Drone-based gamma spectrometry of NORM-affected areas and uranium legacy sites: results and outlook of the DUB-GEM research & development project

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Objectives and outline of presentation

- Introduction to the DUB-GEM research & development project
  - Development of a UAV-based Gamma spectrometry for the Exploration and Monitoring of Uranium Mining Legacies
- Regional setting and project objectives
- Specifications of drone and spectrometers
- Results of test flights
- Discussion of challenges and limitations
- Discussion of opportunities for future use of UAV-based gamma spectrometry
Project area (1)
Project area (2)
Drone: 2.2 m diameter, 25 kg MTOM, 2 x 4 propellers
Aerial view of the test area

Google Earth 2021
Flight area in Kyrgyzstan, waste rock dump no. 3
Flight parameters

- Flight altitude above ground: 10 m
- Ground speed: 3 m/s
- Line spacing: 10 m
- Coverage rate: 30 m²/s
- Effective flight duration: 20 mins (plus 5 mins for approach and return)
- Coverage of one flight: 2.4-3.6 hectares
- Length of averaging time window: 1 s
- Interpolation: spline method
Spectrometer specifications

<table>
<thead>
<tr>
<th></th>
<th>CeBr₃ (Medusa)</th>
<th>NaI (innoRIID)</th>
<th>CeBr₃ (innoRIID)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crystal dimensions</strong></td>
<td>3 x 6</td>
<td>3 x 3</td>
<td>2 x 2</td>
</tr>
<tr>
<td><strong>Crystal volume</strong></td>
<td>700</td>
<td>350</td>
<td>100</td>
</tr>
<tr>
<td><strong>FWHM at 662 keV (%)</strong></td>
<td>&lt; 3.9</td>
<td>&lt; 7.2</td>
<td>&lt; 4.2</td>
</tr>
<tr>
<td><strong>Number of spectral channels</strong></td>
<td>2048</td>
<td>1024</td>
<td>1024</td>
</tr>
</tbody>
</table>

Note: The specific activity of the mining waste material is in the order of some Bq/g, i.e., low-level compared to other applications of drone-based gamma measurements (e.g., lost sources).

The plots on the following are based on data obtained with the Medusa CeBr₃ detector.
Potassium-40
Thorium series
Uranium series
Total count rate
Total count rate vs. ground survey
Assumptions and limitations of data processing

• Usual problems of in-situ-gamma spectrometry with scintillation detectors:
  – Depth distribution of specific activity cannot be resolved
  – No spectral resolution of individual nuclides of the uranium and thorium series
  – Geometry effects, e.g., near berms, slopes and embankments
  – Calibration samples of the material is required: tailings, waste rock/LGO, concentrate
  – Interpolation algorithm to avoid misleading impression of high precision

• Assumptions:
  – Homogeneous extension of the specific activity to infinite depth
  – Homogeneous lateral extension of the specific activity within the detector footprint
  – Bulk density of the soil/waste material
  – Equilibrium within the U-238 and Th-232 decay chains, respectively, or certain nuclide vectors
  – Spline interpolation
On-site infrastructure for flight operations (1)
On-site infrastructure for flight operations (2)
Access to site, operations: challenges

• Transport, customs, permits abroad (dual use)
• Flight planning requires access to the site
  – Aerial photos provide only a rough orientation
  – Logistics and access for staff/technology, rough terrain
• Disturbance of animals (herds) and residents by noise,
  – Unwanted attention of the local population
  – Unfounded concerns over “dangerous sites”
• Steep slopes with thermal problems, vegetation (forest), power pylons, poles
• Favorable weather conditions are required
Flight operations: challenges

- Locally unstable data connection (LTE, WLAN,...) in mountainous terrain
  - Incompatible frequency bands
  - Interference between different wireless connections
- Security, Visibility, VLOS vs. FPV (people, HV lines)
  - Steep embankments, deeply cut valleys require FPV operation
  - Humidity on laser rangefinder may disturb altitude control
  - Wobbly GPS reception
- Battery management on site (charging/changing) and during transport
  - Mobile generator
  - Rotating sets of batteries
- Flammable batteries require extra care (crash in rough terrain)
Spatial resolution of UAV-based gamma spectrometry

- Largest part of counts of a point source stems from a lateral area of the order of h around the source, if no collimator is used (which would add to the payload)

- Various constraints on ground speed, depending on altitude and counting time window
  - Drone must be slow enough to locate a point source within a range of the counting time window of the gamma spectrometer
  - Number of counts registered from a single source must be larger than unity
  - A sufficient number of additional counts must be collected from a point source, compared to the background count rate and the statistical uncertainty

- Lateral resolution of two separate point sources is limited to the flight altitude h (order of magnitude), even for a static detector position
  - Spacing of the sources must be at least in the order of flight altitude to show separate peaks
  - Ground speed of drone must be low enough to differentiate between individual peaks

- For more details see manuscript in the proceedings
Spatial resolution vs. radiological relevance of hotspots

• People walk, but do not usually dwell on radiation hotspots. Isolated radiation hotspots are not radiologically relevant, but the areal average of the gamma radiation is.

• However, gamma radiation hotspots are good indicators of gradually developing failure of cover systems, or a developing landslide.

• The main area of application of drones at ULS is to support long-term stewardship monitoring and maintenance, where limited lateral resolution and limited spectral resolution of individual nuclides are not critical.

• The up-front cost can be spread out over multiple missions of the same ULS, e.g,
  – Periodic (annual) fly-overs of large, remediated legacy sites by operators and/or regulators
  – Convenient investigation of the environmental half-life of contamination on large areas (floodplains)

• Flights can be automated, using the same flight routes and parameters for all subsequent missions
Mining area vs. floodplain (border between KG and UZ)
Requirements on drone operators for long-term surveys

- Continued upkeep of
  - Equipment (batteries, motors)
  - Competence of drone operator personnel
  - Maintenance and flight records

- Other requirements
  - Adhere to pre-agreed time schedule
  - Keep discipline in flight planning
  - Environmental information system for comparison with previous flights

- Human and financial resources secured over many years
Acknowledgments

- Daniela Heilfort, Jens Mossig, IAF,
- Carsten Plath, Malte Ibs-von Seht, BGR,
- Michael Wolkstein, Christian Behrens, 3EA,
- Ulan Ibakov, WISUTEC Central Asia LLC
- Vladislav Bensman, Ecoservice-S
- Asel Seitkazieva, Aibek Kozibaev, MES, Kyrgyz Republic
- Maksat Sharipov, Ministry of Energy, Republic of Kazakhstan
- Tinara Shaildaeva, Kyrgyzstan
- Viktoria Ignatiuk, IAEA
Funding information

- The study was funded by the German Federal Ministry of Education and Research (BMBF) under the CLIENT II program, Grant No. 01LZ1706A-C.

- The IAEA’s CGULS programme has facilitated participation of Central Asian experts in practical workshops and coordination meetings and provided logistical assistance for the field work. CGULS also provided support to practical training of Central Asian experts during the field tests described in this paper.