Environmental monitoring and the use of unmanned aerial systems for radiological surveillance

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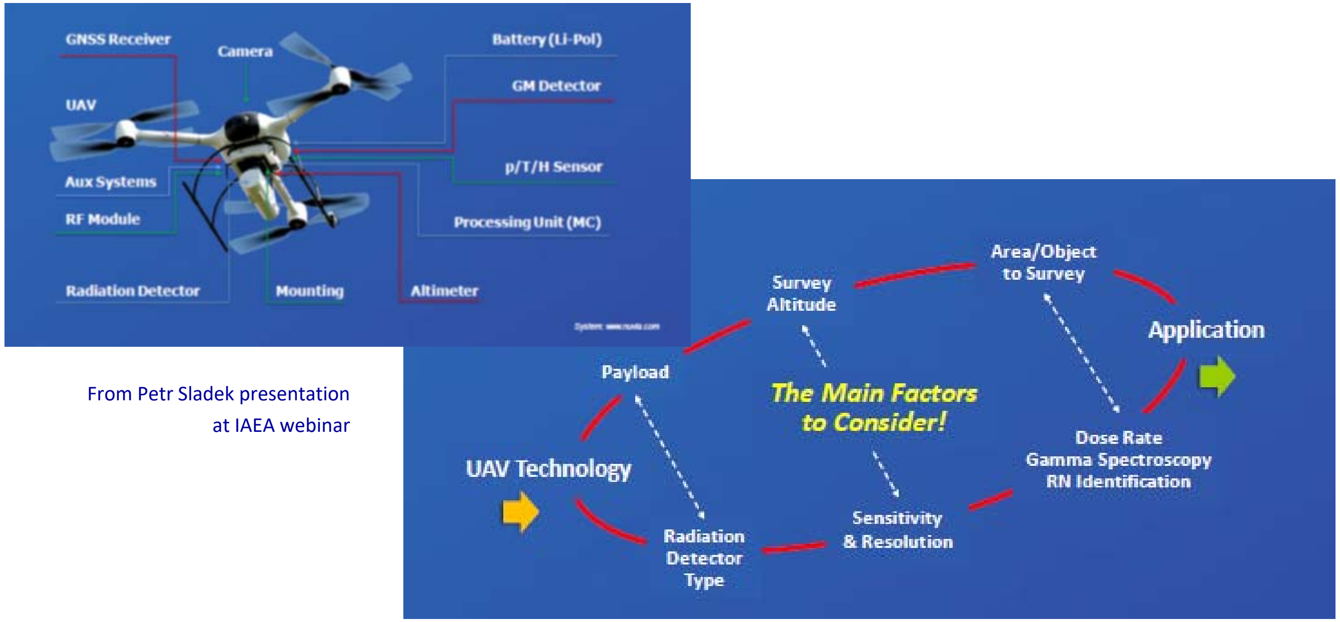
June 15th, 2023
EURADOS Annual Meeting
Porto, Portugal

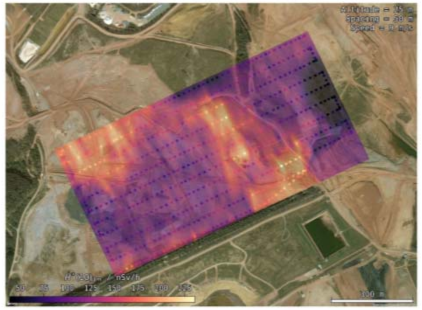
Content

Overview unmanned aerial systems for radiological surveillance

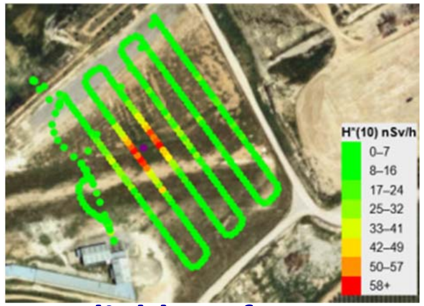


From Petr Sladek presentation at IAEA webinar

mapping



Source location



An airborne unmanned radiological system requires **careful hardware design**, **reliable software implementation** and the **traceable calibration of the detector**.

Rotary Wing Unmanned Aerial system (RWUAS)

The booming drone industry which **brings regular advances in UAV technology** led to recommend **fully decouple** the data acquisition system from the aerial platform. On the other side, **the use of the position and tilt from the UAV could be also a benefit**.

Calssification of RWUAS

It is common to classify RWUAS into three categories:

	Small	Medium	Big
Payload	< 1 kg	< 6 kg	< 50 kg
Detector	CZT, CsI	NaI, $LaBr_3$, $CeBr_3$	HPGe, NaI of high volume
Range	< 2 km	< 5 km	< 20 km
Flight time	< 15 min	< 30 min	< 90 min
Price	≈ 1 k€	≈ 10 k€	≈ 250 k€
Licensing	Easy*	Normal**	Complicated***

* UAVs below 2 kg TOW do not require any licensing

** Under 25 kg TOW, a drone pilot license is required

*** For aircrafts with TOW > 25 kg the full pilot license is required

HPGe ~ 21 kg

NaI, $CeBr_3$, $LaBr_3$
2”, 3” ~ 2 kg

CZT (1cm3)
~ few grams

Localizator ~ 2 kg

Proposed RWUAS category choice for a given radiological emergency scenario

Scenario	Scale	Area	Requirements	UAMS category
Terrorism (dirty bomb)	Small	Populated (stadium, market, festival, etc.)	Quiet and small system to prevent panic, hot spot detection	Small
Illicit trafficking	Small	Not populated (harbour, customs, railway, etc.)	Fast and efficient source localization	Small or medium
Radiation source transportation accident	Small	Localized (city, road, etc.)	Radioactive spill boundary detection; panic prevention if public involved	Small
	Medium	Dispersed (water bodies, air transfer)	Radioactive substance dispersion tracking (e.g., follow river path)	Medium or big
Nuclear accident	Small	NPP territory	Fast assessment, localization and decontamination	Small or medium
	Medium	NPP vicinity (closest town, countryside)	Fast assessment, possible temporary evacuation zones detection	Medium or big
	Big	NPP exclusion zone (30 km radius)	Evacuation stage: Cover tens of km^2 as fast as possible Assessment stage: Detailed mapping of exclusion zone	Big, then medium

There is no optimal drone-detector configuration. The choice of a specific configuration depends on the radiological situation and the assessment of the overall scenario. Therefore, the selection of **the configuration should fit the most common scenarios** that are previously forecasted by the end-user.

Position and altitude

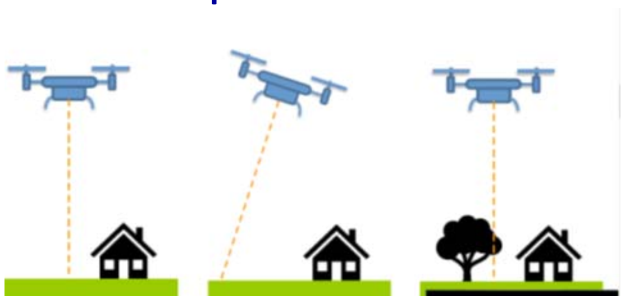
GNSS: Global Navigation Satellite Systems

- Position with precision of a couple of meters that can be extended to a few cm by using RTK (real-time kinematics) which is very expensive
- Precise time stamp for synchronization

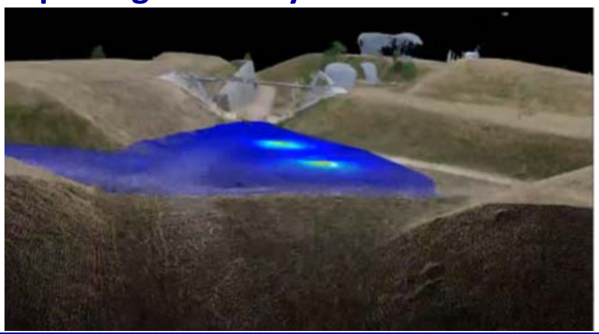
Distance measurement

- The most common are the 1D-Lidar. The 2D –Lidar area also used for Digital Elevation Map
- The use of cameras for photogrammetry (3D maps) could be also an important information for where the scenario has changed due to an explosion, fire,….

Lidar -1D- point measurement

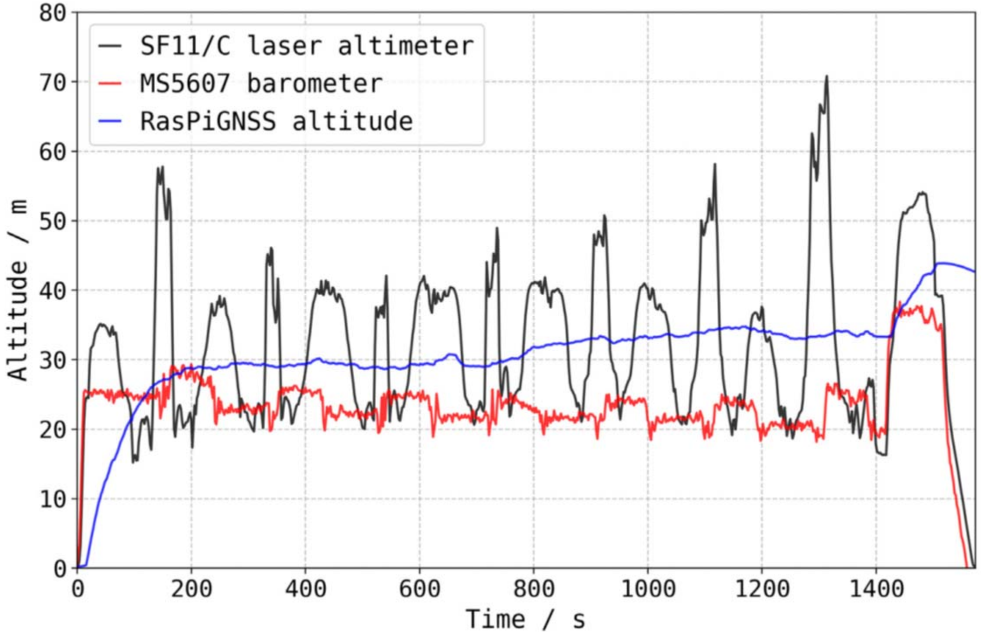


photogrammetry



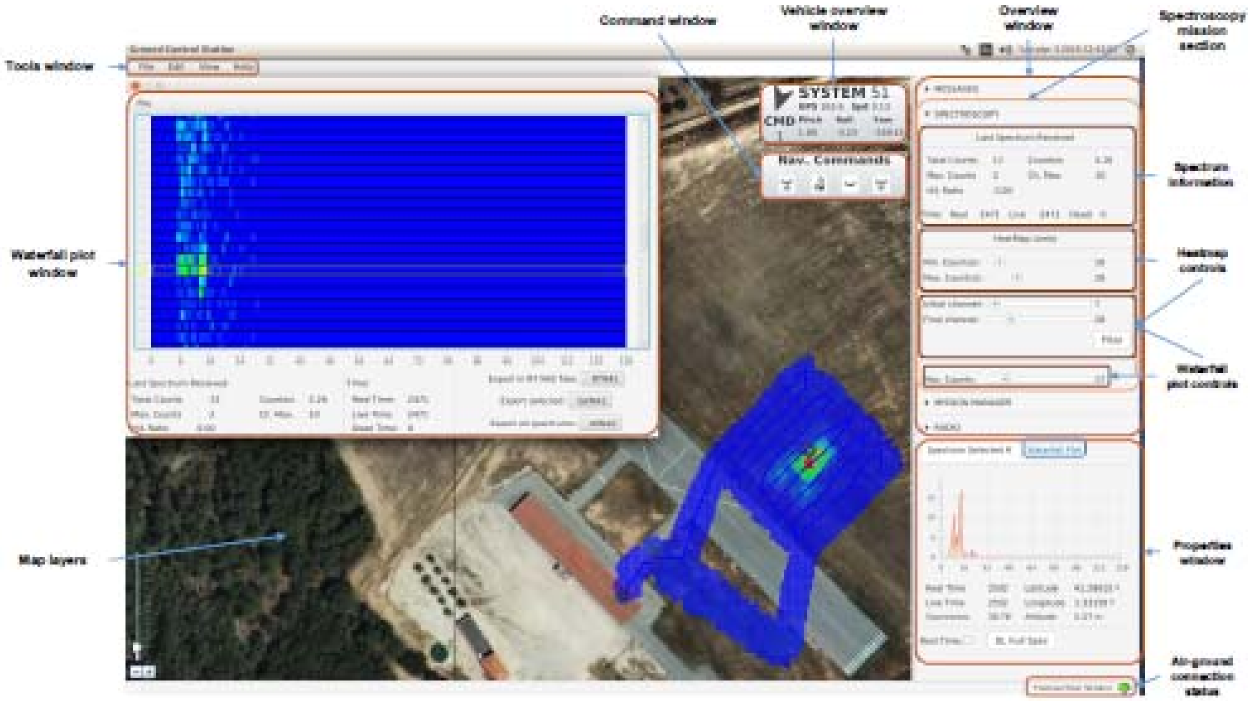
Altitude

Comparison of a laser, barometric and GNSS systems to measure the height AGL in a former Uranium mine



Ground Control Station. On-line visulaization

Definition of the plan Flight



Detector Calibration

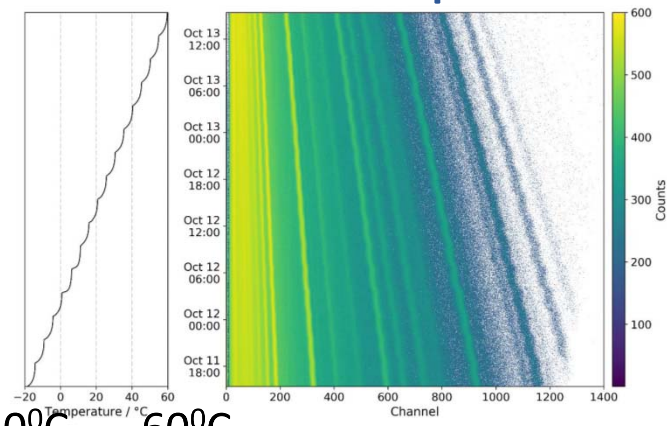



- Linearity
- Energy resolution
- Inherent contamination
- Cosmic response
- Drone effect
- **Stability**
- **Angular response**

Temperature stability

Temperature stabilization (climate chamber with Ra-226 source)

Raw Sepctra

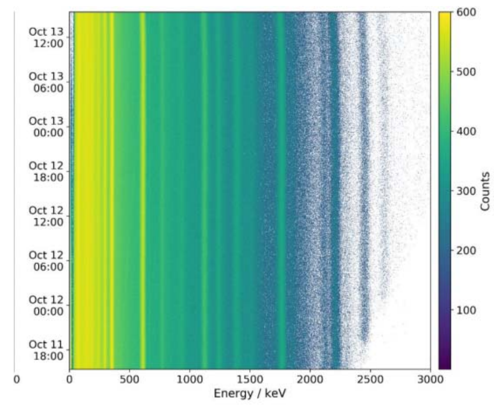


-20⁰C 60⁰C

Different method:

- Temperature correction by formula
- Natural peaks
- Inherent background
- LED peak
- Machine learning

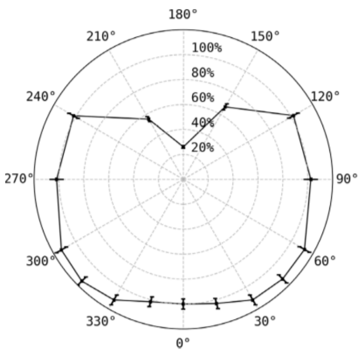
Calibrated Sepctra

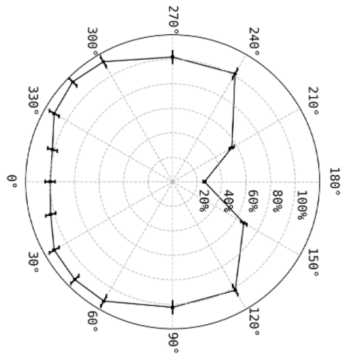


This issue is especially prominent for **scintillation detectors with photomultiplier tubes**, since the scintillating crystal and the PMT have temperature sensitivities. This makes the correction of the temperature drift quite a difficult task.

Angular response

Vertical position



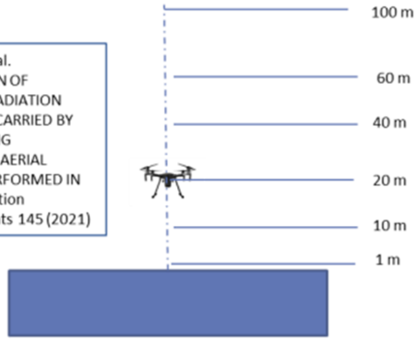


Horizontal position

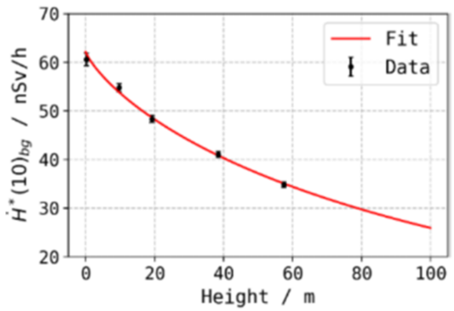
Calibration

1. Background characterization

A. Vargas et al. COMPARISON OF AIRBORNE RADIATION DETECTORS CARRIED BY ROTARY-WING UNMANNED AERIAL SYSTEMS PERFORMED IN SPAIN. Radiation Measurements 145 (2021)



Exponencial integral profile



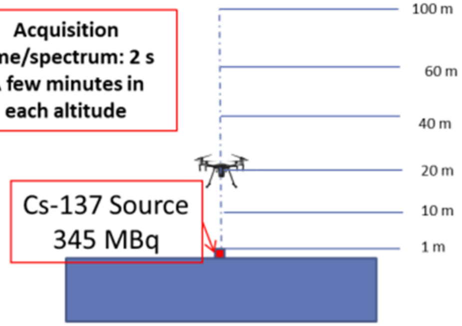
$$E_2(x) = x \int_x^{\infty} \frac{e^{-t}}{t^2}\, dt$$

$$x = \mu z$$

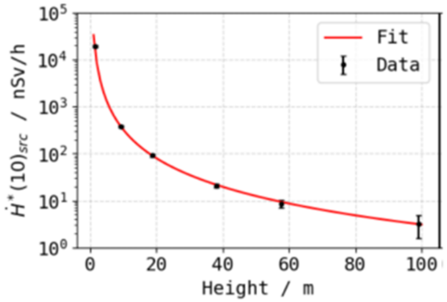
$$H^*(10) = C\ E_2(x)$$

2. Vertical flights over point source

Acquisition time/spectrum: 2 s
A few minutes in each altitude



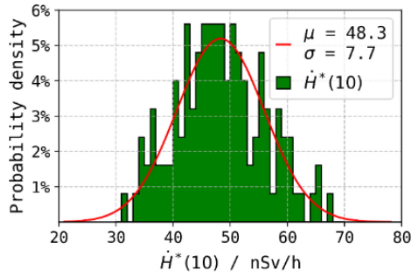
Inverse of the square distance profile



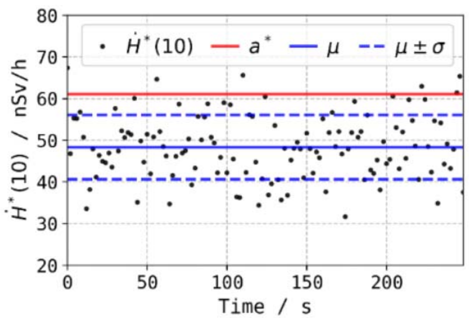
$$H^*(10) = C\ / z^2$$

Calibration

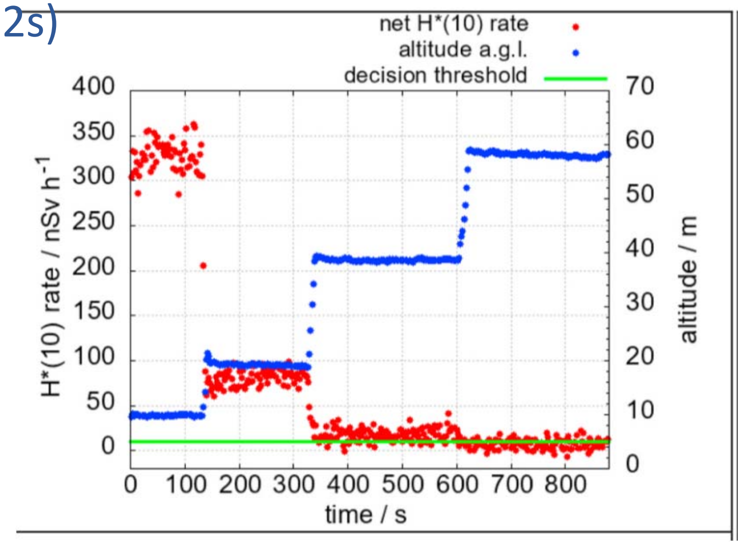
Background $CeBr_3$ *H*(10) rate* at 20 m height
(Δt= 2s)



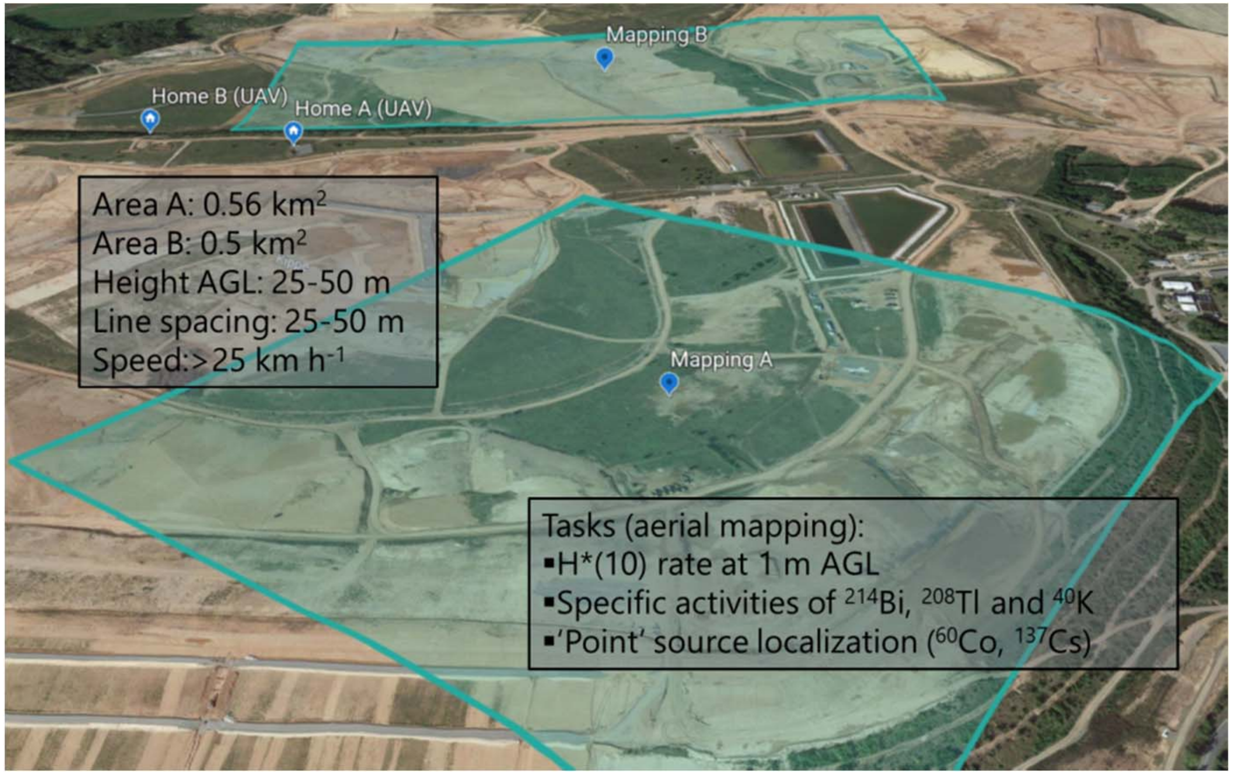
Decision threshold (ISO11929-4) a^*=1.645 σ



Response **$CeBr_3$ net *H*(10) rate*** to a Cs-137 point source of 345 MBq at different heights
(Δt= 2s)



Example: former uranium mine

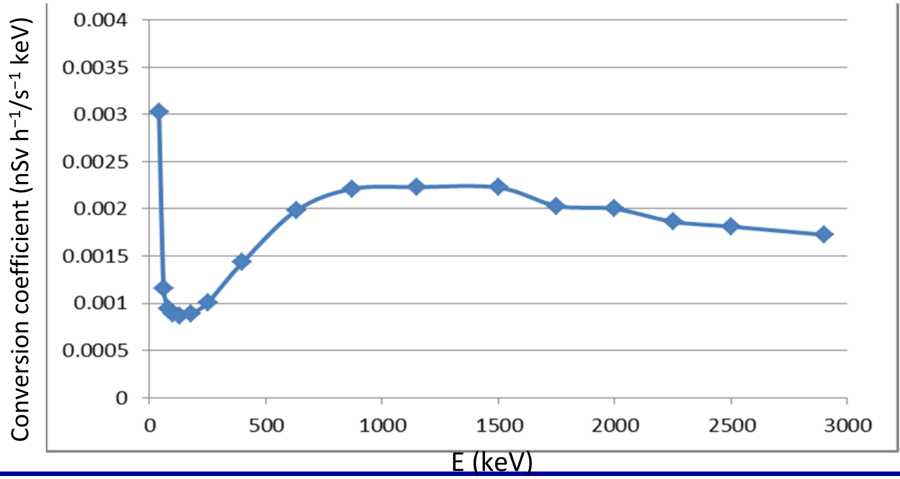


Ambient dose equivalent rate, *H*(10)* rate

- **For *H*(10) rate* calculation, conversion coefficient method** is recommended because is accurate, precise and robust.

$$\dot{H}^*(10) = \sum_{i=1}^{j} w_i \, n_i \, E_i$$

$\boldsymbol{n_i}$ count rate in the the energy bin $\boldsymbol{i}$ (s^{-1})
$\boldsymbol{E_i}$ is the mid energy of bin $\boldsymbol{i}$
$\boldsymbol{w_i}$ is the conversion coefficient for bin $\boldsymbol{i}$ (usually MC simus) ($nSv\ h^{-1}/s^{-1}\ keV$)



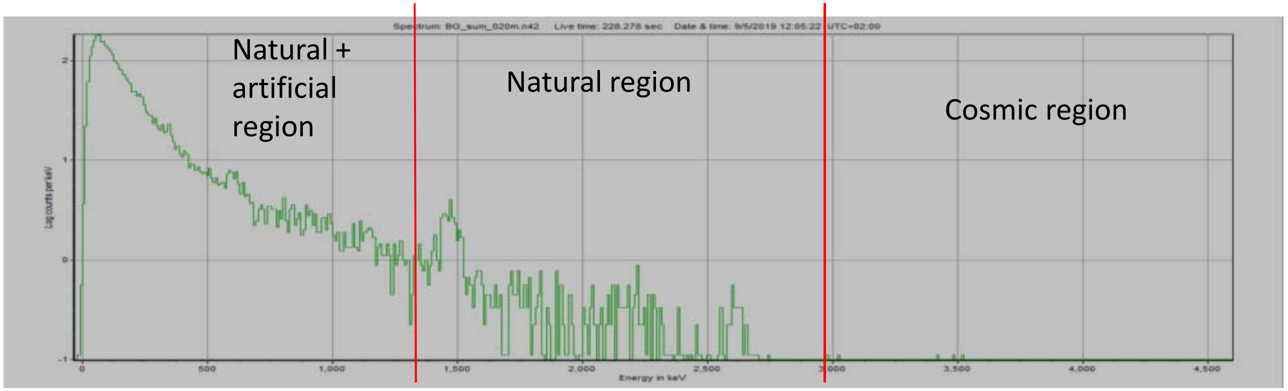
Robust and fast calculations

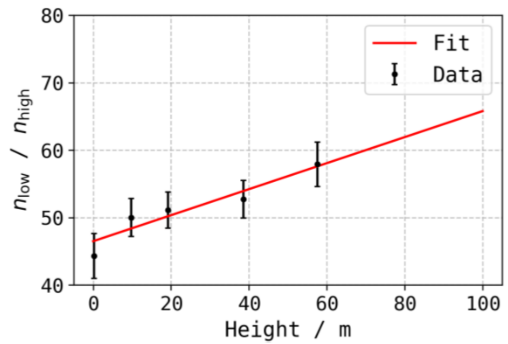
- **Man Made Count Rate (MMCR)** is a robust and fast method to detect artificial radioactivity.

MMCR= $\sum_{320}^{1360} n(E) - ratio \sum_{1360}^{3000} n(E)$

When no artificial radionuclides, then:

$$ratio = \frac{\sum_{320}^{1360} n\,(E)}{\sum_{1360}^{3000} n\,(E)}$$

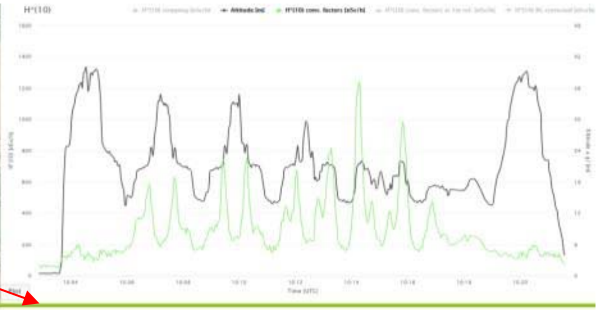




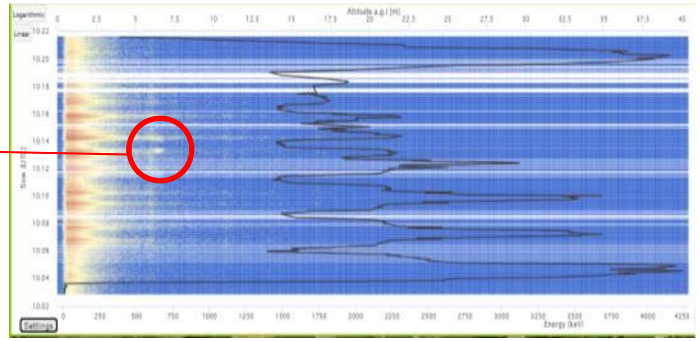
H(10)* and MMCR results

H*(10) rate in the area to find radioactive sources

H(10)* rate and height AGL.

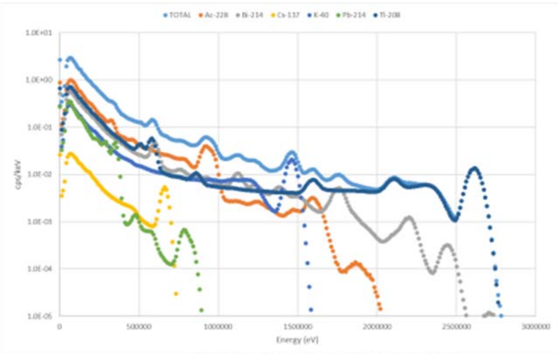


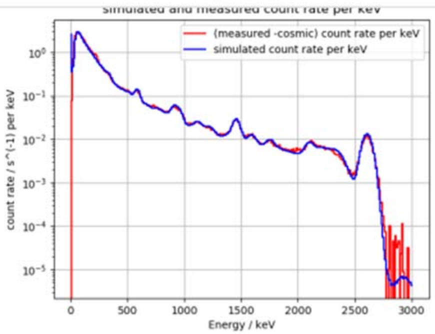
The **MMCR method detects the artificial sources** in a simple way while with the *H*(10)* analysis its detection is not possible. **Spectra analysis by waterfall plot** is also useful



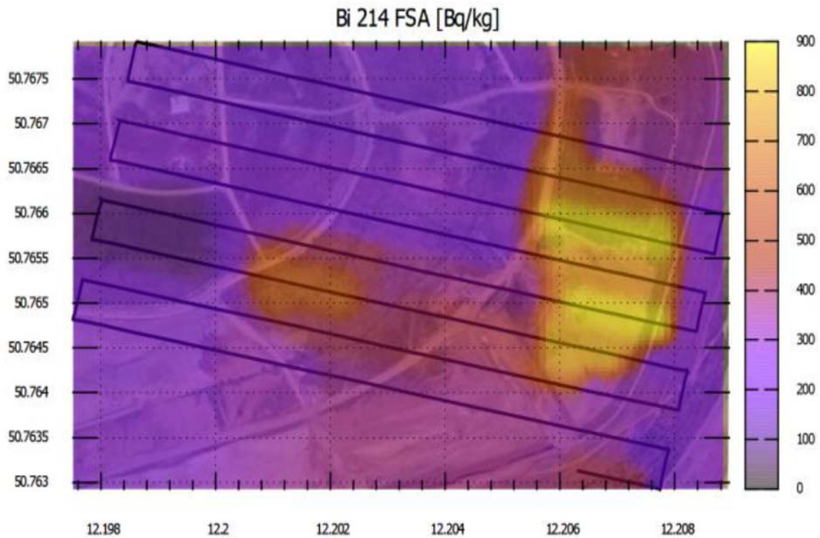
Activity concentrations

Full spectra Analysis is used for activity calculation. Monte Carlo simulations to obtain cps per Bq/kg or Bq or Bq/m^2 for each radionuclide Minimize the measured and simulated spectra.



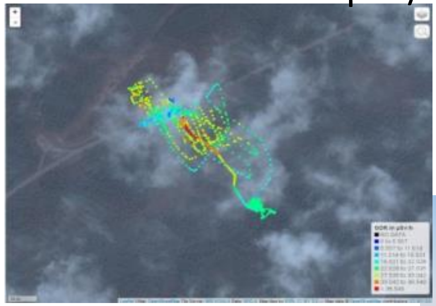


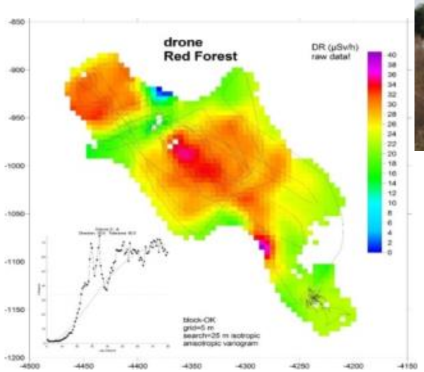
A (Bq/kg))
Ac-228: 165
Ra-226: 90
K-40: 600
Tl-208: 65
Cs-137: 7



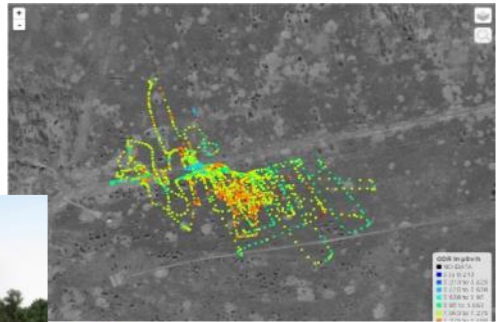
Chernobyl campaign

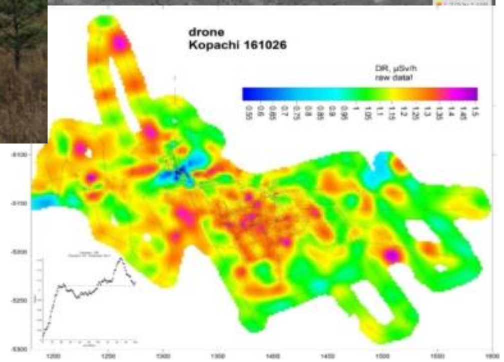
Red Forest:
- Max GDR: ~44 µSv/h





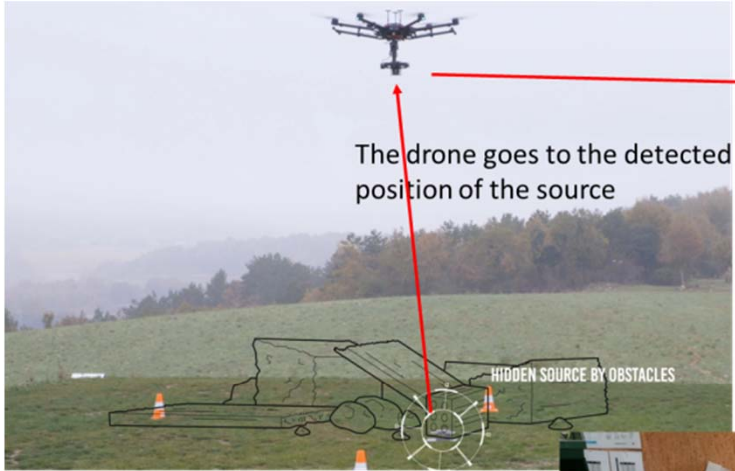
Kopachi:
- Max GDR: ~1.7 µSv/h





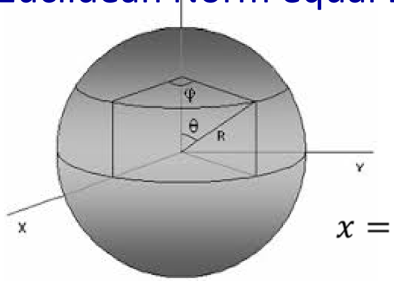
BfS campaign. Pictures from presentation in EURADOS meeting Helsinki 2018 (Ulrich Stöhlker)

Localizer - detector

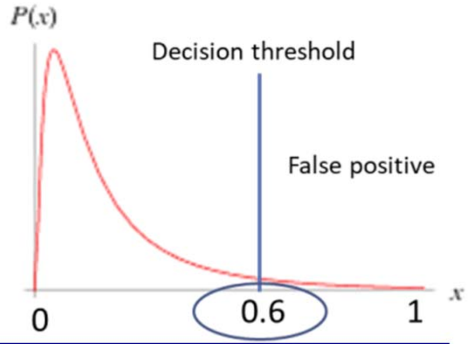


8 x CsI detectors separated by shielding material to calculate the source position

$\vec{R}$ is the vector that indicates the source direction and has and Euclidean Norm equal 1



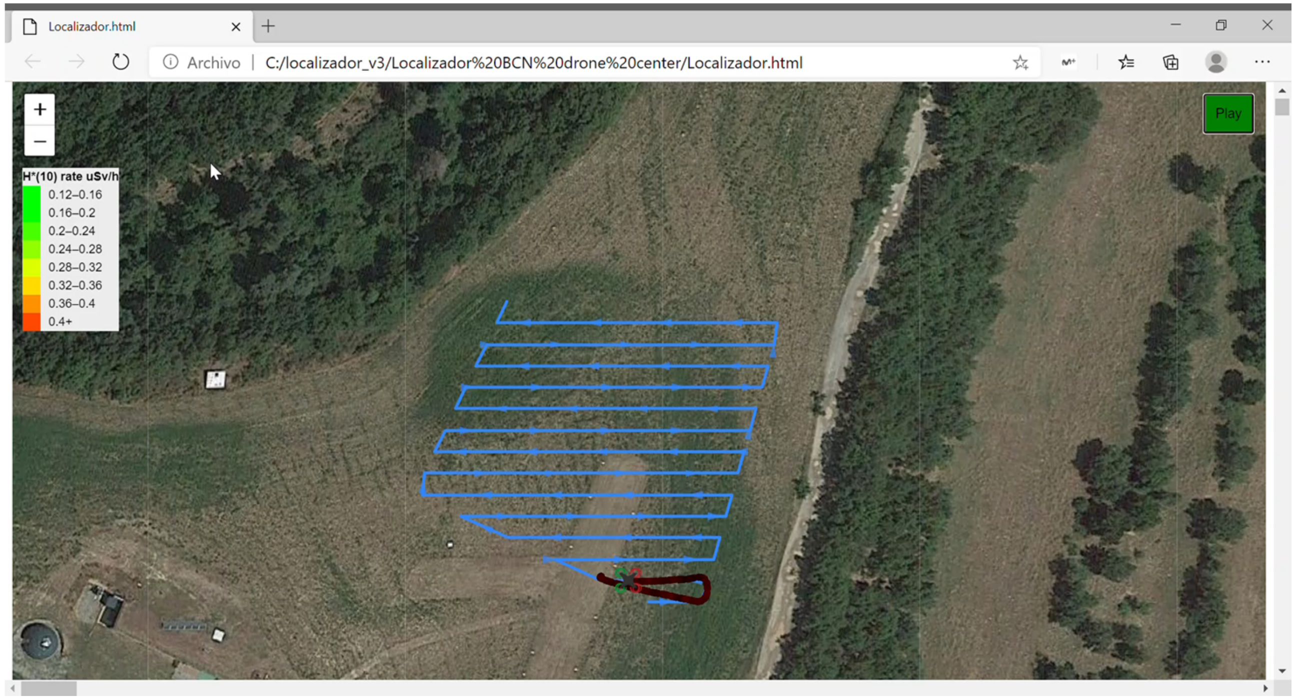
$$x = \frac{1}{n}\left\|\sum_{1}^{n} \vec{R}\right\|$$



Localizer mounted onto gimbal and installed on the DJI Matrice 600 Pro

Localizer - detector

Video preparedness: https://www.youtube.com/watch?v=IV45uvionKI&t=46s.



Localizer - detector

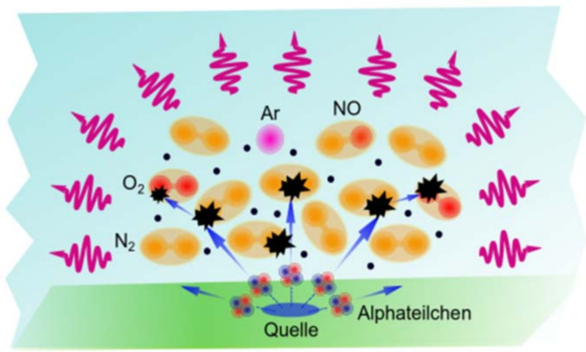
Video preparedness: https://www.youtube.com/watch?v=IV45uvionKI&t=46s.

2) Source: estimated position (black stars)

1) Drone stops when source is detected

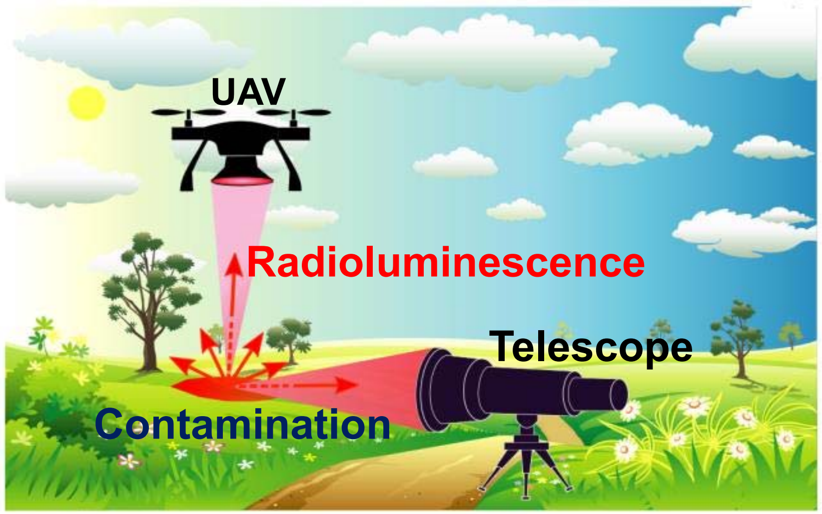
Remote Alpha detection by UAV (remoteAlpha project)

Radioluminescence at a glance



Schematic representation of **air ionization by α-particles.**

Air molecules emit fluorescent light (radioluminescence) in **the UV range** between 200 nm and 400 nm.



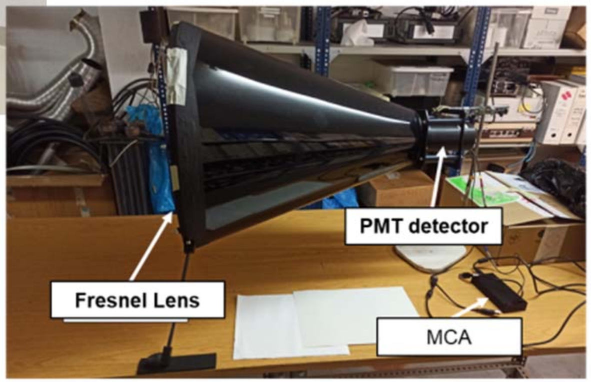
<u>Range in air:</u>

α-particles → 0,04 m

UV light → 500 m

RemoteAlpha

Telescope

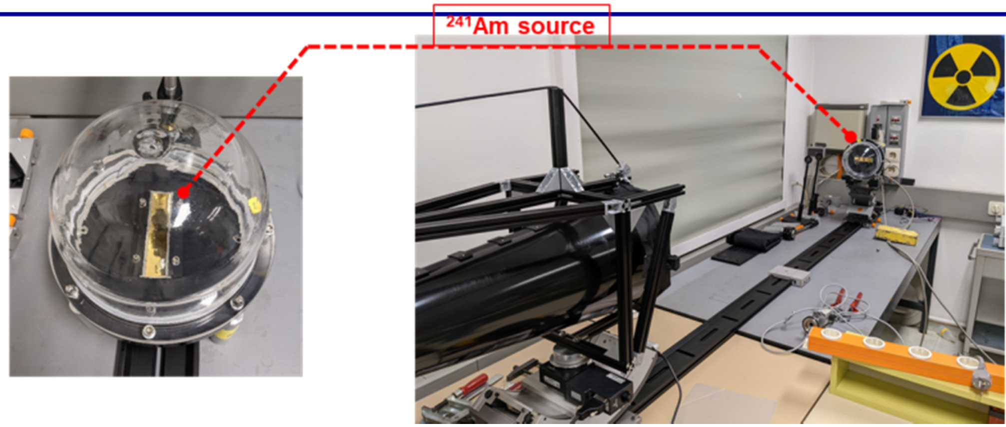


Scaled system for the drone

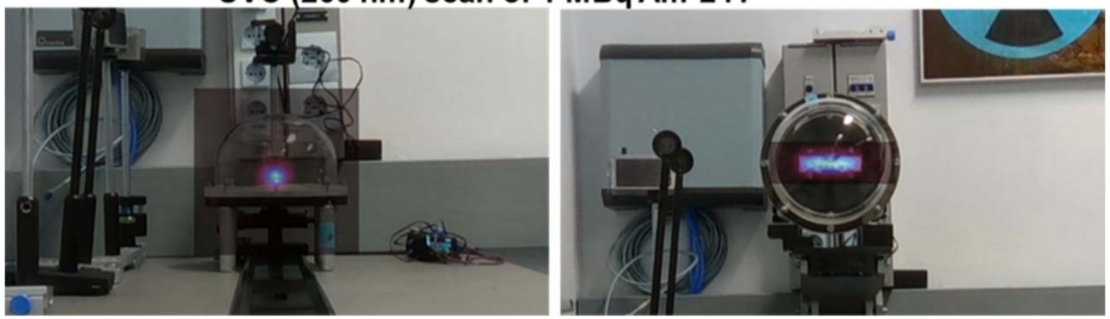
Mounted on the drone and tested in the DroneLab (UPC – Barcelona Tech)

RemoteAlpha

Testing of optical detection systems with Am-241 sources (1 MBq, 10 MBq and 100 MBq)

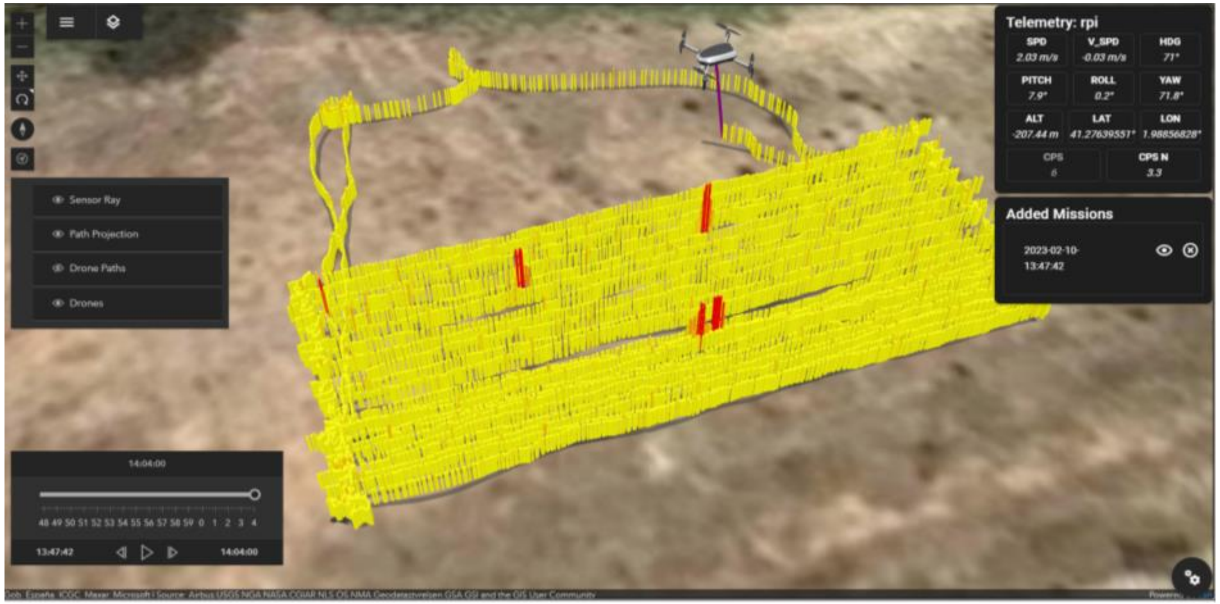


UVC (260 nm) scan of 1 MBq Am-241



Mapping real time

Visualization of the detected count rate in real time
during the flight with 5 UVC source emitters



Area: 15 m x 30 m
Separation between lines:
70 cm
Height: 5 m AGL
Speed: 1 m/s
Measured of count rate:
registered every 100 ms

Mapping real time