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Metrological Preflight Preparation of a NaI(Tl) 2×2” Scintillation Detector for UAV-Based Gamma Spectrometry

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ABSTRACT

The use of unmanned aerial vehicles (UAVs) equipped with gamma-ray spectrometers for radiological mapping and orphan source detection has gained increasing attention. While considerable research focuses on UAV platform integration and flight algorithms, less attention has been given to the systematic laboratory preparation of the detector system that underpins the reliability of subsequent field measurements. A NaI(Tl) scintillation detector (2×2 inch) coupled with an ORTEC DigiBase MCA is a practical choice for airborne applications due to its favourable balance of detection efficiency, energy resolution, weight, and digital signal processing. However, UAV deployment introduces requirements beyond routine calibration: short acquisition times dictated by flight speed, variable source-to-detector distances corresponding to flight altitudes, and environmental factors such as temperature variation and vibration. This work presents a calibration and characterisation methodology developed specifically for preparing a NaI(Tl) detector system for airborne gamma spectrometry, designed as an integrated framework linking laboratory parameters directly to UAV operational constraints. Energy calibration is performed using ^{137}Cs (661.7 keV), ^{60}Co (1173.2 and 1332.5 keV), and ^{241}Am (59.5 keV), covering the energy range of the target radionuclides. Energy resolution (FWHM) is evaluated at each energy, emphasising the ability to resolve ^{137}Cs and ^{60}Co photopeaks — critical for spectral identification in field conditions. A laboratory background measurement is conducted to establish baseline count rates and assess ambient interference. Detector count rate response is characterised at representative source-to-detector distances without performing absolute efficiency calibration, as the operational objective is anomaly identification rather than activity quantification. A key element is the investigation of spectral quality as a function of acquisition time. Peak identification reliability is assessed using a 3σ detection criterion to determine the minimum exposure required for radionuclide discrimination at operational distances — directly constraining flight speed and altitude planning. Statistical uncertainties are estimated from counting statistics under the Poisson approximation. The methodology establishes a reproducible and traceable procedure bridging laboratory detector preparation and airborne survey design, and will be validated through planned field experiments with known-activity sources.

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Motivation: Why UAV-Based Gamma Spectrometry?

The Problem

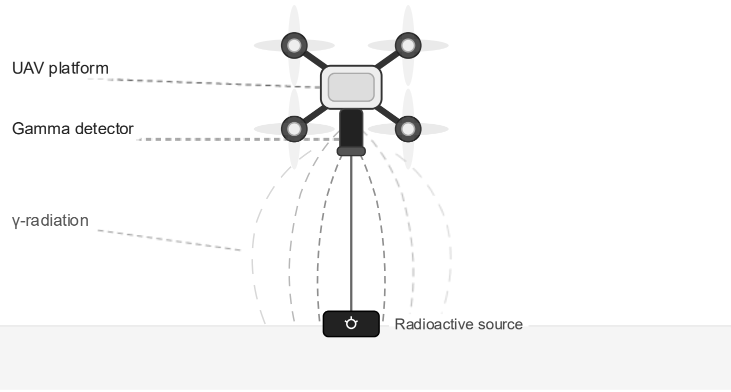
Radioactive contamination monitoring traditionally requires direct human presence in hazardous environments, limiting personnel safety and operational reach — especially for orphan radioactive sources in abandoned facilities and scrap yards.

The Opportunity

Multi-rotor UAVs equipped with NaI(Tl) detectors offer remote, real-time data acquisition without exposing personnel to ionizing radiation. Their ability to hover and manoeuvre at low altitude makes them well suited for localised anomaly search.

The Gap

While considerable research addresses UAV platforms and flight algorithms, systematic laboratory preparation of the detector system — and its direct link to UAV operational constraints — receives insufficient attention. This work addresses that gap.



Remote radioactive anomaly detection without personnel exposure

Detector System Configuration

System Specifications

Crystal	NaI(Tl), 2×2 inch cylindrical
MCA	ORTEC DigiBase-RH
Channels	1024
HV supply	Digitally stabilised
Interface	USB
Software	GammaVision (ORTEC)
Calibration	3-point manual (59.5 – 1332.5 keV)

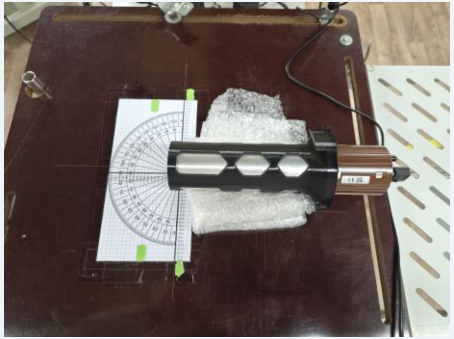
Laboratory Calibration Setup

Reference Sources & Measurement Programme

Source	Energy (keV)	Distances (cm)	Purpose
^{241}Am	59.5	100	Low-energy calibration
^{137}Cs	661.7	200 (5–300 s)	Main calibration + short exposure
^{60}Co	1173.2 / 1332.5	0, 25	High-energy calibration
Background	–	–	1802 s, no sources

Geometry: Front-on, fixed by ruler · Lead shielding to suppress scatter · GammaVision software

NaI detector + DigiBase unit



Lab setup (ruler + lead shielding)

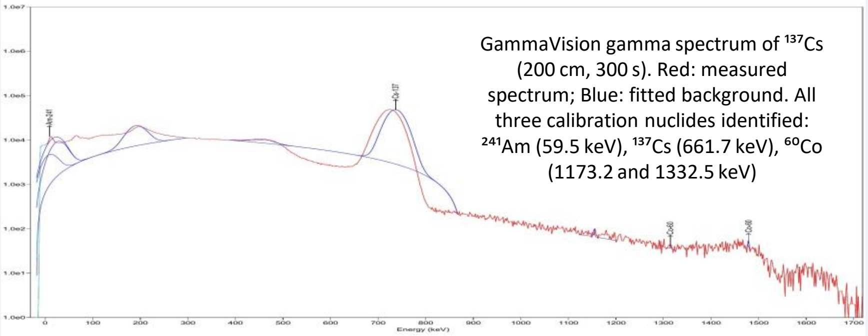
Energy Calibration and Energy Resolution (FWHM)

Calibration function (2nd-order polynomial): $E(ch) = 28.47 + 1.342 \cdot ch + 1.553\times10^{-4} \cdot ch^2$

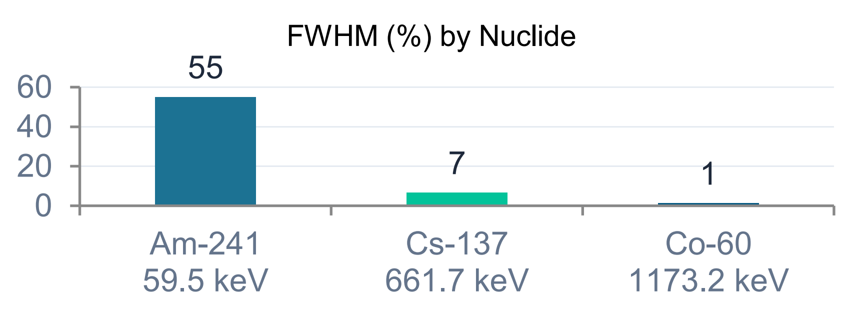
Energy Resolution Summary

Nuclide	Energy (keV)	FWHM (keV)	FWHM (%)
^{241}Am	59.5	32.8	55.1
^{137}Cs	661.7	41–47	6.2–7.1
^{60}Co	1173.2	15.7	1.3

^{137}Cs FWHM of 6.2–7.1% is consistent with NaI(Tl) 2×2″ performance. Broad Am-241 FWHM at 59.5 keV is expected due to poor scintillation light yield at low energies.



GammaVision gamma spectrum of ^{137}Cs (200 cm, 300 s). Red: measured spectrum; Blue: fitted background. All three calibration nuclides identified: ^{241}Am (59.5 keV), ^{137}Cs (661.7 keV), ^{60}Co (1173.2 and 1332.5 keV)



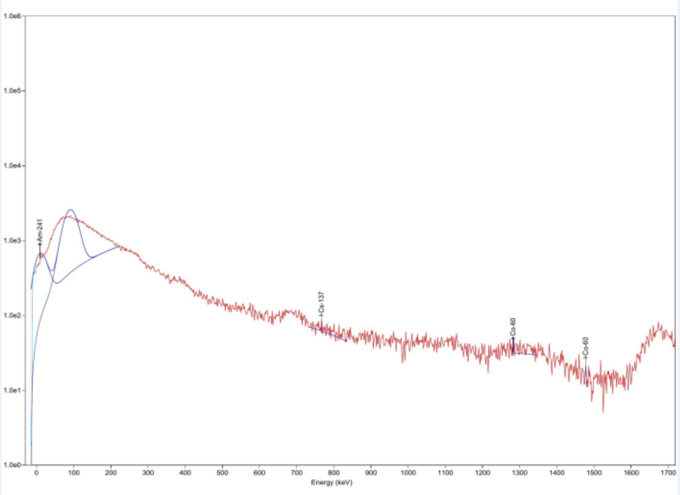
Laboratory Background Characterisation

Background acquisition: 1802 s live time · Dead time: 0.07% · No radioactive sources (intended)

Background Count Rates at Key Energies

Nuclide	Energy (keV)	Net Area (cts)	Rate (cts/s)
^{241}Am ⚠	59.5	15,248	**8.46 !**
^{137}Cs	661.7	362	0.20
^{60}Co	1151	210	0.12

Note: Elevated Am-241 rate (8.46 cts/s) likely reflects incomplete source shielding during background acquisition. For ^{137}Cs at 200 cm, background contribution was negligible (< 1 count at 5 s).



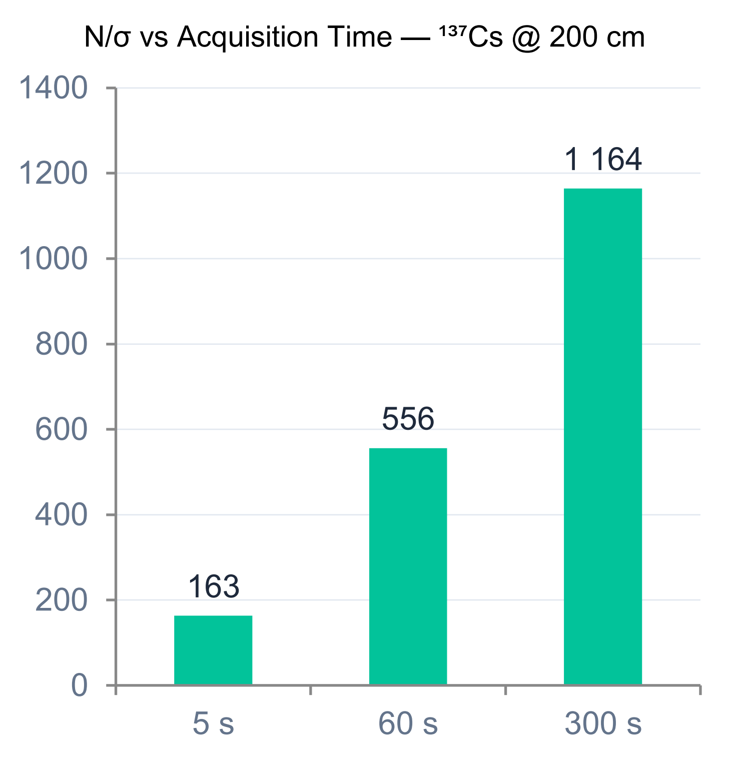
GammaVision screenshot: Background spectrum with Am-241 peak at 59.5 keV labelled

Short Exposure Characterisation — ^{137}Cs at 200 cm

Detection criterion: N/σ ≥ 3 | σ = √N (Poisson) | Background correction applied

Live Time (s)	Net Area N	σ = √N	N/σ	Identified ?
5	26,608	163	**163**	✓ YES
60	308,743	556	**556**	✓ YES
300	1,355,850	1164	**1164**	✓ YES

Key finding: ^{137}Cs reliably identified at ALL tested times (5–300 s). N/σ ≥ 163 at 5 s — well above the 3σ threshold. Dead time stable at ~7.7%. Detection limit lies below the shortest tested exposure for this source activity — discussed under Limitations.



Threshold: N/σ = 3

Co-60 Detectability Assessment

N/σ = 105

Co-60 @ 0 cm · 300 s
N = 10,971 cts

N/σ = 9.1

Co-60 @ 25 cm · 300 s
N = 82 cts (marginal)

N/σ = 14.5

Co-60 in BGR · 1802 s
N = 210 cts (marginal)

Co-60 Detectability Summary — 1173.2 keV photopeak

Condition	Net Area	N/σ	FWHM (keV / %)	Status
Co-60 @ 0 cm, 300 s	10,971	104.7	15.7 / 1.3%	✓ Clearly identified
Co-60 @ 25 cm, 300 s	82	9.1	–	⚠ Marginal / shape fail
Co-60 in BGR, 1802 s	210	14.5	–	⚠ Marginal

Operational implication: Co-60 anomaly detection from UAV altitude would require either a significantly higher source activity or extended dwell times exceeding typical UAV parameters. The low-activity source limits characterisation range in this study.

Limitations of the Present Study

Source Activity Mismatch

^{137}Cs source activity was too high — identification was trivial at all exposure times, preventing discrimination of a minimum detection threshold. Co-60 source was insufficient for characterisation beyond contact distance.

No Statistical Repetitions

Experimental repetitions were not performed due to time constraints. Uncertainties are estimated under the Poisson approximation ($\sigma = \sqrt{N}$), which is valid but does not capture systematic variability between acquisitions.

Background Measurement Integrity

The Am-241 source was likely not fully shielded during background acquisition, resulting in an elevated 59.5 keV background rate. For ^{137}Cs this is negligible, but it affects background characterisation.

Environmental Factors Not Assessed

Temperature dependence, vibration effects, and electromagnetic interference from UAV motors were not evaluated — all relevant to in-flight detector performance.

No Field Validation

The methodology has not yet been validated under real flight conditions with known-activity sources at operational altitudes.

Future Work

1

Source Selection

Use sources better matched to the characterisation objective — lower ^{137}Cs activity and higher Co-60 activity to enable meaningful distance-dependent detectability assessment.

2

Statistical Repetitions

Repeat each measurement point a minimum of three times to enable empirical uncertainty estimation and detection of systematic drift.

3

Environmental Characterisation

Assess detector stability under UAV-representative conditions: temperature variation (5–35°C), mechanical vibration, and electromagnetic interference from UAV motors.

4

Extended Distance Series

Construct a systematic count rate vs. distance curve at 25, 50, 100, 150, and 200 cm to support flight altitude planning.

5

Field Validation

Validate laboratory-derived detection thresholds against real flight conditions. Test source localisation using the inverse square law model as a first step toward operational anomaly detection.

Conclusions

- Three-point energy calibration (59.5–1332.5 keV) successfully established. ^{137}Cs FWHM of 6.2–7.1% confirms NaI(Tl) performance suitable for field radionuclide identification.
- ^{137}Cs (661.7 keV) reliably identified at all tested acquisition times 5–300 s at 200 cm (N/σ ≥ 163). Detection is not the limiting factor at this activity level.
- Co-60 identified at contact distance (N/σ = 105) but marginal at 25 cm, highlighting the need for activity-matched sources in future characterisation.
- Background characterisation revealed laboratory-specific Am-241 interference — a correctable methodological limitation.
- The framework directly links laboratory detector parameters to UAV operational constraints, providing a reproducible preflight preparation procedure for orphan source detection.