U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Potential Use of Drones and Robotics for Radiological Characterization, Survey, and Emergency Response

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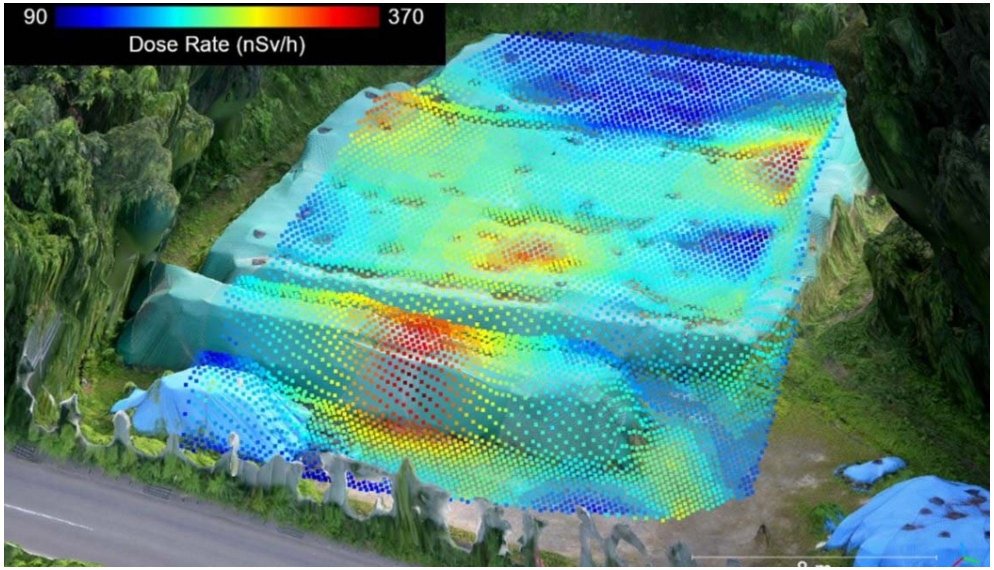
Use of Drones in Radiological Monitoring, Survey, and Emergency

- **Drones (Unmanned Aerial Vehicles, UAVs) could be used for radiation monitoring and surveys, including the application of environmental mapping technology and use of radiation data to develop radiological surveillance maps;**
- **Could be used for onsite/off-site characterization and support for remediation/decontamination focusing on hot spots and elevated areas;**
- **Could be used to support the development of exposure pathways to reduce, or avoid, exposures and to support risk assessment to workers and the public in support of cleanup and remediation;**
- **Drones could be used in hard-to-reach areas and to monitor erosion and potential spread of contamination during incidents/accidents focusing on risk mitigation.**
- **Could be used for managing radioactive waste including monitoring of LLW, UR and tailings, or RCRA waste facilities performance.**

Examples of Potential Drones Applications

- IAEA-developed instrumentation and methodology for Unmanned Aerial Vehicles (UAVs) equipped with radiation detectors, cameras and GPS devices has been tested and validated under real conditions in the Fukushima Prefecture in Japan and is now available for practical use in routine or emergency situations;
- UAVs are being deployed to monitor radiation at uranium legacy sites in Central Asia, including former uranium mining and processing areas in Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan.

Full 3D aerial photogrammetry superimposed with a radiological map was obtained using a single UAV in two consecutive flights. (Image: IAEA and Fukushima Prefecture)

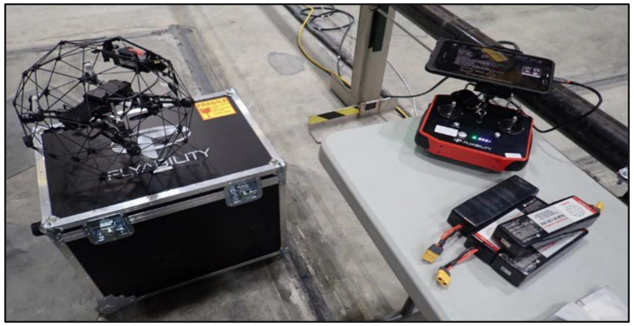


Drones & Indoor Nuclear Facilities Inspections

- Swiss drone developer Flyability has launched an indoor drone equipped with a radiation sensor specifically for conducting inspections at nuclear facilities. The Elios 2 RAD is designed to help maintain low radiation exposure levels for nuclear facility workers. It does this both by taking the place of personnel where possible for visual and radiation data collection, and by providing high-quality data for planning interventions that do require exposure, so that it can be kept to a minimum.

- **A modified inspection drone was used to Create a 3D-Map of obstructions within a high-radiation confined space (INL) using:**

- 4K resolution photogrammetry; Infrared camera; protective cage15.75" diameter sphere; ~10-minute flight time; remote antenna option; and US Government approved radio.
- Oblique lighting



Potential Use of Ground Robotics in Radiological Characterization, Survey, and Emergency

- **Ground robots come in a range of form factors – usually with legs, wheels, or tracks – all capable of navigating different kinds of environments. Many ground robots are strong enough to carry multiple sensors or cameras, making them suitable for a range of data capture purposes.**
- **Ground robots are valuable tools for automating data capture in a wide range of business environments especially in radiological monitoring, characterization and surveys.**
- **Ground robots differ from drones in important ways. They capture data from new perspectives – for example, they can enter buildings or confined spaces in pipes and capture close-up images or videos at ground level.**
- **Robots can be sent on autonomous inspection missions and emergency situations to capture and analyze critical data, integrate data with existing systems, reduce labor costs, and keep workers safe.**

AI Software Needs for Effective Use of Robotics

There is a need for effective software to coordinate and assign work to robots and integrate them seamlessly into the intended business purpose of operations and usage. Such software is typically outside the level of robotic control and isn't provided with the system [e.g.; out of the box].
There is a need for AI software and detection system to serve the intended purpose of usage.

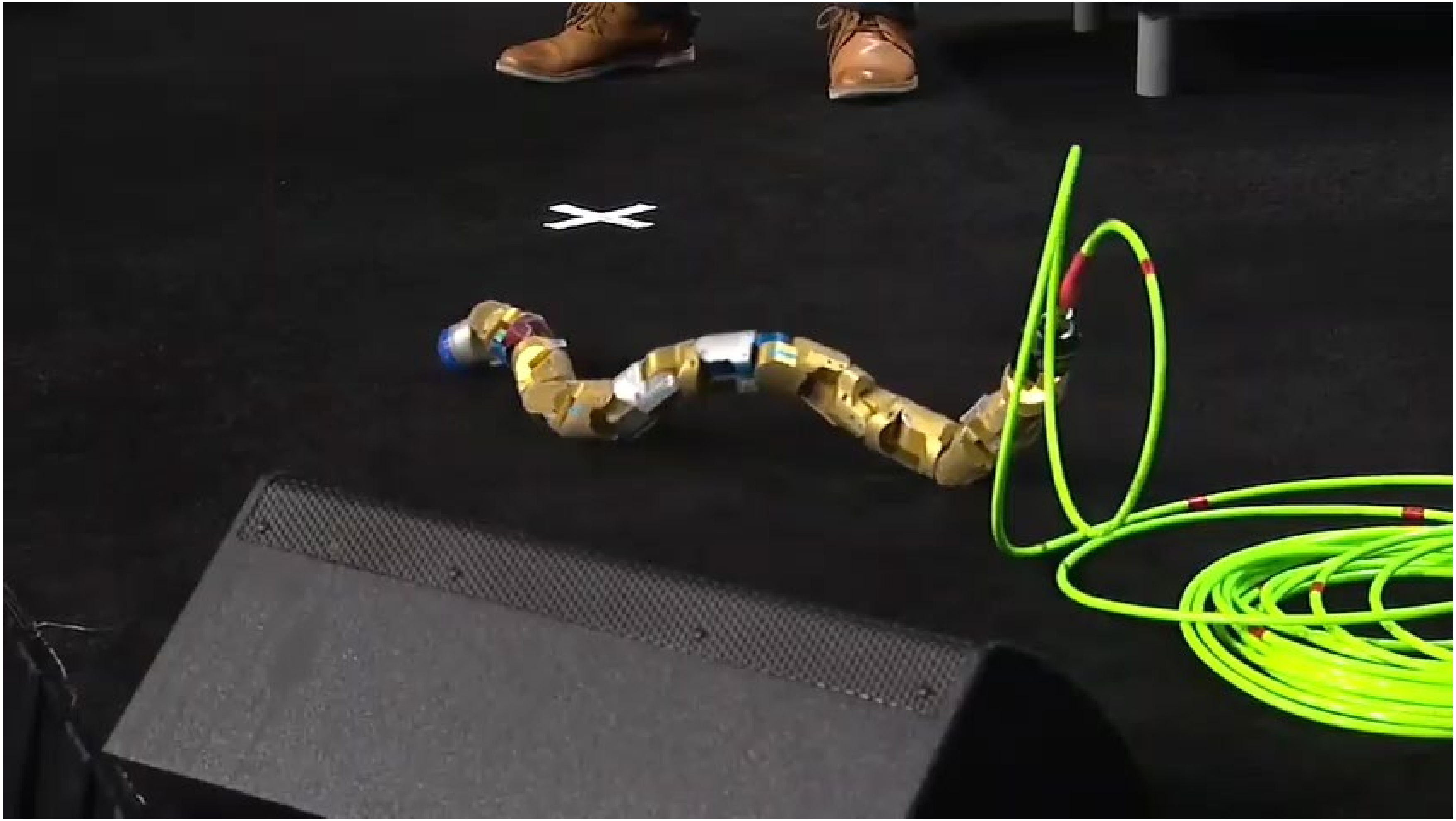
- *Ground robots gather accurate data through cameras or sensors, reducing labor costs and keeping workers out of harm's way.*

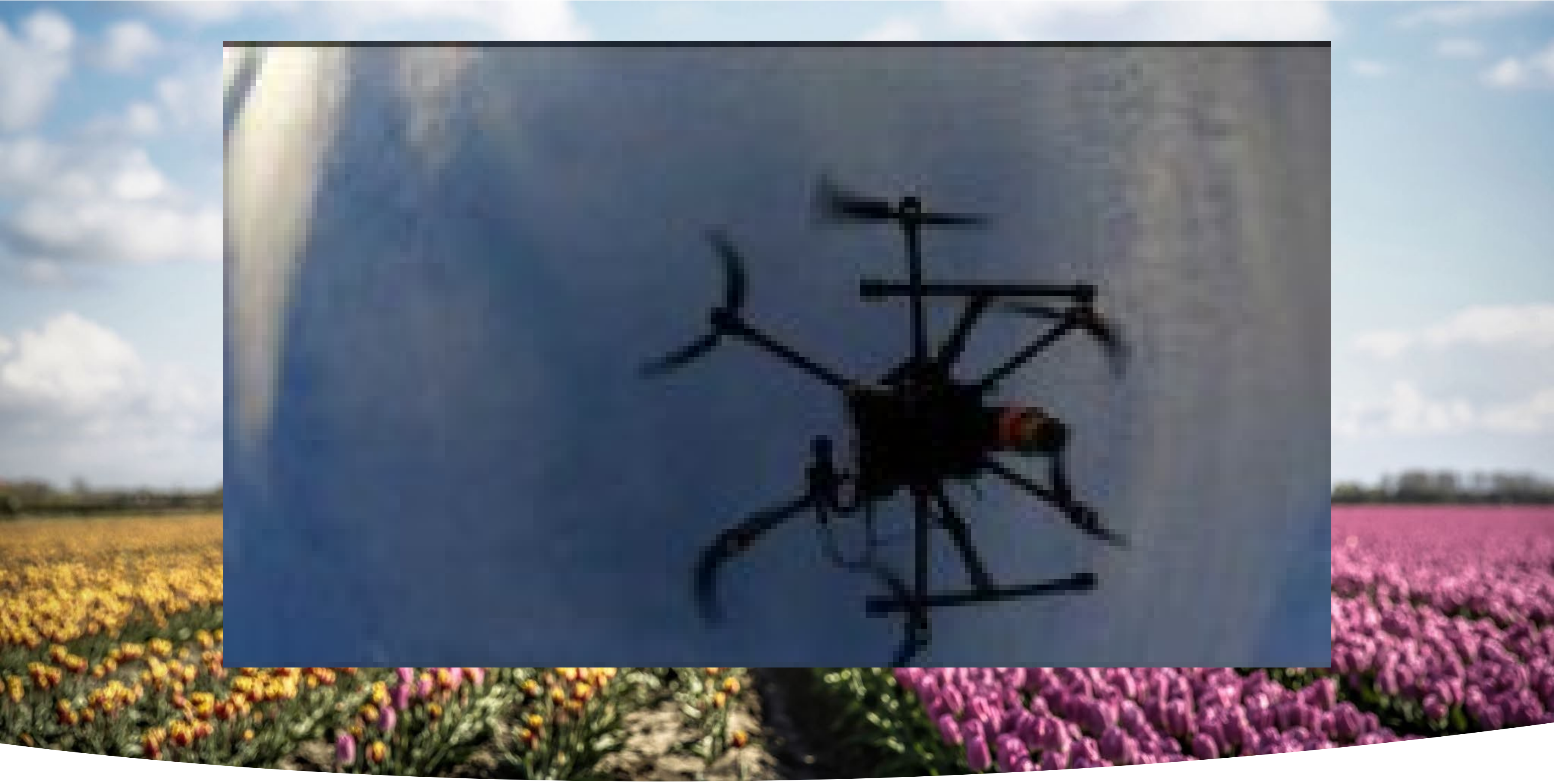
Example of Robotic System for Survey Radioactivity on Surfaces

Parameter	CARMA
Base platform	Clearpath Jackal
Dimensioning including sensor tail (l × w × h)	830 mm × 440 mm × 1,030 mm
Ground clearance	65 mm
Maximum speed	2 ms^{-1}
α/β sensors	Two Thermo DP6
γ	Three Thermo RadEyes
Navigational sensors	Two 20-m lidars, two 3D cameras, one webcam
Battery life	3-4 h
Total cost	US $35,000

Example of Snake Robotic System for Inspection of Radiological Contamination in Pipes

https://www.youtube.com/watch?v=oat582SaTko





Can Drones Be Used For Decommissioning Surveys?

Investigation Results

U.S.NRC Regulations & Guidance

Regulatory Requirements

- 10 CFR Part 20, Subpart E
- TEDE < 25 mrem/yr and ALARA

Guidance Documents

- NUREG-1575 Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)
- NUREG-1507: Minimum Detectable Concentrations with Typical Radiation Survey for Instruments for Various Contaminants and Field Conditions
- NUREG/CR-6364: Human Performance in Radiological Survey Scanning

Future Focused Research (FFR) Driver/Goals

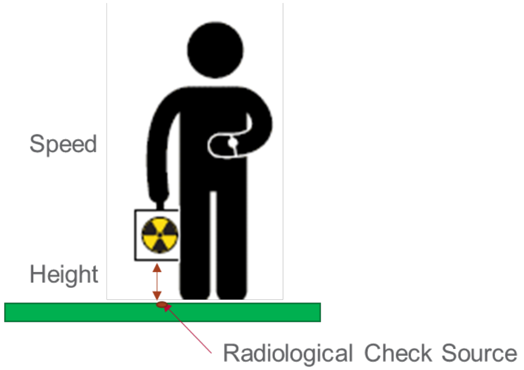
- Proof of concept
- Demonstrate the use of UAVs (drones) for decommissioning activities to:
  - Meet Regulatory Requirements
  - Include in Guidance Documents
  - Improve scanning systems

Proof of Concept and Key Questions for Analysis

Question 1:
Did observed UAV paths differ from human planned paths?

Question 2:
Did survey deviation impact survey results?

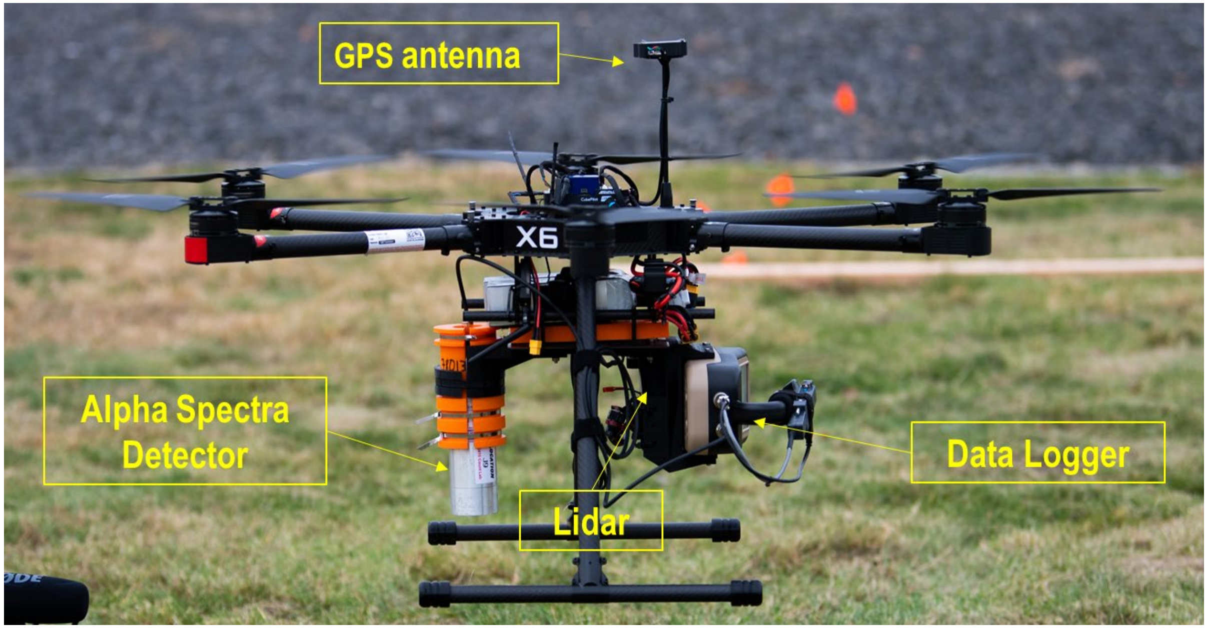
Question 3:
Were radiological measurements from human and UAV surveys significantly different?



Technical Approach:
Small Unmanned Aircraft Systems (sUAS) Selection and Payload

UAV – Aurelia X6

- Includes GPS with navigation system



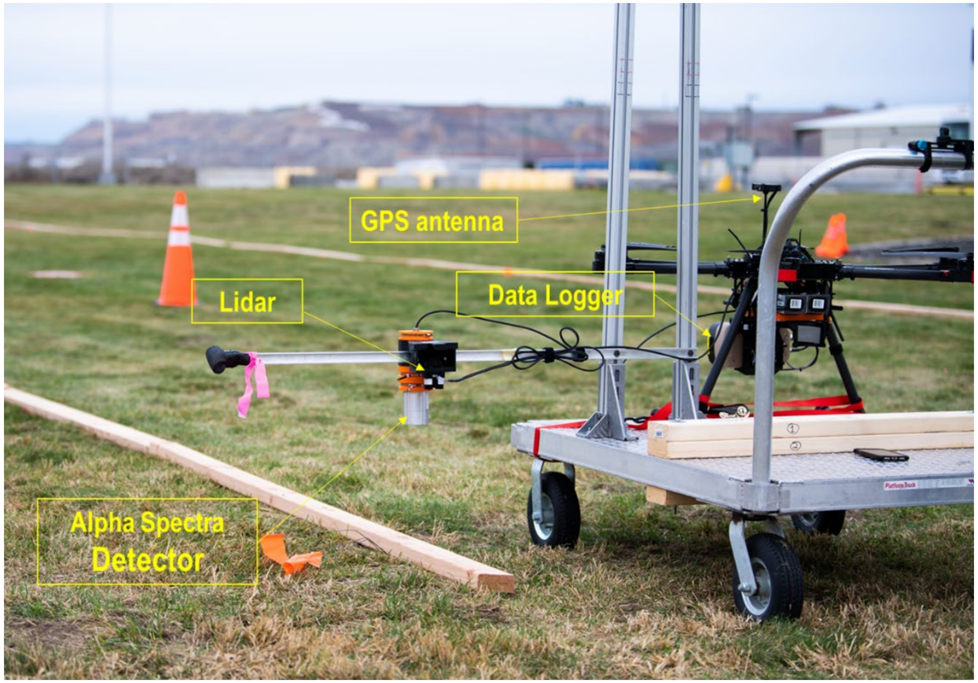
Payload

- Instrumentation for data collection
  - Radiation detector(s)
  - Lidar
  - Data Logger

Technical Approach: Human Surveys - Control

Used cart to provide consistent data collection to the sUAS surveys

- "Control" to sUAS
- Holds radiation detector at position above ground
- Carried same payload (sUAS):
    - GPS (part of navigation system)
    - Lidar
    - Data Logger



Technical Approach: Selection of Radiation Detector

For Proof-of-Concept and to meet NRC Decommissioning criteria:

- Isotopes for evaluation: Co-60, Cs-137, Am-241
- Selected Detector: NaI(Tl) Scintillation Detectors

Isotope	Energy	NaI (0.04” thick crystal) 20 keV - 300 keV range	NaI (2” thick crystal) 250 keV - 1.5 MeV range
Co-60	1173 keV		X
Cs-137	662 keV		X
Am-241	59 keV	X	

Ludlum, Model 44-10 Gamma Detector

Alpha Spectra, Model 8TI040A1/2B (9266) Thin-Open Face Gamma Detector

- Ludlum 3000 data logger - modified
- Calibration of detectors prior to surveys

Technical Approach: Flight Path Layout

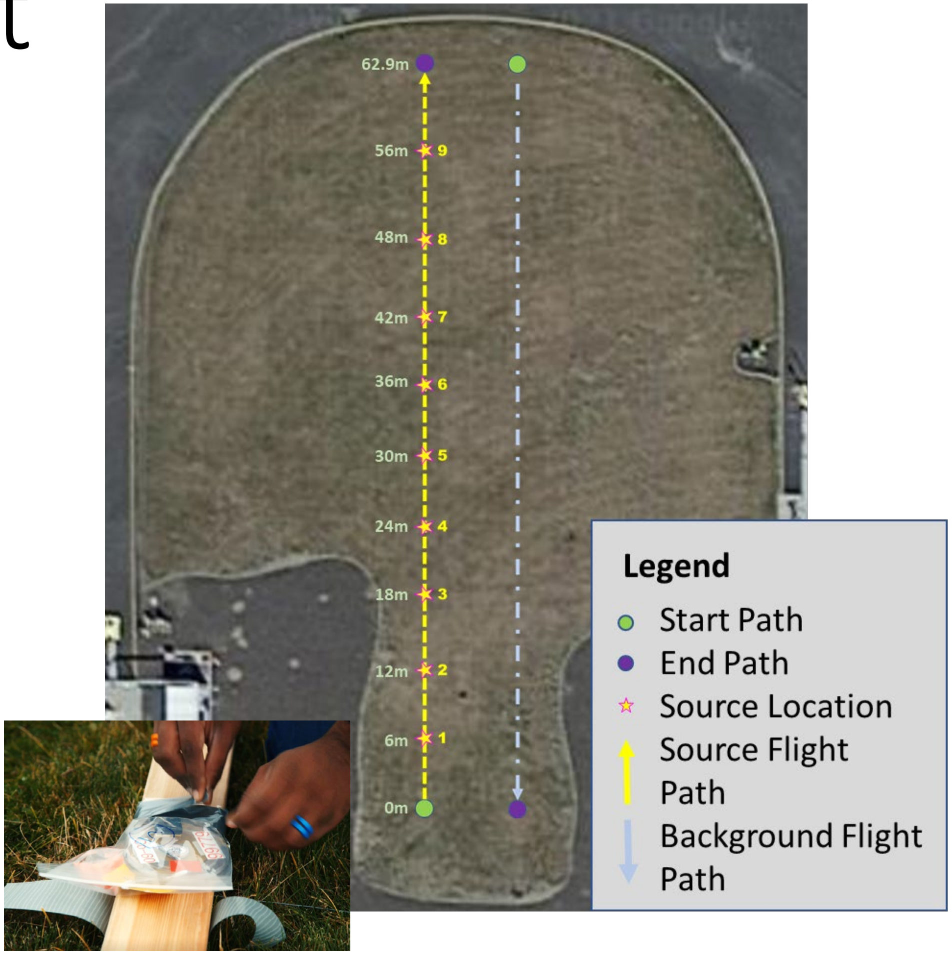
Outbound flight over sources (63 m)

Source #	Isotope	Activity (μCi)
1	Cs-137	13.24
2	Am-241	25.19
3	Cs-137	3.54
4	Cs-137	6.88
5	Co-60	5.39
6	Co-60	10.28
7	Am-241	16.97
8	Co-60	3.63
9	Am-241	39.34

Inbound flight – background (63 m)

Survey Velocity - ~0.2 m/s

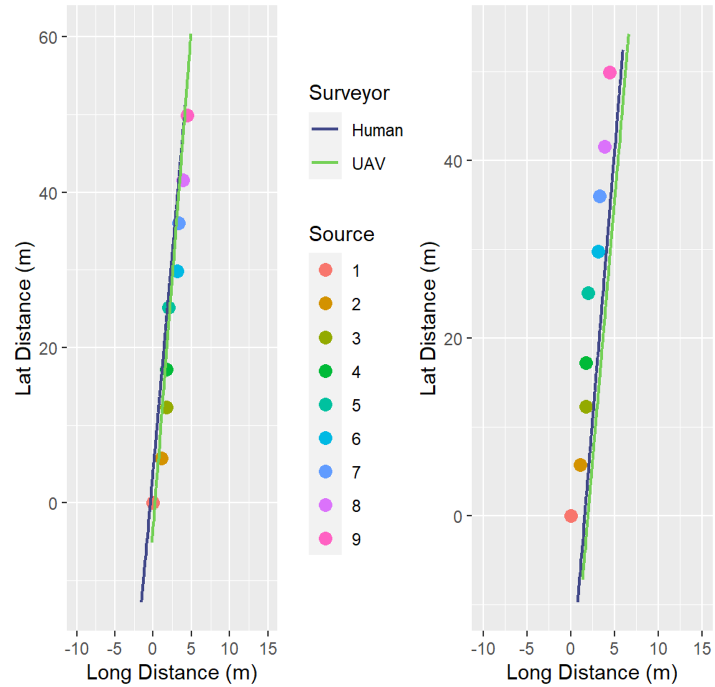
Altitude - low (15-40 cm median altitude) and high (87-105 cm median altitude)



Results, Question 1: Survey path analysis

Results

- Lateral
  - Evaluated based on slope of a regression line
  - Slope = forward movement along the survey path per m of lateral deviation
- No scenarios were statistically different
  - Slopes of source transect, UAV, and human survey paths were statistically equivalent



High Altitude, Ludlum detector (Scenario 3)

Low Altitude, Ludlum detector (Scenario 1)

Results, Question 2: Impacts on survey

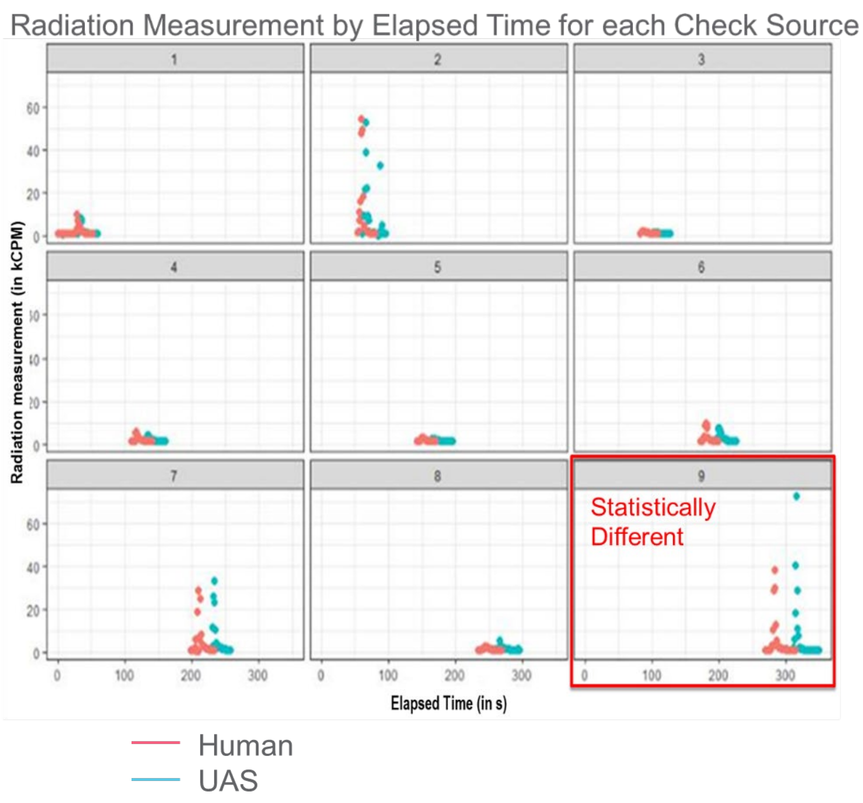
- Velocity:
  - Average velocity of all surveys ranged from 0.18 - 0.26 m/s
    - Equivalent to 3.9 to 5.5 records of CPM recording on the data logger, respectively
  - No more than 0.03 m/s variance with the paired UAV and human survey
- Vertical:
  - Range greater for UAV compared to human because sUAS controls difficult for low & slow flight
  - Median altitude most important parameter

Detector	Survey Altitude	Surveyor	Minimum Altitude (cm)	Maximum Altitude (cm)	Median Altitude (cm)
Ludlum	Low	UAV	**2.3**	201.3	15.3
		Human	26.4	46.4	30.4
Alpha Spectra	Low	UAV	4.2	51.2	26.2
		Human	28.5	51.5	39.5
Ludlum	High	UAV	72.1	**298.1**	87.1
		Human	101.5	127.5	108.5
Alpha Spectra	High	UAV	84.6	130.6	96.6
		Human	97.6	130.6	105.4

Results, Question 3: Comparison of Human to sUAS

Radiation Measurements

- Statistical results based on Kolmogorov Smirnov (K-S) Test
- 36 comparisons (i.e., 4 scenarios, 9 check sources)
- Only 3 comparisons were statistically different (8% of all comparisons)
  1. Alpha Spectra, low altitude, check source 9, 39.34 µCi Am-241

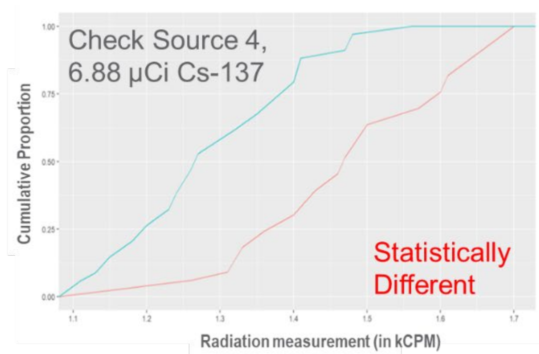


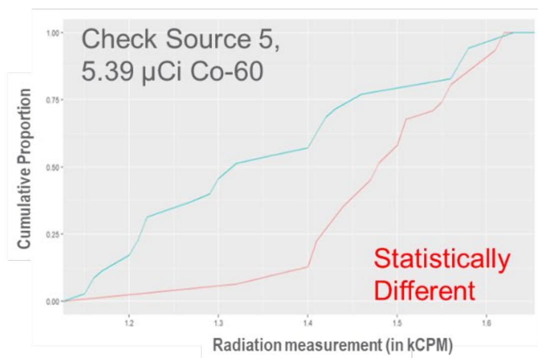
Results, Question 3: Comparison of Human to sUAS

Radiation Measurements

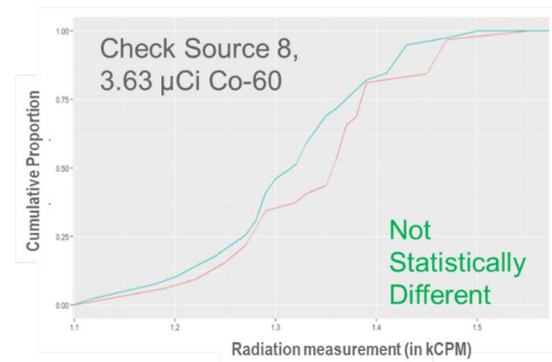
- Comparisons that were statistically different

2. Alpha Spectra, high altitude, check source 4
3. Alpha Spectra, high altitude, check source 5





Comparison of empirical cumulative distribution functions (eCDF)



Human
UAS

Conclusions – Low and Slow!

- Achieved our proof-of-concept goals
  - sUAS performed well
  - Ludlum detector results were similar for radiation measurements at low and high altitude
  - Commercially available instrumentation can be used for radiological surveys for detection at levels needed for decommissioning sites and unrestricted release
- Areas for improvement:
  - Altitude and velocity of the UAV compared to the response time and quality of the radiological measurements
  - Did not have time to evaluate accuracy (comparison of radiation measurements (kcpm) to known activity of check sources)

Recommended Next Steps....

- Optimize integration of radiation detection instruments and sUAS
- Consider other radionuclides and detector types
- Address environmental condition variation in experimental development