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Intercomparison of Nordic Unmanned Aerial Monitoring Platforms

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Abstract

With the forthcoming of UAVs, new possibilities for radiological surveys have arisen. UAVs can be used as a supplement to existing measurement capabilities. UAVs makes it possible to make fast measurements in potential hazardous areas without danger to humans. The NORDUM project makes a first approach to cover and compare different systems and approaches for use of UAVs in the Nordic countries. The project shows that all Nordic countries have UAVs projects but different approaches with each different benefits. Further comparison and discussion of best practice is beyond the scope of the NORDUM project.

Key words

Exercise, RPAS, Drones, Unmanned aerial platforms, measurements, radiation mapping

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Intercomparison of Nordic unmanned aerial monitoring platforms (NORDUM)

Final Report from the NKS-B activity NORDUM

(Contract: NKS-B(16)9)

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Abstract

With the forthcoming of UAVs, new possibilities for radiological surveys have arisen. UAVs can be used as a supplement to existing measurement capabilities. UAVs makes it possible to make fast measurements in potential hazardous areas without danger to humans. The NORDUM project makes a first approach to cover and compare different systems and approaches for use of UAVs in the Nordic countries. The project shows that all Nordic countries have UAVs projects but different approaches with each different benefits. Further comparison and discussion of best practice is beyond the scope of the NORDUM project.

Acknowledgments

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Project partners

- Norwegian Radiation Protection Authority (NRPA)
- Danish Emergency Management Agency (DEMA)
- University of Oulu
- Linköping University
- Finnish Defence Research Agency FDRA
- The Norwegian Armed Forces - Forsvarets ABC-skole (FABCS)
- Andøya Space Center (ASC)
- Institute for Energy Technology (IFE)

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1 Introduction

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 (material out of regulatory control), or search inside buildings that are under the threat of collapsing. For these scenarios remotely controlled radiation measurement systems and sampling using unmanned (aircraft) systems are developed.

The need for unmanned vehicles used for radiation measurements and sampling has been recognized following the Fukushima accident in 2011. Measurements using UAVs have been used during several campaigns in Japan (Sanada and Torii 2015, Martin, Payton et al. 2016). Many countries have investigated such platforms and some have already initiated programs in relation to establishing the platforms as permanent components of their emergency response arsenals.

While a wide number of technical solutions regarding unmanned platforms exist – both off-the-shelf and custom – it is often difficult to fully assess the capability of a system based on specification sheets alone. This problem is compounded when trying to assess how various platforms will perform when combined with detectors and the ancillary systems required to turn a flying platform into a useful radiation measuring system.

In 2014 the NKS-B activity SemUnaRS – Seminar on Unmanned Radiometric Systems, that was held in Linköping, Sweden, was the start-up and an inventory of the capacities for unmanned measurements in the Nordic countries. The seminar hosted many interesting discussions on different approaches to utilizing unmanned platforms, aircraft regulations and the collaborations between universities and the authorities (Gårdestig, Pollanen et al. 2015).

The NKS-B activity NORDUM is the first joint Nordic exercise for unmanned systems. The main objective of NORDUM was to test unmanned aerial platforms in use in the Nordic countries with respect to locating, identifying and estimating the activity of radioactive sources under field conditions. It was also meant to provide an opportunity for those who may be in the process of acquiring/developing one, to assess the performance of various technical solutions in the field.

This was achieved through conducting an exercise during which different sources and configurations were used to fully test the participant teams and their platforms in terms of source location, identification and activity estimates. A seminar was held at the end of the exercise so that the teams had a chance to present their results, discuss challenges and successes and present future plans.

Figure 1-1: NORDUM group pictures from the exercise and workshop days.

2 NORDUM Participating Teams

Five teams from four different Nordic country attended the NORDUM Activity.

Participating Organizations/Teams		
Team id.	**Organization**	**Country**
Team 1	Danish Emergency Management Agency	DK
Team 2	Linköping University	SV
Team 3	Finnish Defence Research Agency FDRA	FI
Team 4	University of Oulu	FI
Team 5	Norwegian Radiation Protection Authority	NOR

Table 2-1: NORDUM participating teams.

Figure 2-1: Picture from the exercise day.

3 Pre-Exercise work

The NORDUM activity timeline according to NORDUM NKS-B application:

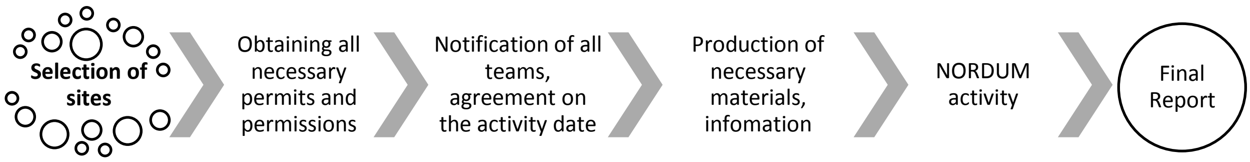

Figure 3-1: NORDUM activity timeline.

3.1 Selection of sites

NRPA as the coordinator had a responsibility to establish sites that were suitable for the NORDUM event that took place in a period of three days:

- Day 0: Test Day
- Day 1: Exercise Day
- Day 2: Workshop

3.1.1 Test Day

The exercise site (Hauerseter leir) is approximately 3 km away from Gardermoen airfield, thus the site is within Gardermoen (Oslo Airport) control zone. Therefore, we needed an additional authorization from Gardermoen control tower.

To obtain this authorization, all the RPAS/Drones had to test and verify their failsafe functions of the RPAS/Drones in a safe environment more than 5 km away from Gardermoen control center, according to the agreement between Gardermoen, ASC and NRPA. For more information, see Appendix A.

3.1.2 Exercise Day:

The exercise site had to fulfill a couple of important requirements, both because of the presence of several radioactive sources, and also the RPAS activity. The requirements for the exercise site were:

- Comply with the project budget
- Closed and restricted area (because of radioactive sources and RPAS activity)
- Big enough to have several different scenarios (RPAS activity requires space)
- Suitable for flying R02 multicopter and possibly fixed-wing
- Preferably 5 km away from Airport (because of the regulations from NCAA)

After considering several locations, NRPA together with FABCS and ASC selected Hauerseter leir as the site for the exercise. Hauerseter leir is a closed and restricted military area close to Oslo. The site was large enough to have three different scenarios as planned. Since only one team had a fixed-wing with measurement system, and ASC advised against the use of fixed-wings for safety reasons, we decided not to use fixed-wing.

3.1.3 Workshop

Since the exercise site did not have facilities for the workshop, the workshop took place at Sessvollmoen military camp, approximately 10 km from exercise site. See Appendix C for workshop program.

3.2 Permits and permissions

NRPA ensured and obtained all necessary permits and authorizations for both entrance and access to the different sites, and approved permits for all teams RPAS/Drones.

- Permits for all RPAS from Civil Aviation Authority (NCAA)
- Request for permission to visit restricted military areas for both the exercise and workshop
- Authorization from Gardermoen control tower to fly within the airport control zone

In January 2016, the NCAA implemented new regulations concerning RPAS/Drones in Norway. As a result of this, the process of applying for an authorization for RPAS operations in Norway became more comprehensive. After considering several possible solutions, and the time constraints, NRPA contacted ASC to assist with the exercise. ASC ensured that all RPAS that participated in the NORDUM exercise were included in the ASC Operation Manual (OM). In June 2016, the NCAA approved the revision of the OM that included all five teams including their RAPS/Drones.

NRPA, together with FABCS, arranged all the necessary permits for all the participants and their vehicles for the restricted military area.

4 Exercise area and the Scenarios

The exercise took place at Hauerseter leir. The exercise site was divided in a basecamp and scenario areas one to three, see Figure 4-1. At the basecamp, the participants had access to necessary basic needs like, power, food, water and restroom. Right outside the camp building, the participants were provided with a calibration area.

The exercise was divided into three different scenarios. You can find detailed information for each scenario later in this text. The program for the exercise can be found in appendix B.

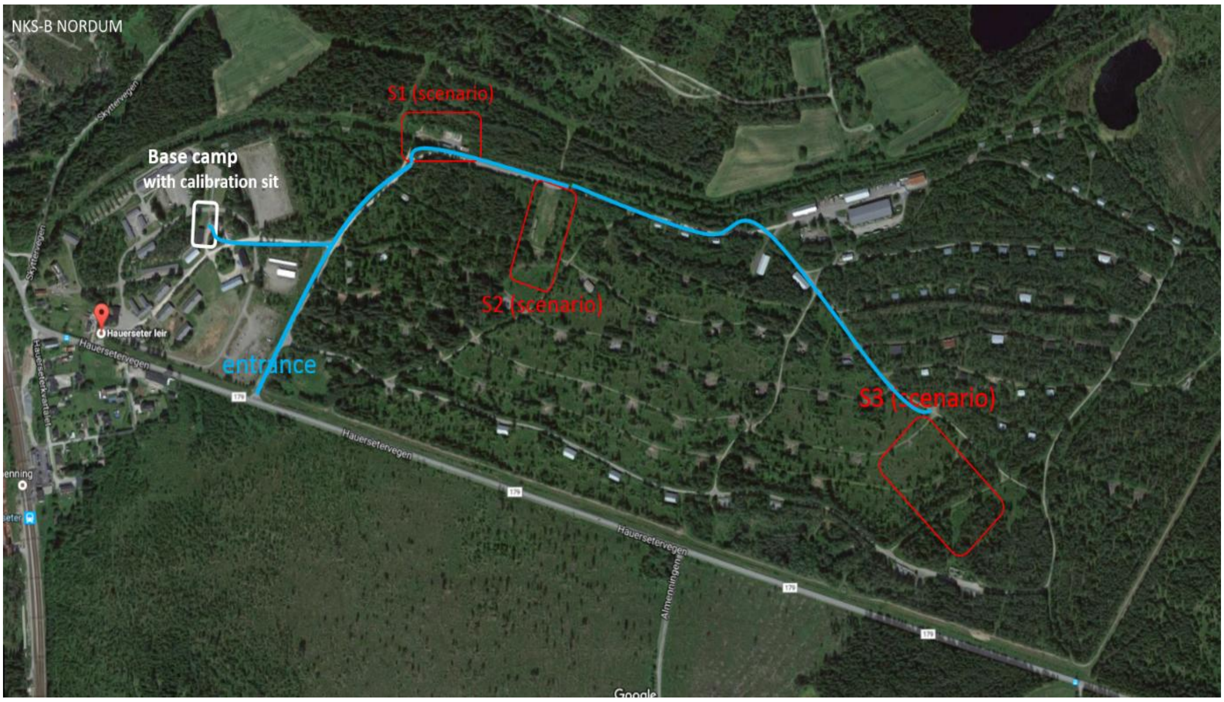

Figure 4-1: NORDUM Exercise area and scenarios.

4.1 NORDUM Exercise - Scenario 1

Location	The location was a small area with containers and storage of metal shelves.
Objective	Search the area for any radioactive sources using unmanned platforms, and report your findings. Provide as much information as possible.
Challenges	Blockage of the radio signals, lot of obstacles, and small area.
Sources	Am-241, Cs-137, U-238, see Appendix E

Table 4-1: Information for Scenario 1.

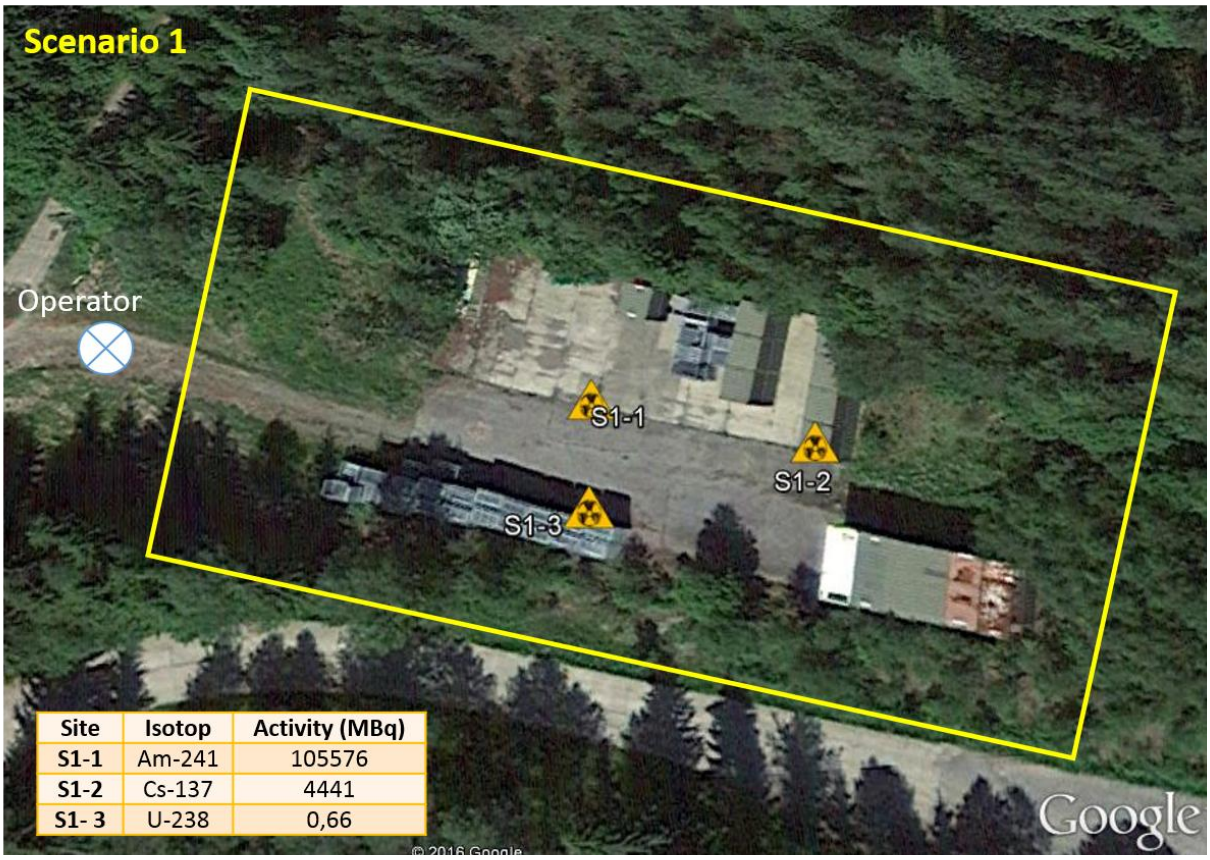

Figure 4-2: Map of the scenario site 1.

4.2 NORDUM Exercise - Scenario 2

Location	The location for scenario 2 was a rectangular shaped open area with a few containers on one side of the field.
Objective	Search the area for any radioactive sources using unmanned platforms, and report your findings. Provide as much information as possible.
Challenges	Hard to get an overview of the sit if the team didn't had a camera on their system
Sources	Eu-152, Two Co-60, and Pu-238, see appendix E.

Table 4-2: Information for scenario 2.

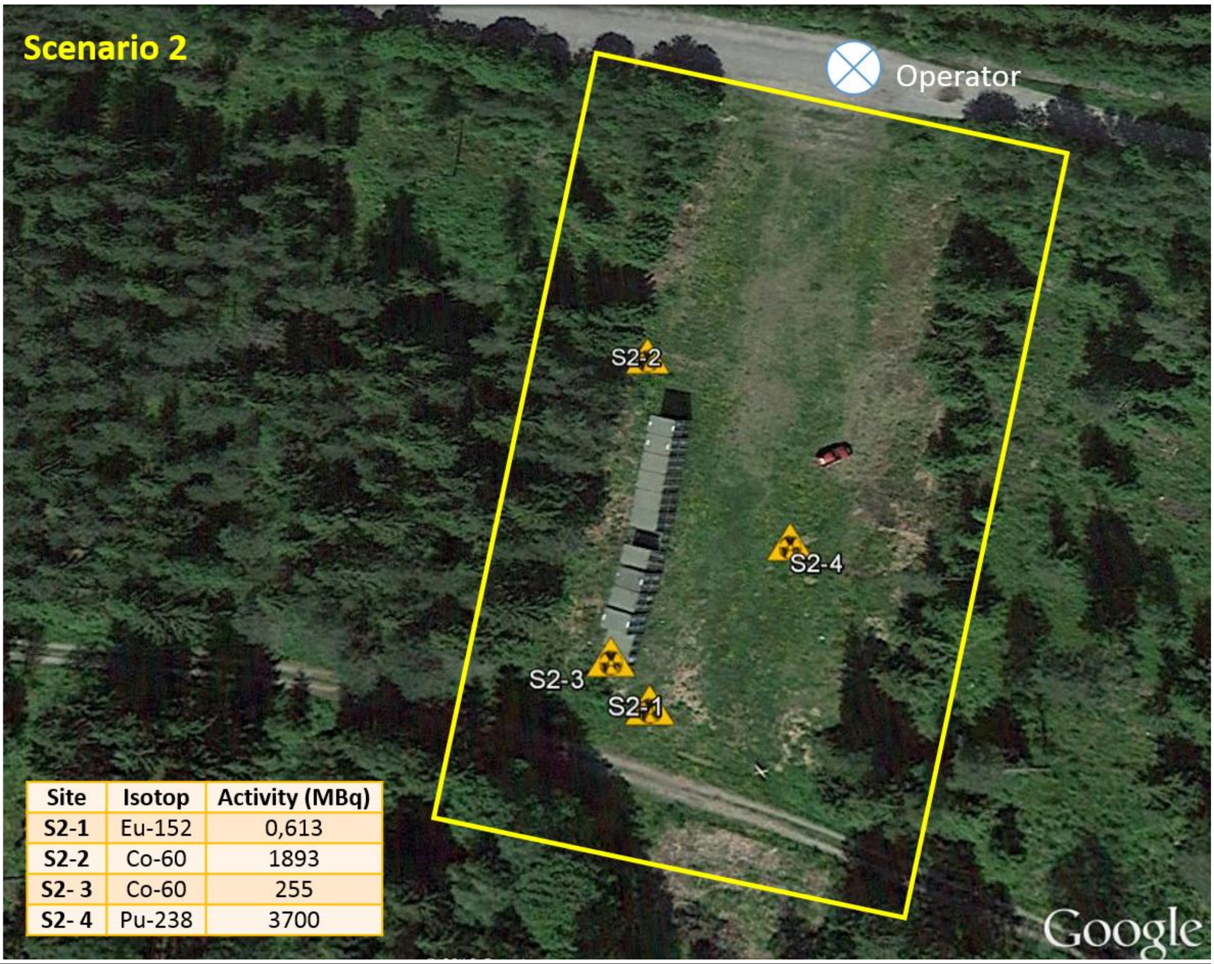

Figure 4-3: Scenario site 2.

4.3 NORDUM Exercise - Scenario 3

Location	Semi-open area with a lots of vegetation and trees
Objective	Search the area for any radioactive fragments using unmanned platforms, and report your findings. Provide as much information as possible.
Challenges	Windy and turbulent area.
Sources	Two Cs-137, Co-60, Sr-90, appendix E

Table 4-3: Information for scenario 3.

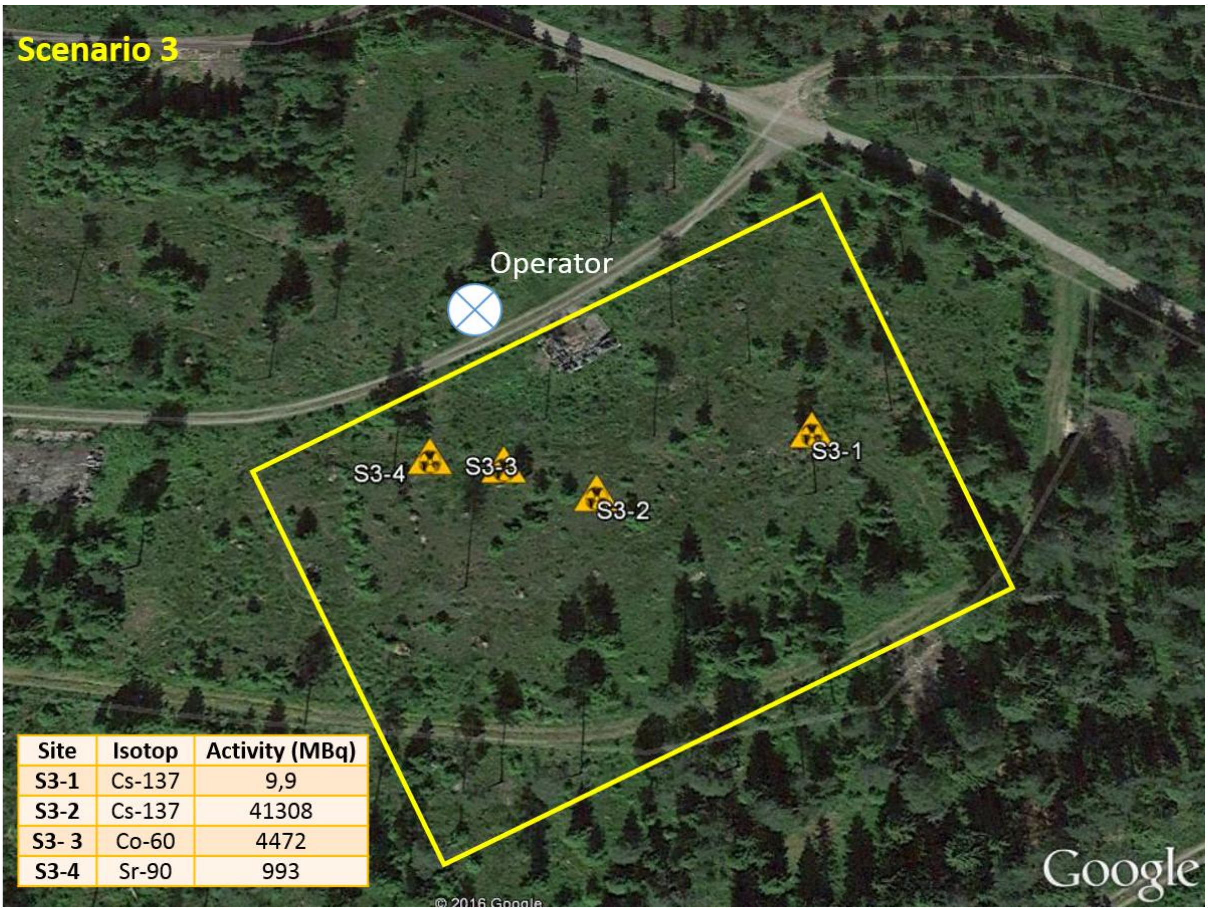

Figure 4-4: Scenario site 3.

5 Implementation and Results

5.1 Team 1 [Danish Emergency Management Agency]

5.1.1 Introduction

Unmanned radiological measurement can be useful for a wide range of scenarios including mapping of plume passage and ground contamination during and after an accident at a nuclear power plant.

The Nuclear Division at DEMA are working with a UAV-concept based on an unmanned X8 helicopter from Danish Aviation Systems ApS carrying an off-the-shelf Canberra Colibri dose rate monitor with a CsI detector. The X8 has a pay load of 1,5 kg and can fly programmed patterns with a fly time of approximately 20 min. The Colibi dose rate monitor has a build-in GPS and a logging function that can store dose rates and GPS coordinates at 1 s intervals. Further specification can be found in appendixes.

Preliminary tests have showed that the system readily can locate radioactive sources on the ground and that the obtained data combined with GIS software can be used to create maps with rough overview of dose rates.

The Danish approach to UAV-measurements are based on simple but robust instruments and UAVs already present in the Danish Emergency Agency. The post processing of data is currently based on manual procedures which includes the following steps:

1) Connecting measurement instrument (Canberra Colibri) to laptop with supplied USB-cable
2) Establishing IP over USB connection to Colibri
3) Downloading and storing LOG and data files to Laptop from Colibri via build in web interface
4) Preparing data files with text editor by removing header line and exchanging demiliator and decimal characters – [,] with [;] and [.] with [,].
5) Importing textfile to Excel, removing of unnecessary columns and converting Sv/h to nSv/h
6) Importing file to QGIS
7) Presentation and visual adjustment of colors with QGIS and ISO-contour plugin

With the described approach it is assured that UAV measurements are anchored both in the Danish preparedness organization and operational. This is important both in regards to education, training and resources. The approach also makes it possible to exchange equipment quickly and develop procedures that makes it useable also for non experts. The concept is developed as a supplement to ground based measurement teams and since the instruments used on UAVs for measurement are purely doserate-meters – follow up by land team with identification capability is needed afterwards.

During the exercise it was a barrier that the team could not use the Ebee UAV for fabrication of high-resolution maps and only had a slow mobile connection to the internet. Updated maps are of great importance when searching for sources and/or during any kind of aerial measurements.

With google maps the team, however, could present some results – and make guesses of the sources approximate position.

Figure 5-1 : Danish Emergency Management Agency vehicle.

5.1.2 Approach to measurement methodology

As mentioned, the Danish approach is focused on direct usability in the emergency preparedness. That combined with an intension to develop a standardized methodology results in a use of equally spaced preprogrammed flight patterns.

Normally a flying height of 90-120 meters is considered suitable for mapping of fallouts but in case of search for sources and with consideration for a small detector and absorption in the air much lower flying heights must be used. “As low as possible” seems to be a reasonable approach and flying height is therefore, in the Danish, approach primarily decided based on what is physically possible in the current situation. In most cases it results in flying heights from 20 to 35 meters.

Above 35 meters, test has showed, that the small detector size of the used instrument makes it very difficult to get useable results.

Before each flight 5 minutes of measurements on ground in good distance from possible sources is done with measurement instrument mounted on the UAV to have a reference level.

Tests have showed that with the used instrument flight speeds around 2-10 m/s produces useable results. Higher speeds results in false tails due to slow and not completely synchronized intervals between the built-in GPS and logging of measurement data.

The measured area on ground during an aerial measurement correspond to the flying height. With narrow gab between flight lines, low flight heights and low speed it is expected that there will be smear between measurements. Test have showed that flight line spacing around 5 meters, a flight speed of 5 m/s at a height of approximately 25 meters produces the most useable results.

5.1.3 Results from Scenario 1:

The instrument lost GPS signal during planned automatic flight, therefore results could only be produced with data from manually controlled flight.

Flight height was approximately 30 meters and velocity was approximately 5 m/s (manually controlled).

Measured data are not normalized to 1 meter.

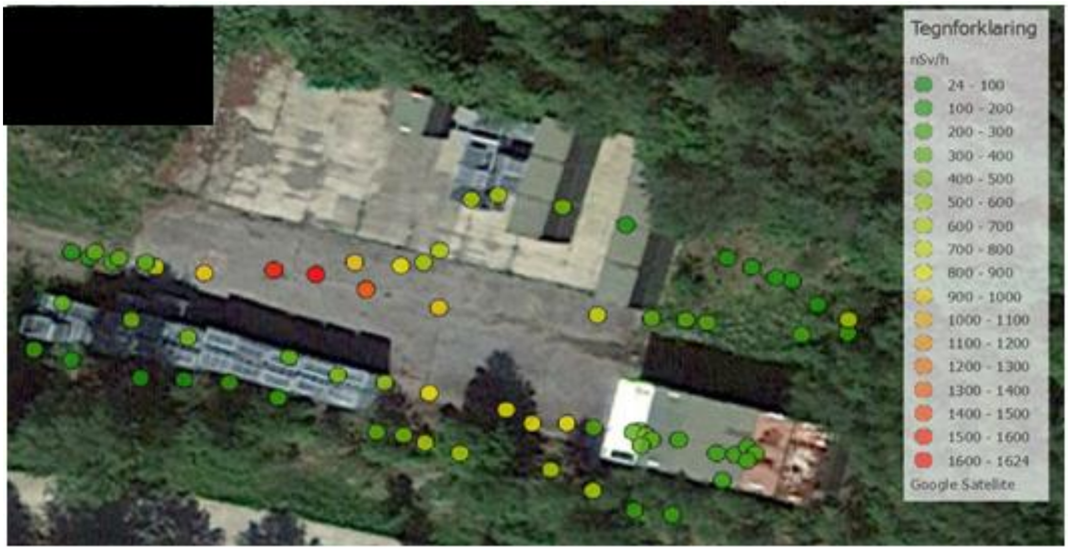

Figure 5-2: Results from scenario 1, the aerial view.

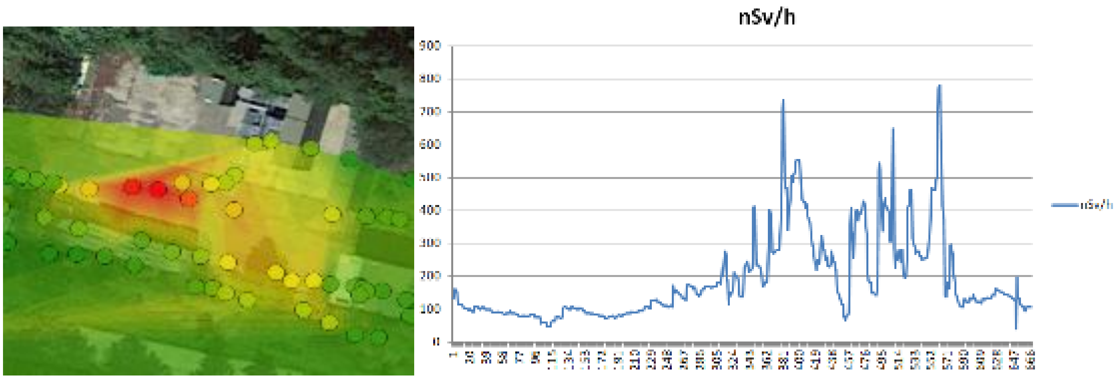

Figure 5-3 : Result from scenario 1.

The team guessedsource placements at:

11.20807,60.18979 and maybe 11.20835,60.18969

5.1.4 Results from scenario 2:

35m height, 5 m/s, 5 m spacing

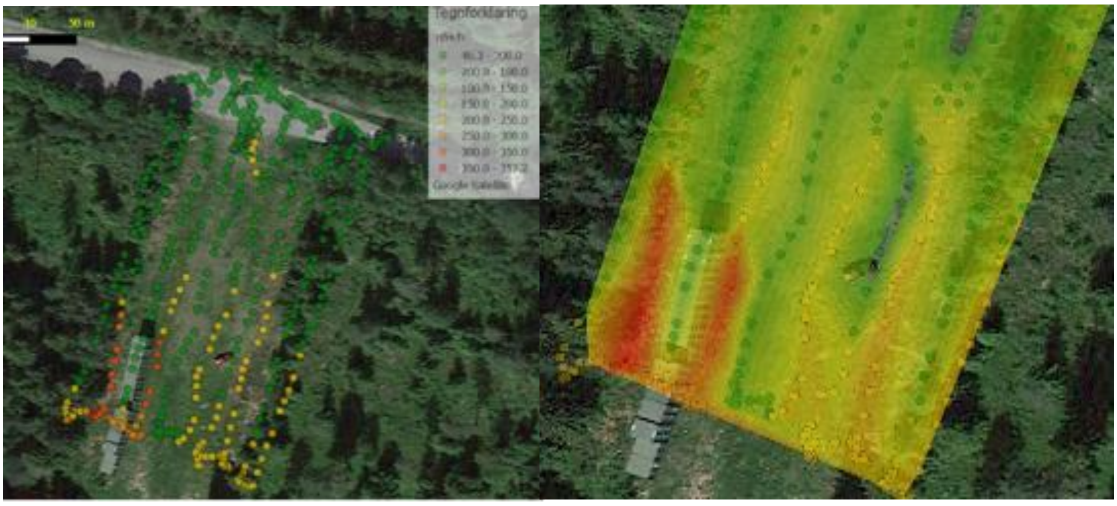

Figure 5-4 : Results from scenario 2, aerial view.

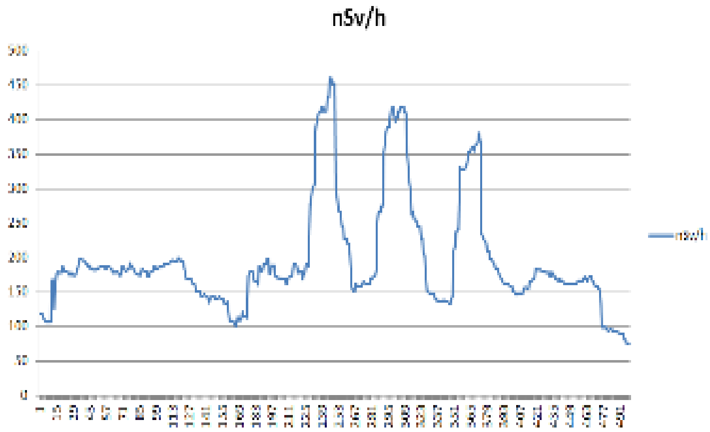

Figure 5-5 : Results from scenario 2.

The team guess source placements at :

11.21055,60.18858 and maybe 11.21105,60.18855

5.1.5 Results from scenario 3:

35m height, 2,5 m/s, 5 m spacing

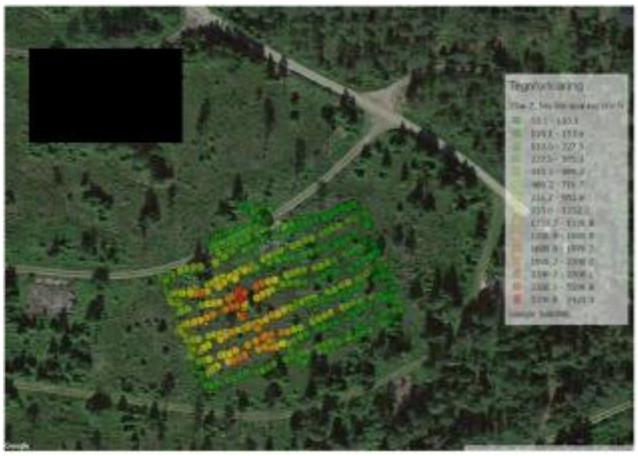

Figure 5-6: Results from scenario 3.

35m height, 1 m/s, 3 m spacing

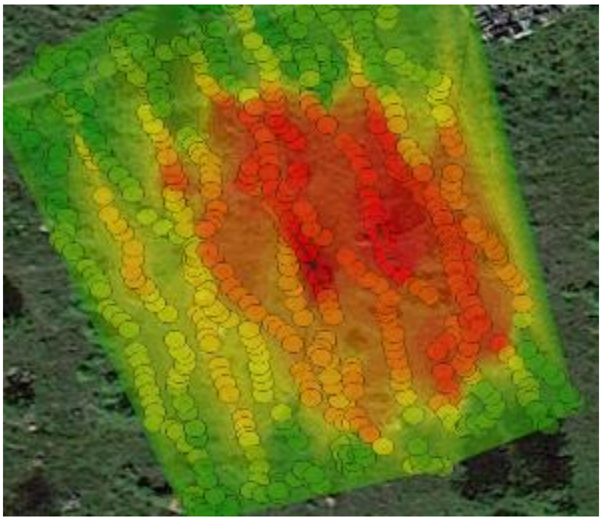

Figure 5-7: Results from scenario 3.

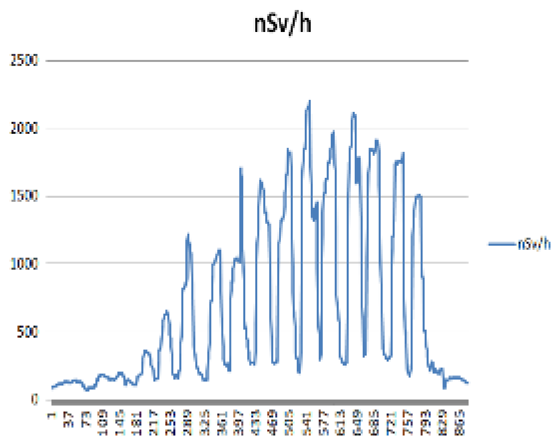

Figure 5-8: Results from scenario 3.

The team guessed source placements at: 11.22161,60.18548, 11.22196,60.18542 and 11.22203,60.18531

5.1.6 Lessons learned

- Data handling and processing takes time and skills!
- I will be beneficial to develop better scripts and routines
- Further research can be done on how to extract the most from available data e.g. with combining altitude, GPS and measurement data.
- There is still work to be done regarding development of consistent routines and procedures and training of those.
- Good and up-to-date maps are necessary
- Internet connection is must be prioritized.
- Increasingly more can be achieved with open source software

5.2 Team 2 [Linköping University]

5.2.1 Introduction

Linköping University, Department of Medical and Health Sciences, Division of Radiological Sciences, Radiation Physics, has been working on unmanned aerial radiometric systems for some years. The intention is to develop and evaluate systems to complement the existing measurement systems in the Swedish radiological and nuclear emergency preparedness organization. Unmanned aerial measurement systems in smaller sizes complement portable instruments as well as car borne or aircraft systems. Small enough aerial systems benefits in availability, portability as well as simpler handling and regulations.

5.2.2 System description

The air frame used during the NORDUM exercise was our traditional Quadcopter, originally intended for pilot training. This vehicle has proven to be a versatile platform for both our detector system. A smaller detector system, based on the Kromek GR1 CZT-spectrometer, was developed for our smaller quadcopter, SAFE, a flat construction with a safety rim holding all the payload. The heavier detector system is based on a NaI(Tl) scintillation detector (up to 3”), mainly intended for our fixed wing vehicle. The quadcopter is however capable of carrying both the systems, which we used during the exercise.

Figure 5-9: The Swedish team was one pilot and one data operator during the exercise.

The vehicle is controlled manually or by the Pixhawk autopilot and monitored with Missionplanner. Two laptops were used on a picnic table, one main laptop and the other as an external screen. A sun screen was used for visibility.

The spectral data is collected with a Raspberry Pi onboard the vehicle and this data is merged with the GPS data from the vehicle and sent to the ground station via XBee data link. The data is also stored on a small flash drive on board.

The XBee 868 MHz system that have an alleged range of up to 40 km in open terrain, covering the demands for the regulated VLOS distance of about 500 meters. During the entire exercise, the data link worked as intended.

On the ground, the data is received, stored and displayed on the laptop with an in-house developed software called UARS Monitor. The data is displayed in a waterfall display, energy spectra in different ROIs, SDI-based survey graph, map as well as the raw spectral channel data.

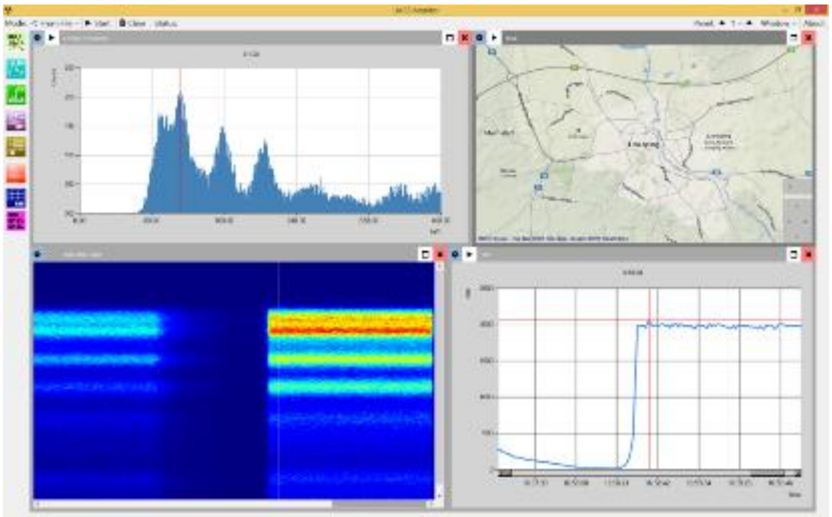

Figure 5-10: an exemple of data presented in the UARS Monitor. Energy spectrum, map, waterfall spectrum and dose rate display.

5.2.3 Search approach

A safety checklist was used for a safe operation. The search approach in the scenarios was an initial course survey of the search area on higher altitude, followed by more thorough measurements on the first indicated spots. The closer approach was made by manual control and in one case in FPV.

5.2.4 Scenario 1

This scenario gave us the opportunity to fly FPV with a small camera in front. Thus we were able to come close to the containers and fly between them with the pilot still at safety distance.

Figure 5-11: Part of the flight pattern in scenario 1. The starting position is in the left part of the satellite map image.

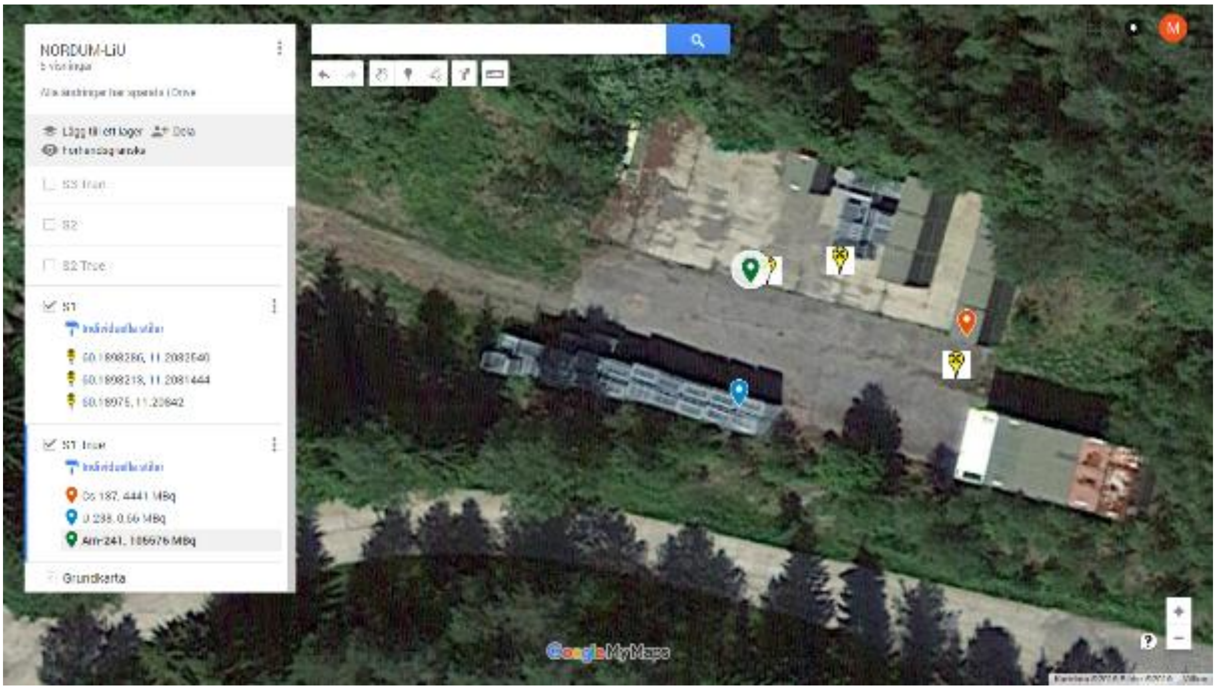

Figure 5-12: Our assessment of the scenario 1 area with our indicated sources displayed in yellow radiac icons. The true positions of the sources are indicated with the colored map markers.

The strongest source (Am-241, 106 GBq) we placed OK on the ground and even the farthest source (Cs-137, 4 GBq) we detected, but misplaced slightly hence it was collimated. Our third indication could be a misinterpretation of the Am-241 source. The weak Uranium source we never detected, it was too weak, the low gamma flux from this source was too challenging for us to detect.

5.2.5 Scenario 2

Figure 5-13: Part of the flight pattern in scenario 2. The starting position is marked with the green map marker labelled «Home».

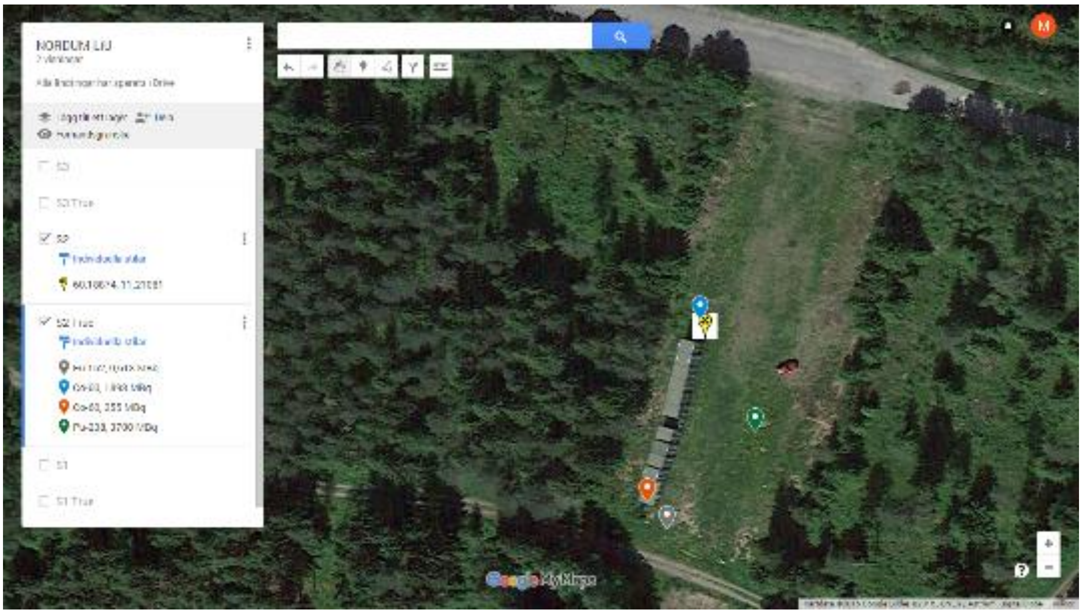

Figure 5-14: Our assessment of the scenario 2 area with our indicated source displayed in yellow radiac icon. The true positions of the sources are indicated with the colored map markers.

In this scenario we assessed the strongest Co-60 source, but used a good time to determine its position. It may have been collimated by the shrubbery. We might not have flown far enough for the other Co-60 source and the Eu-152, and the Plutonium we had no indication of.

5.2.6 Scenario 3

In the beginning of our survey of the scenario 3 area, which in fact was our first mission, we experienced a hard landing which set the MCA out of play. The measurements henceforth were made with the smaller detector system.

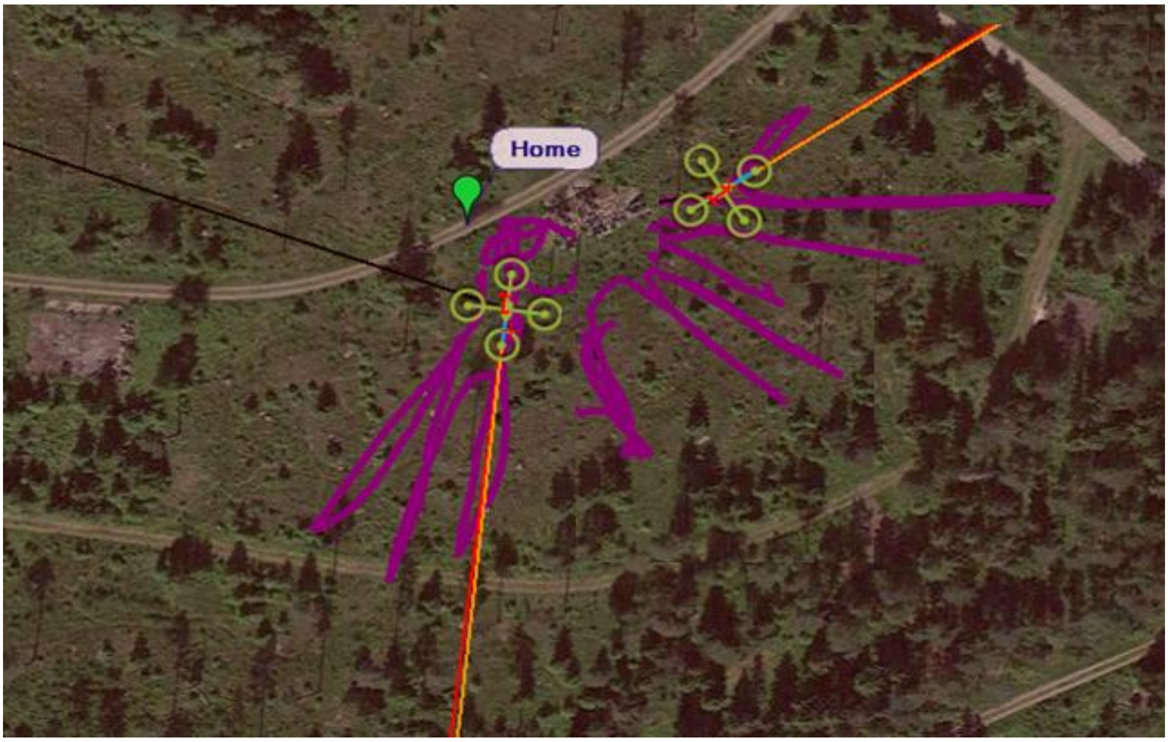

Figure 5-15: Part of the flight pattern in scenario 3. The starting position is marked with the green map marker labelled «Home».

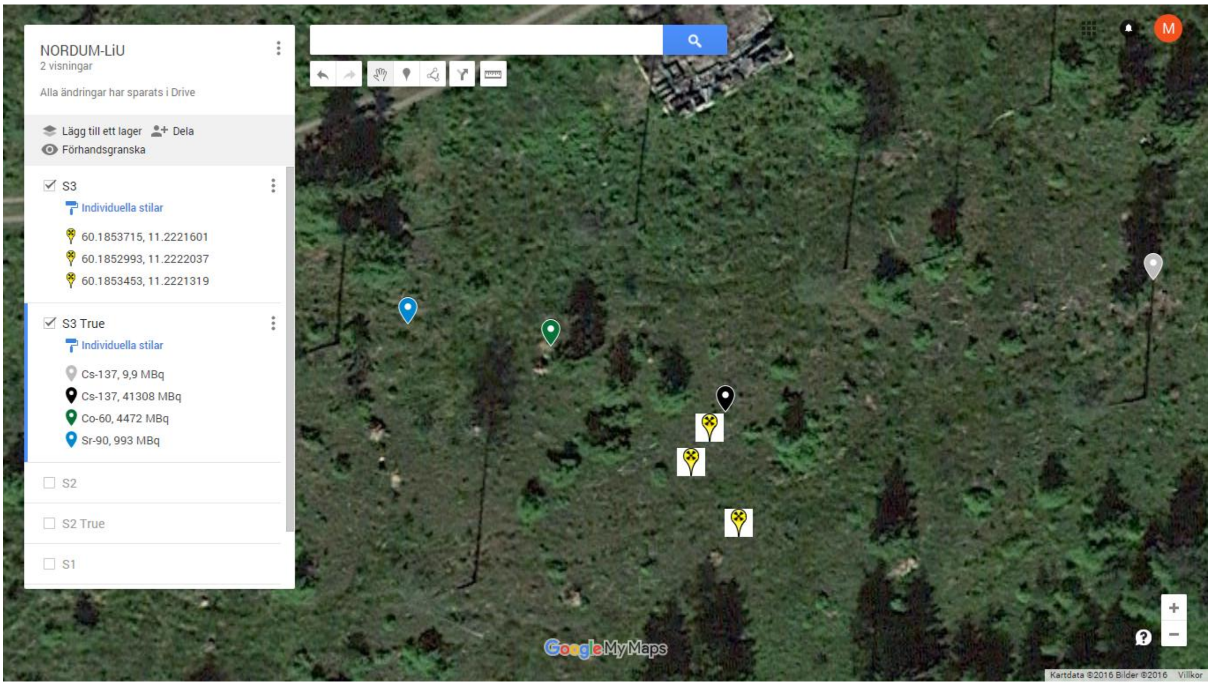

Figure 5-16: Our assessment of the scenario 3 area with our indicated sources displayed in yellow radiac icons. The true positions of the sources are indicated with the colored map markers.

In this scenario we only reported one source, but we misinterpreted the data from several flybys into three different sources. The other Co-60 source we had suspicions of and we spent some time in that area, but could not get data to fully confirm. The weaker Cs source we missed entirely and the Sr source must have been hard to detect, being a pure beta emitter, some bremsstrahlung possibly, but it was outside our coverage.

5.2.7 Lessons learned

A pre-flight day with testing and safety checks was very useful.

An exercise should aim for a linear complexity in regards of activity, nuclide identification, localization and coverage. NORDUM was a great exercise, but might have had to large steps between the source complexities in respect to activity.

Unfortunately, the MCA for the NaI-detector failed after a hard landing during the first mission. Redundancy should be improved by spare parts for all hardware.

Power failure resulted in loss of spectral information, only dose rate data was available. This could be due to the shared power source with the vehicle or interference. Aerial testing prior to the exercise and testing on the ground during the exercise showed no problems.

During the exercise we produced approximately 6000 data files from 100 minutes of measurements. This might be a small amount of data for a similar task. It is still a demanding task to post process this amount of data and produce valid decision support.

Our system is still under development and there are plans for improvements:

- More accurate position data will be possible with RTK enhanced GPS. More accurate position will give more accurate localizations and more accurate altitude will give more accurate activity estimations.
- More calibrations will give activity assessments and activity concentration assessments.
- Post processing of the data is of the greatest importance.

The NORDUM exercise was a great challenge that gave a lot of inspiration for the work ahead.

5.3 Team 3 [Finnish Defence Research Agency FDRA]

5.3.1 Introduction

Defence Forces Research Agency has conducted aerial radiation measurements with manned aircraft (fixed/rotary wing) 25 years. For this purpose we have developed comprehensive measurement software, which can be used with several manufacturers' hardware. The software measure, record and analyze in real time results. We can produce georeferenced map for different nuclides with activity values to be presented in different map systems.

For first step with unmanned radiation survey we decided use small mini helicopter with very small CZT detector (1 cm^3.) For testing we decided to use more efficient 43 cm^3 $LaBr_3$ detector. For measurement computer decided to find small but efficient stick computer with data transfer capabilities

5.3.2 Preparation

We have used ThinClient computer for manned aerial radiation detection. These are too big to be used in small mini helicopter. First we tried compute stick based on ARM7 architecture and RK3188 processor (Quad cortex-A9 CPU) with Linux Ubuntu 12.04 LTS operating system. The packages needed for hardware control program and measurement program could not be installed suitable manner and this cheap solution was not possible realize. Quite near to the solution we did reach.

The final solution was to use Intel 32/64 bit architecture stick with m5 processor. The compute power of the m5 processor is similar than Intel i5 processor, which is used on manned radiation survey Laptop.

We installed all the same programs that we use in manned radiation measurements without any problems.

5.3.3 Choice of mini helicopter

After control of headquarter we decided to purchase Airborne (Threod) KY-6 mini helicopter in the beginning of 2016 and we did get it on March. Flight operator was trained on manufacture's course.

5.3.4 Software installation and testing in laboratory

Operating system, Ubuntu 14.04, and measurement programs were installed on SD card. After successful installation the reliability of compute stick with Kromek analyzer/detector was tested with long test measurement program.

5.3.5 Remote control

For remote control we used WIFI with ad hoc connection. By using SSH connection we started two screen session on compute stick, one for GPS server and one for MCA server. Virtual remote desktop was established using VNCserver program. With these combinations of programs we did get remote control working at least 250 meters distance (visual contact) and if the WIFI connection was disconnected, all programs still run on compute stick. After WIFI connection get back, remote control works again at remote laptop. During NORDUM exercise we didn't have any essential problems with WIFI, GPS or mini helicopter control signal.

After all programs were installed and tested, we did make SD card copies with linux dd – program.

5.3.6 Preparation of mini helicopter for radiation measurements

For measurement Plastic box were produced using 3D printer. Inner fixing structure was also produced with 3D printer. Because the battery what was planned to be used was not suitable for compute stick, we were forced to change it bigger one and the fixing structure came partly useless. Anyway all needed parts (compute stick, Kromek detector/analyzer, usb hub and battery) could be installed inside the box without essentially lower the functionality.

A retention bar was installed to mini helicopter for fixing the box with press coupling. To fix the bigger $LaBr_3$ detector, we used belts, one connected to helicopter battery and on connected to retention bar. These two fixing method did make possible balance the helicopter properly for both detectors.

5.3.7 Detector calibration

Energy and shape calibration for both detectors was made in laboratory using Am-241, Co-57, Cs-137 ja Co-60 calibration sources. Energy calibration was checked at NORDUM exercise just before measurement. Efficiency calibration was not made because lack of time. All presented measurement results activity values are relative.

5.3.8 The modeling of results

The measured data was modeled with GMLINT program, which uses as input coordinates, measured radiation values, altitude and gamma energy of radiation source. With these data program creates radiation surface, which can presented on map systems.

5.3.9 Presentation on map systems

We prepared to present results with Esri ArcGIS 9.3.1 and Google Google Maps map system. We take screenshots from Google Maps and imported the pictures to our GIS-software. That was the first time we used Google Maps (aerial photos) and it worked very well. Before this exercise we have measured larger areas with manned platforms and used topographic maps (mainly in raster format) of various scales. Aerial photos are better suited to small areas like in this exercise and for large areas topographic maps are a better choice. When measurement data is formatted properly (column wise WGS-coordinates and radiation values), it is quite easy to import with the GIS-software and present on the map, whether it is topographic or aerial photo.

5.3.10 RESULTS FROM NORDUM EXERCISE

All activity results from measurements areas S1, S2 and S3 are presented on relative values, because the used Kromek CZT 1 cm^3 detector was not efficiency calibrated. Bigger 43 cm^3 $LaBr_3$ was NOT used because mini helicopters performance was already near safety limit with small detector on exercise’s real wind conditions. All measurements were made from 15 meters altitude.

Area S1, suspected terrorist activity related area

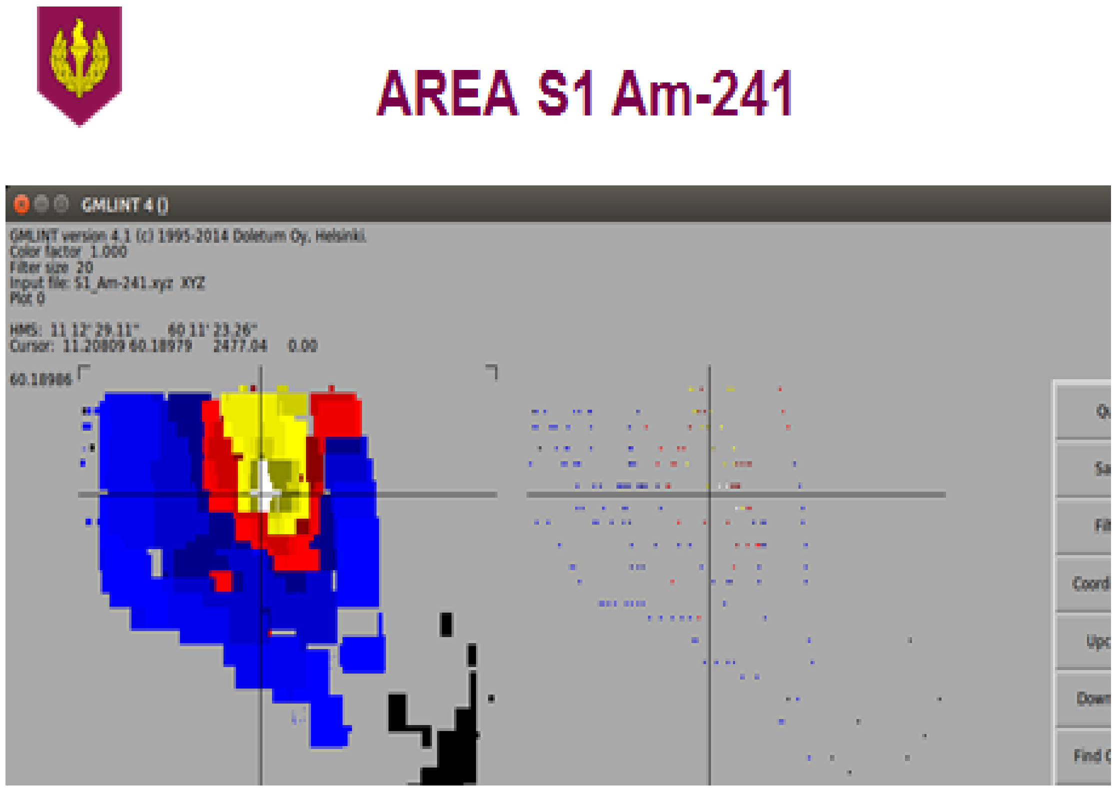

Figure 5-17 : Area S1. Modeled radiation surface (Am-241) produced by GMLINT program. Measurement points are presented on right side. Cursor shows most active point and related co-ordinates and activity value is also shown (2477).

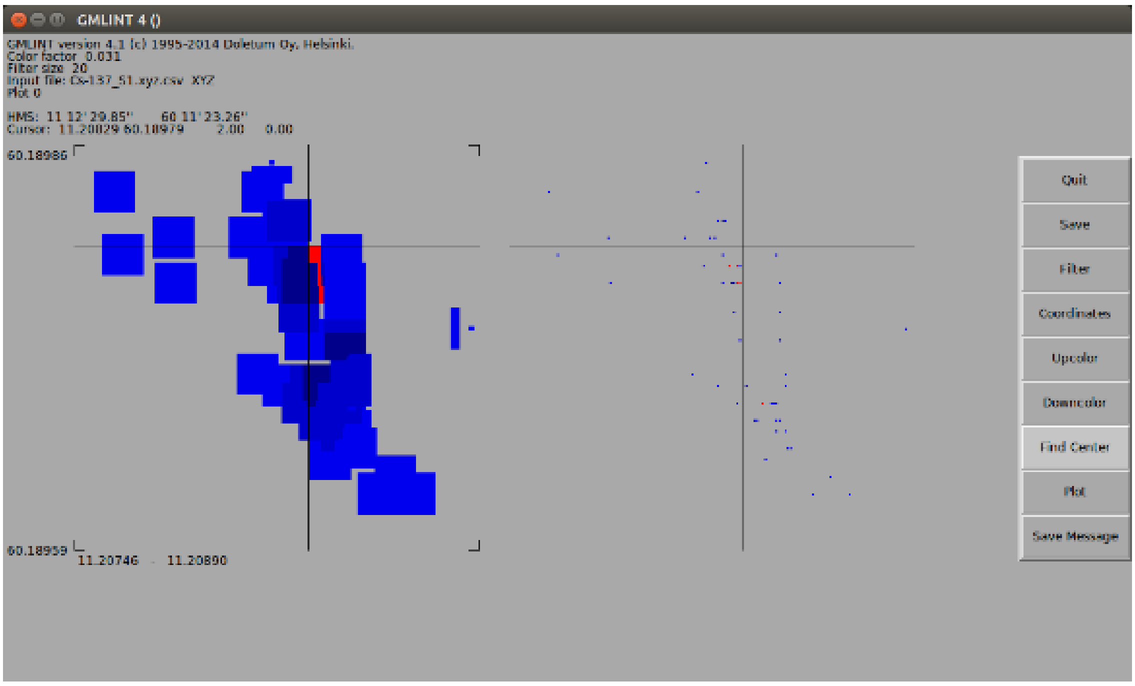

Figure 5-18: Area S1. Modeled radiation surface (Cs-137) produced by GMLINT program. Measurement points are presented on right side. Cursor shows most active point and related co-ordinates and activity value is also shown (2). This radiation source was found after NORDUM exercise when more accurate post processing was made.

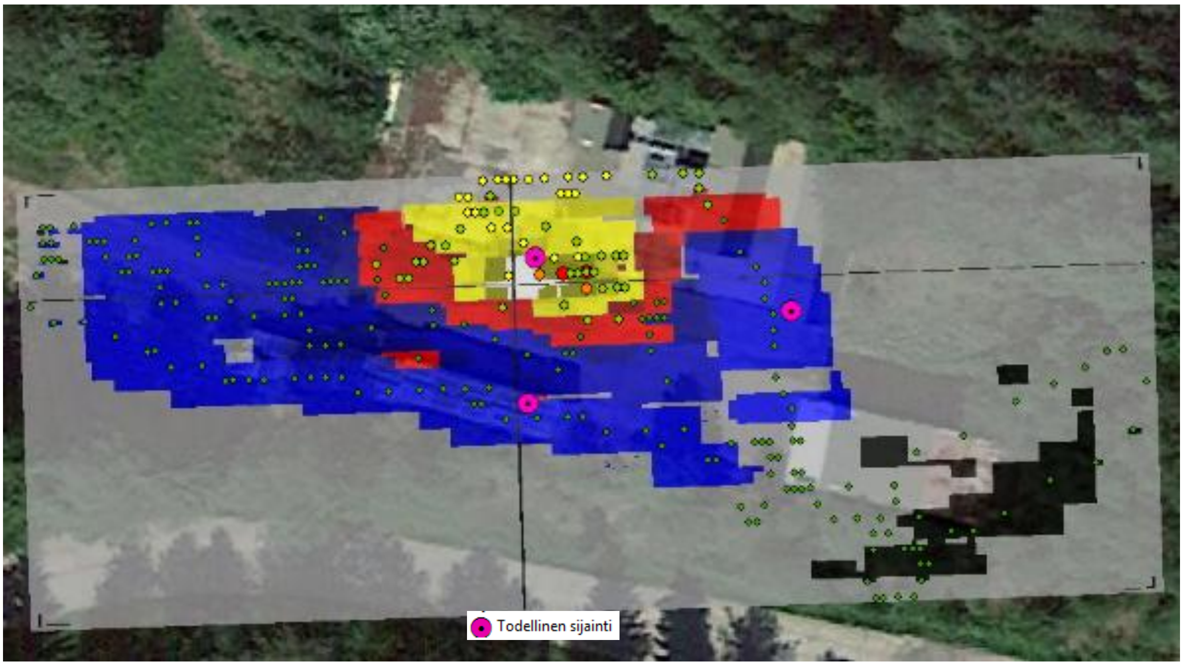

Figure 5-19: Area S1. In this figure is presented measurement points, modeled radiation surface (Am-241) and Google Maps map. The reported location of radiation source is shown by cursor. Real source is presented by purple circle. Distance difference from modeled source to actual source is 3 meters.

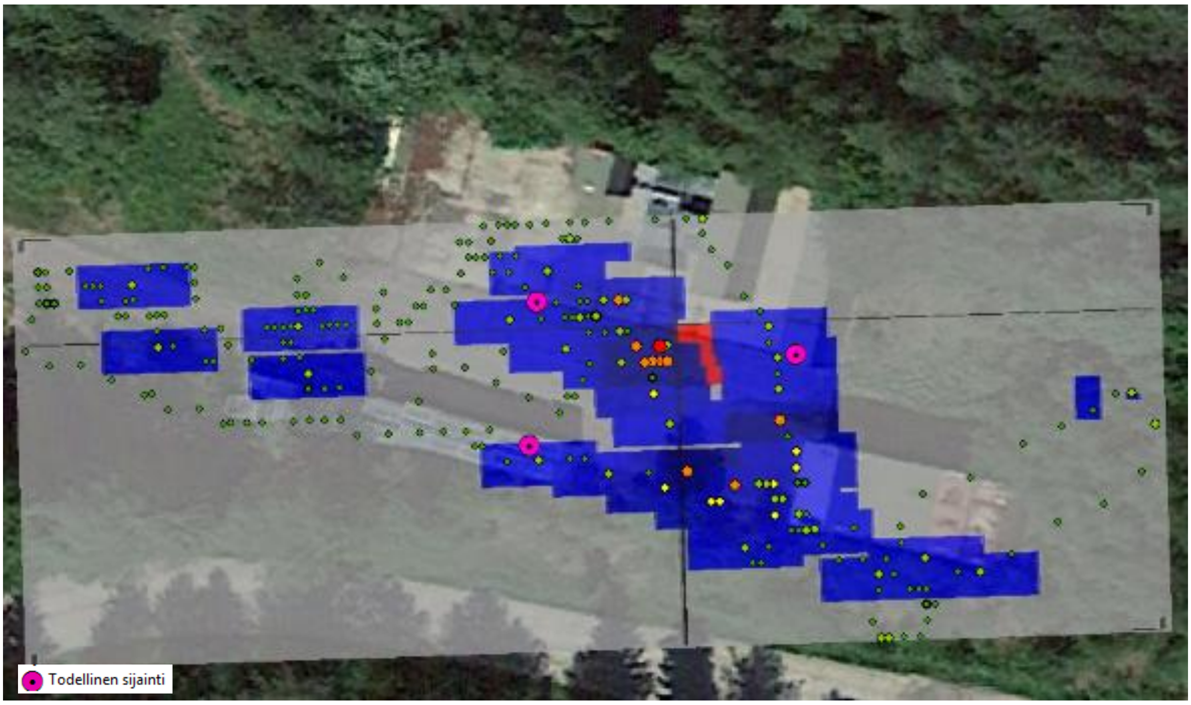

Figure 5-20: Area S1. In this figure is presented measurement points, modeled radiation surface (Cs-137) and Google Maps map. The reported location of radiation source is shown by cursor. Real sources are presented by purple circle. Distance difference from modeled source to actual source is 8 meters. The difference is mainly due fact that all measurement points near the actual source (most right one in the picture) are on left from source and partly because source was collimated (directed 45 degrees upward).

Area S2, suspected terrorist activity related area

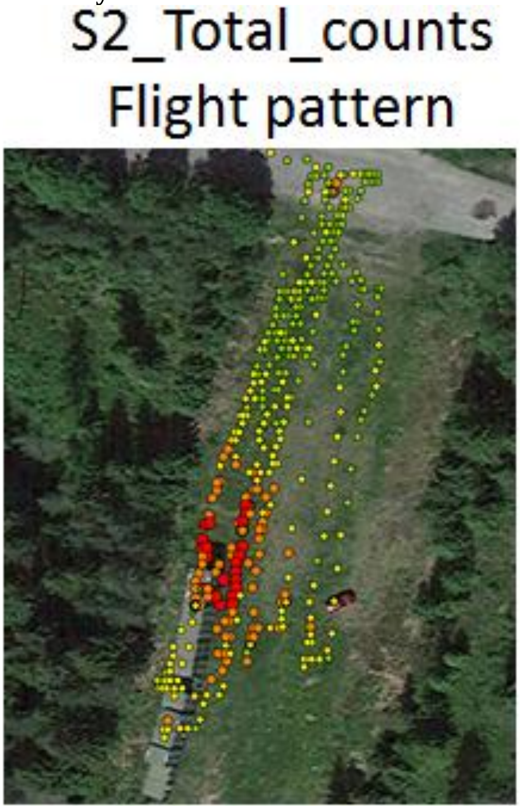

Figure 5-21: Area S2. Measured total counts presented on Google Maps map.

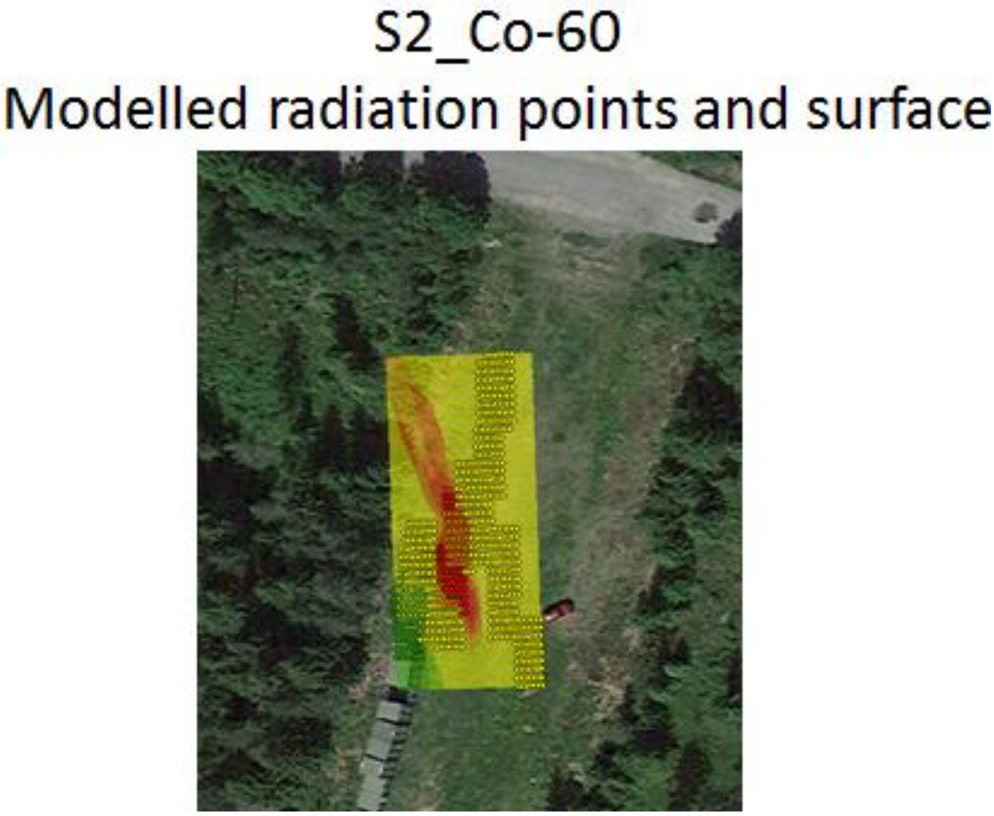

Figure 5-22: Area S2. Combined Co-60 surface model (from lattice produced by GMLINT) presented using ArcGIS program's Inverse Distance Weighted model and Google Maps map. ArcGIS model has the feature to extend values to the border of measurement area. This effect was not disabled and result is clearly seen in the right upper corner of modeled area where there is no true measurement points. Compare with next figure.

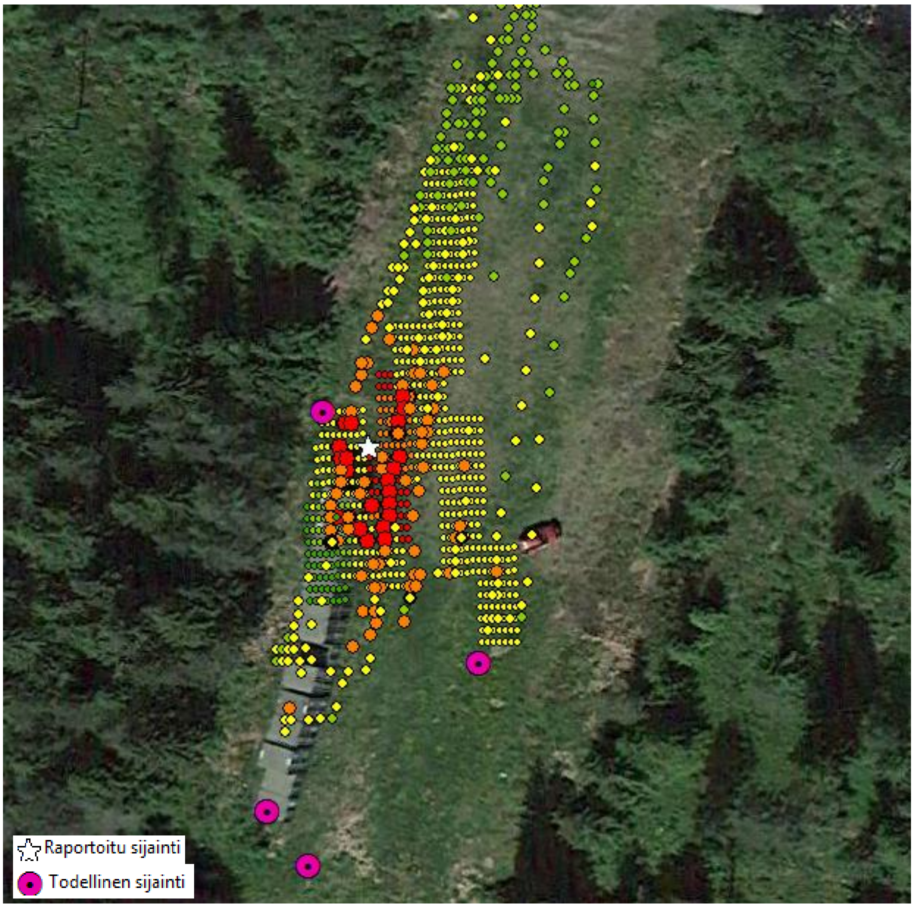

Figure 5-23: Area S2. Combined Co-60 surface model lattice produced by GMLINT modeler and Google Maps map. Reported source location is marked by asterisk. Real source is presented by purple circle. The modeled location differs from real location 5 meters.

Area S3, debris of collided satellites

Figure 5-24: Area S3. Combined Co-60 and Cs-137 surface model lattices produced by GMLINT (Cs-137 point's red and Co-60 mainly blue) and Google Maps map. Reported source location is marked by asterisk. Real source is presented by purple circle. The modeled Co-60 location differs from real location 2 meters and Cs-137 location 5 meters.

5.3.11 Conclusions

1) Manned and unmanned aerial radiation survey is in principal similar tasks. The use of same software on both platforms has many synergy benefits. Today is available very efficient small stick computer capable run comprehensive software packages offering all tools for data analysis and presentation for different map systems. Also reach back type support is essentially easier for one system vs. two different systems.

2) Compute stick properties
    A. Small size and still efficient computer
    B. Wifi connection for radiation measurements works rather long distance (at least 250 meters, visual contact). For longer operating distances other suitable data transfer channel have to be utilized
    C. Operating system and software installation on SD memory card make easy compose predetermined different measurement strategies to be used in different scenarios

3) Kromek analyzer stops working after temperature reach 40 degrees of Celsius. The efficient compute stick produce heat and combined intensive sun shine together can easily rise temperature over 40 degrees Celsius inside installation box, if air ventilation of the box is too low and box outside color is too dark

4) Detection limit for fallout mapping with small 1 cm^3 CZT detector when is around 100 kBq/m^2 (estimate for Cs-137, integration time 2 seconds and measurement altitude 35 meters). With bigger Vasikka 43 cm^3 $LaBr_3$ detector detection limit is smaller.

5) Search for radioactive sources on predefined area
    The results of locating sources on predefined area are dependent on how uniform and dense coverage can be reached (the time available for scanning, possibility to reach all parts of area and weather optimum measurement altitude is available), radiation sources properties and detector efficiency.

    Examples: The far end of area S2 was difficult to reach (sources S2-1, S2-3) because we didn't have camera installed on helicopter and accidentally we didn't go enough near source S2-4 (Pu-238). On area S3 the corner where source S3-1 was placed was also too difficult to reach for us and source S3-4 (Sr-90) could not be detected from 15 meters altitude and some 3 - 4 meters horizontal deviation.

6) Mini helicopter performance requirements for operational mission
    The used Airborne KY-6 mini helicopter performance was not sufficient for carry and operates with heavier Vasikka $LaBr_3$ detector/analyzer. The NORDUM exercise was successfully conducted satisfactory with small Kromek detector/analyzer (no camera installed), but we had to limit the flight time to 15 minutes. So short flight time is not enough for operational purpose, which needs 30 - 40 minutes flight time with 2 - 2.5 kg payload. Mini helicopter must also resist rainy and cold circumstances. Steering response must be good in gusty wind (wind speed 14 - 15 meters per second in gust).

    Mini helicopter must have video camera installed and real time video link between copter and land base to assist remote control and to allow terrain reconnaissance.

5.4 Team 4 [University of Oulu]

5.4.1 Project outline

The aim of this project was to collect radiation data from the environment using an *unmanned aerial vehicle* (*UAV*). The testing area was located in Norway, Hauerseter Leir military camp site.

The UAV used was the DJI Inspire 1 quadcopter [27]. The sensor used to detect radiation was Kromek GR1-A [28], which is a USB-powered gamma spectrometer employing 1cm3 CZT detector. This type of sensor has been utilized previously in many mapping applications using quad copters, like in the references [24], [25] and [26]. In the constructed self-contained sensor package including GPS localization and wireless data transmission, the gamma ray sensor is attached to a Raspberry Pi 3 Model B [29] microcomputer. For GPS localization we used u-blox C94-M8P-3 GNSS [30] module, however we did not use a fixed ground point support station which would have allowed much higher precision. Therefore, the localization error should be expected to be around 5 meters. The data was transmitted from the sensor package wirelessly to the measurement PC.

5.4.2 Implementation of the sensor package using the Kromek sensor

The casing of the sensor package was implemented using semi-hard PE (Polyethylene) packing foam. The sensor package was hanging from the copter with a 1.5 meter long knotted steel chain. The potential advantages of this approach is that the sensor package is less susceptible to EMI (electromagnetic interference) produced by the quadcopter platform and taking the sensor closer to the measured points. The disadvantage is that the package can swing like a pendulum, which can raise some control issues, especially in windy conditions.

In the sensor package, each device was put in to a separate layer of foam that were then stacked together. The bottom layer, closest to ground, contained only the Kromek GR1-A gamma-ray spectrometer. The second layer contained the Raspberry Pi 3 Model B microcomputer and a FUJ:TECH LITE 2600 mAh power bank. The power banks was sufficient in powering the system for at least three hours. The third layer contained the PCB of the u-blox C94-M8P-3 GPS module. The fourth and topmost layer contained the GPS-antenna and the 3DR serial radio used for transmitting data. As the sensor and the GPS were both contained in the sensor package, the package could be carried on almost any mobile platform as a self-contained measurement unit.

The sensor package hanging from a quadcopter is shown in Figure 5-25 below. The devices contained within the package are shown in Figure 5-26

Figure 5-25. The radiation sensor package hanging from a quadcopter, which was utilized during the NORDUM exercise.

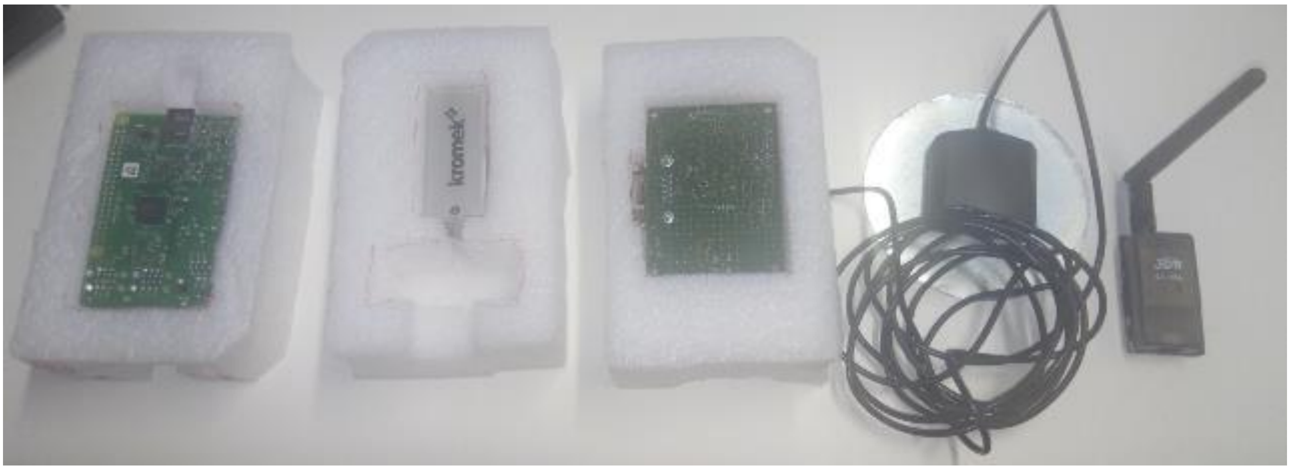

Figure 5-26. The sensor package equipment from left to right: the Raspberry Pi 3 model B, Kromek GR1-A, u-blox C94-M8P-3 and 433 MHz 3DR serial radio. The weight of the fully assembled sensor package was around 0.6 – 0.7 kg. The dimensions of the package were 14 x 9 x 18 cm + the height of the antennas, which added approximately 10 cm to the package height. Therefore, the total dimensions with the antennas were 14 x 9 x 28 cm.

5.4.3 Initial testing of the Kromek sensor

Initial testing was performed using a laptop and the KSpect 1.2.0 spectrum analyzer software. For testing, two very low radiation sources available from the student labs in the faculty of physics of the University of Oulu were used, Cs-137 and Co-60.

5.4.4 Effect of distance to a sample and the angle of the sensor

The testing were performed using two different distances and three different angles. Distances are set at ±2.5 cm accuracy and the angle ±5°. The sample and the sensor were laying on a flat surface.

In the first test, the radioactive Cs-137 sample was placed 50 cm away from the Kromek GR1-A. The angles used were 0°, 90° and 180°, rotated clockwise and 0° was the angle when the sensor was pointed towards the sample as it is shown in Figure 5-27. The used measurement time in each test was 1 minute, ±1 second.

All of the tests shown here were performed in room temperature (20 – 25 degrees C).

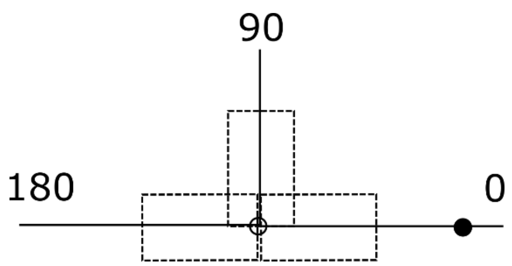

Figure 5-27. Kromek sensor points toward the transparent circle at each test, the black spot is the sample.

5.4.5 Initial tests with Cs-137 and Co-60

In the initial tests, the two samples were placed, each in turn, roughly 1 cm apart from the front of the sensor. The Cs-137 sample was measured for 178 seconds and the Co-60 for 252 seconds. The activity of the samples was approximated to be 10 µCi and the samples were very small, i.e. can be considered as point sources in the scales of our tests. As has been discovered in the earlier tests done in STUK (Finnish Radiation and Nuclear Safety Authority) laboratories with the sensor, the sensor's sensitivity was much smaller in higher gamma ray energy levels. The results of our initial tests are shown in Figure 5-28.

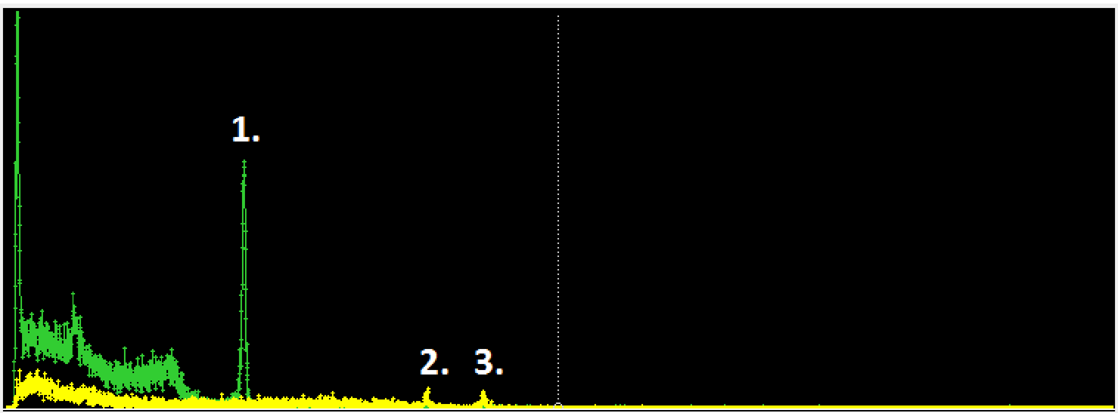

Figure 5-28. Low activity Cs-137 and Co-60 measurements. The energy spike of 662 keV of Cs-137 is shown at 1., the energy spikes 1.17 MeV and 1.33 MeV of Co-60 at 2. and 3. correspondingly.

5.4.6 Measurements at 0.5 meters from the Cs-137 sample

Data for each of the following tests were recorded for 60±1 seconds and three different angles were used. 0° result is shown in green, 90° result in yellow and 180° result in purple (Figure 5-29 – Figure 5-31). 0° result is shown in all plots for reference. It can be seen, that with these three angles and the used time, the effect on the measurement result was negligible. This makes sense as the CZT sensor within the Kromek GR1-A has the form of a cube with a volume of 1 cm^3. The observed counts-per-second (CPS) reading increased roughly 50% (from around 10 to 15) when the Cs-137 sample was brought to 0.5 m from the sensor.

If the CPS is not affected by the quadcopter noise, the sensor may be used in the detection of radiation when flying at 0.5m height at a relatively slow speed.

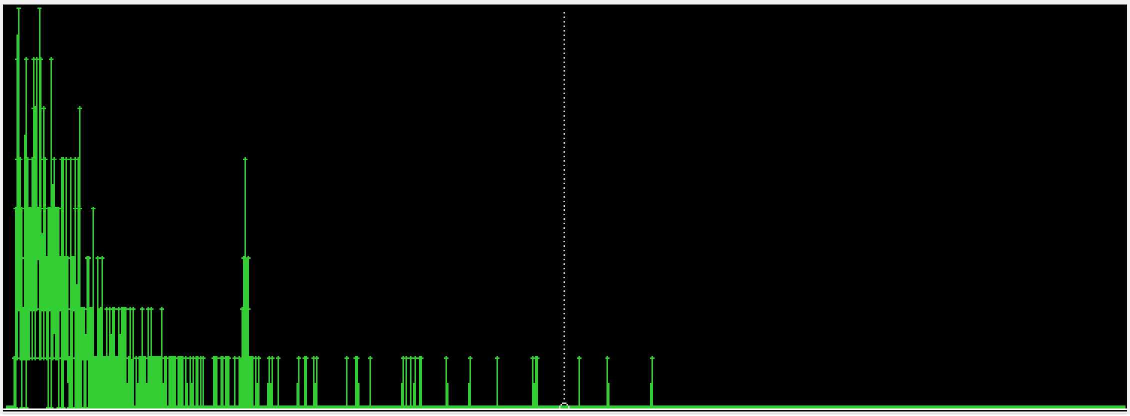

Figure 5-29. Sensor at 0° angle with respect to the sample.

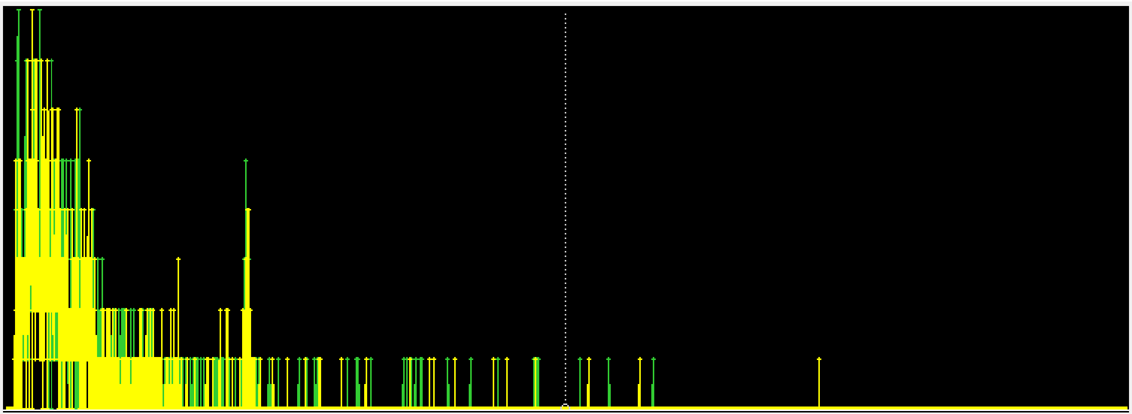

Figure 5-30. Sensor at 90° angle (yellow), no observable difference to 0° situation (green).

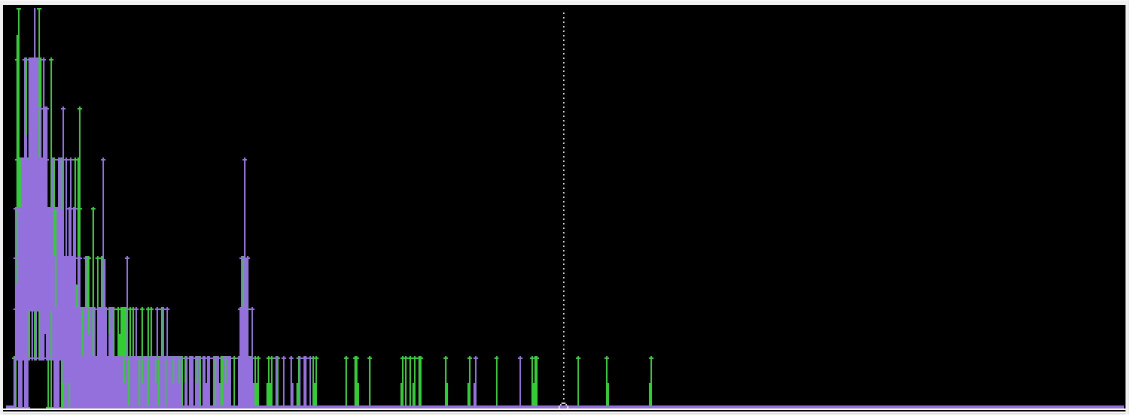

Figure 5-31. Sensor at 180° angle, not much difference to see here either.

5.4.7 Measurements at 0.25 meters from the Cs-137 sample

At a smaller distance, the detected energy spike is much clearer as expected. The angles still have no noticeable difference in the measurement spectrum (Figure 5-32 – Figure 5-34).

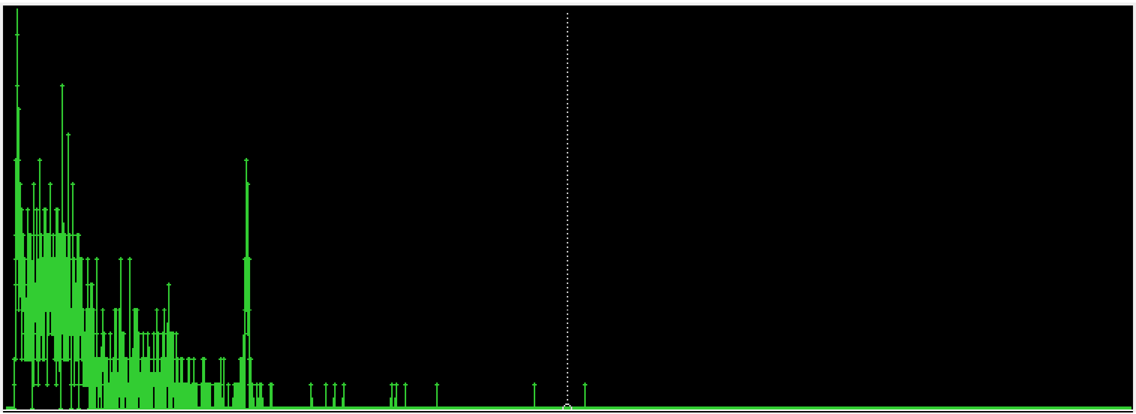

Figure 5-32. Sensor at 0° angle.

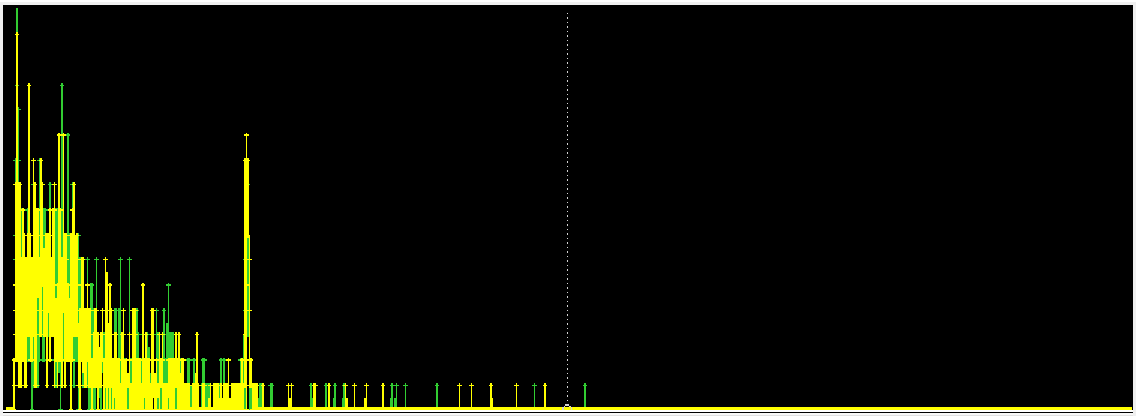

Figure 5-33. Sensor at 90° angle.

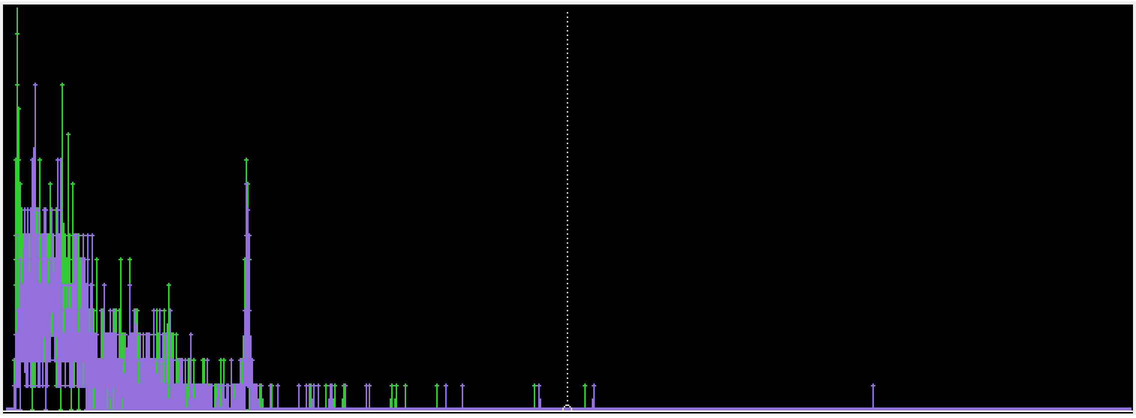

Figure 5-34. Sensor at 180° angle.

5.4.8 Data recording over serial-radio connection from the Kromek sensor

In order to test the sensor onboard the DJI Inspire 1, additional software had to be made for displaying real-time data, transmitted over 57600 Baud serial-radio connection to measurement PC. The experimental data recording program was made using Python 2.7 programming language. The user interface of the program is shown in Figure 5-35.

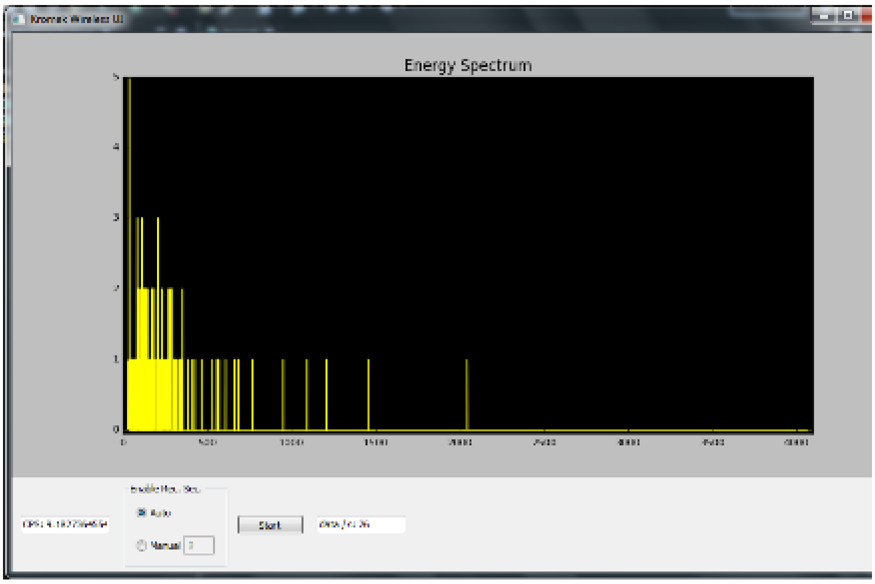

Figure 5-35. The UI of the real-time data logging software implemented for data reading over wireless serial link running on the measurement PC.

5.4.9 Summary of the Kromek field tests at the NORDUM exercise area

The aerial view of the test area captured from Google Earth [31] application is shown below in Figure 5-36. In the results presented in this chapter, it should be noted that the calibration of the Kromek GR1-A has not been made exact in laboratory conditions but has been calibrated simply by linearly fitting the kromek ADC sensor readings to data points collected from Cs-137 and Co-60 samples, which were shown in Figure 5-28.

The data values should be assumed to have an error of at least + / - 10 kEV. There were also very few data points, due to technical problems we had, and the sensor is not very sensitive, so the results should not be considered as absolute. In all of the tests, the quadcopter moved the sensor package 0.5 – 5 meters above the spots being measured. The absolute height of the package from the ground is currently not available, but a maximum of height of 5 meters can be assumed and may be taken in to account in the localization of the hot spots.

Unfortunately, quite a lot of our measurement samples were dropped, especially near the hot spots, due to radio issues and a bug in the data collection software running on a laptop PC. The bug crashed the PC measurement software frequently near the hot spots which restricted the ability to make better energy spectrums of the most interesting areas. These issues are elaborated more in the summary section of this report.

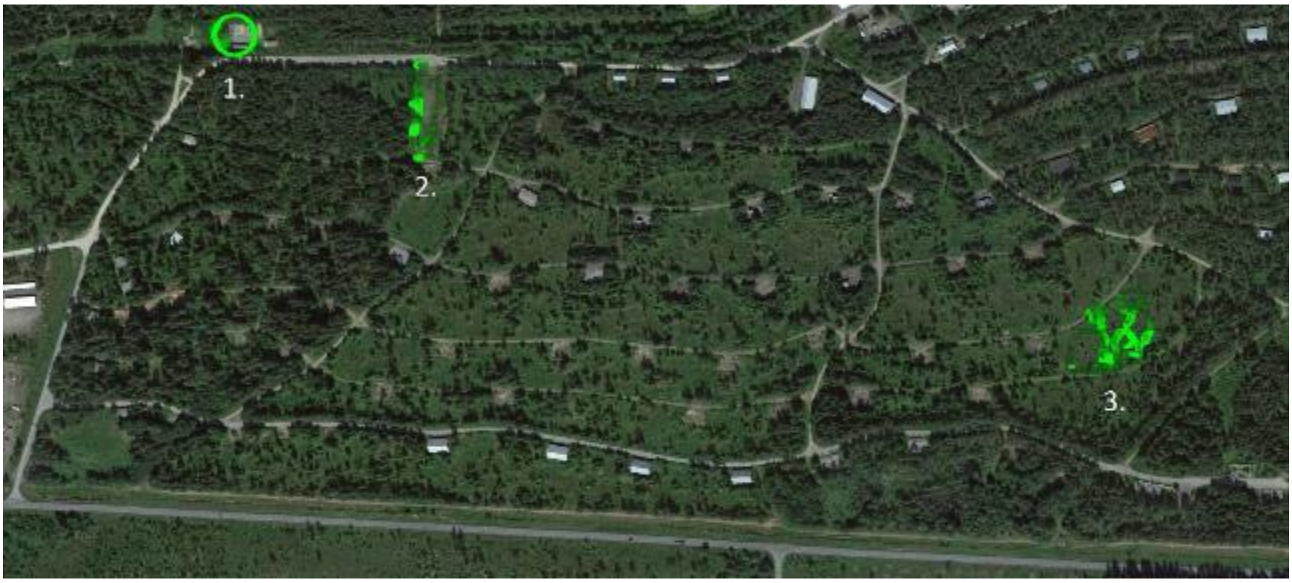

Figure 5-36. The aerial view of the test area from the Google Earth application and the collected data sample positions from scenarios 1. – 3.

5.4.9.1 Scenario 1

The scenario 1 was a small open area with a lot of metal containers and other metal structures. These structures blocked most of the radio signals from both of the GPS satellites and from the 3DR serial radio on board the sensor package.

Due to these radio link related and missing GPS signal issues, we could not get much coherent data from scenario 1. There was also a large artifact in the CPS count, which was possibly caused by a blocked radio signal that buffered data between missing GPS time stamps. Therefore, analysis of this scenario site is fruitless and is omitted. The overhead image of the area captured with the overlaid sensor data is shown in Figure 5-37.

Figure 5-37. Overview image of the scenario 1 area. Green circles mark the measurement spots, the size of the circle and the intensity of the color is proportional to the measured counts per second (CPS). The big circle is an artifact.

5.4.9.2 Scenario 2

The scenario 2 had a few big metal containers in a small open field and also a large pile of cut tree branches near the containers. In this scenario, measured areas 1. and 2. showed clear increase in measured CPS value. Area 3. had a weak radio signal and further looking in to the spectrum, there was no clear pattern to be detected. The overview of the area is shown in Figure 5-38.

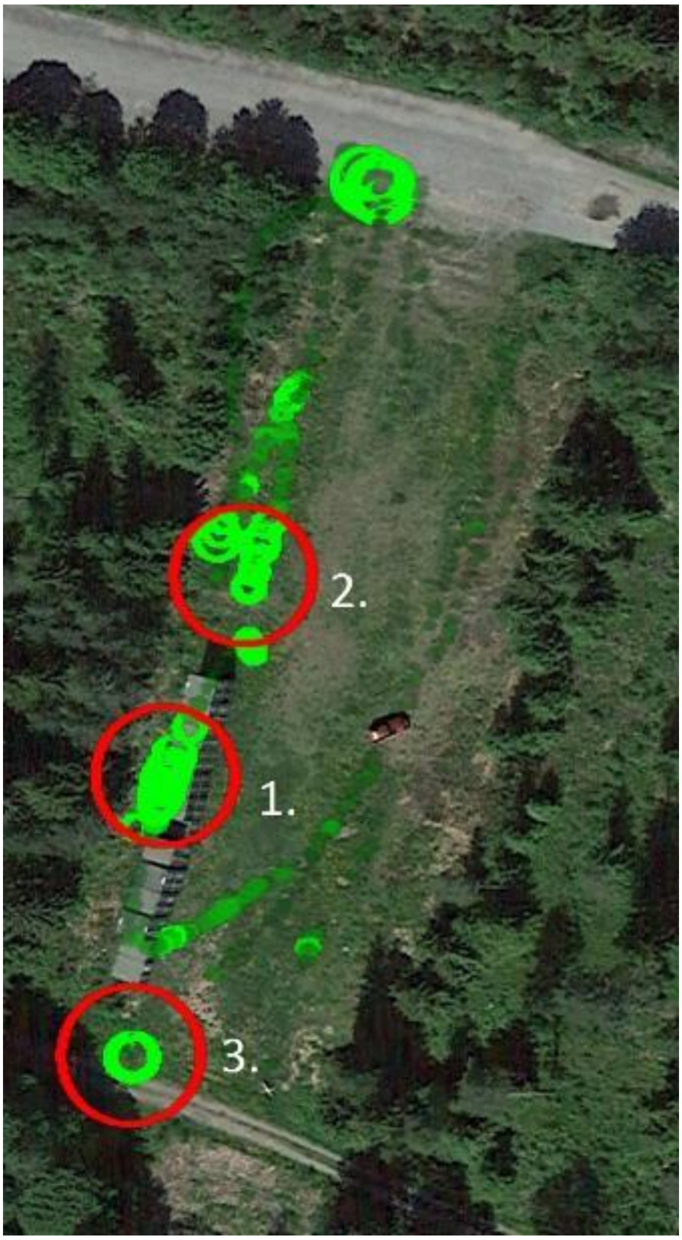

Figure 5-38. The measured data overlaid with Google Earth map from scenario 2. The image is not up to date with the moment the testing was performed. At least the car was absent from the actual field. The more interesting areas with elevated detected CPS are enclosed within the red circles. 1. and 2. which most likely contained radiation hot spots and 3. may have been just an artifact. Also the topmost hot points were right at the quadcopter take-off point, which might have been artifacts caused by the sensor package touching the ground.

Interest area 1. of scenario 2.

The collected spectrum of the area enclosed within red circle 1. is shown below in Figure 5-39. The average CPS for the enclosed samples was 102. A weak spike can be seen at 771.4 keV, which might be indicative of the presence of I-132 (Iodine) nearby. The theoretical gamma energy level of I-132 is 773 keV. Also in all of the following scenarios, a lot more samples would have needed to have been collected to be sure of the identified substance.

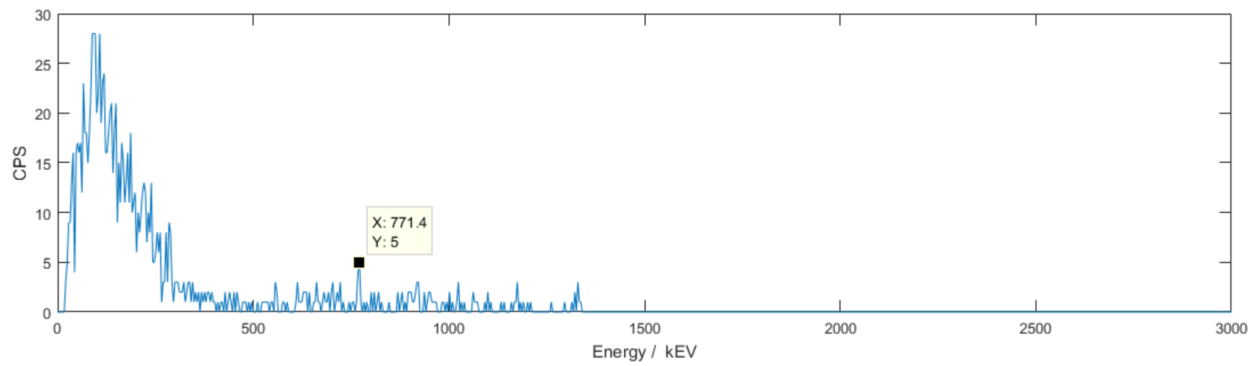

Figure 5-39: Local spectrum of interest area 1. in scenario 2. The GPS location (latitude, longitude) was (60.188647040072787, 11.210689309343547) and the average CPS was 102.

Interest area 2. of scenario 2.

The collected spectrum of the area enclosed within red circle 2. is shown below in Figure 5-40. The average CPS for the enclosed samples is 108. In this area, two spikes may have been forming at energy levels 1167 and 1326 keVs. The closest substance might be Co-60 (Cobalt) with theoretical energy levels of 1173.2 and 1332.5 keVs.

The hints of these energy levels may also be present at the spectrum of interest area 1, shown in Figure 5-39, however, there are too few data points to be sure.

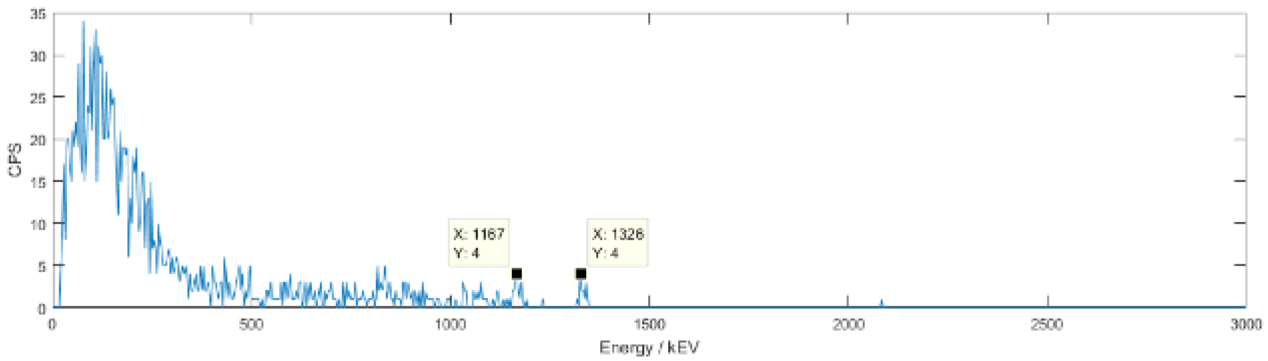

Figure 5-40: Local spectrum of interest area 2. in scenario 2. The GPS location was (60.188829530832585, 11.210830210689682) and the average CPS 108.

Interest area 3. of scenario 2.

The collected spectrum of the area enclosed within red circle 3. is shown below in Figure 5-41. The radio link to this location was very weak and there were too few samples to make a reliable histogram due to dropped packets, so this result should be omitted. Also the two weak spikes does not seem to correspond to any probable radiation source. Also the CPS counts from these measurements may be an artifact and therefore these measurements should be omitted.

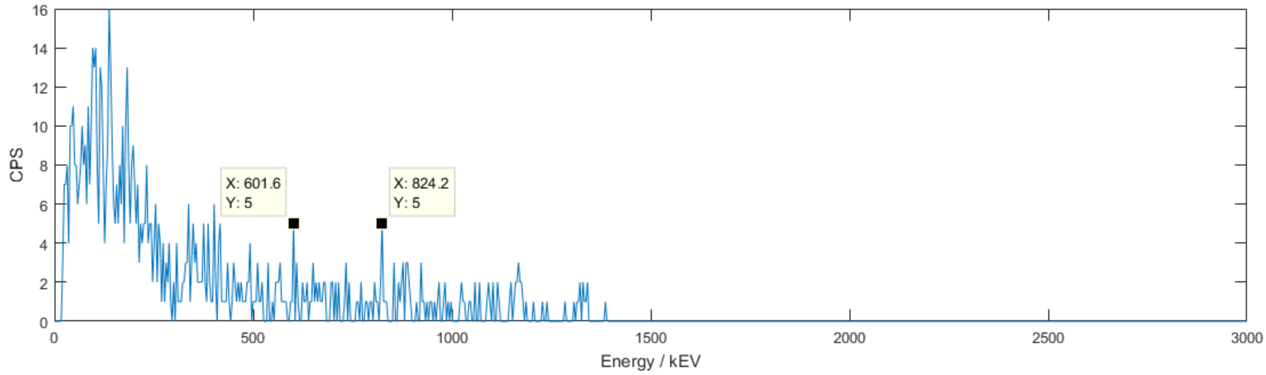

Figure 5-41. Local spectrum of interest area 3. in scenario 2.This spectrum has too few values due to radio link issues and has odd energy spike values, therefore it is omitted.

5.4.10 Scenario 3

The scenario area 3 was semi-open area with a lot of small birch and pine trees, mostly less than 2 meters tall. This scenario showed several hotspots, but again making the local histograms from the limited data we gathered presents difficulties for trying to identify the radiation sources. The overview image is shown in Figure 5-42.

Figure 5-42. The measured data overlaid with Google Earth map from scenario 3. Again, the Google Earth data is not from the time the tests were performed, but the area was still pretty much the same. The data and interest areas are marked similarly as was done in Figure 5-38.

Interest area 1. of scenario 3.

The collected spectrum of the area enclosed within red circle 1. is shown below in Figure 5-43. The average CPS of the enclosed samples is 119. Two Spikes may be seen from the spectrum at 122.6 and 330 keVs. The 330 kEV spike might be indicative of the presence of Iridium, either Ir-192 or Ir-194, which are near that energy level. We will not go in to speculation what substance might be emitting the spike in the 122.6 kEV range.

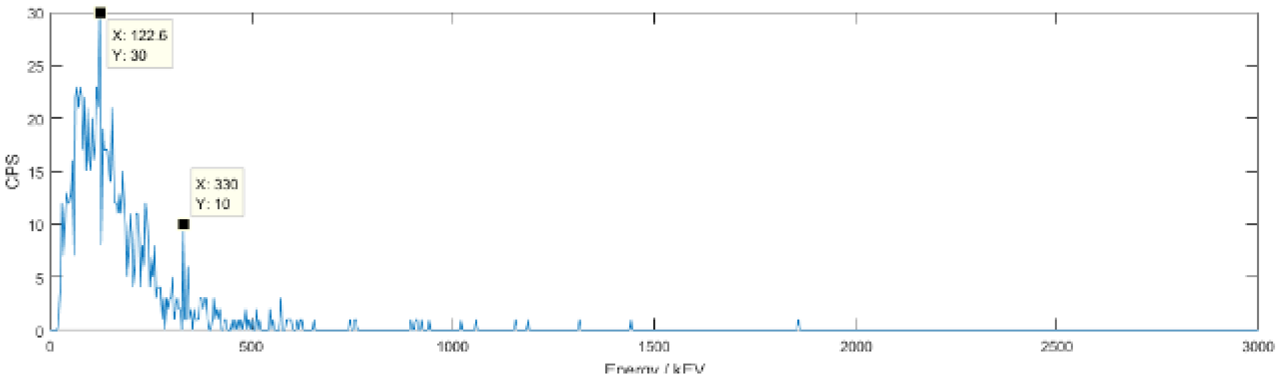

Figure 5-43. Local spectrum of interest area 1. in scenario 3. The GPS location was (60.185552311618707, 11.221668603130317) and the average CPS 119.

Interest area 2. of scenario 3.

The collected spectrum of the area enclosed within red circle 2. is shown below in Figure 5-44. The average CPS here is 66, but based on the overview image there might have been a hot spot at the center where we did not get nearly enough data from, most likely due to the radio and software issues mentioned earlier. From the data available, we have a very weak spike at 662 kEV range, which may be indicative of the presence of Cs-137 (Cesium) by some small probability with its gamma ray energy level being 661.64 keV. However, this result is so weak that the spectrum is not reliable enough for actual identification of the substance.

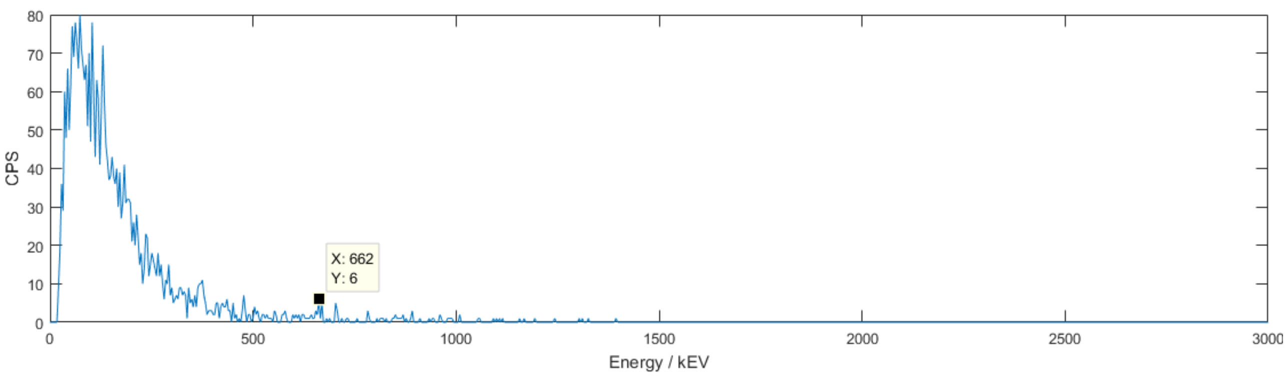

Figure 5-44. Local spectrum of interest area 2. in scenario 3. The GPS location was (60.185402505821770, 11.222150471200848) and the average CPS 66.

Interest area 3. of scenario 3.

The collected spectrum of the area enclosed within red circle 3. is shown below in Figure 5-45. The average CPS for these samples is 107. Here we have the clearest indication of something visible in the spectrum, at the 662 keV energy level. This is most likely indicative of Cs-137 (Cesium) with the energy level of 661.64 keV.

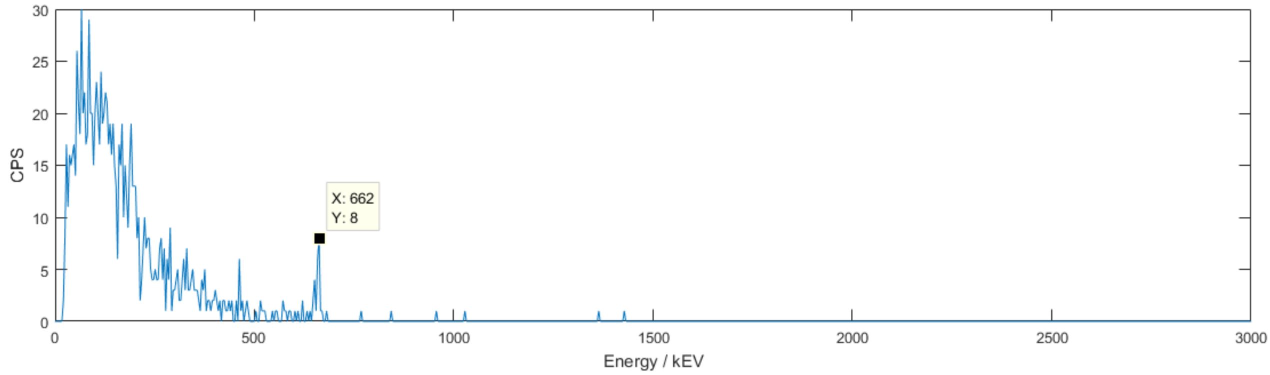

Figure 5-45. Local spectrum of interest area 3. in scenario 3. The GPS location was (60.185292345669112, 11.222505228340426) and the average CPS 107.

Interest area 4. of scenario 3.

The collected spectrum of the area enclosed within red circle 4. is shown below in Figure 5-46. The average CPS for the enclosed samples here is 88. No meaningful energy spikes are seen on this spectrum either, unfortunately.

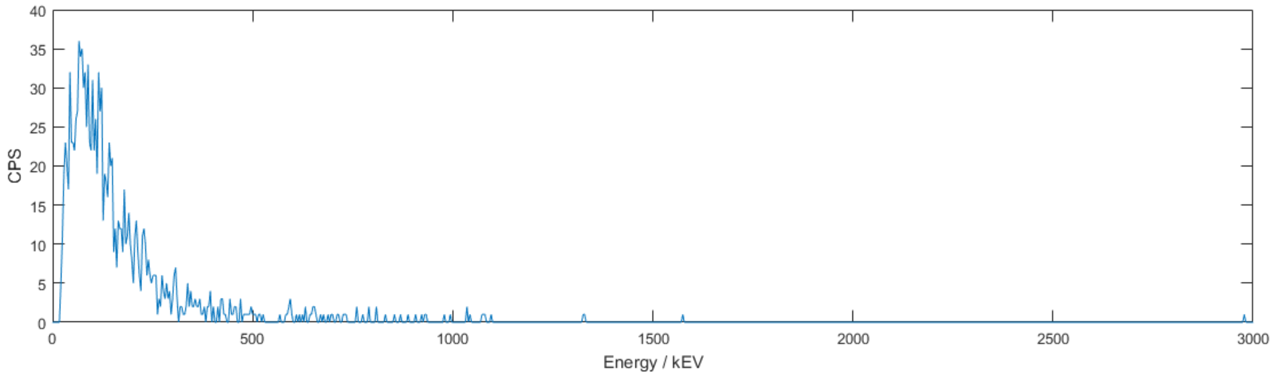

Figure 5-46. Local spectrum of interest area 4. in scenario 3. The GPS location was (60.185313285990333, 11.221726338256392) and the average CPS 88.

5.4.11 Post analysis of the obtained results

When this report was initially written, we did not know the actual location of the radiation sources. After the event we have been given the actual locations of the radiation sources. The actual radiation source locations are shown below for each scenario.

Comparing the hot spots we detected and the actual locations of the radiation sources, we can see that especially the GPS accuracy should be improved in future revisions of the sensor package. This can be done by deploying a GPS support point for relative GPS positioning enabled by the u-blox C94-M8P-3 GPS module.

The Kromek GR1-A sensor itself looks to be sensitive enough for detecting the presence of most of these sources. Even identification of gamma ray emitting source materials is possible at least at in the sub 1 MeV energy levels. Cs-137 and Co-60 were the most identifiable in the seen energy spectrums.

There most problems we had was identifying Sr-90 as the energy spectrum showed clear spikes and as a result, we speculatively miss classified it to be potentially Ir-192 or Ir-194. However, according to Wikipedia, Sr-90 more of a beta particle source and gamma emissions are infrequent. Still, its presence was clearly noticeable at least in the CPS reading of the gamma-ray sensor.

We also dismissed the data points collected near Eu-152, even though we did see an indication of increased activity near it. Due to radio link issues, there was just too little data from that location.

5.4.12 Summary

We managed to collect some usable data from scenarios 2. and 3. that could be used for at least roughly localizing the radiation sources. The background CPS level measured with the sensor hovered somewhere around 10 – 20 CPS. Anything over 30 CPS was considered indicative of increased activity and these regions were visualized utilizing the Google Earth application. From the collected energy spectrums, at least two locations showed potential that the sensor package could also be used to identify the source material of the radiation.

The sensor package was fully self-contained with GPS localization and was hanging from the copter with a 1.5 meter long chain. This approach was different from what the other teams used and worked surprisingly well. Maneuvering the sensor very close to ground and measured objects was somewhat difficult but not too much. The DJI Inspire 1 handled the load hanging way below the copter quite well, even when there were gusts of wind affecting the quadcopter and the sensor package.

Using the quad copter camera, we could also take videos from the areas being measured. An example of a recorded video can be found from link [32]. This video was taken from Scenario 1 and shows the potential of using the onboard 4K camera of a DJI Inspire 1 when trying to maneuver the sensor package.

5.4.13 Encountered issues with the measurements

In our application, all collected data was gathered through a 57.6 kBaud serial radio link from the quadcopter to a remote monitoring laptop PC. Unfortunately, some of our data was lost as the data was not recorded locally in the sensor package as it was supposed to. As the serial radio link was occasionally weak, this resulted in corruption of data being transmitted over the radio link. The corrupted data crashed the data collection software on the PC listening the radio, resulting in data being lost during the periods the PC software was being restarted. Corruption happened more regularly when a lot of data was being transmitted over the link, resulting in the PC recording software crashing more frequently especially in the hottest spots where the radiation was detected. Therefore, the ability to construct good gamma ray energy spectrums to identify the radiation source was made difficult as the data collected from the hotspots was the scarcest.

The loss of data would have been averted if the data was recorded also locally in the Raspberry Pi microcomputer in the sensor package being carried by the quad copter. However, for real time monitoring, the data would naturally not be more accessible from the sensor remotely other than by improving the serial radio link quality. This can be achieved possibly by utilizing stronger transmitters, adding some error checking and by implementing more robust sanity checks in the PC monitoring software to avoid crashes due to corrupted data packets received.

5.4.14 Future work

The greatest issues were caused by the radio link from the sensor package to the measurement PC. These may be alleviated with better data compression and error checking. The signal of the antenna could also be stronger as right now the transmitting power was less than 10 mW. Data can also be collected within the sensor package, which it currently was not. The sensor package itself was quite large, but largely due to oversized insulation layer around the electronics. The size could be cut down by half if we utilized smaller form factor Raspberry Pi, like the Raspberry Pi Zero [33], and remove excess insulation.

Implementing automated control of the quad copter and to perform minimum sampling of the interest points, some advanced control algorithms would need to be developed. Currently, we also do not get reliable height measurements for the sensor, so the copter provided height measurements would need to be utilized. In the future, utilizing a bigger copter, we might also have the ability to combine LIDAR data with the radiation sensor data.

5.5 Team 5 [Norwegian Radiation Protection Authority]

5.5.1 Introduction

NRPA started a project for unmanned aerial monitoring in August 2015. Due to a limited budget, we decided to use consumer grade products for this project. We decided to go for a DJI S1000 octocopter with capacity to carry our current equipment. We also bought a DJI Phantom 3 for flight training and video recording. For measurements, we can choose between several 2” and 3” NaI detectors. These are connected to an Osprey MCA (Canberra) for which we have a programming SDK. This equipment is connected to a Raspberry Pi, along with an external GPS. Our software on the Raspberry Pi stores data on disk and transfers them to the ground for real time analysis. For this exercise, we decided to use standard internet communication (mobile broadband) for this purpose.

For the ground station, we developed software for controlling the Raspberry Pi and for analyzing the spectrums. This software gives us the option to view the data as a waterfall rendering, List of ROI’s, collection of spectrums, subtraction of background, dose rate calculation, plotting on map, energy calibration and several other options.

5.5.2 Preparations

The equipment was tested at different outdoor locations several times before the exercise. The dose rate calculations was tested at the NRPA SSDL laboratory. During this test, we exposed the detector to different nuclides with different activities and angles. This test showed that the dose rate calculation was a bit off, but acceptable for the time being.

We defined and calibrated three detectors in our software before the exercise. Because NaI detectors need frequent energy calibrations due to variations in temperature among other things, we were prepared to do an energy calibration onsite.

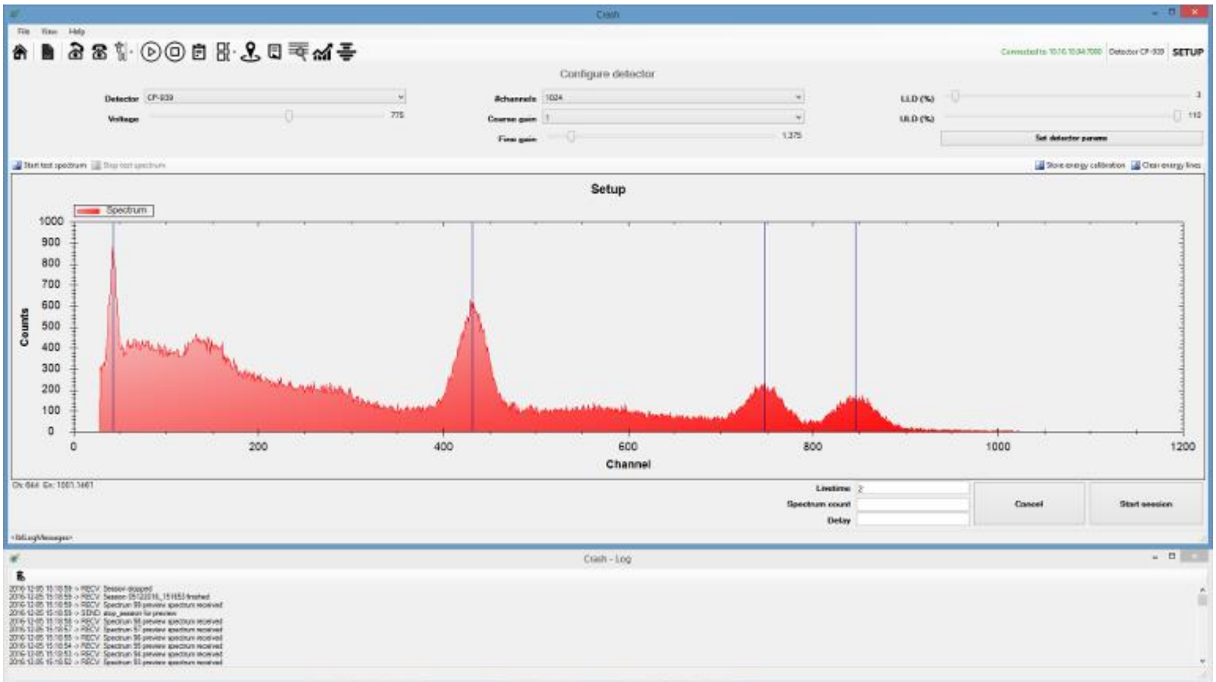

Figure 5-47 : Energy calibration with Am-241, Cs-137 and Co-60.

5.5.3 Results

Site 1

This site was small and contained many obstacles in the form of trees and containers. At this site, we started doing an overall scan before going in more detail. We then went in for a more detailed scan, using the small camera drone to assist navigation between the containers. Due to a very slow and unstable internet connection, we were unable to receive data in real time. Data for our last scan was also lost, possibly due to network buffer overruns in the software. This resulted in missing measurements for certain parts of the area. Our results are therefore based only on the first scan of the area.

At this site, we found one interesting spot (see Figure 5-48).

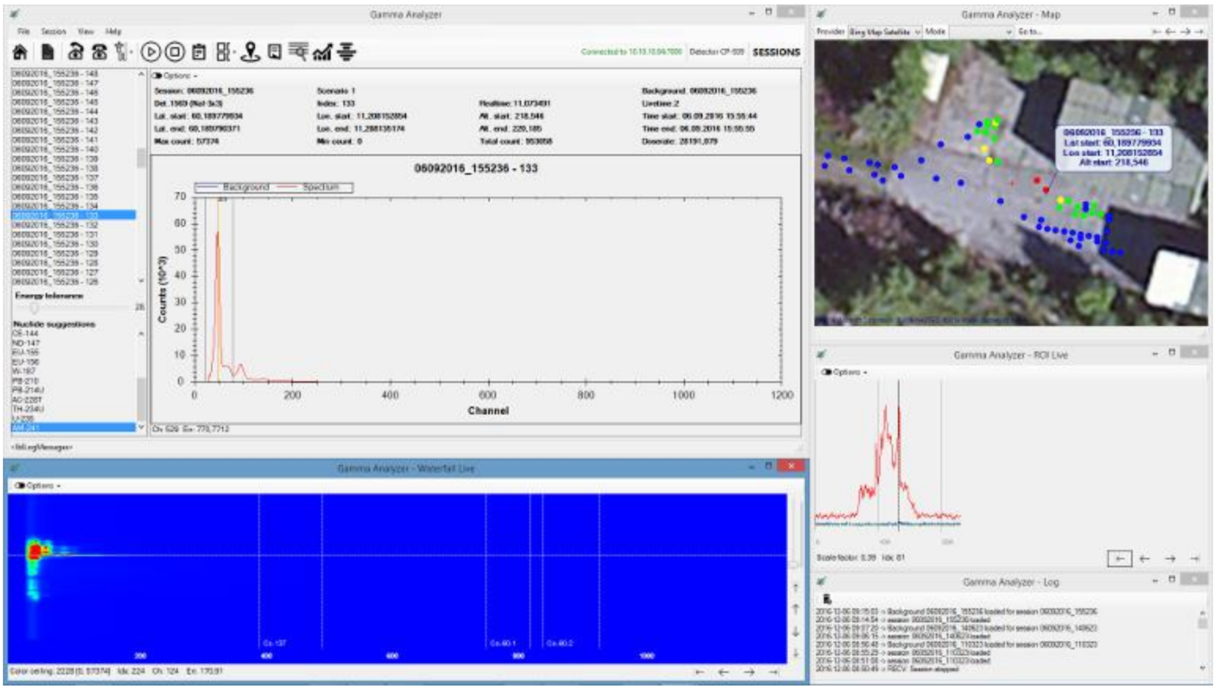

Figure 5-48 : Am-241 found in spectrum at site 1

The Am-241 source at Site 1 was so strong that the whole area was affected. The 59 keV peak was visible all the way from the starting point, and throughout the entire scan. This caused some confusion when we analyzed the spectrums.

Site 2

This area was an open field with a container column on the west side. Our strategy at site 2 was to take an overall grid scanning assisted by video streaming using the small drone. This site had some wind turbulence and an unstable internet connection. After the first overall scan, we focused on flying close to the containers in the area, trying to cover all angles around the containers. We started the scanning of this area using the 2” NaI detector, and later on continued with the 3” detector.

At this site we were able to analyze the spectrum data after the first scan, and this indicated two interesting spots. One on each side of the container column. The spectrum data clearly suggests two Co-60 sources (see Figure 5-49, Figure 5-50).

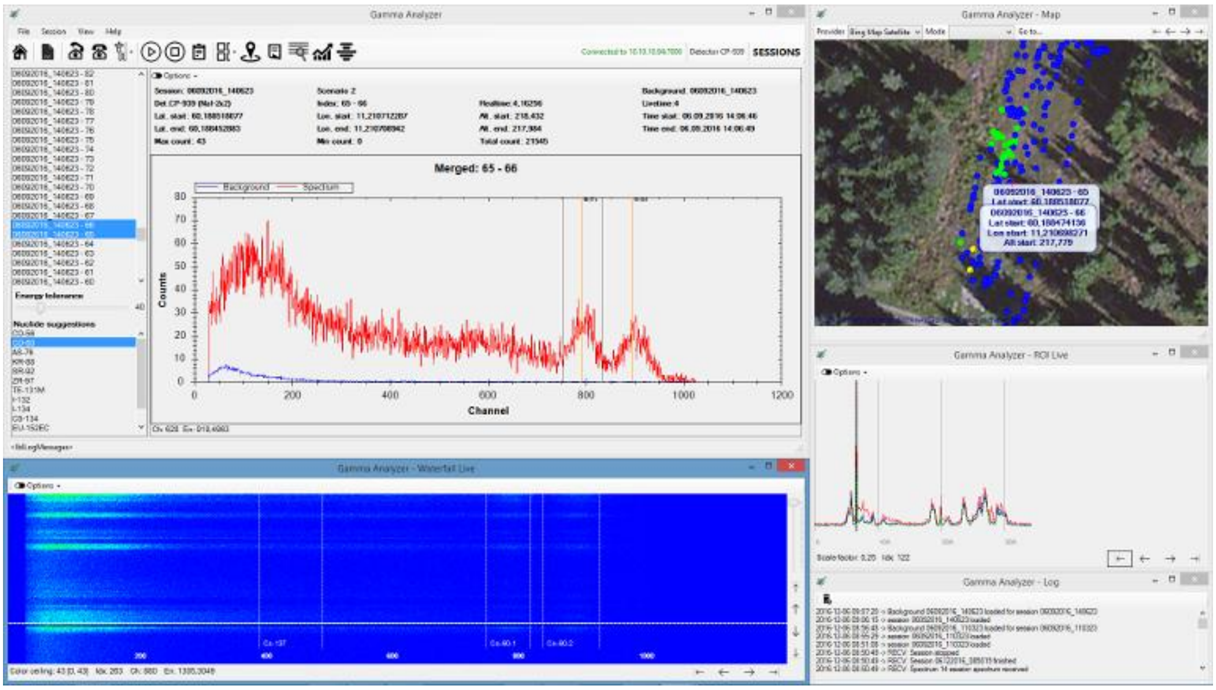

Figure 5-49 : Co-60 found in spectrum at site 2

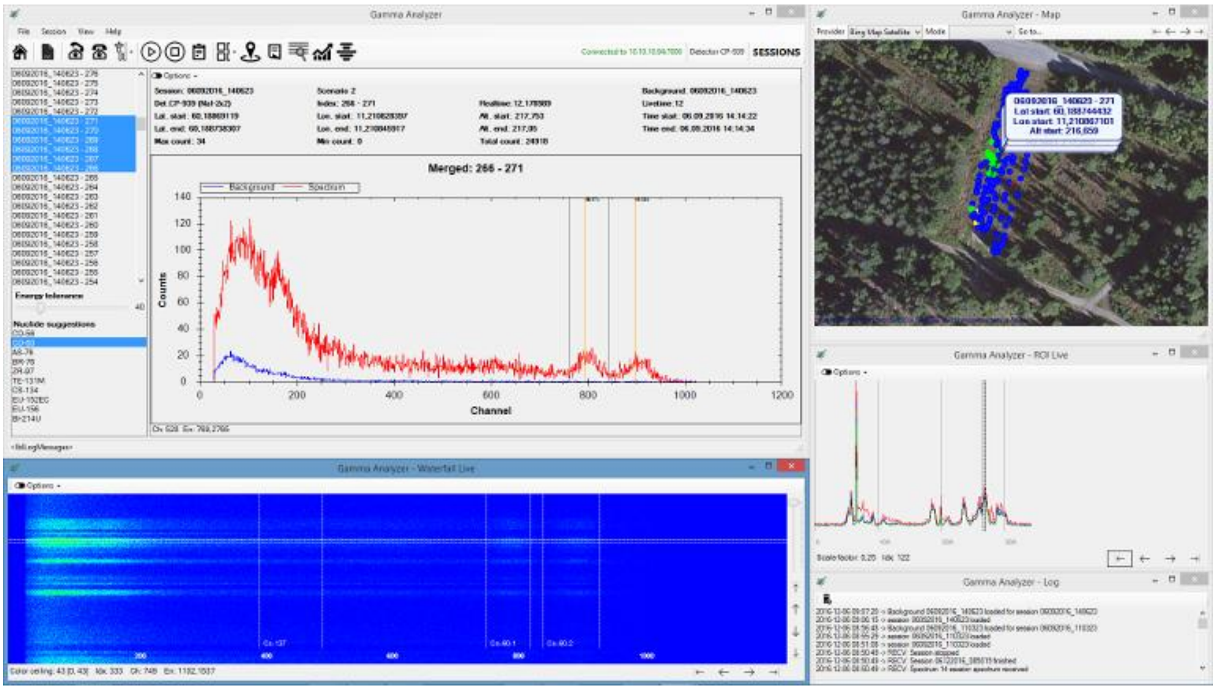

Figure 5-50 : Second Co-60 peak found in spectrum at site 2

Site 3

This area was open but contained a lot of scattered vegetation and high trees. This made it challenging to navigate the drone. Our strategy at site 3 was to take an overall scanning of the area to locate the hot spots, followed by finer grained scanning. This strategy failed due to difficult wind conditions and an unstable internet connection. However, we managed to complete the overall scanning with decent results.

We detected two interesting spots in the area. One indicating a Co-60 source (see Figure 5-51), and the other one a Cs-137 source (see Figure 5-52).

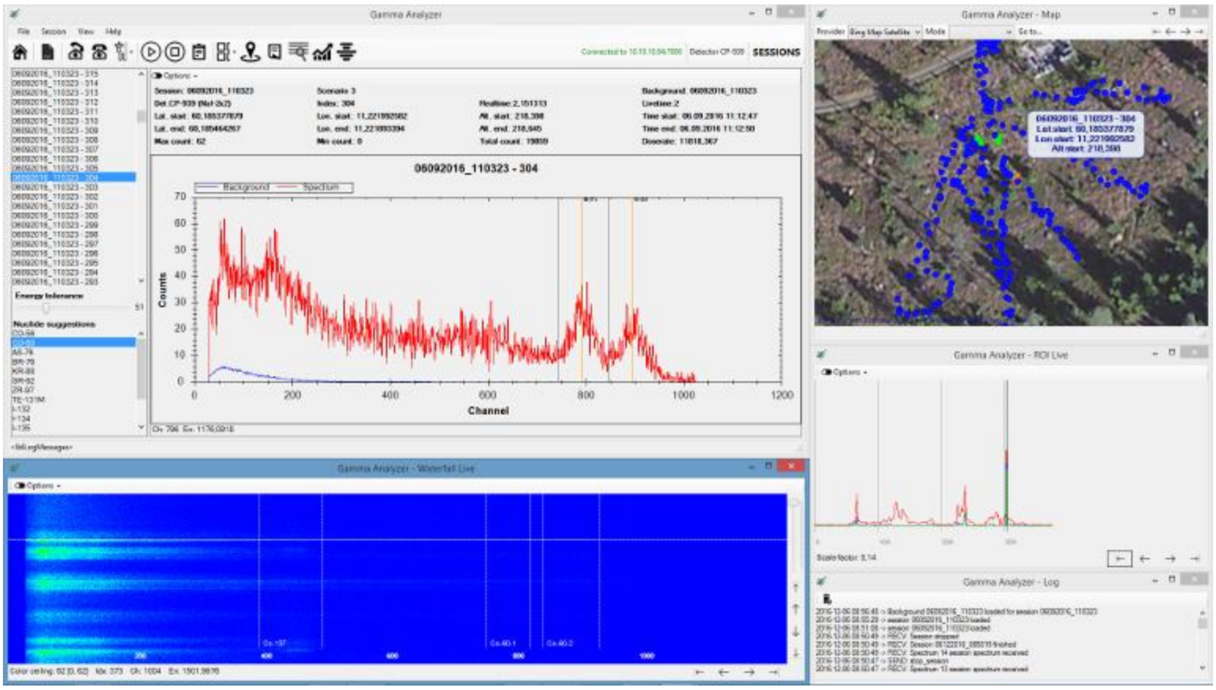

Figure 5-51 : Co-60 found in spectrum at site 3

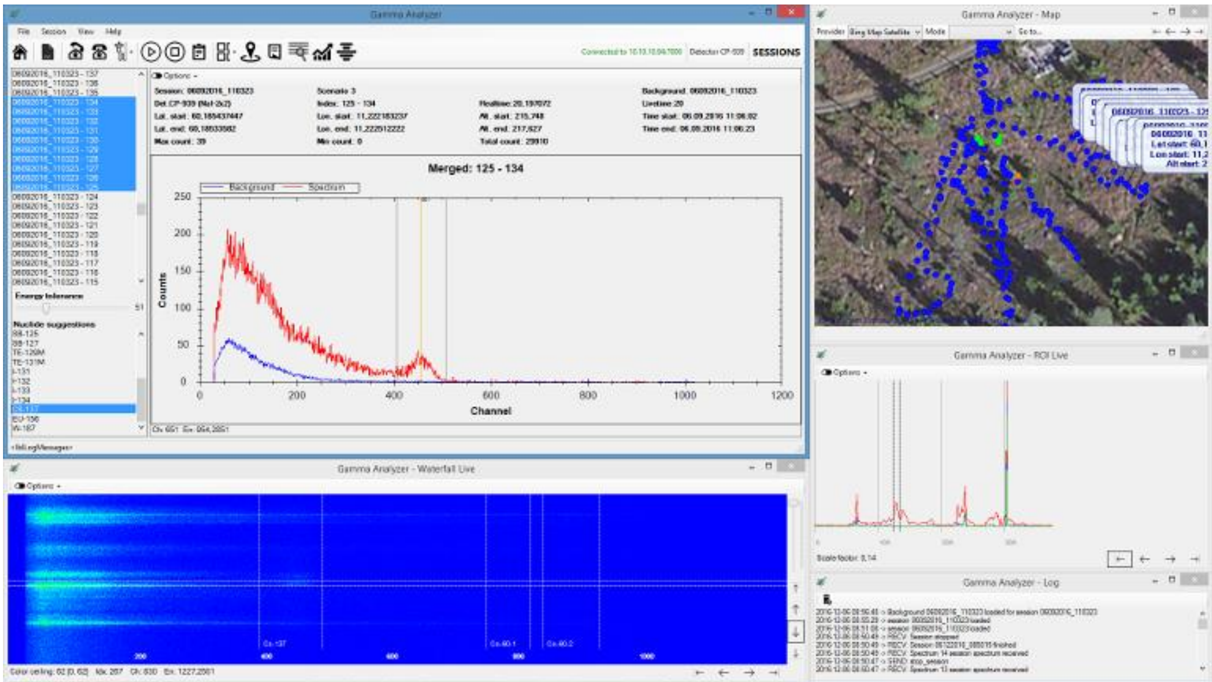

Figure 5-52 : Cs - 137 found in spectrum at site 3

Considering the spectrum data, we suggest that the sources were collimated to radiate in specific directions.

5.5.4 Future improvements

Improve dose rate calculations.

Reduce weight by connecting the Raspberry Pi to the main power source of the drone. Replace the external GPS with the GPS on the flight controller.

Supplementing data communication with more alternatives, like local Wi-Fi and radio transmission.

Consider using UDP rather than TCP to transfer data considering the high probability of instability and temporary connection loss during a flight. This should provide a more robust data transfer, at the expense of potentially some dropped data packets during flight. Any lost packets can be retransmitted once the connection is stable, or after landing.

Consider using data compression for more efficient use of bandwidth.

Add the ability to run different types of detectors simultaneously.

Improving and adding more features to the software.

5.5.5 Conclusions

The unstable internet connection made it challenging to perform live data interpreting and planning the next scan. It also made it difficult to perform an onsite energy calibration, which is crucial when it comes to identifying the exact nuclides in the spectrums.

We were unable to estimate any source activities, because our dose rate calculations were inaccurate and because the distance to the source was unknown.

We consider this exercise a success, and our technological solutions worked fine and we learned some interesting lessons for the future.

6 Exercise summary

The NORDUM exercise as a whole was a success. We were able to deliver most of the objectives and discovered some new challenges. This is something that could be useful for any future RPAS exercises.

The different complexity of the scenarios, and the different type of sources contributed to a more challenging exercise.

Many of the participants have systems that are still under development and are working with improvements and new functions, like autonomous operations, protection against difficult weather conditions, data exchange formats and issues with data communications like GPS radio and internet.

The NORDUM activity had several preconditions in order to become a successful exercise, like implementation of safety measures, acceptable weather, etc. In order to fulfill the preconditions, the area containing radioactive sources were restricted. A test session was organized before the exercise for all the teams to configure their RPAS failsafe functions.

The different teams had different types of equipment and different measurement strategies for the scenarios. This resulted in different challenges for each team, like GPS tracking accuracy, data communication issues, and weather conditions like wind.

Because of the different approaches taken by the teams, and the fact that there were several teams gathered at the same event, we learned a lot from each other. However, given more time, the teams could have learned more from each other, unfortunately this was not possible due to a limited budget.

Unmanned aerial measurements in the form of smaller RPAS are to be considered complementary to car born and backpacks. The risk of contaminating the detector systems is less with the unmanned systems.

Regarding the future, a collaboration forum has been created for the Nordic countries as an extension of the NORDUM seminar at the end of the event. This can be used to improve cooperation, standardization and common strategy.

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[30] https://www.u-blox.com/en/product/c94-m8p

[31] https://www.google.com/earth/

[32] http://www.ee.oulu.fi/~makechu/DJI_video/DJI_0006.MOV

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Appendix A. Test and verification of the RPAS

The exercise part of the NORDUM event were at a closed military area called Haureseter leir where the RPAS flying were to be conducted. Haureseter leir is approximately 3 km away from Gardermoen airfield. It lies within Gardermoen control zone. Therefore, for the exercise, we had to obtain an authorization from Gardermoen control tower. To obtain such authorization it was agreed through ASC that all drones/RPAS had to be programmed to:

- Max altitude 50 meter
- Come home function – climb to 45 meter – come home
- Geo fence – 200 meter from take-off point

For that reason, a day before the exercise (called Day 0 in this report) we arranged test flights for all the teams to configure and test the “come home”, “failsafe” and “geo fence” function in a safe environment, at least 5 km away from the Gardermoen control zone.

The schedule for test and verification is set up according to your arrival to Oslo	
Team	**Start Time**
Team 5 (NRPA)	13:30
Team 1 (Danish Emergency Management Agency)	14:30
Team 4 (University of Oulu)	15:30
Team 2 (Linköping University)	16:30
Team 3 (Finnish Defence Research Agency FDRA)	17:30

Table A-1: The schedule for test and verification day.

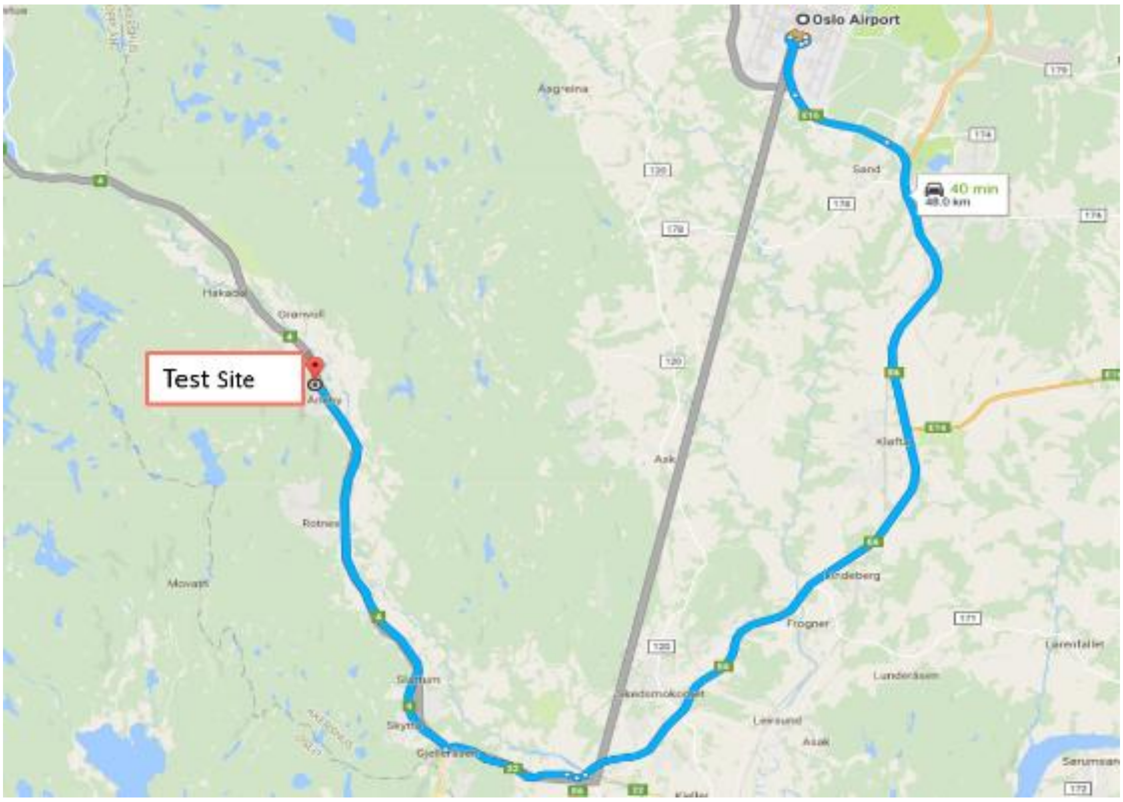


Figure A-1: Map, direction to the test and verification site from Oslo Airport.

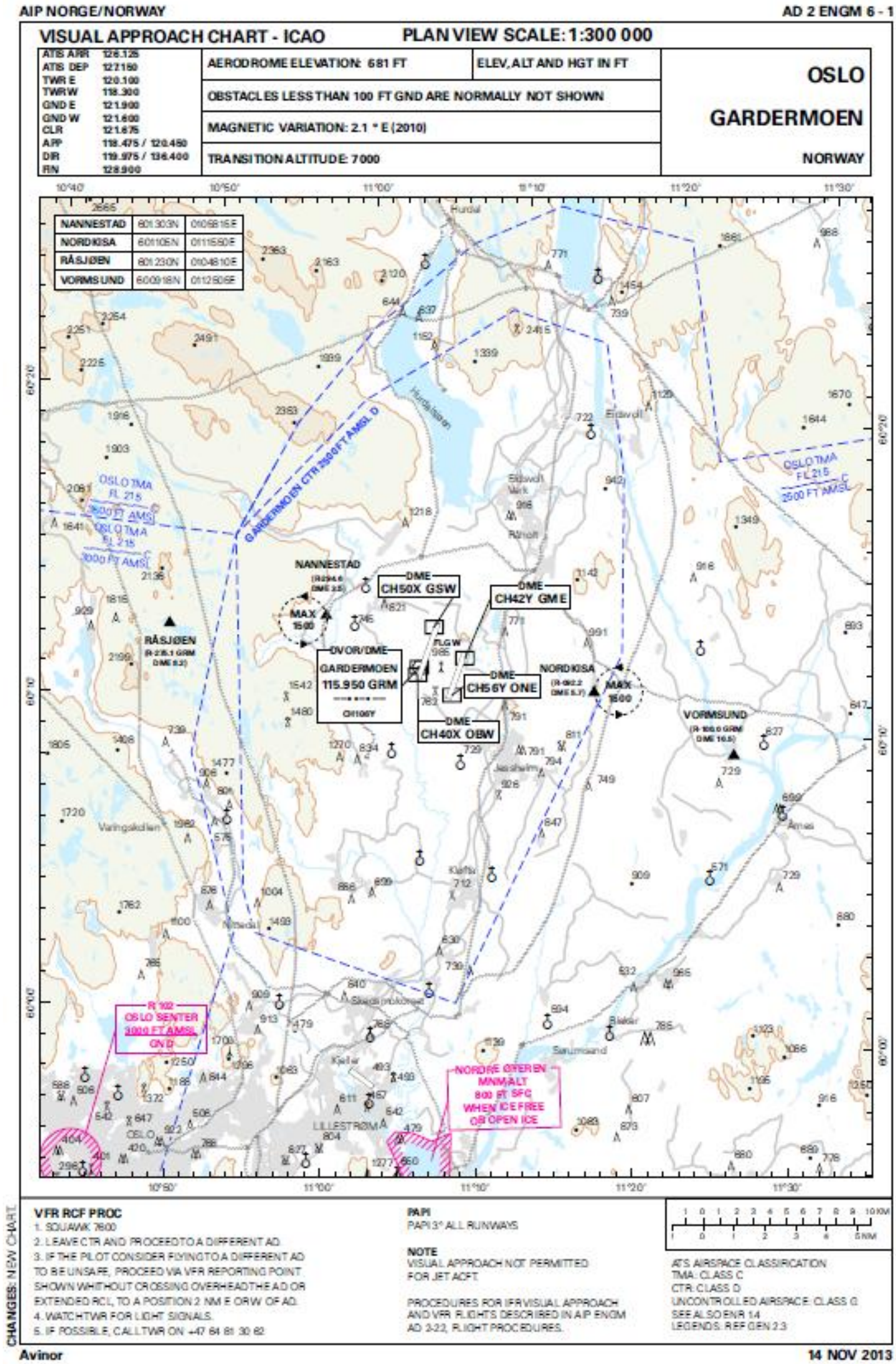


Figure A-2: Map, Visual Approach chart.

Appendix B. Exercise program

FABCS from The Norwegian armed forces provide facilities for the NORDUM exercise at Hauerseter leir. The restricted area was divided in four parts, basecamp with calibration site, and three different scenario sites.

NKS NORDUM – Exercise - Day 1					
	08:00 – 09:00	Welcome by - NRPA: Øyvind G. Selnæs & Kasra Tazmini - ASC (Andøya Space Center) - Preparation			
Flight Id	**Time**	**S1 (scenario)**	**S2 (scenario)**	**S3 (scenario)**	**C1 (Calibration Site)**
F1	09:00 -10:30	Team 1	Team 4	Team 2	on the ground
Break	10 min	Transport to next Scenario/ Break			
F2	10:40 - 12:10	Team 4	Team 3	Team 5	on the ground
Break	10 min	Transport to next Scenario/ Break			
F3	12:20 – 13:50	Team 2	Team 1	Team 3	Close
Break	10 min	Transport to next Scenario/ Break			
F4	14:00 -15:30	Team 3	Team 5	Team 4	close
Break	10 min	Transport to next Scenario/ Break			
F5	15:40 – 17:10	Team 5	Team 2	Team 1	Close
FABCS	17:00 – 19:30	Exercise brief by NRPA for FABCS at 17:00 FABCS Exercise at site 1 and site 2 (without RPAS)			

Table B-1: Program for NKS NORDUM exercise day.

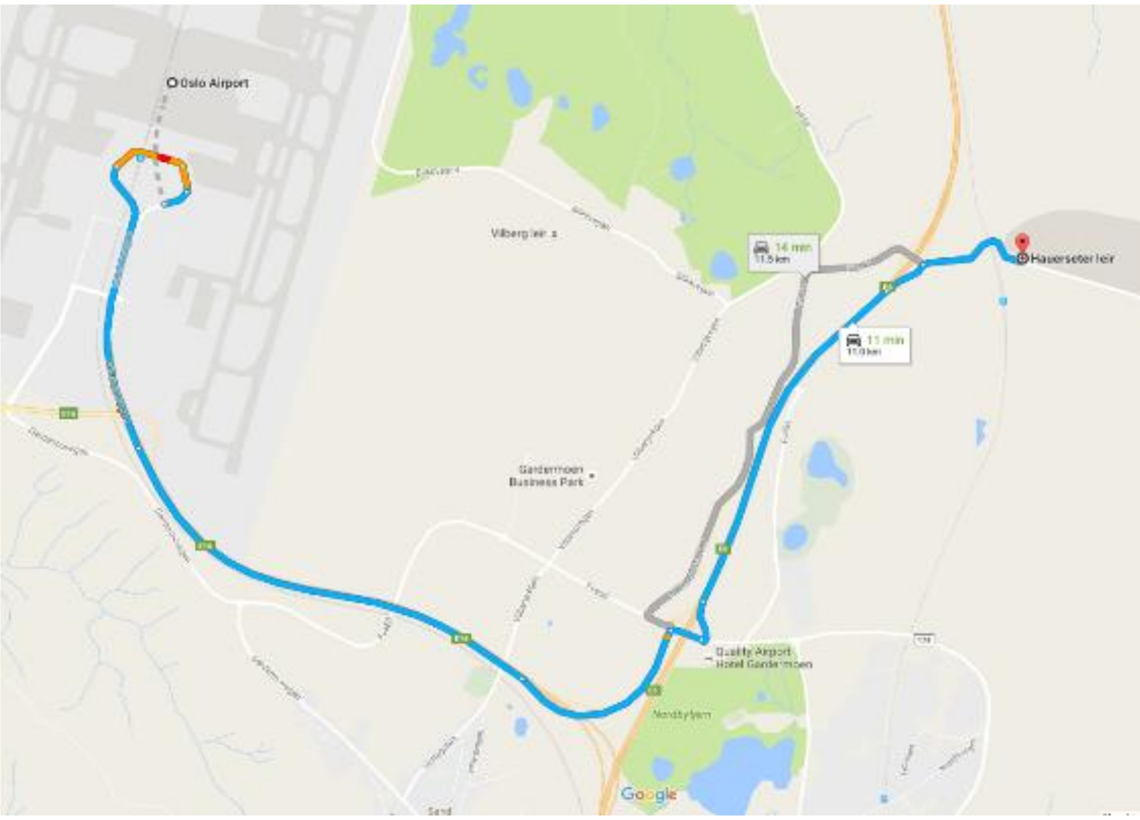


Figure B-1: Map, direction to the exercise site from Oslo Airport.

Appendix C. NORDUM Workshop program

FABCS from The Norwegian armed forces provide NORDUM with workshop facility at Sessvollmoen.

09:00 – 09:30	Welcome NRPA, introduction
09:30 – 10:00	Team 1 – presentation system and data
10:00 – 10:15	Coffee Break
10:15 – 10:45	Team 2 – presentation system and data
10:45 – 11:15	Team 3 – presentation system and data
11:15 – 12:00	**Lunch**
12:00 – 12:30	Team 4 – presentation system and data
12:30 – 13:00	Team 5 - presentation system and data
13:00 – 13:15	Coffee Break
13:15 – 13:45	Exercise Leader - Presentation of solution/answer for three Scenarios
13:45 – 15:00	The road ahead
Finish	

Table C-1: Workshop program, Day 2.

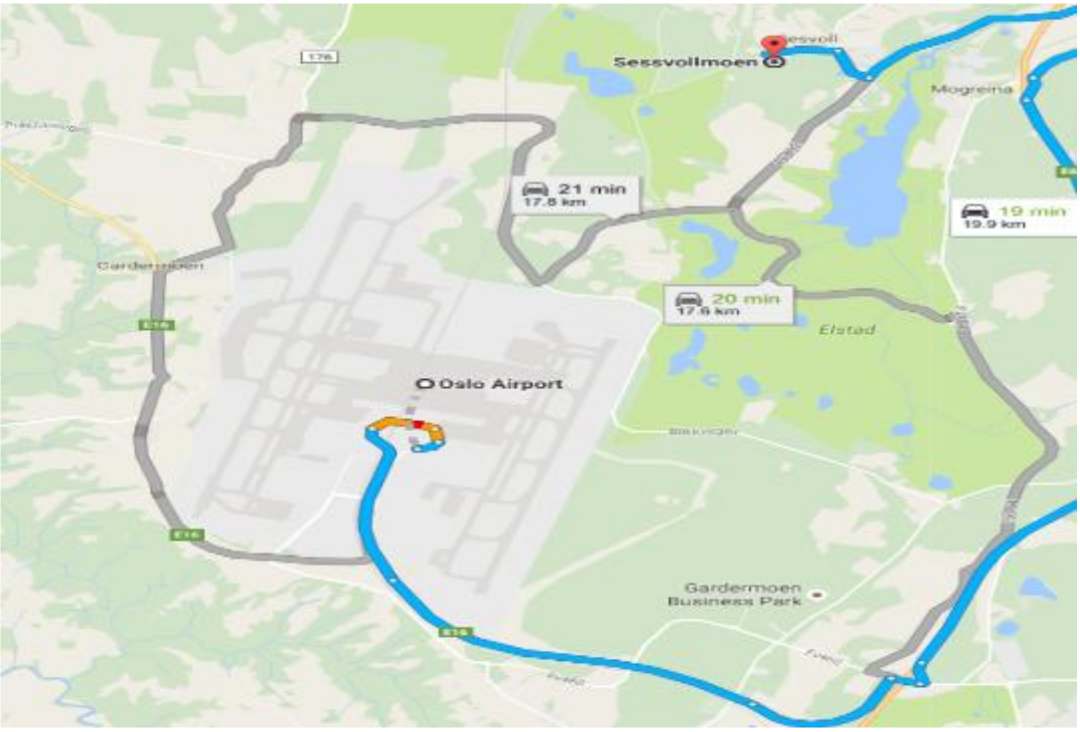


Figure C-1: Direction map from Oslo Airport to workshop location, Sessvollmoen.

Appendix D. Technical Sheet

D.1 Team 1 [Danish Emergency Management Agency]

Manufacturer	Danish Aviation Systems ApS	Sensefly
Length	55 cm	40 cm
Width	55 cm	96 cm
Height	45 cm	10 cm
Aircraft Weight	5240 g	690 g
Max payload Wight	1,5 kg	230 g
Max kinectic energy	374 Joule	140 joule
IO/IR cam, weight x kg	HD-livefeed camera Inormal or termal, (6kg total incl. camera)	Normal and NIR-camera, (690g incl. camera)
Gamma Detector, weight	~630 g	NA
Other sensors, weight		
Automatic flight	Yes	Yes
Fail-safe system	Return to home, auto land, low battery land, return in case of link loss	Return to home, auto land, low battery land, return in case of link loss
Usage	Used for carrying standard of-the-shelves measurement instrument with GPS and LOG capability. Instruments are mounted with special 3d-printet mount.	Used for offline fabrication of high-resolution map with DEM (Digital Elevation model) over area to be measured.
Remarks		The Ebee was not allowed to fly so it was not used during the Exercise.

Table D-1: The technical sheet for team 1.

Figure D-1: Danish Aviation Systems ApS and Sensefly

Instrumentation

Canberra Colibri VLD/BLUETOOTH/GPS

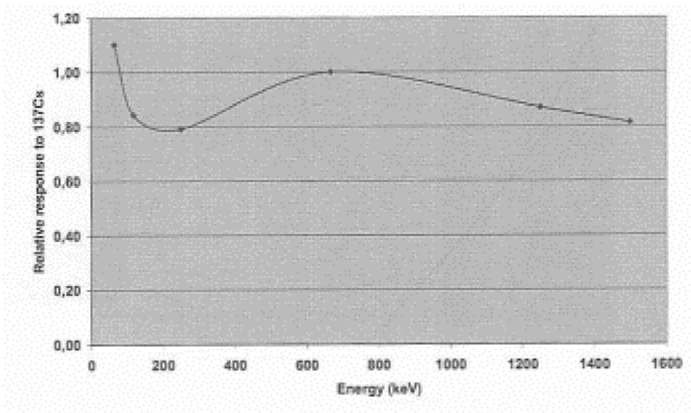
Sensitivity 0,7 c/s by µSv/h (^{137}CS)

Energy range: 59 keV – 1,5 MeV

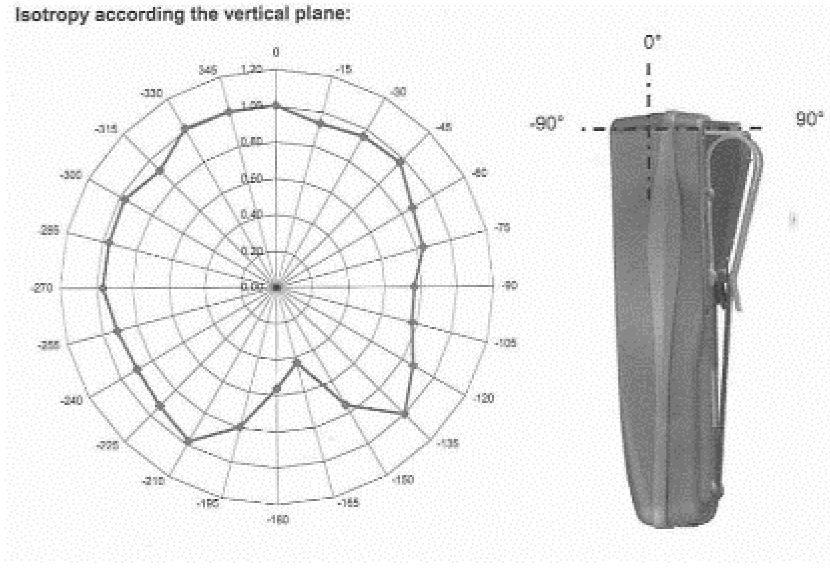
Measurement range: 10 nSv/h – 1 mSv/h

Measurement range 8iED 60846): H_0 =100 nSv/h – 1 mSv/h

Energy response:



Angular response (^{137}CS)



D.2 Team 2 [Linköping University]

Name	Quad	RadiaCopter	Bus	RadiaWing
Picture	Fig D-1	Fig D-2, D-3	Fig. D-4	Fig D-5
	Used during NORDUM			
Type	Quadcopter, center body with 4 arms	Quadcopter, Integrated safety rim	Fixed wing, polyhedral wing	Fixed wing, polyhedral wing
Temperature range	0–40 C	0–40 C	0–40 C	0–40 C
Engine	Electric, KV 620	Electric, KV620	Electric, KV620	Electric, KV 690
Battery	6S	6S	6S	6S
Propellers	12x4.5/305x114	10x5/250x125	12x6 foldable	14x8 foldable
Configuration	X	X	Tractor	Tractor
Manufacturer	Tarot Iron Man 650	Claes Meijer	Claes Meijer	Claes Meijer
Controller	PixHawk	3DR APM 2.5	3DR APM 2.6	Pixhawk
RC	Futuba S.Bus T10J 2.4 GHz	WFLY WFT07 2.4 GHz	WFLY WFT07 2.4 GHz	Futuba S.Bus T10J 2.4 GHz
Telemetry	3DR 433 MHz			
Data link	XBee Pro SS 868 MHz			
Ground control	MissionPlanner by 3DR telemetry			
Length			1,1 m	1,6 m
Width	0,8 m	0,67 m		
Height	28 cm	7 cm	52 cm	62 cm
Wingspan (if fixed wing)			2,2 m	3 m
Aircraft Weight (1 battery)	2,5 kg	1,6 kg	3 kg	4 kg
Extra battery, ea	825 g	365 g	825 g	825 g
Max payload Weight	2 kg	0,5 kg	2 kg	4 kg
Max Gross Take-off Weight	5 kg	2,5 kg	6 kg	9 kg
Max speed	20 m/s	20 m/s	18 m/s	20 m/s
Cruise speed	NA	NA	10 m/s	15 m/s
Stall speed (fixed wing)			7 m/s	10 m/s
Launch type (fixed wing)			Throw, skid landing	Throw, skid landing
Endurance	25 min	15 min	40 min	40 min
Wind tolerance	<6 m/s	<6 m/s	<6 m/s	<6 m/s
Automatic flight	GPS Waypoints			
Fail-safe system	Yes, return home or land	Yes, return home or land, props guarded by rim.	Yes, return home or land, Wings break off on impact	Yes, return home or land, Wings break off on impact
Detectors	2” NaI(Tl) or 1	1 cm^2 CZT	2” NaI(Tl) or 1	2” or 3” NaI(Tl)

Name	Quad	RadiaCopter	Bus	RadiaWing
	cm^2 CZT		cm^2 CZT	or 1 cm^2 CZT
	60 g/700 g	60 g	700 g	700/1900 g
MCA	Bridgeport Instruments oemBase		Bridgeport Instruments oemBase	Bridgeport Instruments oemBase
	140 g		140 g	140 g
On-board computer	Raspberry Pi 2 B+/Zero			
Software	Raspian, Collector(C, kromekusb, BPI_eMorpho, MAVLink)			

Table D-2: The technical sheet for team 2.

Figure D-2: Quad

Figure D-3: RadiaCopter frame on the table, no payload.

Figure D-4: RadiaCopter in air. Prototype payload. Payload is now more integrated in the frame.

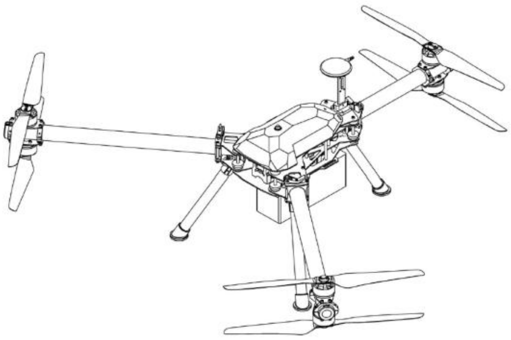
Figure D-5: Fixed Wing Bus with 2,2 m wingspan.

Figure D-6: Fixed Wing RadiaWing with 3 m wingspan. Same principal construction as Bus. Ground control laptop is shown.

D.3 Team 3 [Finnish Defence Research Agency FDRA]

Kromek GR1-A+ usb powered gamma spectrometer with 1x1x1cm^3 co-planar grid CZT detector Energy range 30 keV - 3.0 MeV Energy resolution 2%FWHM@662keV Electronic noise < 10 keV 4096 channels (12 bit) Differential nonlinearity <$\pm$ 1% Temperature range 0 to +40^{O}C
Canberra Osprey + Saint-Gobain $LaBr_3$ detector Osprey Universal digital MCA Tube Base 2048 channels (total channels 8092) 32 bit Differential nonlinearity $\pm$ 1% Temperature range -10 to +50^{O}C $LaBr_3$ detector Energy range 30 keV - 3.0 MeV Size 1.5 x 1.5 inch Energy resolution 2.7%FWHM@662keV Temperature range -10 to +50^{O}C
Intel Compute stick STK2mv64cc Physical Address Extension 32-bit Processor Inter core m5-6Y57 SD card MicroSDXC with UHS-I support USB 3.0 Integrated Wifi Integrated Bluetooth Memory 4 GB
GlobalSat G-STAR IV usb GPS receiver SiRF Star IV 48-Cannel All-In-View Tracking USB 2.0 Interface **Dell Latitude E6420 ATG Laptop** i5 processor SSD 256 GB Integrated Wifi Integrated Bluetooth

Airborne Threod KY-6 mini helicopter



Manufacturer	Airborne Mechatronics Ltd
Flight Controller	3D Robotics, Pixhawk
GPS	Ublox Neo-M8N, GPS with Compass
Remote Control	Futaba T14 SG
Ground Control	Samsung 10” Tablet with Tower App, 3DR Telemetry
Battery	6S LiPo 10Ah - 16Ah
Height	360mm
Width	1190mm (motor to motor 800mm)
MTOW	6,5kg
Maximum Payload	2,0kg
Endurance	10-15min with Payload, 16Ah Battery

Table D-3: The technical sheet for team 3

D.4 Team 4 [University of Oulu]

Quadcopter platform	
Manufacturer	DJI
Model name	Inspire 1
Model	T600
Weight w. battery	2935g
Maximum speed	22 m/s
Maximum ascend speed	5 m/s
Maximum descend speed	4 m/s
Battery	DJI TB48, 5700 mAh, 6 cell Li-Ion, 22.2V nominal
Camera	DJI X3, 4k resolution @ 24 – 30 fps
Gimbal	ZENMUSE X3
Remote controller	DJI C1
Operating temperature	0 – 40 °C
Maximum additional payload	~660g
Fligtht time with the sensor package below	~10 minutes

Table D-4: The technical sheet for team 4, quadcopter platform.

Stand-alone sensor package	
GPS	u-blox C94-M8P-3 GNSS
Radio	433 MHz 3DR 100 mW radio modem
Computer	Raspberry Pi 3 Model B
Battery	3.7 V Li-Ion, FUJ:TECH LITE 2600 mAh
Gamma ray spectrometer	Kromek GR1-A
Total weight w. chain	Approximately 0.6 kg

Table D-5: The tecnhical sheet for team 4, senor package.

Gamma-ray spectrometer	
Manufacturer	Kromek
Model name	GR1-A
Sensor type	1 cm^3 co-planar grid CZT detector
Energy resolution	2 % FWHM @ 662 keV
Electronic noise	< 10 keV FWHM
Maximum Throughput	30 000 counts/s
Channels	4096 (12 bits)
Differential non-linearity	< ±1%
Power consumption	250 mW
Dimensions	25 x 25 x 63 mm
Weight	60 grams
Temperature	0 – 40 °C

Table D-6: The technical sheet for team 4 gamma-ray spectrometer.

Remote monitoring PC for the stand-alone sensor package	
Manufacturer	IBM
Model	Lenovo X61s
CPU	Intel Core 2 Duo L7700
RAM	2 GB
OS	Windows 7 Enterprise 64-bit
Radio	433 MHz 3DR 100 mW radio modem

Table D-7: The technical sheet for team 4, monitoring PC.

D.5 Team 5 [Norwegian Radiation Protection Authority]

RC helicopter		
Name	NRPA 1	NRPA 2
Platform	Spreading Wings 1000+	Phantom 3
Flight Controller	A2	
Type	Multicopter	Multicopter
Manufacturer	DJI	DJI
LxWxH	1100x1100x305 mm	~59x59x20 cm
Aircraft Weight	4.4 kg (just aircraft)	1.216 kg (including battery)
Max Gross Take-off Weight	11.0 kg (4.4 +6.6)	2.216 kg (1.216 + 1.0)
Max speed	15-20 m/s	16 m/s
Endurance	15 min – 25 min	20 minutes
Automatic flight	Yes	Yes
Fail-safe system	Yes	Yes
IO/IR cam, weight x kg	NO Camera	2.7 k Video Camera
Gamma Detector	Yes, Weight 2.5 Kg	NO
Accessories	IOSD Mark II 2.G Bluetooth Datalink (iPad GS)	
Computer Radio System	Futaba T14SG	DJI

Table D-8: The technical sheet for team 5, RC helicopter.

Measurement system for RC helicopter NRPA 1 (Spreading Wings 1000+)	
Detector	
Type	2” NaI detector or 3” NaI detector
Energy Range	10-1500 KeV
Energy Resolution	7-9 % (at 661 KeV)
MCA	
Model	Osprey MCA
Size	62 mm diameter and 108 mm length
Weight	280 g
On-board computer (CTRL)	
Card	Raspberry Pi 2 card
OS	Archlinux ARM
Software	NRPA Gamma Collector (Python, GPSd, Osprey SDK)
Plugin	GPS: External G-Star IV Wi-Fi: USB Dongle
Ground unit	
PC	Dell Lattitude E5540
OS	Microsoft windows 7
Software	NRPA Gamma Analyzer (C#.NET)
Com	Ice.net mobile internet for data IPad app for streaming video

Table D-9: The technical sheet for team 5, the measurement system.

Figure D-7: Picture on left side is our DJI S1000 with our measurement system, and on the right side is our DJI phantom

Appendix E. Exercise Source Summery and Location

IFE provided with the radioactive sources, and were in charge of the radiation safety for each scenario. List of the radioactive sources that was used during the exercise, see Table E-1. This information was provided by IFE.

IFE is an international research foundation for energy and nuclear technology
https://www.ife.no/no

Sit e	Location (approximately)	Isotop	Activity (MBq)	Doserate (1 m) (µSv/t)	Measured doserate in contact (µSv/t)	Measured doserate at 1 meter (µSv/t)	Comment regarding the location
1	60°11'23.18"N/ 11°12'30.40"E	Cs-137	4441	338	1400	35	**(S1-2)** Collimated, in the corner of the container, directed 45° upward
1	60°11'22.99"N/ 11°12'29.16"Ø	U-238	0,66	-	4,8	0,1	**(S1-3)** on top of the steel frame farthest from the pilot
1	60°11'23.32"N/ 11°12'29.22"Ø	Am-241	105576	315	1,8	1	**(S1-1)** open ground in grass
2	60°11'18.30"N/ 11°12'38.46"E	Eu-152	0,613	0,076	2,1	0,1	**(S2-1)** on the ground at the field center line (difficult to detect)
2	60°11'19.68"N / 11°12'38.64"E	Co-60	1893	580	1600	35	**(S2-2)** in shrubbery in front of the container, open
2	60°11'18.47"N / 11°12'38.22"E	Co-60	255	78	1000	22	**(S2- 3)** Inside the furthermost container, collimated
2	60°11'18.90"N/ 11°12'39.54" E	Pu-238	3700	-	1	0	**(S2-4)** on the ground at the field center line (difficult to detect)
3	60°11'7.74"N / 11°13'22.20"E	Cs-137	9,9	0,8	5,3	0,6	**(S3-1)** Under spruce tree, collimated
3	60°11'7.38"N / 11°13'19.86"E	Cs-137	41308	3144	660	28	**(S3-2)** Under spruce tree, collimated
3	60°11'7.56"N / 11°13'18.90" E	Co-60	4472	1370	480	14	**(S3-3)** Under spruce tree, collimated
3	60°11'7.62"N/ 11°13'18.12"	Sr-90	993	?	10	3,5	**(S3-4)** Inside a steel box out in the terrain

Table E-1: List of the radioactive sources that was used during the NORDUM exercise

Appendix F. Appendix F: List of participants

Representative	Country	Organization	Role
Kasra Tazmini	Norway	Norwegian Radiation Protection Authority	Participate
Jon Drefvelin	Norway	Norwegian Radiation Protection Authority	Participate
Dag Robøle	Norway	Norwegian Radiation Protection Authority	Participate
Jeppe Vöge Jensen	Denmark	Danish Emergency Management Agency	Participate
Lars Mattich	Denmark	Danish Emergency Management Agency	Participate
Michael Lund	Denmark	Danish Emergency Management Agency	Participate
Sune Juul Krogh	Denmark	Danish Emergency Management Agency	Participate
Steven John Friberg	Denmark	Danish Aviation Systems ApS	Participate
Magnus Gårdestig	Sweden	Linköping University	Participate
Claes Meijer	Sweden	Linköping University	Participate
Markku Kettunen	Finland	Finnish Defence Research Agency [FDRA]	Participate
Petri Wallgren	Finland	Finnish Defence Research Agency [FDRA]	Participate
Tapio Heininen	Finland	Finnish Defence Research Agency [FDRA]	Participate
Juha Röning	Finland	University of Oulu	Participate
Marko Kauppinen	Finland	University of Oulu	Participate
Kasper Grann Andersson	Denmark	DTU	Observer
Marie Solberg	Norway	Norwegian Radiation Protection Authority	Observer
Justin Gwynn	Norway	Norwegian Radiation Protection Authority	Observer
Terje Kristensen	Norway	Norwegian Radiation Protection Authority	Observer
Thor Engøy	Norway	FFI	Observer
Christian Lexow Andersson	Norway		Observer
Guy Robert Finnbråten	Norway	FABCS	Exercise staff
Øyvind Gjølme Selnæs	Norway	Norwegian Radiation Protection Authority	Exercise staff
Tore Ramsøy	Norway	IFE	Exercise staff
Krasigora Mechkarska	Norway	IFE	Exercise staff
Cato Wendel	Norway	IFE	Exercise staff
Mats Mikalsen Kristensen	Norway	Andøya Space Center [ASC]	Exercise staff
Jostein Sveen	Norway	Andøya Space Center [ASC]	Exercise staff
Ole Morten Roa	Norway	Andøya Space Center [ASC]	Exercise staff

Table F-1: List of all participants, observer, and exercise staff.

Appendix G. Abbreviations & Terms & Definitions

Ref. http://luftfartstilsynet.no/ and https://andoyaspace.no/:

ASC: Andøya Space Center

EVLOS/E-VLOS: Extended Visual Line of Sight

VLOS operations above 400 ft. AGL and/or where an agreement for maintaining visual control with the aircraft beyond the pilots line of sight has been acquired from Civil Aviation Authority.

BLOS: Beyond Line Of Sight

Flying unmanned aircrafts beyond line of sight for pilot and/or observer. BVLOS/B-VLOS Beyond Visual Line of Sight. Subgroup/specification of BLOS, same criteria as BLOS.

BRLOS/B-RLOS: Beyond Radio Line Of Sight

Subgroup/specification of BLOS where there is no direct link between ground station and the aircraft, and another form of relay is used (for example, Satcom, Mobile technology, etc.). The aircraft can physically be VLOS/EVLOS, but is not considered an VLOS/EVLOS operation without specific approval.

DEMA: Danish Emergency Management Agency

IFE: Institute for Energy Technology

N-CAA : Norwegian Civil Aviation Authority

NRPA: Norwegian Radiation Protection Authority

Operator: A person, organization or enterprise engaged in or offering to engage in an aircraft operation.

RPAS - Remotely Piloted Aircraft System

Just like UAS, but is used as a subgroup of UAS, to describe that there is at all times a person in control of the remotely piloted aircraft.

RPA - Remotely Piloted Aircraft

The flying part of a RPAS. Also corresponds to the Norwegian term “unmanned aircraft.”

RPS - Remote Pilot Station

The ground station where the pilot is steering one or more RPAs. Can be compared to a cockpit, only on the ground.

UAS - Unmanned Aircraft System

Formally we use the term unmanned aircraft, but the normal term is drone.
Describes the entire system, consisting of a ground station and the aircraft that is operated from there, in addition to all the other components that is needed for operating the system, such as equipment for launch, communication, and automatic landings etc.

UAV - Unmanned Aerial Vehicle
Only describes the flying part of the UAS. This definition is on its way out in civilian application, but is still used by the military. Corresponds to the Norwegian term "unmanned aircraft."

VLOS: Visual Line Of Sight
Flying an unmanned aircraft must be carried out so that the aircraft can at all times be seen without visual aids such as binoculars, camera or other tools, except glasses. The aircraft must also be operated in such a manner so that collisions with other aircraft, people, vehicles, vessels, and ground construction can be avoided. Maximum height of operation in Norway is 400 ft. AGL.

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Abstract max. 2000 characters	With the forthcoming of UAVs, new possibilities for radiological surveys have arisen. UAVs can be used as a supplement to existing measurement capabilities. UAVs makes it possible to make fast measurements in potential hazardous areas without danger to humans. The NORDUM project makes a first approach to cover and compare different systems and approaches for use of UAVs in the Nordic countries. The project shows that all Nordic countries have UAVs projects but different approaches with each different benefits. Further comparison and discussion of best practice is beyond the scope of the NORDUM project.
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