UAV
Speed	150 kph	90 kph
Endurence	5 hrs	3-4 hrs
Payload	40 kg	1.5 kg
System complexity	High	Low
Deployment speed	Slow	Fast

Most notable differences are payload capacity and deployment speed. Ranger’s 40 kg payload capacity enables larger and thus more sensitive detectors which enable higher flight altitudes leading to larger surveillance footprints. On the other hand, the complexity of the Ranger system impedes rapid response to a sudden event.

The Finnish Police and larger regional rescue departments are considering the use of small multirotor UAVs (quadcopters, octocopters) for situational awareness in complex security events and accidents. These can also be used as platforms if they become into use in the fore mentioned organizations. Currently the short endurance of the small multirotor UAVs limits their use for radiation surveillance only to small scale events.

Tethered UAVs are also considered for long endurance surveillance and monitoring mainly for security related events. These UAVs are also usable for radiation surveillance in security related events. Their virtually unlimited endurance and high bandwidth data link via tethering cable are significant advantages of tethered UAVs.

Radiation surveillance mission types

Radiation surveillance missions can be divided in three main types: plume mapping, fallout mapping and detection/location of radioactive sources.

Plume mapping is the most suited mission type for UAVs. Plume mapping is both dirty and dangerous, thus not well suited for manned aircraft due to contamination risk of the aircraft and the exposure of the pilot to radiation and radioactive material. UAVs also have the contamination risk in plume mapping missions, but their smaller size and simpler structure makes the decontamination task simpler compared to manned aircraft. In some cases the contaminated UAV can be discarded all together due to the low cost of replacing it.

Fallout mapping can be done with manned aircrafts and in large scale radiological events they are the most suitable platforms for the task. In smaller cases when the level of details required or the surroundings (e.g. urban area) call for low level and slow speed flying, UAVs have the advantage.

Detection and location of radioactive source(s) is also quite suitable mission type for UAVs if the search area is small. As mentioned above the UAVs can fly lower and slower than usually is considered safe for manned aircraft. This enables the use of very detailed and complex search patterns. In case of rotary winged UAVs they can even hover above or land near the source without any radiation safety risk to help marking the exact position of the source. Confirmation of the absence of radioactive sources can be viewed as a special case of this type of missions. Tethered UAVs would be very suitable for this type of special case missions because they can easily provide continuous surveillance over the area of interest.

Payloads for radiation surveillance missions

Payloads for the radiation surveillance missions can be divided into three main categories: radiation counters, spectrometers and air samplers.

Simple total radiation counters have rather simple electronics with low power consumption which make them ideal for the smallest UAVs. Radiation counters also have low data rates which mean that simpler, thus less power hungry, data links can be used. The level of detail of the information total radiation counters provide is rather low, but in many cases it is enough to establish the prevailing radiation safety situation. In the search of radioactive sources total radiation counters are also adequate because in most cases the characteristics of the missing source are a lower priority or already known beforehand.

Spectrometers are needed when radionuclide identification is relevant. Radionuclide identification can be used to predict the temporal behavior of the radiation safety situation or evaluate the significance of the detection of radioactive source (e.g. innocent detection vs. security threat). Spectrometers are usually somewhat fragile and require more sophisticated electronics than total radiation counters. Further on the data processing onboard or raw data transmission to the ground station require even more elaborate electronics with larger power consumption which means that spectrometer could not be installed to the smallest and simplest UAVs.

Sampling is usually relevant only in plume mapping missions. The simplest air samplers that are always collecting can be installed even to mini-UAV scale. The control of sampling require some electromechanical components that prevent them being installed to the smallest UAVs. The fact that sampling usually utilizes the air speed of the UAV to draw air through the sampler makes fixed wing UAVs preferable platforms for air sampler due to their capability for higher air speeds.

Rules of the air in Finland considering UAVs

The Finnish civil aviation regulatory authority is planning to loosen the regulations regarding the non-recreational use of smaller remotely piloted aircrafts. In the draft national aviation regulation the use of remotely piloted aircraft is exempted from aviation work licensing if the following criteria is met:

- Maximum take-off weight of the aircraft is less than 25 kg.
- Flying altitudes are less than 150 m above ground level.
- Distance from the ground station (pilot) is less 500 m, the visual line of sight is maintained unassisted and visual flight rules can be obeyed.
- The range can be extended with spotters who have duplicated two way communication links to the pilot.
- Aircraft has means for safe termination of flight in case there is a loss of control.
- Air traffic control approval is needed for flying in controlled air space and the pilot has a two way aeronautical radio (requires a license).
- The pilot has received training for the type of remotely piloted aerial system used.

- Aircraft flies more than 150 meters away from densely populated areas and large crowds of people (police, customs, border guard and rescue services may be exempted).

If the distance from the ground station is required to be more than 500 m (without spotters) or flying altitude is required to be higher than 150 m AGL, the flight requires a temporarily segregated air space or the UAV must be accompanied by a chase plane. Segregation of the airspace can be requested from the aviation regulatory authority. In all other cases the aviation work license is required.

Criteria described above make it possible to use mini-UAV size fixed wing UAVs and multicopters for radiation surveillance missions rather freely when maximum distance from the ground station rule of 500 m can be obeyed. This encompasses fallout mapping after small scale releases and detection and location of radioactive sources in small areas. The short timescale of the dispersal of radioactive material in small scale release make plume tracking extremely difficult due the slowness of deployment compared to the dispersal time.

Requirement of a chase plane in non-segregated air space completely negate the advantages of the use of UAV in fallout mapping and source finding on large areas. Temporary segregation of the airspace in most cases is difficult to justify because both mission types can be executed with manned aircrafts. This leaves the plume mapping the only viable scenario for the large scale events. The fact that airspace at risk of radioactive contamination is usually closed for normal air traffic for radiation safety reasons makes the use of UAVs without chase plane in large scale dispersal events possible.

Conclusions

Taking into consideration all the facts presented, the most viable use of UAVs for radiation surveillance in Finland is the use of mini-UAVs and multicopters with spectrometric detectors in small scale events.

NRPA's considerations of unmanned measurements of radiation.

Thomas Bandur Aleksandersen, NRPA

Stationary unmanned systems:

After the Chernobyl accident, Radnett, a network of unmanned radiation monitoring stations was build all across Norway. The system was upgraded and modernized between 2006 and 2008 and today boasts a total of 33 stations with at least one in every county. The purpose of this network is to give an early warning of fallout or other nuclear incidents affecting Norway. Further, the data collected will aid the decisions of the Crisis Committee for Nuclear Preparedness in the early stages of a crisis.

Each station is equipped with a detector that measure dose rate (µSv/h) and a device for measuring downpour. Dose rates are updated hourly, and automatic systems are evaluating the measurements in regards to quantity and quality. Each station is connected to a computer terminal at the NRPA, and alarms will go off if the readings exceed a certain limit.

The results from these stations are also published in yearly reports of radiation monitoring in Norway. These reports as well as the hourly up to date readings are publically available on our webpages.

Mobile unmanned systems:

To this date we got no unmanned mobile systems for radiation detection of our own or in collaboration with other departments or agencies. The topic has been discussed over the years, but as of yet it has not been a priority to acquire such a system for our purposes. This has mainly been due to the fact that the cost of the systems themselves and training to operate them has been regarded as too high in comparison to the benefits. Recently however, we've seen that both the costs and training required for these systems have been going down to acceptable levels. To investigate the matter further we joined the NKS activity SemUnaRS to learn the current state of the art, and what others already have accomplished in this field.

Appendix 3 Seminar participants

Table 1. *List of participants*

Name	Organization	Country
Grann Andersson, Kasper	NKS, DTU	Denmark
Pöllänen, Roy	STUK	Finland
Smolander, Petri	STUK	Finland
Aleksandersen, Thomas Bandur	NRPA	Norway
Carlsson, Marie	Linköping University	Sweden
Gårdestig, Magnus	Linköping University	Sweden
Pettersson, Håkan	Linköping University	Sweden
Kock, Peder	SSM	Sweden
Meijer, Claes	Scandicraft AB	Sweden

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No. of references	43
Abstract	There are several scenarios related to ionizing radiation or the release of radioactive materials where the use of unmanned vehicles certainly reduce the risk of receiving high doses to the personnel performing measurements. Other advantages are low costs of the equipment, operation, maintenance and services. The seminar on unmanned radiometric systems was held in October 2014. The seminar was dedicated to presentations on the status of unmanned mobile measurement capacities in the Nordic countries. An introduction to the topic of unmanned measurements covered some examples on systems of unmanned aerial, rotary and fixed wing, systems as well as ground based systems. A short description was given on the work of ERNCIP. Linköping University presented their considerations on their ongoing development of unmanned gamma-ray spectrometry systems and presented their rotary wing and fixed wing platforms developed by Claes Meijer.

STUK presented their experience to develop radiation monitoring instrumentation to unmanned aerial vehicles. A set of radiation detectors and a sampling unit was mounted to a mid-size Ranger military UAV. A lightweight sampler and a gamma-ray detector was installed to a small-size fixed-wing UAV. Extensive tests were done for both set of instruments.

On the second day of the seminar there was time scheduled for open discussions on the way forward for Nordic collaborations regarding unmanned mobile measurements.

The seminar revealed that the Nordic capacities of unmanned mobile measurements are diverse, but no country has a system operating today. Each country have different strategies on how to meet this demand; university research, military collaboration or procuring turn-key systems.

There is a need for continued and concerted activities to strengthen the Nordic knowledge and capacities in the field of unmanned mobile measurements.

Key words Unmanned mobile measurements, UAS, UAV, air sampling, emergency preparedness

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