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RADON EXHALATION OF THE URANIUM TAILINGS DUMP DIGMAI, TAJIKISTAN*

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Abstract. *In a joint project of Forschungszentrum Jülich and the Khujand State University, a radioecological survey of the Digmai uranium tailings dump was carried out in the period from 2012 to 2014. In order to investigate the seasonal variation of the radon emission, automatic long-term measurements of the radon exhalation rate were performed at one location using a new device developed at Forschungszentrum Jülich. Area-wide measurements in 90 places showed the local variation of the exhalation rate all over the dump surface. In addition to exhalation measurements carried out on the horizontal tailings surface, measurements were also performed on the vertical walls of desiccation cracks where the radon exhalation rate was found to be significantly higher. The total annual radon emission of the tailings dump can be estimated at approximately 250 TBq. Beside the radon measurements, area-wide dose rate measurements were carried out on the surface of the tailings and in tailings samples the Ra-226 activity concentration was measured by means of gamma-ray spectrometry.*

Key words: *Radon exhalation, uranium tailings, uranium mining, radium*

1. Introduction

The Digmai (other spellings: Digmay, Degmay, Dehmoy) uranium tailings management facility (Fig. 1) is situated in Northern Tajikistan near Khujand, the second largest Tajik city. The distance to the centres of Khujand and Chkalovsk, another nearby town, and the distance to the river Syr Darya is approximately 6 km. The nearest settlement, a southern suburb of Khujand, is only about 1 km away from the tailings.

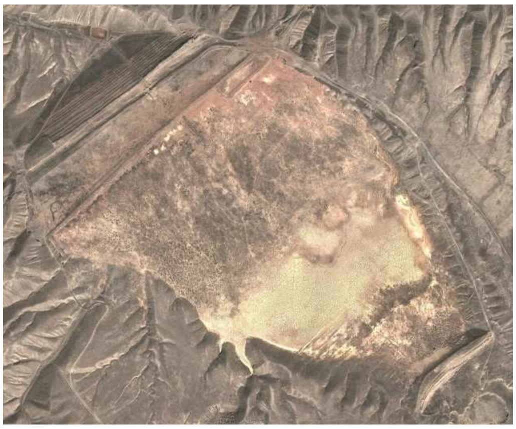

Figure 1. Uranium tailings dump Digmai (Satellite photograph; map data: Google, DigitalGlobe)

Since 1963, uranium ore processing residues in slurry form were pumped into the tailings pond Digmai until the uranium production in Tajikistan was stopped in the 1990s. Until 2000, the surface of the tailings completely dried up and in the central and southern part of the tailings dump, deep desiccation cracks occurred, which formed irregular polygonal patterns in plan view (Fig. 2). Approximately 28 % of the surface area is characterized by desiccation cracks (region 2 in Fig. 3). The surface of region 2 is encrusted and there is no loose sand or dust. The material in this area seems to consist predominantly of fine tailings. Coarse tailings are characteristic of region 1 with a mostly plain and sandy surface which is partly covered with bulrush vegetation. The surface area of the dump is approximately 1 km^2 and the total quantity of the uranium tailings is estimated at 36 million tons [1]. Because the dump is uncovered, the radon resulting from the high radium content in the tailings can be easily released into the atmosphere.

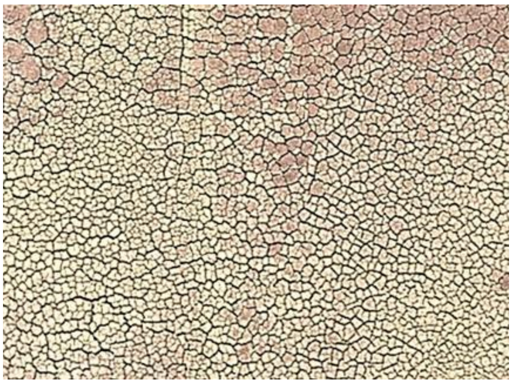

Figure 2. Desiccation cracks in the surface of the tailings (Satellite photograph; map data: Google, DigitalGlobe)

In a joint project of the Research Centre Jülich (Forschungszentrum Jülich GmbH, FZJ) and the Khujand State University (KSU), a radioecological survey of the Digmai uranium tailings dump was carried out in the period between 2012 and 2014. The

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focus of this paper is radon; the results of water and air monitoring will be published elsewhere.

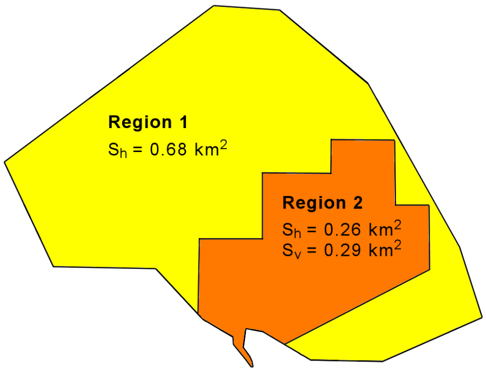

Figure 3. Classification of the tailings surface (S_h = horizontal surface, S_v = vertical surface)

For the planning, execution and documentation of the measurements and sampling, a regular grid was defined with 90 numbered measuring points evenly distributed over the whole dump area (Fig. 4); the distance between adjacent points is 100 m. The geographic coordinates of point 35 in the centre of the dump are N40°13.628', E69°37.658'.

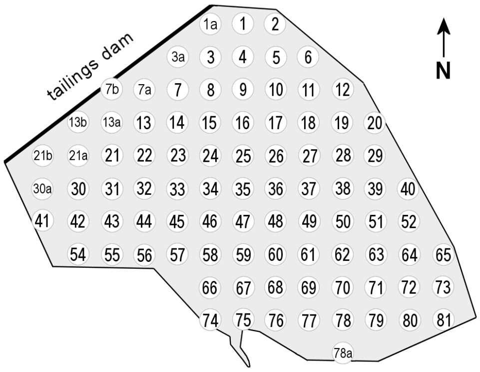

Figure 4. Measuring points

2. Materials and Methods

2.1. Radon exhalation measurements

All radon exhalation measurements were performed using the accumulation method. The open face of a cylindrical accumulation container is placed on the surface to be investigated and the radon activity concentration C in the accumulation container is measured by means of an alpha-spectrometric radon/thoron monitor RTM1688 (SARAD GmbH, Dresden) connected to the container by radon-tight PVC hoses.

A small pump integrated into the radon-measuring instrument circulates the air continuously within the measuring system. In the initial phase (0.5 – 1.5 h) of the accumulation process, the increase of the radon activity concentration can be approximated by a straight line. From the slope $\Delta C/\Delta t$ of the best-fit straight line, the radon exhalation rate E (in Bq m^{-2} s^{-1}) of the investigated surface can be approximately determined according to ISO 11665-7 [2]:

$$E = \frac{\Delta C}{\Delta t} \cdot \frac{V}{S} \tag{1}$$

V is the effective gas volume of the measuring system (accumulation container, hoses and radon measuring instrument). S is the effective surface, i. e. the internal surface of the open face of the accumulation container that is covering the surface under investigation. ΔC is the increase of the radon activity concentration during the measurement time Δt.

A new device for the automatic long-term measurement of radon exhalation rates was developed at Forschungszentrum Jülich, on the basis of the accumulation method. After each accumulation period (40 – 100 min), a ball valve in the air outlet of the accumulation container is opened and an external diaphragm pump replaces the radon-bearing air within the container by fresh ambient air until the radon activity concentrations inside and outside the container are nearly equal. After this ventilation period (1 – 2 h), the pump is turned off and the ball valve is closed to make the accumulation container gas-tight again and another accumulation period follows. The diaphragm pump and the ball valve are controlled by a microprocessor and the duration of accumulation and ventilation periods can be adapted to the measured exhalation rates by a programming device. The automatic sequence of accumulation and ventilation periods is only limited by the data memory of the radon monitor and the electrical power supply of the measuring system. The new device was optimised with respect to planned outdoor applications in Central Asia; it has to be modular, rugged, weatherproof, maintenance-free and easily transportable. The cylindrical accumulation container is made of stainless steel with a diameter of 20 cm and a height of 10 cm. The effective surface and volume of the measuring system is 0.031 m^2 and 0.0034 m^3, respectively.

In addition to radon/thoron monitors, small DOSEman instruments (SARAD GmbH, Dresden) were also used for radon exhalation measurements. In this case, the measuring instrument is placed within a stainless steel bucket which serves as an accumulation container. Radon diffuses through a membrane into the measurement chamber of the DOSEman where the disintegrations of the daughter product Po-218 are detected by an alpha-particle spectrometer. A small fan circulates the air within the accumulation container to ensure a uniform radon concentration inside the measuring system. The effective surface of the steel buckets is 0.036 m^2, the effective volume is 0.0061 m^3.

When an accumulation container is placed on the surface under investigation, at least one orifice must be open to prevent overpressure. For this purpose, either a ball valve was used or a drilled hole in the steel bucket which can be closed with synthetic rubber during the measurements. To minimise leakage of the measuring system synthetic rubber (Terostat-VII, Henkel AG & Co. KGaA) was also used as a sealing between the edge of the accumulation container and the tailings surface. During the measurements, the accumulation containers were covered with circular white Teflon discs which shield them from intense sunlight and thus avoid excessive heating. On top of the Teflon disc, a heavy stone was placed to press the accumulation container against the ground. The duration of the accumulation periods was chosen short enough (40 – 90 min) so that back diffusion of radon from the accumulation container into the soil is expected to be negligible. The sampling interval (integration interval) of the radon monitors was set to 10 min as a compromise between good time resolution and a small relative uncertainty of the measured radon activity concentration values. By a linear regression of the radon activity concentration as a function of time, a best-fit straight line was determined for each measurement and the slope of this line was used to calculate the radon exhalation rate. Depending on the linearity of the data only the first 3 to 5 measured values of each accumulation period were used for the regression analysis (Fig. 5).

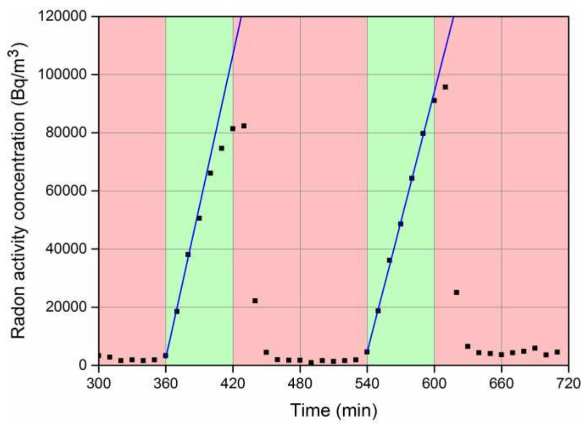

Figure 5. Data example from an automatic long-term exhalation measurement (blue: best-fit straight line, green: accumulation period, red: ventilation period)

In order to assess the reliability and comparability of the different radon measuring instruments (6 DOSEman and 2 RTM1688) intercomparison exercises were performed at various locations. For this purpose, up to 7 exhalation measuring systems were placed on the tailings surface within an area of 2 m² and the radon exhalation rate was measured simultaneously in order to compare the results.

In addition to the exhalation measurements on the horizontal tailings surface, the radon exhalation rate was also measured on the vertical walls of the desiccation cracks. For this purpose, an auxiliary device was built from two lab jacks (SwissBoy 110, Grauer AG). This device can be used to press the accumulation container against the crack wall during a measurement (Fig. 6).

Figure 6. Exhalation measurement on a crack wall

2.2. Dose rate measurements

With a thoroughly calibrated dose rate meter automess 6150 AD 6/E (Automation und Messtechnik GmbH, Ladenburg, Germany), the ambient dose equivalent rate was measured all over the dump area at ground level and in some places at a height of 1 m. The measurement time was at least one minute to keep the relative count-statistical uncertainty below 5 %.

2.3. Gamma-ray spectrometry

A total of 21 tailings samples were collected in 9 locations from various depths. Subsurface samples were taken at the vertical crack walls after discarding the outer layer which may be leached out by rain. After drying at 110°C for three days, the samples were weighed and filled into 100 ml aluminium containers and the screw coupling was sealed with a two-part epoxy adhesive. Radon exhalation measurements have shown that the containers were gas-tight. The samples were stored for at least 30 days until the radioactive equilibrium between Ra-226 and its short-lived daughter products (Rn-222, Po-218, Pb-214, Bi-214, Po-214) was approximately reached. Then the activity of Ra-226 in the samples was measured in a gamma-ray spectrometer with four HPGe detectors using the gamma radiation of Pb-214 (295.2 keV, 351.9 keV) and Bi-214 (609.3 keV, 1120.3 keV, 1764.5 keV). Two background spectra were recorded immediately before and after each sample measurement to subtract the natural background from the sample spectra. A suitable efficiency calibration for the used measuring geometry was calculated by means of Monte Carlo simulations with the software package MCNP5 (Los Alamos National Laboratory), using a precise model of the spectrometry system [3]. The systematic error of the efficiency calibration is estimated to be less than 5 % and the count-statistical uncertainty of the sample measurements was always less than 3 %. The gamma-ray spectrometry software Genie 2000 (Canberra Industries Inc.) was used to record and analyse the spectra.

2.4. Land survey

The horizontal surface area S_h of the tailings dump can be easily determined from satellite photographs (Google Earth) or GPS tracks. More difficult is the estimation of the vertical tailings surface, i.e. the vertical walls of the desiccation cracks. For this purpose, an idealised and simplified hexagonal model of the desiccation cracks can be used (Fig. 7) because the crack pattern in dried mud evolves towards a hexagonal geometry if the material is repeatedly wetted and dried [4]. The actually irregular network of cracks is replaced by a regular hexagonal network (dark grey) surrounding hexagonal prisms of tailings material (light grey) in the model. Using this model, the vertical tailings surface S_v can be approximately calculated by the following formula, where A is the base area of the hexagonal prisms, b the crack width and d the crack depth:

$$S_v = \frac{S_h d \sqrt{\frac{2A}{\sqrt{3}}}}{\left(\sqrt{\frac{A}{2\sqrt{3}}} + \frac{b}{2}\right)^2} \qquad (2)$$

To estimate the parameters *d* and *A*, the depth of the desiccation cracks was measured with a laser rangefinder (Bosch PLR 50) in 270 different places, and the base area of the prismatic columns surrounded by cracks was estimated by measuring the circumference of the columns in 162 places with a tape measure. Irrespective of the actual shape of the polygonal surface, a regular hexagon was assumed for the calculation of the surface area using the measured circumference. For these measurements, only clearly defined cracks ($d > 0.5$ m) were considered; shallow depressions were ignored.

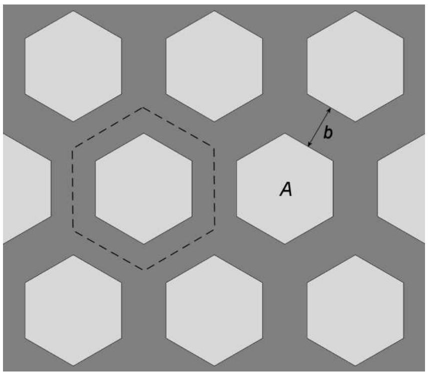

Figure 7. Horizontal cross-section of the hexagonal model of the desiccation cracks (a unit cell of the model is indicated by the dashed hexagon; explanation see section 2.4)

2.5. Data analysis software

For the analysis and visualisation of the measured data, the following software was used: Microsoft Excel 2010, Mathematica 10.0 (Wolfram Research, Inc.), OriginPro 2015G (OriginLab Corporation), Paint Shop Pro X (Corel Corporation).

3. Results and Discussion

3.1. Effective surface area of the tailings

For an estimation of the total radon emission of the tailings dump, the effective (total) surface area is required which can be calculated by means of equation 2 using the parameters *d*, *b* and *A*. Fig. 8 shows the frequency distribution of the measured crack depths *d* and the corresponding best-fit log-normal probability density function. The mean value of *d* is 1.76 m, the median 1.60 m and the geometric mean 1.54 m; 1.7 m was adopted as an estimate of *d*. The frequency distribution of the base areas *A* of the prismatic tailings columns and the corresponding log-normal probability density function are shown in Fig. 9. The mean value of *A* is 28.4 m², the median 19.7 m² and the geometric mean 19.2 m². The 5% trimmed mean is 24.4 m²; this value was used for further calculations. The width *b* of the desiccation cracks varies from 0.2 m to 0.8 m. The exact value of the crack width has little influence on the result of equation 2; therefore, the mean value of *b* was estimated at 0.4 m from only some dozens of measurements. With the estimated parameters $d = 1.7$ m, $b = 0.4$ m, $A = 24.4$ m² and $S_h = 0.26$ km², equation 2 yields approximately 0.29 km² as the vertical surface area S_v of region 2. The (horizontal) surface of region 1 is 0.68 km²; thus the total surface area of the tailings dump is 0.68 km² + 0.26 km² + 0.29 km² = 1.23 km². Fig. 10 shows a sensitivity analysis for the ratio of the vertical surface area S_v to the horizontal surface area S_h. The true value of *d* is expected to be most likely in the range from 1.5 m to 1.9 m. The true value of *A* is very probably greater than 18 m² and less than 30 m². Thus the possible values of the ratio S_v/S_h are in the relatively small range between 0.9 and 1.4 (green area in Fig. 10).

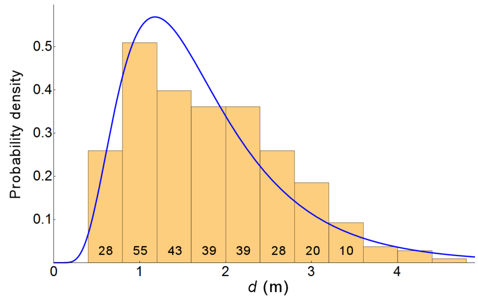

Figure 8. Frequency distribution (histogram) and probability density function (blue curve) of the measured crack depths *d* (numbers in the bars are frequencies)

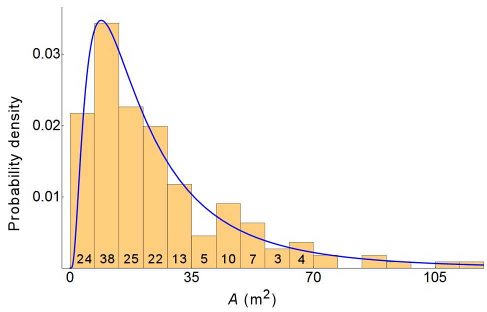

Figure 9. Frequency distribution (histogram) and probability density function (blue curve) of the base areas *A* of the prismatic tailings columns (numbers in the bars are frequencies)

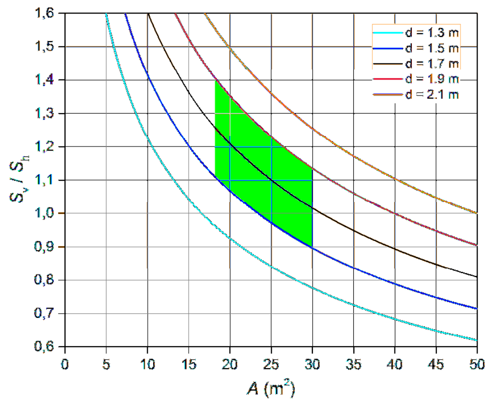

Figure 10. Sensitivity analysis for the ratio S_v/S_h (explanation see section 3.1)

3.2. Radium concentration in tailings samples

Table 1 shows the measured radium activity concentration in dried tailings samples from 9 different locations and various depths up to 2.2 m. The material from the central part of the dump (region 2) contains between 18 and 32 Bq/g Ra-226 with a mean value of 25 Bq/g. These results agree well with the findings of

Skipperud et al. [1]. There is no general correlation between the radium concentration and the depth of the sampling point. In the samples E, F, 18 and 22 from the surface of the northern part of the dump (region 1), the Ra-226 concentration is considerably lower (9.5 to 21.7 Bq/g). It is not surprising that the fine tailings in region 2 contain more Ra-226 than the coarse tailings in region 1, because it has been well known for a long time that the specific activity of radium in uranium mill tailings is generally inversely proportional to the particle size [5].

At measuring point 71, two clearly distinguishable horizontal layers of tailings material were carefully separated by means of a sharp knife. The radium content of the light grey (sample 71g) and the yellowish brown layer (sample 71b) is practically identical.

Table 1. Radium-226 concentration in tailings samples

Sampling point	Geographic coordinates	Depth (m)	Ra-226 (Bq/g)
A1	N40°13.471'/E69°37.718'	0.0	26.6
A2		0.5	26.1
A3		1.0	22.8
A4		1.4	17.7
B1	N40°13.450'/E69°37.719'	0.0	25.0
B2		0.5	20.9
B3		1.0	26.5
B4		1.5	20.9
C1	N40°13.446'/E69°37.758'	0.0	22.0
C2		0.7	26.1
C3		1.4	25.2
C4		1.8	28.1
C5		2.2	22.7
D1	N40°13.482'/E69°37.933'	0.3	23.7
D2		1.6	23.8
E	N40°13.680'/E69°37.413'	0.0	9.5
F	N40°13.652'/E69°37.429'	0.0	11.2
18	N40°13.736'/E69°37.799'	0.0	14.9
22	N40°13.682'/E69°37.444'	0.0	21.7
71b	N40°13.466'/E69°37.941'	0.1	31.5
71g		0.1	32.4

The mean Ra-226 activity concentration over the whole dump area can be estimated at 17 Bq/g from measured dose rates according to equation 3 (see next section). A rough estimate of the total Ra-226 activity of the tailings is 600 TBq (≈ 16 kg).

3.3. Surface dose rate

The results of the dose rate measurements at ground level are summarised in Fig. 11. The measured values of the ambient dose equivalent rate range from about 1 µSv/h along the dam to a maximum of 12.1 µSv/h in region 2. The mean values are 4.9 µSv/h in region 1, 9.2 µSv/h in region 2 and 6.4 µSv/h over the whole dump area. On average the dose rate at a height of 1 m is 11 % lower than at ground level.

Previously published dose rates from Digmai are somewhat ambiguous and contradictory. The maximum values reported by Lespukh et al. [6] and Stegnar et al. [7] are greater than 20 µSv/h. A detailed comparison of the measurement results is difficult because information about the used measuring instruments and the exact measurand is not available.

In principle, the dose rate at the dump surface depends on several parameters such as radium concentration, thickness, density, chemical composition and humidity of the tailings material. Monte Carlo simulations have shown that only the upper layer of the tailings with a thickness of approximately 0.5 m is relevant to the surface dose rate; deeper layers practically do not contribute to the dose rate because of the self-shielding of the tailings material. Provided that the thickness of the tailings is at least 0.5 m and the chemical and physical properties are relatively constant all over the dump, the following linear correlation can be derived from the measured Ra-226 activity concentrations C_{Ra} and ambient dose equivalent rates $\dot{H}^*(10)$:

$$\dot{H}^*(10) = 0.36\ \mu\text{Sv h}^{-1}\ \text{g Bq}^{-1}\ C_{Ra} + 0.28\ \mu\text{Sv h}^{-1} \quad (3)$$

This equation can be used to estimate the radium content in the tailings material on the basis of measured dose rates.

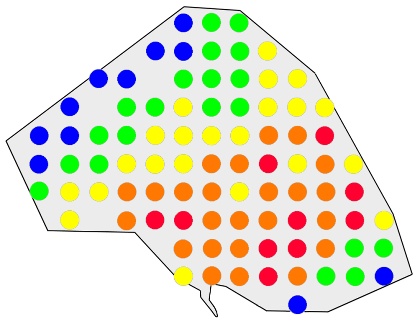

Figure 11. Measured ambient dose equivalent rate $\dot{H}^*(10)$ at the tailings surface (blue: $\dot{H}^*(10) < 2.5$, green: $2.5 \le \dot{H}^*(10) < 5.0$, yellow: $5.0 \le \dot{H}^*(10) < 7.5$, orange: $7.5 \le \dot{H}^*(10) < 10.0$, red: $\dot{H}^*(10) \ge 10.0$ µSv/h)

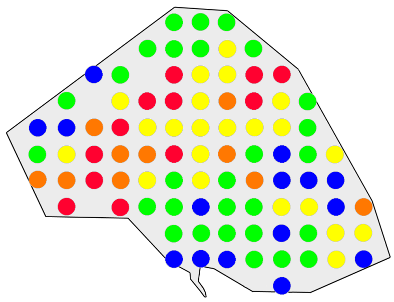

Figure 12. Measured radon exhalation rate E_h at the horizontal tailings surface (blue: $E_h < 1.2$, green: $1.2 \le E_h < 2.4$, yellow: $2.4 \le E_h < 3.6$, orange: $3.6 \le E_h < 4.8$, red: $E_h \ge 4.8$ Bq m^{-2} s^{-1})

3.4. Radon exhalation rate

In June 2013, the radon exhalation rate was measured all over the horizontal dump surface with DOSEman instruments; the results are shown in Fig. 12. The measured values range from 0.3 Bq m^{-2} s^{-1} on the edge of the dump area to 6.8 Bq m^{-2} s^{-1} in the western region. The mean exhalation rate is 3.2 Bq m^{-2} s^{-1} in region 1 and 1.7 Bq m^{-2} s^{-1} in region 2. Unexpectedly, there seems to be no clear correlation between the dose rate and the 'horizontal radon exhalation rate' E_h (see Figs. 11 and 12). But there is a linear relationship between the 'effective exhalation rate' E_{eff} (i. e. the weighted mean of the exhalation rates on the horizontal and vertical surface) and the dose rate all over the dump area:

$$E_{eff} = 0.56 \text{ Bq m}^{-2} \text{ s}^{-1} \text{ h } \mu\text{Sv}^{-1} \dot{H}^*(10) \qquad (4)$$

From May 2012 to May 2013, automatic long-term measurements of the radon exhalation rate were performed at one location (N40°13.590', E69°37.867') in region 2 in order to investigate the seasonal variation; the results are summarised in Table 2. The monthly mean values are usually between 1 and 3 Bq m^{-2} s^{-1}. Only in April and May a significant rise of the exhalation rate was found, which was probably caused by heavy rain. Usually the tailings material in Digmai is very dry; thus an increasing soil moisture results in an increase of the emanation coefficient (i.e. the fraction of the produced radon which is released from mineral grains into the pore space of the soil) and the radon exhalation [8].

Table 2. Long-term measurements of the radon exhalation rate E (in Bq m^{-2} s^{-1}) at location N40°13.590'/ E69°37.867'

Measuring period	Number of measure-ments	E_{min}	E_{max}	Mean radon exhalation rate (± standard deviation)
2012				
May 12–14	15	2.7	17.2	8.7 (± 4.1)
May 16–19	25	0.9	3.4	2.2 (± 0.7)
June 04–07	23	0.7	2.8	1.4 (± 0.7)
June 18–21	22	1.7	3.0	2.4 (± 0.4)
July 05–07	18	1.3	3.7	2.6 (± 0.7)
July 20–22	21	1.3	1.8	1.5 (± 0.2)
Aug. 7–10	18	1.1	2.1	1.6 (± 0.3)
Aug. 18–20	16	1.5	3.4	2.6 (± 0.6)
Sept. 04–06	12	0.5	1.2	0.7 (± 0.2)
Sept. 22–25	18	0.6	3.2	1.6 (± 0.8)
Dec. 14–15	6	2.1	3.8	2.8 (± 0.8)
Dec. 25	4	1.6	2.9	2.1 (± 0.6)
2013				
Jan. 10–11	7	0.8	1.1	0.9 (± 0.1)
Mar. 01–03	15	1.6	3.6	2.4 (± 0.7)
April 04–06	16	3.9	19.8	10.7 (± 5.3)
April 17–19	15	2.7	21.0	7.3 (± 5.2)
May 04–07	21	0.8	4.0	2.4 (± 1.0)
May 21–24	23	2.2	8.9	4.5 (± 1.7)
Annual average [1)]				3.2

1) May 2013 not included in the annual average

In 7 places, the radon exhalation rate was measured at the vertical crack walls and compared to the values from the horizontal surface at the same location. The results are summarised in Table 3. The horizontal and vertical measurements were made either simultaneously with two radon monitors RTM1688 or one immediately after the other with the same instrument. In any case, the radon exhalation rate on the crack wall (E_v) was significantly higher than at a nearby horizontal surface (E_h). The ratio E_v/E_h varies from 2.5 to 6.8 with a mean value of 4.4. Using this experimental ratio, the mean exhalation rate for the vertical surface of region 2 can be estimated at 4.4 · 1.7 Bq m^{-2} s^{-1} = 7.5 Bq m^{-2} s^{-1}. The difference in the horizontal and vertical exhalation rates is probably caused by the pronounced layer structure of the tailings sediment. Most likely, the radon diffusion is much faster along the horizontal layers than perpendicular to them; thus the horizontal transport of radon towards the crack walls is favoured by the layers and the upward transport is hindered.

From the area-wide snapshot data measured in June 2013, a daily radon exhalation of 0.41 TBq can be calculated for the total (horizontal and vertical) dump surface. But this value is only valid for the climatic conditions in June and a correction factor is required to take into account the seasonal variation of the radon exhalation. In our long-term measurements, we found an annual average of 3.2 Bq m^{-2} s^{-1} and a monthly average of 1.9 Bq m^{-2} s^{-1} for June (Table 2). Using the correction factor 3.2/1.9 = 1.7, the total annual radon exhalation of the uranium tailings dump Digmai can be estimated at approximately 250 TBq.

Table 3. Comparison measurements of the radon exhalation rate (in Bq m^{-2} s^{-1}) on the horizontal (E_h) and vertical (E_v) tailings surface

Meas-uring point	Geographic coordinates	E_h	E_v	Depth of the vertical measure-ment (m)	E_v/E_h
68	N40°13.466' E69°37.728'	1.3	4.2	0.5	3.2
68a	N40°13.480' E69°37.753'	1.2	8.1	0.4	6.8
A	N40°13.471' E69°37.718'	1.1	7.0	0.5	6.4
B	N40°13.450' E69°37.719'	1.0	3.4	0.5	3.4
C	N40°13.446' E69°37.758'	0.7	3.8	0.7	5.4
C	N40°13.446' E69°37.758'	0.7	2.1	2.2	3.0
D	N40°13.482' E69°37.933'	0.6	1.5	1.6	2.5

As a consequence of the high radon release of the tailings surface, the radon activity concentration in the ambient air is considerably higher than usual. Several measurements approximately 0.5 m above the tailings surface, in various locations under different climatic conditions, showed values in the range between 300 and 1000 Bq/m^3.

4. Conclusions

Results from several uranium mining areas all over the world show that the radon exhalation of uranium tailings can vary by at least three orders of magnitude from less than 1 to more than 10 Bq m^{-2} s^{-1} [e.g. 9, 10], depending on many parameters such as the radium activity concentration, grain size distribution, porosity, temperature and moisture content of the soil as well as wind speed, atmospheric pressure and air temperature. Most of the radon exhalation rates measured at the uranium tailings dump Digmai were found to be in a rather typical range between 1 and 10 Bq m^{-2} s^{-1}.

The radon release of the uranium tailings management facility Digmai is not expected to pose a direct threat to the population because there are no workers who have their permanent workplace there. At a distance of about 1 km from the dump, no elevated radon activity concentrations were detected in the ambient air.

One cause for concern might be the enrichment of long-lived solid radon daughter products in the surroundings of Digmai. There are only two important wind directions in the Khujand region: west-south-west and east-north-east. The wind from western directions blows the radon and its daughter products towards the lake Kairakkum, for example into the towns Kairakkum and Chkalovsk. During east wind, the village Digmai is probably most affected. In the areas east and west of the tailings dump, the long-lived radionuclides Pb-210 and Po-210 are expected to be found in above-average concentrations because radon daughter products attached to aerosols are deposited there by wind or washed out by rain. There seems to be no danger for the large city Khujand north of Digmai because wind from southern directions is very rare in this region.

The results of this work can serve as input data for atmospheric dispersion modelling to investigate the accumulation of radon progeny in the environment. The measured radon exhalation and dose rate data may also be useful to assess the effectiveness of future remediation measures in Digmai.

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