The analytical approach of Drone use in radiation monitoring

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Abstract — During the traditional way of radiation field monitoring – walking measurements – is possible to encounter inaccessible or dangerous areas. For this case, the National Institute for Nuclear, Chemical and Biological Protection (SUJCHBO) has created the method of aerial measurement of ambient dose equivalent rate (ADER) using the drone equipped with gamma-spectrometer. This paper presents two methods on estimation of near-surface gamma radiation based on aerial measurements with Drone equipped with gamma-spectrometer D230A. The D230A was first tested in a room fitted with walls with a higher amount of natural radionuclides from uranium series. The aerial measurements were done at SUJCHBO’s Heliport at three altitudes (6, 11 and 16 m) and from the obtained data, the values of ADER for the altitude of 1 m were calculated and compared with the data measured in the altitude of 1 m. From the two proposed methods, the first one serves for evaluation of the whole measured area while the second method serves for evaluation of zones of interest. In the case of the first method, the highest difference between the calculated and measured data for the altitude of 1 m was 20% and, in case of the second method, the difference of –13.3% and –8.2% was achieved.

Keywords: radiation / monitoring / drone / aerial measurement / ADER

1 Introduction

As society pressure on the radiation monitoring increases, especially after the Fukushima disaster, there is a growing need to find a faster field screening method. Research showed that radiation monitoring has to be done not only near uranium mines but also in areas adjacent to thermal coal power plants (Ashoka et al., 2005; Papastefanou, 2010; Pandit et al., 2012; Hany et al., 2013; Amin et al., 2013). Until recently, the only way to reliably map the radiation distribution around mines, large landfills and in the areas contaminated with radionuclides was to walk through the area with a spectrometer or a dosimeter with GPS. Another option is to collect samples for laboratory analysis (Taskin et al., 2018; Garcéz et al., 2019). The classic approach, including walking field measurement is time-consuming and is not possible in all terrains, such as sludge ponds, large areas of former mining and tailing ponds.

There has been a lot of progress in the development and increased usage of unmanned aerial propellers drones, which can be used for rainfall recovery monitoring (Zahawi et al., 2015), monitoring of emissions of gasses from ships (Xia et al., 2019), monitoring of solar photovoltaic power plants (Kumar et al., 2018; Márquez and Ramírez, 2019), etc. This trend has not been avoided even in the field of radiation protection (MacFarlane et al., 2014; Martin et al., 2016; Okuyama et al., 2005; Zhang et al., 2018). Drones found great use during radiation monitoring after the Fukushima disaster (Sanada and Torii, 2015; Sanada et al., 2016).

Modern drones can carry loads up to several kilograms, quickly reach less accessible locations, visualise distant objects, and also have the great advantage of staying in the air at one point at a certain altitude, which is very useful for acquiring the gamma-ray spectrum. For these reasons, drones are undoubtedly very useful. Nevertheless, the following must be considered while using a drone: terrain in the area of interest, flight conditions and accuracy requirements for the desired measurement. Aerial measurements with drones have many advantages in comparison with walking ground measurement — excellent reproducibility, the exact same flight path of drone can be repeated in different time, altitude and speed, the measurement is safer for the operator, and there is no risk of contamination of the operator with radioactive isotopes, which can cause the distortion of the measurements.

Thus the main goal of the research was to develop and verify two methods for estimation of near-ground ambient dose equivalent rate (ADER) from aerial measurements and to...
test its reliability on an area contaminated with natural radionuclides. As a testing locality, the vicinity of Pribram was chosen. The uranium was mined there extensively during the second half of 20th century (Suran and Veselý, 2001), and a large number of uranium waste dumps and other burdens are still present in the landscape.

In the vicinity of Pribram, the drone was already used for radiation monitoring during the construction of a local highway, which foundations were made of waste dump material and for the monitoring of uranium waste dumps.

2 Instruments

For the measurements, two gamma spectrometers were used, one with combination with a drone – gamma spectrometer D230A – and one for walking measurements – spectrometer GT-40.

Drone Kingfisher (Robodrone Ltd.) (Fig. 1, left) is a six-propeller drone with battery life around 20 min with a maximum payload of 3.5 kg. The drone can fly during the wind up to 10 m·s⁻¹. The drone’s flight path can be preset and stored using the computer program Mission planner 1.3.37. The flight path can be repeated at different altitudes and speeds. The drone is equipped with a GPS locator and a barometric altimeter.

Spectrometer D230A (Georadis Ltd.) (Fig. 1, right) is a device for aerial measurements of ADER, which, based on the results of National Metrology Institute, meets the requirements of EC 61017:2016 (2016). Spectrometer D230A is equipped with 2× NaI(Tl) with volume 104 cm³, dia. 51×51 mm (cylinder), with bi-alkal PMT. The measured parameter was ADER (H(10)).

The GT-40 is a device capable of accurate measurement of ADER values from near 0 nSv·h⁻¹ to 0.5 mSv·h⁻¹ in an energy range 25 keV–3 MeV with a resolution of 200 ns. The GT-40 is also equipped with GPS and straps and can be carried like a backpack, with the detector approximately 1 m above the ground. The information about ADER and GPS coordinates are stored once per second.

2.1 Instrument quality control

The reliability of the used device – spectrometer D230A – was tested in the testing room. The testing room is a room provided with a radioactive source in the form of concrete walls (in the corner of the room), which has a higher concentration of radionuclides of uranium decay series. There is a bench with a ruler attached to the walls pointing to the center of the room. The values of ADER on the bench go from 200 to 1650 nSv·h⁻¹ (from the middle of the room to the corner). There is also a cell made of lead bricks designated to simulate the lowest possible ADER with values under 40 nSv·h⁻¹. The measured parameter was ADER ($H(10)$).

The spectrometer D230A was compared with the spectrometer GT-40 in five measuring points in the Testing room – four on the bench in the range of 4 m, 2.5 m, 1.5 m and 0.7 m from the source and the 5th in the lead cell. 90 s long measurement was taken at each point. During the measurements in the testing room, mainly the linearity between both spectrometers was checked.

3 Measurements

3.1 The Heliport

The Heliport is located in the vicinity of Pribram and lies approx. 100 m far from the local uranium waste dump No. 3. The Heliport is a plain area characterized by a part, in the south-west corner, formed by material originating from uranium waste dump with an increased amount of natural radionuclides from uranium-series (Fig. 2). The values of ADER in this part go up to approx. 1200 nSv·h⁻¹ 1 m above the ground. There is also a concrete square with ADER values about 130 nSv·h⁻¹.

Fig. 1. Drone and the spectrometer D230A.
The data for both methods of estimation of ADER near the ground and for map creation were acquired at the Heliport. The flight path of the drone was preset to cover the whole area of the Heliport, and the speed of the drone was set to 1 m \cdot s^{-1}. For the best results, the aerial measurements were done during calm and dry weather, even though the drone can operate in the wind up to 10 km \cdot h^{-1}. The preset flight path was flown at three different altitudes – 6 m, 11 m and 16 m. The ADER at an altitude of 1 m was measured by walking measurement with GT-40.

The first method was based on SUJCHBO’s certified methodology for radiation measurement with the drone (Černý et al., 2016). The values of the ADER for the 25th, 50th, 75th, 90th and 95th percentiles were calculated from data obtained in each altitude, and the results were fitted with a trendline. From the equation of the trendline, the values of ADER for each percentile for an altitude of 1 m were calculated. The calculated results were compared with data measured at 1 m during walking measurement.

The second method was based on the estimation of gamma radiation from values from different distances. Two zones (zone 1 and zone 2) were established above the area of the radiation source. The average value of ADER was calculated for each zone in each altitude (6 m, 11 m and 16 m) and the values were fitted with a trendline. From the equation of the trendline, the value of ADER for an altitude of 1 m was calculated. The calculated results were compared with data obtained at 1 m during walking measurement.

The data from measurements were processed in MS Excel 2013, and the maps were created in the freeware QGIS version Las Palmas 2.18.

5 Results and discussion

5.1 Instrument quality control

The comparison of spectrometer D230A with GT-40 on five measuring points in the testing room showed that the spectrometer D230A in the same conditions measures less than GT-40 in the range 38–1643 nSv \cdot h^{-1}. The difference of D230A from GT-40 was –18.4%, –21.4%, –23.3%, –16.8% and –17.3% for the lead cell, 4 m, 2.5 m, 1.5 m, and 0.7 m respectively (Tab. 1) with mean of –19.4%. However, correlation between both devices was found (Fig. 3), thus the correction factor 1.21 was estimated and applied. After the application of the correction factor on the data measured by the spectrometer D230A, the highest difference from GT-40 was –7.1% with mean of –2.4%.

The difference in measured values between D230A and GT-40 might be caused by the different size of NaI(Tl) detectors, different geometry of the detectors, the device design and calibration, which depends on previously mentioned. While the GT-40 is a device designed for walking measurement and has one cylindrical detector with dimensions 76 × 76 mm placed in the tube-shaped coating, the D230A is a device designated for aerial measurements equipped with two cylindrical detectors with dimensions 51 × 51 mm, placed next to each other in block coating.

5.2 Methods

The parallel measurements of the radiation on the Heliport allowed us to compare the results from walking measurement and calculated results from the aerial measurements. Set of four maps of ADER distribution was created (Fig. 4) from the measurements, first map for walking measurement at an altitude of 1 m above the ground (marked A) and one map for each altitude – 6 m (B), 11 m (C) and 16 m (D). A gradual decreasing of the intensity of radiation with increasing altitude can be seen in the maps, the differences are almost negligible for the zones with low ADER (blue and turquoise dots) and increases with higher values of ADRE, and this can be also seen in Table 2 and Figure 5. However, even from the altitude of 16 m – D – the difference in ADER distribution is certain, and it is possible to identify the position of the source of radiation even though the source is relatively weak (measured maximum is 1200 nSv \cdot h^{-1} at 1 m) and formed by natural radioisotopes of uranium series.

The measured values for each altitude were firstly evaluated by using five different percentiles (25th, 50th, 75th, 90th and 95th). It is appropriate to use the quartiles, which gave the information about lower and medium values, supplemented with 90th and 95th percentiles for evaluation of higher values. The values of each percentile in each altitude were interlaced with trendlines and the values of ADER for the altitude of 1 m were calculated from the equations of the trendlines. Calculated data were compared with real data measured at an altitude of 1 m (Tab. 2, top and Fig. 5) with GT-40. The differences between measured and calculated data for the altitude of 1 m go from 20 to –15.9% with the lowest differences (–9.1%) at 90th percentile.

The second method was based on the estimation of the radiation levels near the ground from the average values of ADER in two outlined zones (Fig. 4). The average values measured in each zone and each altitude were again interlaced with trendlines from which equations the values of ADER for the altitude of 1 m were calculated. Comparison of calculated and measured values for the altitude of 1 m (Tab. 2, bottom and Fig. 6) showed that the calculated values are lower than measured values by –8.2% for zone 1 and –13.3% for zone 2.
In the case of the “method of 5 percentiles” is assumed that the differences between the calculated and measured data would be lower with exactly the same path of walking and aerial measurement. The geometry of the source has a potential influence on the results of both methods, the source of radiation in the south-west corner of the Heliport can be considered flat and close to infinite as we approach near the ground, but with the rising altitude, the source appears finite. Also, the use of other than linear function, such as power function or exponential function, would affect the calculated values for 1 m, but in case of this area in combination with selected altitudes an with only three different heights, the linear function seemed to be most suitable. For the second method, it would be appropriate to adjust the area of the zones according to altitude and expand the zones considered for the calculation with rising altitude since the radiation is not emitted only in upward direction but is omnidirectional.

### 7 Conclusion

During the instrument quality control of the spectrometer D230A, the correction factor of 1.21 was estimated and was used in further measurements for better results. It was possible to identify the source of radiation in the maps even from an altitude of 16 m. The highest difference between values calculated and values measured was 20.0% for “method of 5 percentiles” and −8.2% for zone 1 and −13.3% for zone 2 in the case of the second method. Based on these results, both methods were proven useful for the fast and quite accurate evaluation of the area of interest. While the “method of 5 percentiles” can give us approximate numerical information about the values of ADER near the ground, the second method can give us the information about the situation in selected zones. However, further experiments on different places with different radioactive sources are intended and the use of different than linear function should be considered when applying discussed methods in different areas and altitudes.

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**Table 1.** Measured data of D230A and GT-40 with statistical values, corrected values of D230A and percentage differences between both devices before (% difference 1) and after the correction (% difference 2) with correction factor of 1.21.

<table>
<thead>
<tr>
<th>Point</th>
<th>Device</th>
<th>Mean [nSv·h⁻¹]</th>
<th>Deviation</th>
<th>rel. dev. %</th>
<th>D230A corrected (1.21)</th>
<th>% difference 1</th>
<th>% difference 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead cell</td>
<td>GT-40</td>
<td>38</td>
<td>6.6</td>
<td>17.4</td>
<td>38</td>
<td>−18.4</td>
<td>−1.2</td>
</tr>
<tr>
<td></td>
<td>D230A</td>
<td>31</td>
<td>6.5</td>
<td>20.6</td>
<td>38</td>
<td>−18.4</td>
<td>−1.2</td>
</tr>
<tr>
<td>4 m</td>
<td>GT-40</td>
<td>238</td>
<td>12.9</td>
<td>5.4</td>
<td>227</td>
<td>−21.4</td>
<td>−4.8</td>
</tr>
<tr>
<td></td>
<td>D230A</td>
<td>187</td>
<td>13.8</td>
<td>7.4</td>
<td>227</td>
<td>−21.4</td>
<td>−4.8</td>
</tr>
<tr>
<td>2.5 m</td>
<td>GT-40</td>
<td>433</td>
<td>17.1</td>
<td>3.9</td>
<td>402</td>
<td>−23.3</td>
<td>−7.1</td>
</tr>
<tr>
<td></td>
<td>D230A</td>
<td>332</td>
<td>19.2</td>
<td>5.8</td>
<td>402</td>
<td>−23.3</td>
<td>−7.1</td>
</tr>
<tr>
<td>1.5 m</td>
<td>GT-40</td>
<td>1110</td>
<td>31.4</td>
<td>2.8</td>
<td>1118</td>
<td>−16.8</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>D230A</td>
<td>923</td>
<td>30.7</td>
<td>3.3</td>
<td>1118</td>
<td>−16.8</td>
<td>0.8</td>
</tr>
<tr>
<td>0.7 m</td>
<td>GT-40</td>
<td>1643</td>
<td>40.0</td>
<td>2.4</td>
<td>1645</td>
<td>−17.3</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>D230A</td>
<td>1358</td>
<td>33.1</td>
<td>2.4</td>
<td>1645</td>
<td>−17.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Fig. 4. The maps of ADER distribution on Heliport.

Table 2. Percentiles at different altitudes and comparison of calculated and measured values for the altitude of 1 m (top).

<table>
<thead>
<tr>
<th>Percentile</th>
<th>16 m</th>
<th>11 m</th>
<th>6 m</th>
<th>calc. for 1 m</th>
<th>1 m</th>
<th>% difference *</th>
</tr>
</thead>
<tbody>
<tr>
<td>25th [nSv·h⁻¹]</td>
<td>270</td>
<td>262</td>
<td>252</td>
<td>280</td>
<td>233</td>
<td>20.0</td>
</tr>
<tr>
<td>50th [nSv·h⁻¹]</td>
<td>320</td>
<td>309</td>
<td>290</td>
<td>336</td>
<td>285</td>
<td>18.0</td>
</tr>
<tr>
<td>75th [nSv·h⁻¹]</td>
<td>445</td>
<td>406</td>
<td>359</td>
<td>489</td>
<td>415</td>
<td>17.9</td>
</tr>
<tr>
<td>90th [nSv·h⁻¹]</td>
<td>629</td>
<td>539</td>
<td>436</td>
<td>728</td>
<td>801</td>
<td>−9.1</td>
</tr>
<tr>
<td>95th [nSv·h⁻¹]</td>
<td>656</td>
<td>569</td>
<td>459</td>
<td>759</td>
<td>902</td>
<td>−15.9</td>
</tr>
</tbody>
</table>

The values of averages for different altitude in zone 1 and zone 2 (bottom).

<table>
<thead>
<tr>
<th>Altitude</th>
<th>16 m</th>
<th>11 m</th>
<th>6 m</th>
<th>calc. for 1 m</th>
<th>1 m</th>
<th>% difference *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>avg. [nSv·h⁻¹]</td>
<td>424</td>
<td>513</td>
<td>587</td>
<td>670</td>
<td>730</td>
<td>−8.2</td>
</tr>
<tr>
<td>Zone 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>avg. [nSv·h⁻¹]</td>
<td>449</td>
<td>553</td>
<td>642</td>
<td>744</td>
<td>858</td>
<td>−13.3</td>
</tr>
</tbody>
</table>

Averages for different altitudes in zone 1 and 2, and calculated averages for the altitude of 1 m compared with measured averages (bottom).

* The percentage difference between measured and calculated values in 1 m.
Fig. 5. Values of percentiles of ADER measured at 1 m (crosses) in comparison with values counted from the aerial measurements (orange triangles).

Fig. 6. Averages from different altitudes in zone 1 and 2, and calculated averages for the altitude of 1 m (orange triangles) compared with measured averages at the altitude of 1 m.

References


