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Remote characterisation of buried and spatially distributed radioactive sources using full-spectrum analysis

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Remote identification of buried or spatially distributed radioactive material is difficult because surface measurements mix natural background with any anthropogenic contribution. Activity may lie on the ground surface or be buried beneath sediment, and these geometries impose different attenuation and scattering effects that distort spectra. Burial depth suppresses photopeaks, hardens the spectrum and reduces count rate, making shielded activity appear indistinguishable from genuinely low activity. This distinction matters operationally, as concealed sources or vertically migrating legacy discharges can present signatures similar to benign material unless depth effects are accounted for. Effective remote sensing therefore requires analytical methods able to interpret these spectral modifications, attribute them to source depth or distribution and convert measurements into reliable dose and activity estimates for environmental and emergency-response applications.

This work presents a scenario specific full spectrum analysis (FSA) approach for extracting information on buried or distributed sources from remotely acquired gamma spectra using uncrewed aerial vehicles (UAVs). FSA treats the measured spectrum as a non-negative combination of Monte Carlo generated unit spectra that represent isotopes of interest (U-238, Th-232, K-40, Cs-137 and others) under different physical source geometries that can be modelled to best explain the physical environment. By exploiting the full spectral shape rather than relying solely on photopeaks, FSA captures the influence of scattering, attenuation and depth effects that distort spectra from buried or mixed sources. This enables a more accurate activity estimation and qualitative discrimination between surface bound and subsurface contributions in scenarios where conventional region-of-interest or window-based methods lack the ability to separate overlapping isotopic components.

The methodology is demonstrated using UAV collected gamma spectrometry data across the River Esk estuary at Ravenglass in Cumbria. A salt-marsh environment containing naturally occurring K, U and Th within the sediment alongside well-documented anthropogenic contaminants from historical Sellafield discharges, including Cs-137, Am-241, Sr-90 and plutonium isotopes. Two UAV survey campaigns have been conducted over two years, using first a 37 cm³ CsI detector and later a larger 237 cm³. A Monte-Carlo-based ambient dose equivalent H*(10) pipeline yielded a maximum dose rate across the surveyed marshland of 0.092 $\mu\text{Sv h}^{-1}$. This is in close agreement with recent Sellafield Ltd. and RIFE (Radioactivity in Food and the Environment) ground-sample studies of the same location, which report a maximum dose of 0.098 $\mu\text{Sv h}^{-1}$. Application of FSA to the same dataset provided spatial activity (Bq) estimates for NORM isotopes and successfully identified Cs-137 in regions consistent with documented deposition patterns. The approach enabled clear spatial discrimination between NORM and Cs-137 and produced isotope-specific activity maps that could be directly compared with the dose distribution. The highest dose regions were geospatially coincident with the areas of greatest Cs-137 activity, while NORM contributions were laterally homogeneous across the wider marsh. This combined interpretation provides surveyors and responders with clearer situational understanding, supporting defensible risk assessment and targeted remediation.

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