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Assessment of the radiation situation in the territory of the Saumalkol village, located near the mothballed uranium mine of the North Kazakhstan region

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For the first time after the mothballing of the uranium mine, comprehensive studies were carried out to assess the radiation situation in the territory of the Saumalkol settlement in the North Kazakhstan region. On the territory of the Saumalkol settlement, pedestrian and automobile gamma surveys were carried out, the rates of the ambient equivalent dose of gamma radiation, the flux density of α and β particles and the equivalent equilibrium volumetric activity of daughter products of ^{222}Rn and ^{220}Rn isotopes in residential premises were measured. Samples of soil, water and bottom sediments were taken for laboratory radio spectrometric and radiochemical analyzes. At all measurement points, geographic coordinates were determined using a satellite navigation device. On the territory of the abandoned mine and in some areas of the Saumalkol settlement, anomalous areas with a high value of gamma radiation power from 0.35 to 1.08 μSv/h were revealed. In the residential premises of the Saumalkol village, the equivalent equilibrium volumetric activity of daughter products of radon isotopes is up to 8 times higher than the norm (200 Bq/m^3).

Keywords: uranium mining industry, radioecological research, radionuclides, radioactive waste, equivalent equilibrium activity of radon isotopes.

Introduction

The development of the uranium mining industry has led to an aggravation of the radioecological situation in the territory of the Republic of Kazakhstan. The total amount of radioactive waste accumulated on the territory of the country, due to the activities of these enterprises, is estimated at 240 million m^3, of which 95% is waste from uranium processing plants [1].

One of the most potentially dangerous objects of the uranium industry in Kazakhstan is the Koshkar-Ata tailing dump, located 5 km from the city of Aktau (Mangistau region). Disposal of solid radioactive and toxic waste after uranium ore processing was carried out in a trench-type repository without control and without waterproofing. The actual mass of radioactive waste disposed in the tailing dump is about 360 million tons with a total activity of 11 000 Curie. After carrying out comprehensive environmental studies, as well as reclamation work at especially hazardous radiation sites [2], in 2021, work began on the complete reclamation of the territory of the Koshkar-Ata tailing dump.

At present, radioactive waste has accumulated on the territory of the country in the form of tailings from concentrating plants, heap leaching piles, tailing dumps of hydrometallurgical plants, dumps of poor commodity and unprocessed commercial ore, posing a great danger as a source of radioactive and chemical pollution of the environment and having a harmful effect on public health [3, 4].

In Northern Kazakhstan, as a result of mining and processing of uranium ores, about 61 million tons of radioactive waste with a total total activity of 168.4 thousand Curie have been accumulated. Radioactive waste with an uncontrolled release becomes permanent technogenic factors of radiation exposure of the population living near uranium mining enterprises [5, 6].

The main work on the conservation and liquidation of uranium deposits in the North Kazakhstan region was completed in 2007 [6]. However, in this program and other scientific and technical programs there are no measures for monitoring the radioecological state of natural environment objects. To date, an analysis of the available data shows that the radiation situation in uranium mining regions has not been sufficiently studied, the radioecological studies begun in the 1990s have not been completed to the end, there are no systemic scientific studies to study the degree of danger of contaminated areas around the mothballed uranium industry enterprises. In this regard, the study of the radiation situation in the territory of settlements located near uranium ore deposits is an urgent task.

One of the objects of the uranium industry subject to priority inspection are spent uranium mines in the area of the village of Saumalkol (the regional center of the North Kazakhstan region). In this work, studies of the radiation situation in the territory of the Saumalkol settlement, located near the mothballed mine, have been carried out.

Materials and research methods

Field research consisted of measuring the dosimetric characteristics of the environment. Radioecological studies were carried out in accordance with certified methodological guidelines using instruments and measuring devices that passed state verification in 2021.

The exploration gamma survey of the studied areas was carried out using a mobile radiological laboratory "Gamma-Sensor". Traffic routes were planned locally on a daily basis. The daily volume of automotive gamma survey was (0.4-0.6) km^2. Arrivals were carried out along the steppe roads (and off roads) near the territory of the abandoned mine, as well as in the territory of the Saumalkol settlement. When examining each territory, the starting and ending points were linked to the map. The spectrum acquisition time on the spectrometer was set equal to 10 s. With such a recruitment time, the statistical deviation of the measured value of the ambient dose equivalent rate (ADER) of gamma radiation at a given point from its root-mean-square value was no more than 0.005 μSv/h at a confidence level of 0.95. The speed of the car during the shooting was (6-10) km/h. The spectrometer was calibrated in terms of energy at the control point every day, while the calibration in terms of the dose rate and the values of geodetic coordinates were checked. After a working day on the way back, measurements were also taken at the control point. The systematic error in determining the position of the spectrometer was eliminated by the fact that the starting and ending points of the routes were snapped to the map.

During the survey of the area, measurements were also made of the ADER of gamma radiation, the flux density of α- and β-particles and the equivalent equilibrium volumetric activity (EEVA) of daughter products of ^{222}Rn and ^{220}Rn radon isotopes. Pedestrian gamma survey on the territory of the village of Saumalkol was carried out over a network (500×500) m with detailing in areas of radioactive contamination. Soil samples were taken layer by layer from (0-20) cm. Radiometric measurements were carried out with DKS-96, RKS-01-Solo dosimeters and a «Ramon-avtomat» radon monitor. With the help of an air intake device, aerosols of alpha-emitting daughter products of radon and thoron were sampled. To determine the coordinates, a satellite navigation device "Garmin" was used, which allows determining the location of points in a geographic coordinate system.

Laboratory methods for determining the radiation parameters of environmental samples included the use of highly sensitive radiometric and spectrometric instruments using radiochemical methods for concentrating and isolating isotopes. The total alpha and beta activity of solid samples was measured on a low-background semiconductor radiometer UMF-2000; The radionuclide composition of gamma emitters was determined on a scintillation spectrometer with a detector based on a NaI (Tl) single crystal (100×450) mm in size with a lead well, in the energy range (300-3000) keV, using the Progress-alpha software. The duration of the measurements of the samples was 3600 s, the main error did not exceed $\pm 30\%$.

The assessment of the annual effective dose of external exposure of the population was made according to the following formula:

$$E^{ext} = k^e(0.8P_{gamma,in} \cdot 0.2P_{gamma,out})T, \quad (1)$$

where, k^e – dose factor value (0.0007 mSv/μSv); $P_{gamma,in}$ and $P_{gamma,out}$ – measured values of ADER of gamma radiation indoors and outdoors in μSv/h; T is the total exposure time during the year, equal to 8800 h/year, 0.8 and 0.2 are the proportions of the time spent in residential premises and on the street, respectively [7-8].

The estimation of the annual effective dose of the inhabitants' exposure due to radon isotopes in the premises was calculated by the formula:

$$E_{\mathrm{Rn}} = 5.1 \cdot 10^{-6}\mathrm{mSv/Bq} \cdot V_{population} \cdot (0.8C_{in} + 0.2C_{out}), \quad (2)$$

where $5.1 \cdot 10^{-6}$ mSv/Bq is the conditional dose transition coefficient for the population; $V_{population}$ – from 1.0 to 8.1 thousand m^3, depending on age; C_{in} and C_{out} are the average annual values of EEVA of radon isotopes in indoor air and in open areas in Bq/m^3 [7, 9].

Research results

Mine administration No. 5 is located 5 km from the Saumalkol village in the Aiyrtau district of the North Kazakhstan region. The territory of the mining administration was 116 hectares of the mining allotment area provided for the development of uranium deposits. The mine administration included endogenous uranium deposits: Grachevskoe (complex, uranophosphoric series, concentration of ^{238}U - less than 0.3%), Kosachinskoe (monoelement, uranium ores, uranium content 0.1-0.3%) and Fevralskoe and others, which include to the Grachevsko-Chaglinsky uranium ore deposit of the North Kazakhstan uranium ore province. The mined uranium ore without preliminary enrichment and transshipment at intermediate stations was delivered to the central industrial site of the mining administrations in open gondola cars, which were filled to 2/3 of the full load to prevent blowing out and possible spillage of ore. At the central industrial site, the ore was partially enriched by the heap leaching method, and then it was transported on containers along the railway to the Stepnogorsk hydrometallurgical plant.

The water supply was carried out by underground waters of the Shok-Karagai and Ozerny water intakes. The territory of the mining administration allotment included Lake Bolshoy Koskol, which served as a reservoir for waste, mine and industrial waters. Water was discharged through a pipeline into this lake, which is not used for economic purposes. Previous studies have shown that the content of ^{238}U in water is 0.20 mg/l, the total activity of ^{226}Ra is 3.5 pCu/l, ^{232}Th is 1.73 pCu/l [10-13].

At present, Mining Administration No. 5, in accordance with program 008 "Mothballing of inactive uranium mining enterprises and elimination of the consequences of the development of uranium deposits for 2001-2010", approved by the Decree of the Government of the Republic of Kazakhstan No. 1006 dated 25.07.2001, has been mothballed, mined open pits are filled with waste rock from mines.

Our pedestrian gamma surveys of the territory of the abandoned mine showed that the ADER of gamma radiation ranges from 0.14 μSv/h to 1.08 μSv/h. In the western side of the mine administration (geographic coordinates: 53 ° 18′40.4"/68 ° 01′04.1"), areas with a violation of the integrity of the mothballed mine were identified with ADER of gamma radiation (0.40-0.57) μSv/h, with this background terrain 0.14 μSv/h. It should be noted that in these places the local population took samples of soil and sand for construction (Figure 1). On the territory of the abandoned mine, anomalous areas with a high ADER of gamma radiation from 0.35 to 1.08 μSv/h were revealed. On the territory of the mine administration there is a wood processing workshop and a warehouse for storing agricultural equipment, where the ADER of gamma radiation is (0.25-0.53) μSv/h. At 200 meters from the mine fence on the western side, the ADER of gamma radiation ranges from 0.12 to 0.27 μSv/h.

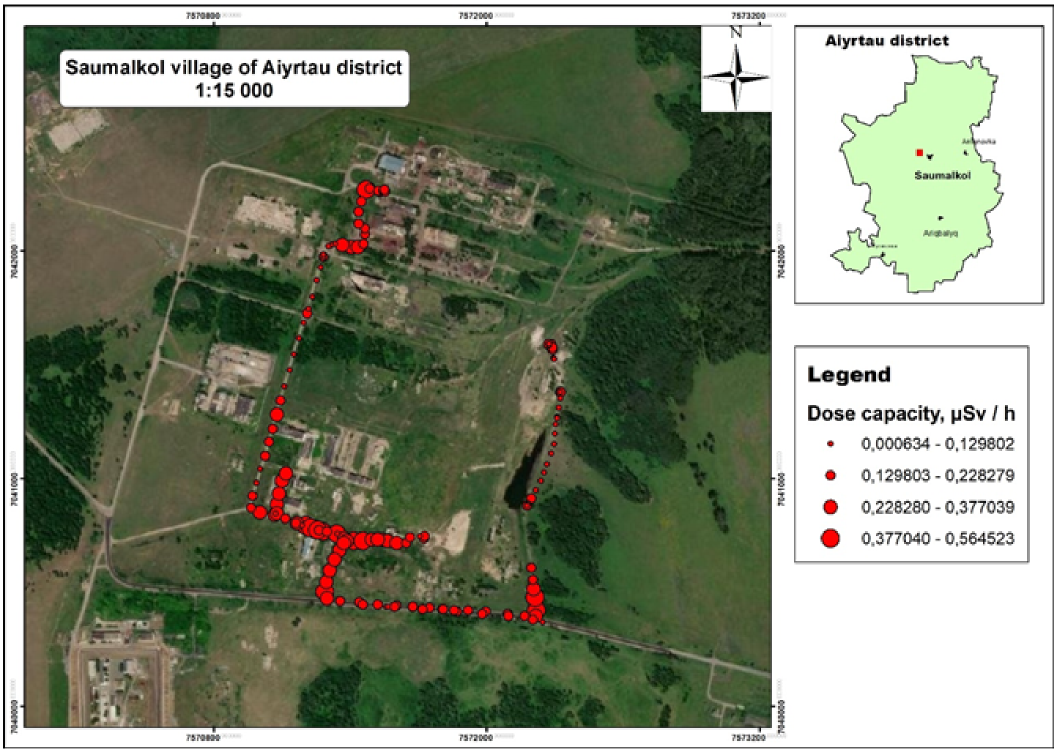

Figure 1. Pedestrian gamma surveys of the abandoned mine.

On the territory of the village of Saumalkol, ADER of gamma radiation ranged from 0.10 to 0.56 μSv/h. Along Energetikov street, near a crushed stone quarry, an anomalous area with ADER of gamma radiation up to 0.53 μSv/h was revealed (Figure 2).

The data of measurements of the nuclide composition in the soil surface from the anomalous area of the Saumalkol village were determined. The activity of ^{226}Ra, ^{232}Th, ^{40}K and other radionuclides in the soil surface is up to 7.37, 0 and 12.11 Bq, respectively. The concentration of other radionuclides varies from 34.81 to 38.4 Bq.

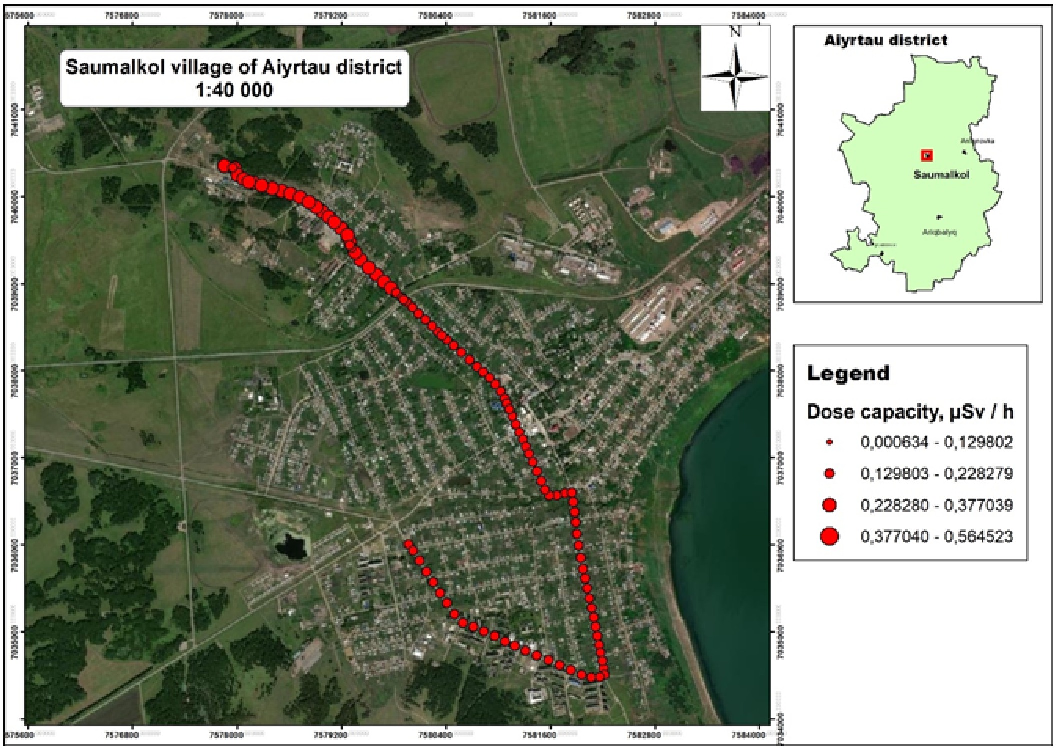

Figure 2. Anomalous areas of the Saumalkol village.

Studies of an open pit have shown that the ADER of gamma radiation varies from 0.31 to 0.91 μSv/h, which on average exceeds the background values of the area up to 6 times. Crushed stone from this quarry is used by local residents for backfilling personal plots, cellars, roads near the house, etc. Laboratory studies of the effective specific activity of natural radionuclides (^{226}Ra, ^{232}Th, ^{40}K) showed that crushed stone belongs to the 2^{nd} class in terms of hygiene requirements.

Among all sources of natural radioactivity, the main contribution to the annual effective dose is made by the radioactive gas-radon. The study of the equivalent equilibrium activity of radon isotopes in the village of Saumalkol showed that the radon level in residential premises varies from 173 to 1717 Bq/m^3 (see Table 1). In the private sector at 7/1 Energetikov Street in a residential building, the radon content is 8 times higher than the maximum permissible concentration. In the cellar of one of the houses in Saumalkol, the EEVA of radon is 56904 Bq/m^3.

In the course of the survey of the settlement, it was found that residential buildings with a high concentration of radon are concentrated near a crushed stone quarry, and within this local zone, the values of the EEVA of radon in the air, even in nearby houses, may differ. Spectral analysis of the soil showed that in the depth samples taken in the Saumalkol settlement, the specific activity of ^{226}Ra is 2 times higher than the average values for the republic. The specific activity of ^{232}Th, ^{40}K is within the admissible values.

Table 1.
EEVA of radon in residential premises of Saumalkol settlement, Bq/m^3 .

No.	Location	EEVA of radon, Bq/m^3
1	Energetikov street, 1/2	418
2	Energetikov street, 2	431
3	Energetikov street, 3/1	173
4	Energetikov street, 3/2	860
5	Energetikov street, 8/1	292
6	Energetikov street, 7/1	1717
7	Energetikov street, 10/2	903
8	Energetikov street, 10/2, in the cellar	56904
Maximum permissible concentration		200

The study of drinking water showed that the total alpha-activity in samples taken from the following water sources – in the Baiterek microdistrict and along M.Yanko street exceeds the maximum permissible concentration 2 times, on Energetikov street up to 5 times higher than the maximum permissible concentration (see Table 2).

Table 2.
Total alpha-, beta-activity of drinking water samples, Bq/l.

No.	Sampling locations	Total alpha activity	Total beta activity
1	Well in the microdistrict "Baiterek"	0.40	0.83
2	Energetikov street, 2 Well from a depth of 12 m	0.29	0.51
3	Mikhail Yanko street, well	0.44	0.27
4	Energetikov street, 10/2, Well from a depth of 75 m	0.97	0.20

When calculating the total annual effective radiation dose, the International Commission on Radiation Protection recommends that people spend 80% of their time in buildings. Therefore, the data on the annual effective dose of external exposure of the population was obtained on the basis of the measured values of ADER of gamma radiation in the premises of residential and public buildings and on the open territory of the settlement. The calculations showed that for the inhabitants of the Saumalkol settlement, living near the crushed stone quarry, the probable annual effective dose of external irradiation is 1.23 mSv/year. The probable annual effective dose of radiation to the inhabitants of this area due to radon isotopes is 22.52 mSv/year, while the admissible for the population is 10 mSv/year. The reason may be the presence of zones with an intense flow of radon or the use of prohibited building materials (crushed stone). For a detailed study, it is necessary to measure the radon concentration using integral dosimeters throughout the year. The discovered local area of radioactive contamination and high concentrations of radon in the living quarters of the Saumalkol village require appropriate measures to be taken to ensure the radiation safety of the population.

Conclusion

As a result of gamma imaging, an anomalous area was discovered and investigated on the territory of the village of Saumalkol, where the ADER of gamma radiation is up to 0.36 μSv/h, with a background of 0.14 μSv/h. The EEVA of radon isotopes in residential premises on Energetikov Street is up to 8 times higher than the maximum permissible concentration, in the cellar of one house this value reaches 56904 Bq/m^3.

Crushed stone from an open pit on Energetikov street of Saumalkol village belongs to the 2^{nd} class in terms of hygiene requirements and poses a danger to the population.

Radio spectrometric analysis of soil samples showed that the concentration of ^{226}Ra is 2 times higher than the average values for Kazakhstan. The total alpha activity in drinking water samples is up to 5 times higher than the maximum permissible concentration.

The probable annual effective dose of radiation for certain groups of the population in Saumalkol is 23.75 mSv/year, while the admissible for the population is 10 mSv/year.

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