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Abnormal High Radon Exhalation Levels on the Mount Beshtau, North Caucasus

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Abstract. The measurements of radon exhalation rate, radon concentration in the air, gamma-doze rate and radium content in soils on the Mount Beshtau were carried out. The very high radon levels were discovered in local zone on the western slope. The radon exhalation rate in the anomalous zone achieves 15,000 mBq/m^{2}s, and the radon concentration in the atmospheric air exceeds 4000 Bq/m^3. These levels sufficiently exceed the local background. The extremely high values of radon exhalation rate in the anomalous zone cannot be explained by local sources of radon. Anomalous levels of radon exhalation probably result from radon transport out of fracturing zones with convective air flows. This thesis is confirmed by repeated measurements.

1. Introduction

Currently the attention of researchers from across the globe is focused on the geological aspects of radon risk mapping, i.e. on the study of the conditions for radon release from the geological environment [1-3]. Great attention is also paid to studies of radon concentration in uranium mines [4], radon exhalation from the surfaces of uranium tailings and dumps in frame of environmental activities related to uranium production. It was shown in [5,6] that the exhalation of radon from the surface of uranium dumps can achieve high values (more than 20,000 mBq/m^3), and the concentration of radon in the atmospheric air sometimes exceeds permissible levels for dwellings.

In Russia, one of the most radon-hazardous regions is the Caucasian Spas (North Caucasus). This region is characterized by the increased radioactivity of rocks, a system of deep faults, radioactive groundwater discharge. Both natural and man-impacted factors cause extremely high radon concentrations in some dwellings of this region [7]. In the area of Mount Beshtau the mining of the Beshtaugor uranium ore deposit was carried out and a uranium ore processing plant operated from 1949 to 1985. During the uranium mining a large number of galleries was excavated without subsequent laying of a mine space. Currently the entrances to the galleries are in most cases plugged with concrete. Radon in the subsurface environment is formed as a result of ^{226}Ra emanation from the walls of fissures in the uranium ore zones [8].

From the end of the 70s and up to the present rehabilitation measures are being carried out at the territory of the mine. To evolve the contribution of the man-impacted component to exposure of the population of towns and settlements located near Mount Beshtau, the background levels of the components of natural terrestrial gamma radiation in the open environment unaffected by technogenesis during the development of the mine needs to be determined. In this connection, studies were carried out on the conditions of radon exhalation in the area of the western slope of Mount Beshtau. After remediation, this area is used as a recreation zone for residents of nearby cities. Currently, this area is Beshtaugorsky Nature Park.

2. Materials and methods

Field studies on the western slope of Mount Beshtau were carried out in June 2017 along the border running between the upper (magmatic) and lower (sedimentary) parts of Beshtau. The daytime air temperature during the measurements varied from +25 to +32 °C, there were no precipitations at the time of measurements, atmospheric pressure fluctuated insignificantly in the range 748–753 mmHg. For the layout of the measuring points, see Fig. 1. At the measuring points, the radon exhalation rate from the soil surface, the ambient gamma dose equivalent rate (*H(10)/dt), and air radon activity concentration were measured. In addition, samples of soil and bedrocks were collected to determine the content of radionuclides with the γ-spectrometry in the laboratory.

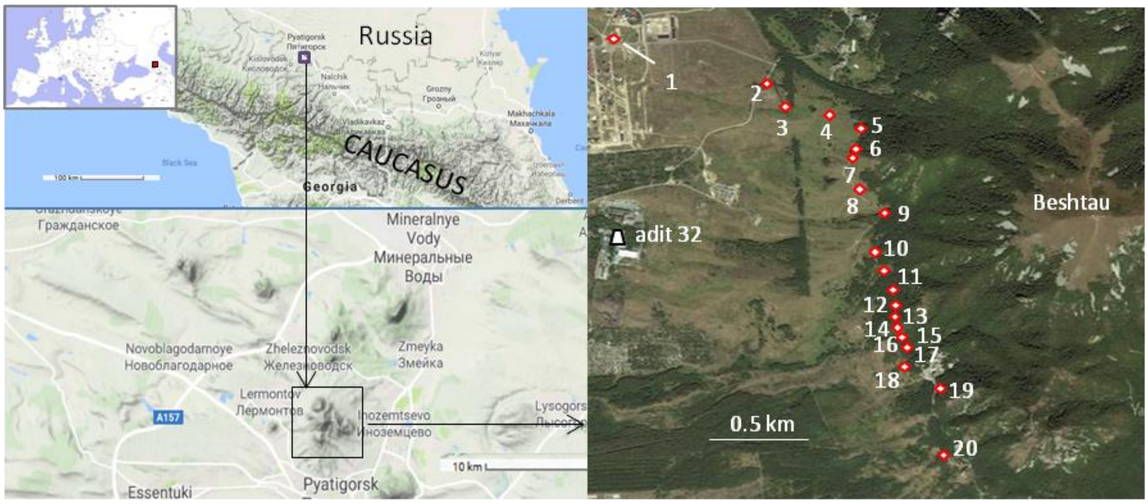

Figure 1. The location of the research area and layout of the measuring points.

The ambient dose rate was determined at a height of 0.1 m above the ground using the Geiger-Muller probes DKG-07D “Drozd”, the error of measurement is 15% (2σ). Radon activity concentration in the air was measured using an "Alpha-AERO" dose-rate meter, which was installed on the surface of the ground. The air was pumped through an analytical filter at a constant rate with simultaneous measurement of the α-emitting radionuclides activity using a semiconductor detector. For radon exhalation rate measurements, a measuring monitoring complex "Camera-01” was used. The open charcoal chamber method was applied. The principle of the open charcoal chamber is in the absorption of radon atoms exhaling from the limited soil surface by the activated charcoal layer, located in the accumulation open chamber. Chambers with activated charcoal were installed on the ground surface. The exposure time of the chambers was 4–8 hours. The relative short exposure time of the chambers causes low uncertainty of charcoal method because the relative humidity in air, temperature and other factors can not have a significant influence on the efficiency of radon collection at the short terms of exposure. The activity of ^{222}Rn in the charcoal was determined upon the activity of β-emitting radon progenies. The error of the activity measurement is at most 20% (2σ) [9]. Measurements of the content of ^{226}Ra in the soil and rock samples were carried out by γ-spectrometry using complex "RADEK" based on detector NaI(Tl) with the measurement error of at most 30% (2σ).

3. Results and discussion

Table 1 shows the results of measurements of radon exhalation rate from the soil surface, radon activity concentration in the air, content of radionuclides in soil and rock samples, and gamma dose rate. The central part of the mountain composed of magmatic rocks, is characterized by the high values of radon exhalation rate. The lower part of the mountain slopes mainly composed of colluvian and deluvian soils, the values of radon exhalation rate are much lower.

Table 1. Radioactive characteristics for the western slope of Beshtau.

#	Radon exhalation rate, mBq/m^2s	Radon activity concentration in air, Bq/m^3	Content of ^{226}Ra radionuclides in soils and rocks, Bq/kg	$^*H(10)/dt$, μSv/h	Type of surface substrate
1	419±64	8 ± 7	182±34	0.21	Maikop clay
2	398±61	<27	-	0.27	soil
3	226±35	9±8	57±10	0.28	soil
4	136±22	<24	62±18	0.21	soil
5	573±87	4±3	-	0.20	soil
6	58±11	<6	44±10	0.12	marl
7	3370±500	3±3	280±50	0.42	beschtaunite
8	75±14	<5	-	0.18	marl
9	485±74	<17	-	0.31	soil
10	843±120	<15	120±30	0.31	soil
11	783±120	<13	-	0.30	soil
12	3360±500	9±7	214±13	0.38	beschtaunite
13	972±140	<18	-	0.32	soil
14	15000±2300	4062±1800	156±32	0.48	soil
15	2750±390	10±5	203±38	0.53	beschtaunite
16	1210±180	62±29	160±34	0.49	soil
17	1670±215	<12	-	0.40	soil
18	897±140	<14	-	0.27	soil
19	337±51	11±6	151±24	0.43	beschtaunite
20	520±78	6±5	102±17	0.29	soil

At the measure point # 14, an anomalously high radon exhalation rate (15,000±2300) mBq/m^2s was registrated. This value is an order of magnitude higher than the background level determined by us for this part of the Beshtau and almost 500 times exceeds the world average value [10]. Radon concentration in the air at point # 14 was (4062±1800) Bq/m^3. The maximum air radon activity concentration is more than 400 times exceeds the world average value [10]. The anomaly is confined to the zone of temporary groundwater discharge. In the anomalous zone, the soil is characterized by increased permeability and moisture.

To clarify the results of measuring and the position of the anomalous zone in the area, near the measure point # 14, the measurements were taken at five additional points located along the short profile at a distance of 7–12 m from each other. The total length of the profile was 50 m. The values of the radon exhalation rate along the additional profile are given in Table 2. The additional points were numbered from south to north. Measurements showed that the zone of anomalously high radon exhalation rate is about 25 m wide and is clearly delineated in the area of groundwater seepage. The radon exhalation rate in this zone ranges from 12,700 to 15,000 mBq/m^2s. The radon activity concentration in air is (1500–4062) Bq/m^3. The content of ^{226}Ra in the soil sample collected at point # 14 was (156±32) Bq/kg. This value is typical for forest soils on the western slope of mount Beshtau and cannot explain the formation of abnormal high radon levels. In this case, it is obvious that the radon moves to the surface from the fault system.

Table 2. Results of additional measurements of radon exhalation rate in the anomalous zone.

Point #	Distance from the anomaly (p. #14), m	$^*H(10)/dt$, μSv/h	Air radon activity concentration, Bq/m^3	Radon exhalation rate, mBq/m^2s
14-1	27	0.34	12±6	1150±171
14-2	7	0.40	1500±250	12700±1900
14	0	0.45	4060±1000	15000±2300
14-3	12	0.37	<8	747±110
14–4	23	0.36	10±6	3900±550

There are a lot of known natural radon anomalies characterized by high radon levels exceeding the local background by more than an order of magnitude [11-15]. These are usually spatially localized areas; in which radon is generally assumed to be transfered for relatively large distances through permeable zones with gas or groundwater flows. Despite the high spatially localization of anomalous zones, the extremely high radon levels in them can lead to very high concentrations of radon in dwellings. It makes these zones the most significant factor of high radon risk [14]. The causes of the radon anomalies formation in natural conditions are the subject of discussion. These phenomena are associated with the circulation of convective air flows in a well-permeable geological environment due to the temperature difference between the rock mass and the atmosphere [14], with deep, possibly mantle degassing in active faults [12,15], and with radon transfer with the groundwater flows [13]. That is, observed phenomenas are similar but given explanations are different.

Furthermore such high values of radon exhalation rate from the soil and radon concentration in the air, as we have recorded, have not yet been encountered in the natural environment. So far, radon exhalation rate of more than 10,000 mBq/m^2s have been recorded only on the surface of uranium tailings [5], where a high level of radon exhalation was associated with a very high concentration of ^{226}Ra in uranium tails (from thousands to hundreds of thousands Bq/kg). Air radon activity concentration at these facilities was in the range (50–200) Bq/m^3. In Schlema-Alberoda in Saxony, Germany, during the rehabilitation of the sites of uranium corporation WISMUT, the values of radon exhalation rate up to 20,000 mBq/m^2s and radon activity concentration in the air up to 4500 Bq/m^3 were recorded at the foot of the dumps [6]. These values are comparable to those obtained by us. In this case, the very high radon levels were explained not by the high content of ^{226}Ra in the dump, but by the seasonal convective circulation of air in the dump body (a mechanism similar to [14]). In the summer descending flows of cold air enriched with radon were formed within the dump, these flows were discharged at the foot of the dump, creating the radon anomaly.

In our case the source of the anomalously high radon exhalation rate and air radon concentration probably can be convective radon transfer in the well-permeable tectonic fissures.

4. Conclusion

The studied area is a zone of increased radon risk due to the increased radon exhalation rate from the soil surface, which is stipulated by the high radium content in soils and rocks and is not associated with abandoned uranium mining. At the same time, on the slopes of Mount Beshtau an anomalous zone was revealed, where the radon exhalation rate achieved 15,000 mBq/m^2s. Such high levels of radon exhalation led to formation of the anomalously high concentration of radon in the atmospheric air that achieved 4062 Bq/m^3. The formation of the anomalous radon zone is possibly connected with the radon transfer from the rock mass with convective air flows in the summer time. The radon transfer with groundwater is also possible. To obtain more information on the origin of the revealed anomaly, further research is planned.

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