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Comparison of UAV and Human Surveys for Decommissioning

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Future Focused Research (FFR) Driver/Goals with Nuclear Regulatory Commission

- Proof of concept
- Demonstrate the use of Unmanned Aerial Vehicles(UAV) for decommissioning activities to:
  - Meet regulatory requirements
  - Include in guidance documents
  - Improve scanning systems

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U.S.NRC Regulations & Guidance for Decommissioning

Regulatory Requirements

- 10 CFR Part 20, Subpart E
- Total Effective Dose Equivalent (TEDE) < 25 mrem/yr and as low as reasonably achievable (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

Proof of Concept and Key Questions for Analysis

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

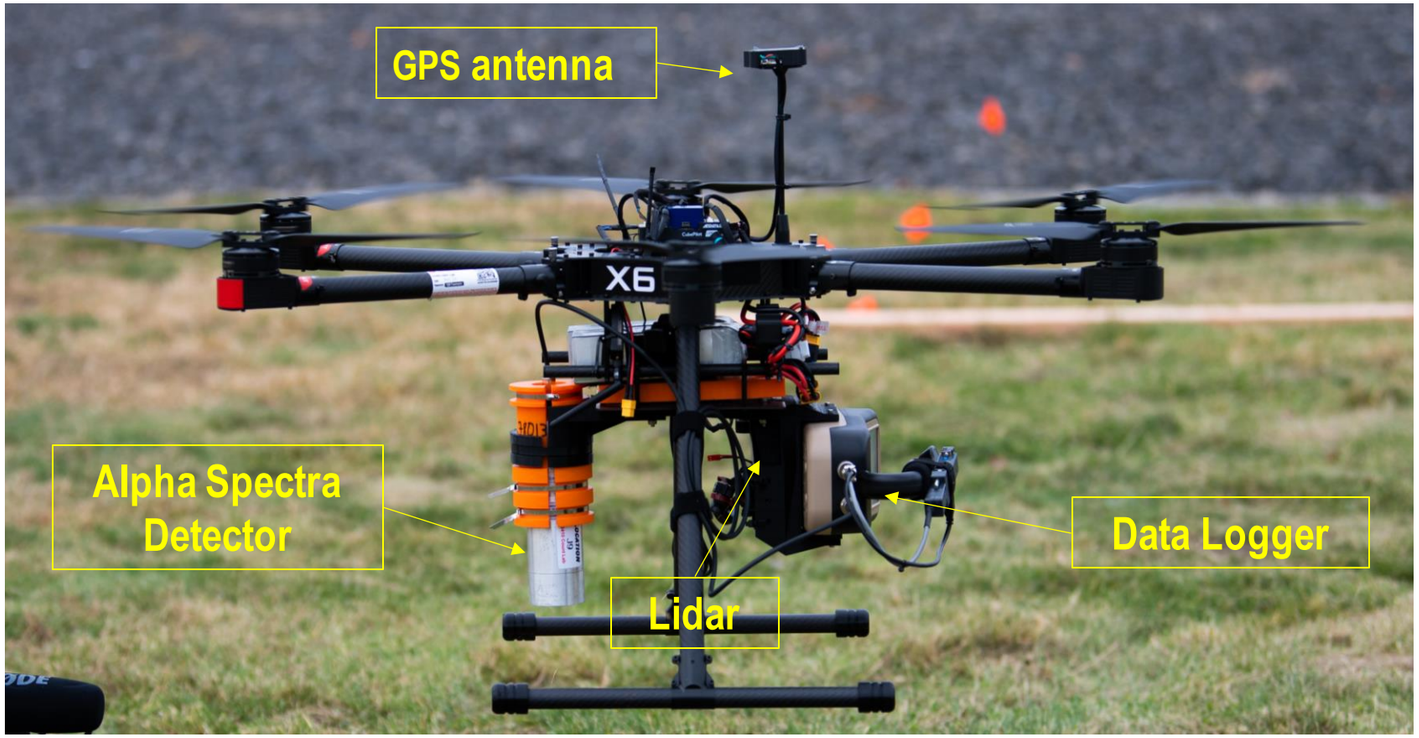
Question 2:
Did survey deviation impact survey results?

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

Technical Approach: UAV Selection and Payload

UAV – Aurelia X6

- Includes GPS with navigation system



Payload

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

Technical Approach: Human Surveys - Control

- Used cart to provide consistent data collection to the UAV surveys

Technical Approach: Selection of Radiation Detector for Payload

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 (¼" thickness crystal) 20 keV - 300 keV range	NaI (2" thickness crystal) 250 keV - 1.5 MeV range
Co-60	1173 keV		X
Cs-137	662 keV		X
Am-241	59 keV	X	

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

Ludlum, Model 44-10 Gamma Detector

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

Technical Approach: Data Collection

- Flight location: PNNL Campus at our 3440 facility
  - Secure location for placing radiological sources in the field
- Operations:
  - Approved Aviation Safety Plan (DOE requirement)
  - FAA certified pilot and visual observer
  - Staff to assist with navigation system and weather observations (flew in November)
  - Staff to collect information with cart (re: Human)

Technical Approach: Flight Path Layout

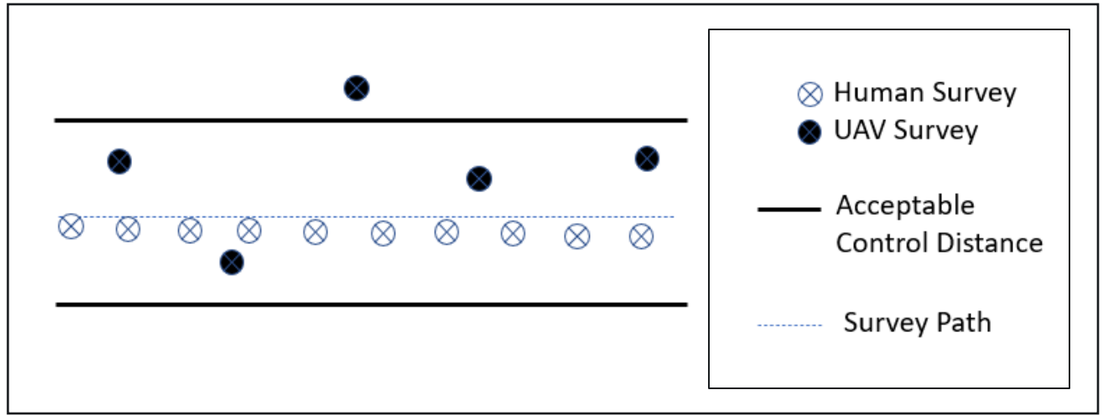
- Outbound flight over sources (63 m)

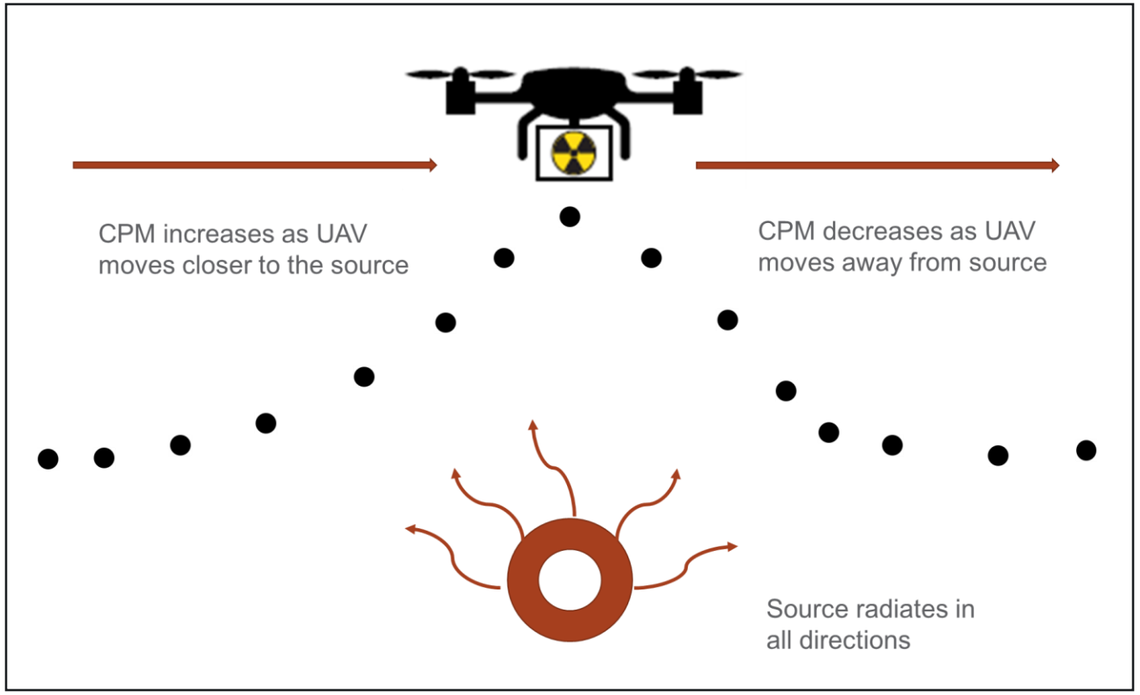
Source #	Isotope	Activity (µCi)
1	Cs-137	13.24
2	Am-241	25.19
3	Cs-137	3.54
4	Cs-137	6.88
5	Co-60	5.39
6	Co-60	10.28
7	Am-241	16.97
8	Co-60	3.63
9	Am-241	39.34

- 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)

Technical Approach: Lateral Deviation

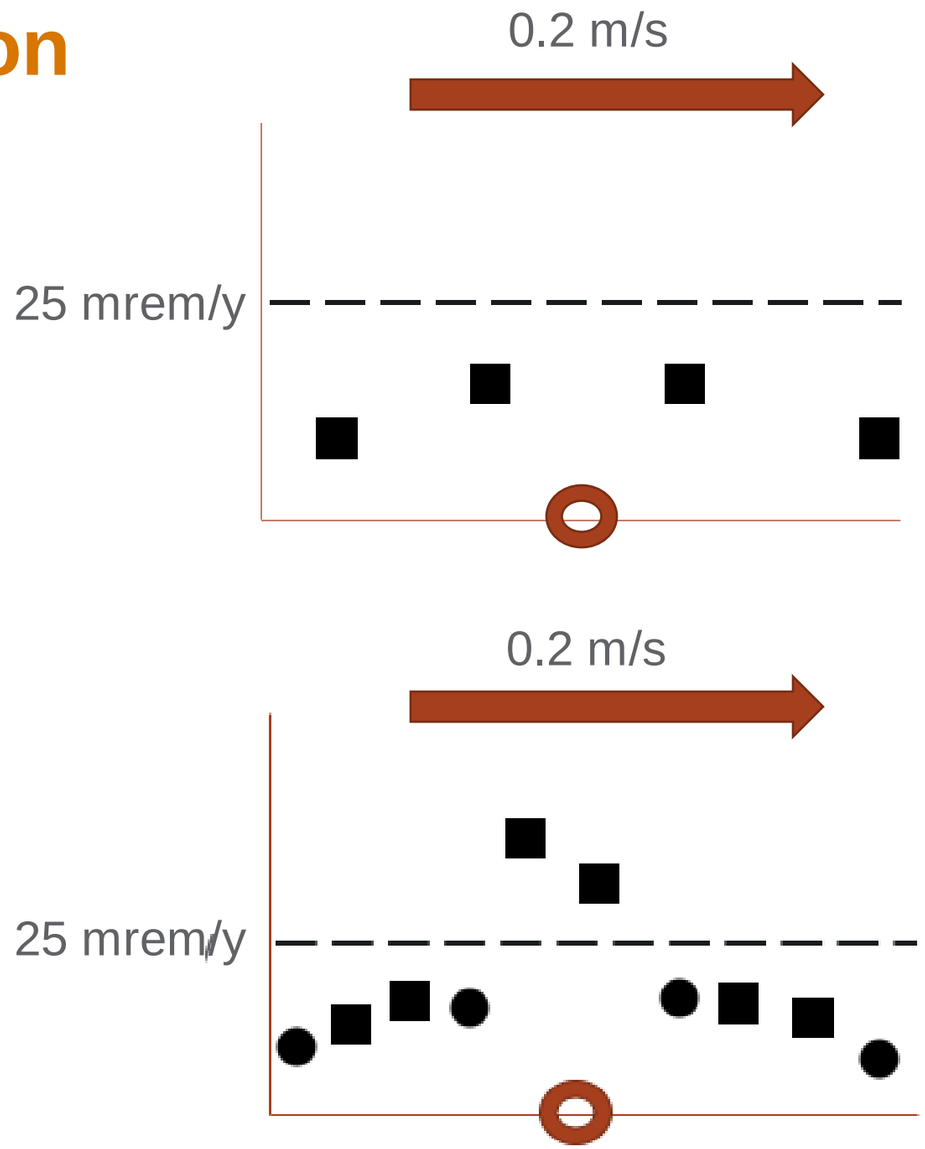
- Related to Question 1: Distance between actual location of detection and pre-determined UAV flight path
- Data analysis to address Lateral Deviation: Kolmogorov Smirnov Test (distribution)
  - Compares mean, standard deviation, and shape of two dependent datasets
- Pattern comparison





Technical Approach: Rate of Data Collection

- Related to Question 2: Date collection meet the acquisition ability of the scenario surveys
- Example: UAV flying at 0.2 m/s and data is collected every 1 m/s
  - 0.2 m between data points
- Radionuclide source is ~2 cm
- Optimize data collection such that data logger to collect at least every 20 cm



Summary of Scenarios and Survey Data

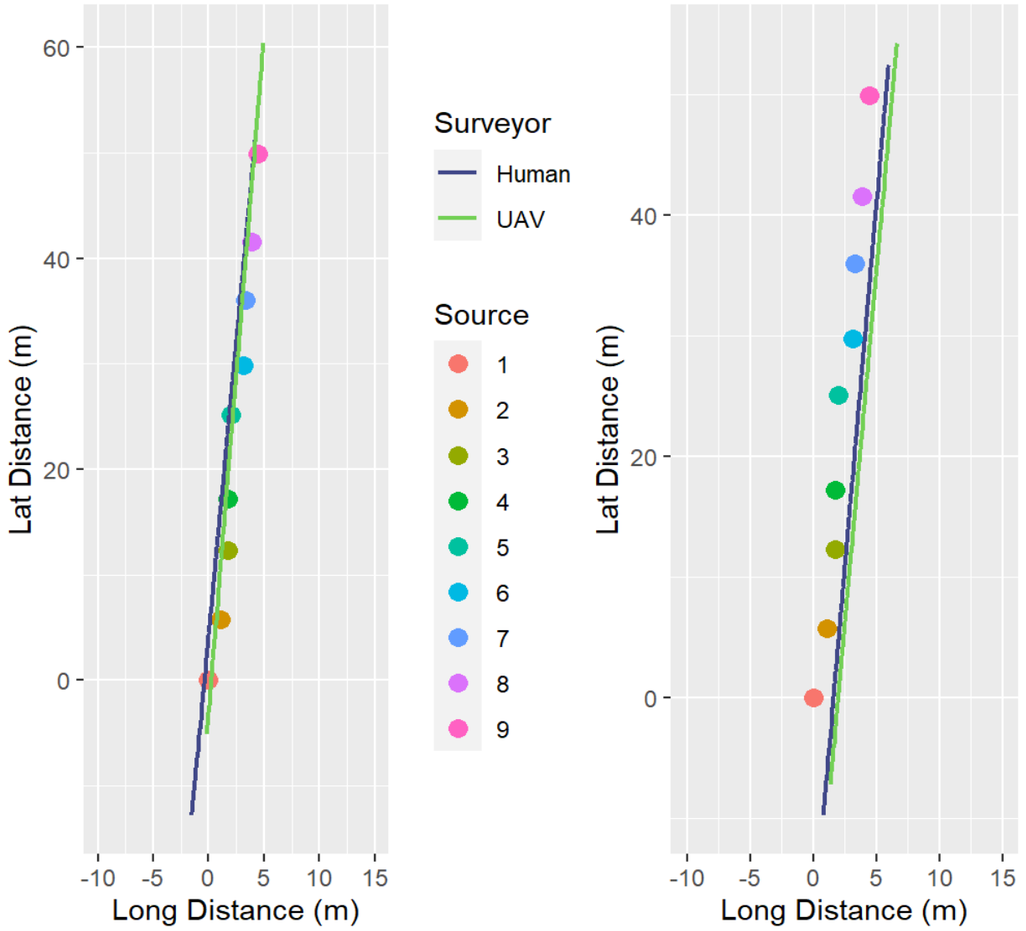
Scenario	Detector	Survey Altitude	Survey	Surveyor	Minimum Altitude (cm)	Maximum Altitude (cm)	Median Altitude (cm)	Average Velocity (m/s)
1	Ludlum	Low	9	UAV	2.3	201.3	15.3	0.20
			10	Human	26.4	46.4	30.4	0.20
2	Alpha Spectra	Low	11	UAV	4.2	51.2	26.2	0.19
			6	Human	28.5	51.5	39.5	0.21
3	Ludlum	High	1	UAV	72.1	298.1	87.1	0.23
			2	Human	101.5	127.5	108.5	0.20
4	Alpha Spectra	High	12	UAV	84.6	130.6	96.6	0.19
			4	Human	97.6	130.6	105.4	0.20

[a] Calculated altitudes for human surveys do not factor in the height of the lumber the sources were secured to and therefore, altitudes are likely higher than observed by the radiological detectors.

Note: Not all the surveys meet the requirements for further evaluations. For example, a survey where the UAV malfunctioned was excluded from further consideration.

Results, Question 1: Survey path analysis

- Question addresses whether the UAV covered the same path as the human survey
- 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 UAV controls difficult for low & slow flight
- Median altitude most important parameter

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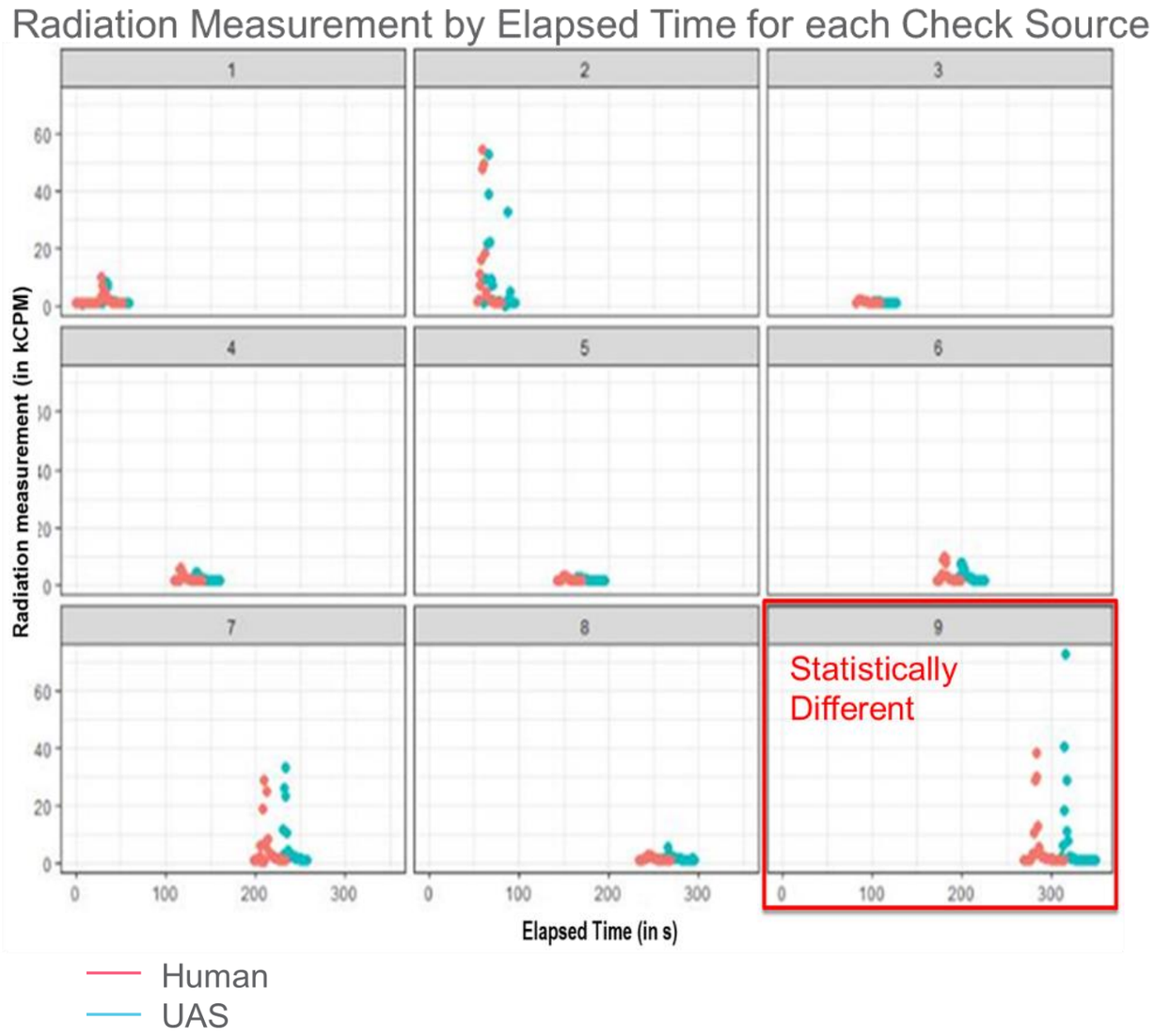
Results, Question 3: Comparison of Human to UAV (part 1 of 2)

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

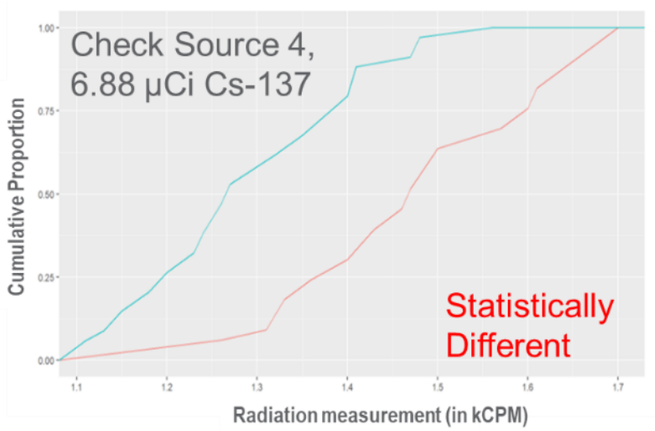


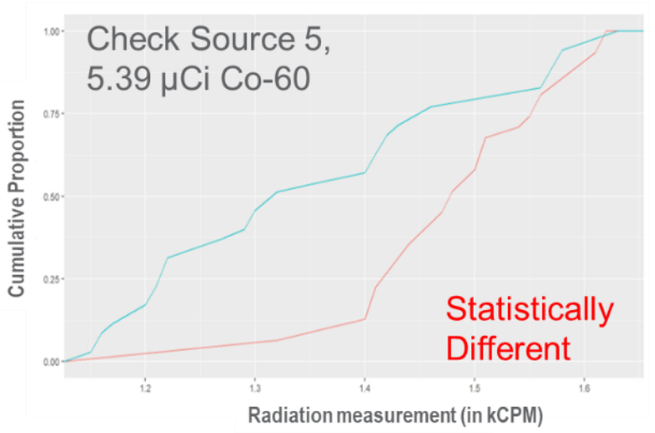
Results, Question 3: Comparison of Human to UAV (part 2 of 2)

Radiation Measurements

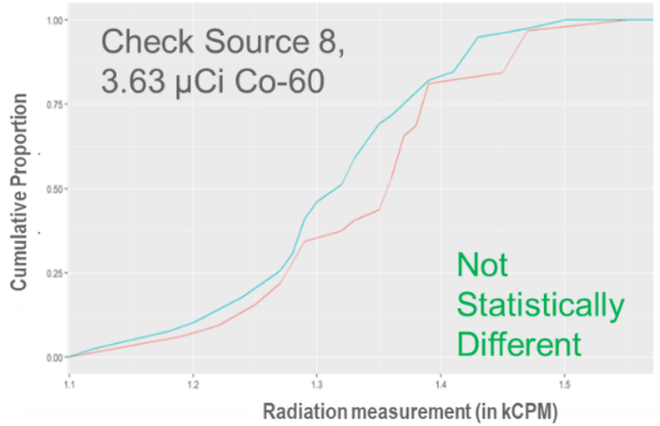
- Comparisons that were statistically different

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





Comparison of empirical cumulative distribution functions (eCDF)



Conclusions – Low and Slow!

Achieved our proof-of-concept goals

- UAV 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 UAV
- Consider other radionuclides and detector types
- Address environmental condition variation in experimental development

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Thank you