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Assessment of the Potential Radiation Hazard of the Adrasman Tailing Dump (Tajikistan) for the Population Living Around It

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Abstract: The article features the outcomes of radiation monitoring in the territory of the Adrasman tailing dump and around it. Radiation monitoring was carried out by dividing the study area into several parts using the PackEye FHT1377 radiation detection kit. Some local points with increased values of ambient dose rate of gamma radiation were discovered. This is due to the transfer of radioactive material from the body of the tailing dump through atmospheric precipitation waters. Mudflows after heavy rains, flowing over the surface of the tailing dump, destroy its coating on the edges and carry the tailing material down the relief, polluting the environment. It has been established that at the destroyed boundary of the radioactive Adrasman tailing dump, the ambient dose rate reaches 3.7 μSv/h. Within the populated part of the Adrasman settlement, the ambient dose rate ranges from 0.10 to 0.30 μSv/h. The situation is aggravated by the fact that the contaminated area is used by residents of nearby houses for agricultural production and livestock grazing, as well as the use of tailing material in the construction of residential buildings. These circumstances negatively affect the radiation situation in this area. The study results demonstrated that the values of annual radiation doses are in the range from 3.15 to 21.47 mSv/year. The most significant contribution to exposure is made by: external gamma radiation; radon emitted from the surface of the tailing dump (if people stay on its surface); radon emitted from the structures of houses in the construction of which tailing materials were used. The given estimate of the dose up to 21.47 mSv/year is quite high and unacceptable in comparison with the accepted safe dose limit for the population of 1 mSv/year over the natural background. Based on the results of the radioecological monitoring carried out, it is proposed: to stabilize the radiation situation and to prevent the tailing material from being washed away, to build a drainage channel; in the future, aimed at actually improving the radiation situation, to carry out a set of reclamation measures in the area of the radioactive Adrasman tailing dump.

Keywords: Adrasman, Tailing Dump, Radiation, Monitoring, Dosimeter, Radiometer of Radon, Dose, Assessment

1. Introduction

1.1. Issue Relevance

The works [1, 2] give the history of the formation of the uranium tailing and its state on the territory of the Adrasman village. Intensive processing of uranium ores in the territory of the Adrasman village during 1941-1957 led to the formation of six radioactive tailing dumps with a volume of 60 to 100 thousand tons of waste. The hydrometallurgical plant (HMP) was built at the highest point of the Adrasman village, so that the tailing dumps would go down by gravity along wooden gutters. The mountain ravines below the plant, after being blocked by a pioneer dam (a highly specialized term for the method of building a dam by blocking a gorge in eolian bulk) were used as tailing dumps.

In the 1960s, around the formed uranium tailing dumps and on the surface of some tailing dumps, the local village authorities allocated land plots for the local population to construct residential buildings.

In the late 1970s due to the decrease in uranium ore production for processing, it was decided to transport the third tailing dump, which was located near the village motor depot, for recycling to the HMP in Chkalovsk (now, Buston city). The content of uranium in the materials of this tailing dump was up to 0.05%. Since the materials of the Adrasman tailing dump were alkaline, during processing together with acid-intensive ores, which were processed at the Chkalovsk HMP, a technological process was disturbed at the leaching unit. This fact forced to recycle the waste, and it was decided to combine all six tailing dumps into one. The second tailing dump was in the ravine with a capacity of 100 thousand tons. It could accommodate another 300 thousand tons. Therefore, it was decided to move the remaining tailing dumps Nos. 1 and 3-6, located within a radius of 10 km, to tailing dump No. 2 (Figure 1).

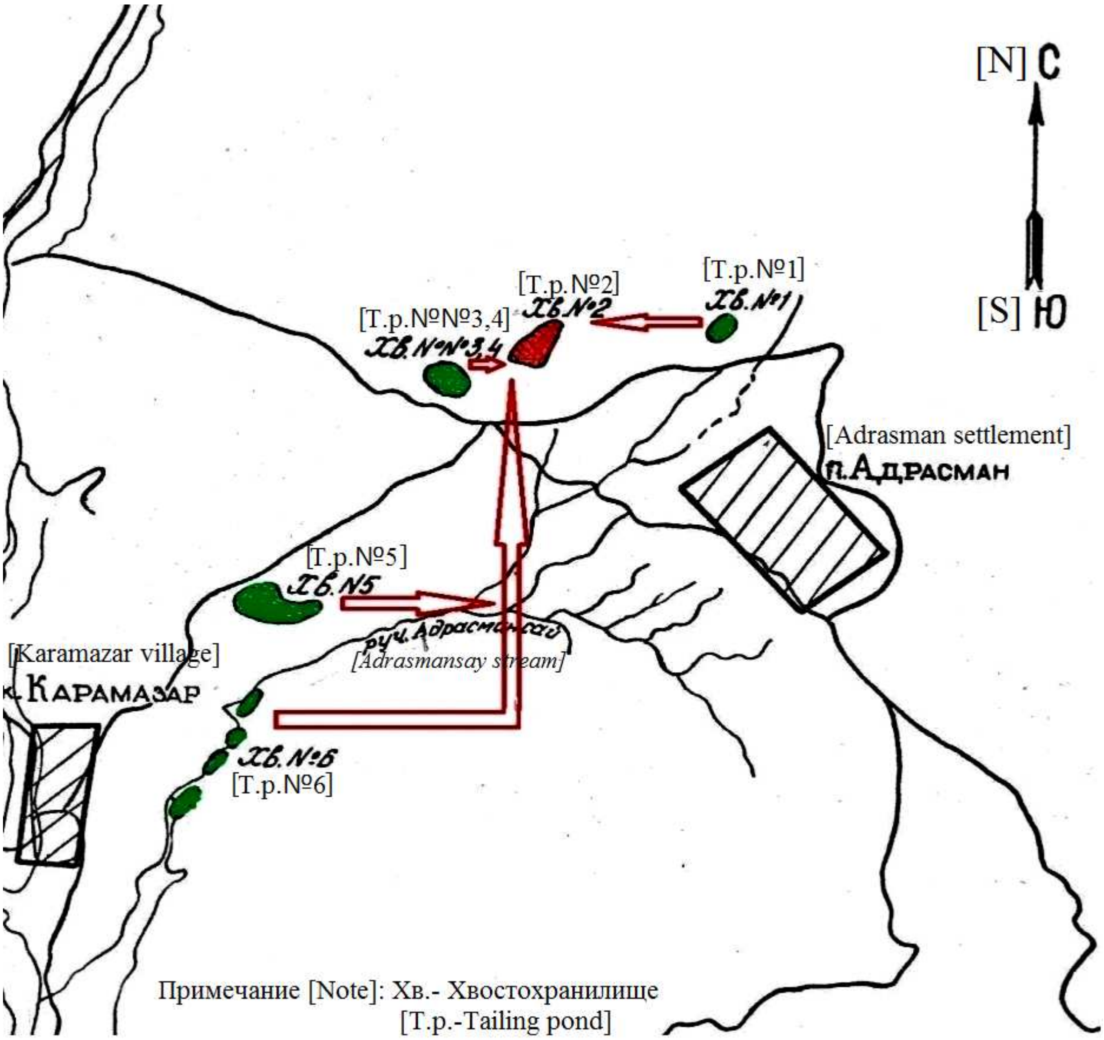

Figure 1. *Layout of radioactive uranium waste disposal.*

From 1992-1993 work began for the reburial of smaller tailing dumps into one – tailing dump No. 2. First, containers and metal structures contaminated with radionuclides were buried from tailing dump No. 5 (at a depth of 14-15 m under tailing dump No. 2). Due to the absence of clayey soil on the mountain massifs of tailing dump No. 2, it was decided to cover with a layer of 0.5-0.7 m of off-balance ores of the operating lead-zinc processing plant.

It currently occupies an area of about 2.5 hectares. It contains about 400 thousand tons of tailing material with a total activity of 5.92 TBq (160 Curie).

The tailing dump consists of two sites:

1) lower - corresponds to the position of the crest of pioneer dam;
2) upper - the final mark of waste warehousing and conservation.

Pioneer dam is composed of rubble-woody soils with loamy aggregate (up to 40%). The apparent thickness of the dam is 4.5 m.

There is no drainage system. Therefore, due to storm-flood waters, erosion occurs on the surface of the tailing dump.

1.2. The Purpose of the Study

The Purpose of this study is to assess the potential radiation hazard of the Adrasman tailing dump for the population living around it.

2. Materials and Research Methods

Radiation monitoring was carried out by dividing the study area (Figure 2) into several parts using the PackEye FHT1377 radiation detection kit ("Thermo Scientific", Germany) [3] and dosimeters ДКС-96 (Research and Production Enterprise "Doza", Russia), ДКС-АТ1123 ("Atomtech", Belarus). All devices have a certificate of metrological calibration, the measurement error of these devices is up to 20%. The PackEye FHT1377 radiation detection kit includes two Li-6 flat scintillation detectors and an extremely sensitive natural background radiation (NBR) plastic scintillation detector with voltage divider and photomultiplier. The energy measurement range is from 20 keV to 3 MeV.

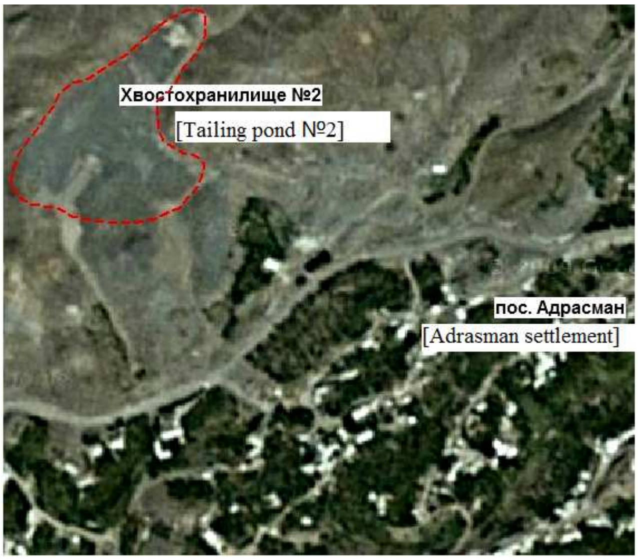

Figure 2. *Adrasman tailing dump.*

Radon monitoring was carried out using an PPA-01M-03 radon radiometer. The measuring complex, consisting of the PPA-01M-03 radon radiometer and the ПОУ-04 sampling device, was used to measure the radon flux density (PFD) from the earth's surface according to the well-known method [4, 5].

To convert the volumetric activity (VA) of radon to the equivalent equilibrium volumetric activity (EEVA) of radon, the value of the radioactive equilibrium coefficient F_{Rn} was used, equal to 0.4 for indoor air and 0.6 for atmospheric air, in accordance with the data of the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 and 2006 and recommendations of the International Commission on Radiological Protection (ICRP) [6-8].

To analyze the specific activity (SA) of natural radionuclides (NRN) in the soil, samples were taken from the tailing material in the study area according to the methods [9, 10]. Soil sampling was carried out according to the indicated methods, three samples from each point, from the ground surface to a depth of 25 cm. Each sample at the sampling point was cleaned from stones, roots, and other inclusions. More than 1 dm^3 of the sample was taken from the total mass by quartering. The samples were dried to an air-dry state, ground in a mill, and sieved through a sieve with a hole diameter of 2 mm. For gamma-spectrometric measurement of samples, a standard vessel "Marinelli" with a volume of 1 dm^3 was used. Soil samples were measured using a gamma spectrometer with a high-purity germanium detector (CANBERA, Genie-2000 software) with a measurement uncertainty of 5 to 12%, at the accredited Technical Services Laboratory of the Agency for Chemical, Biological, Radiation and Nuclear Safety of the Tajikistan's National Academy of Sciences. The gamma ray spectrometer was calibrated with a standard reference source, which is a homogeneous mixture of Am-241, Cd-109, Ce-139, Co-57, Co-60, Cs-137, Sn-113, Sr-85 and Y-88 isotopes. The isotopes are uniformly placed in a solid gel into a Marinelli vessel with a volume of 1 dm^3.

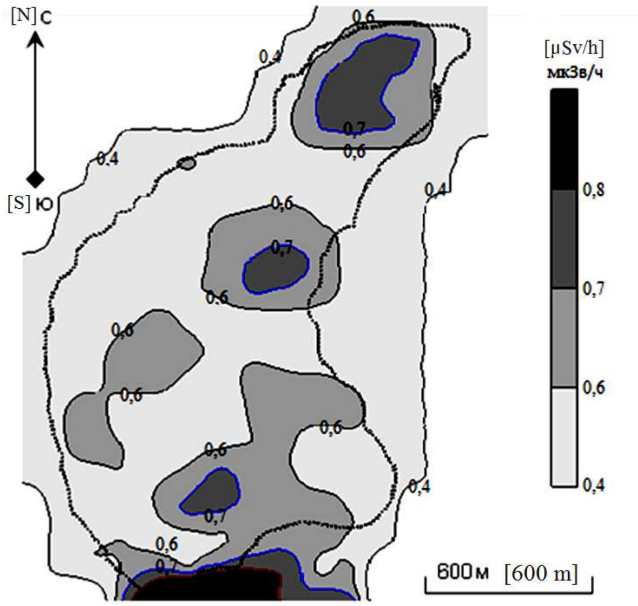

Figure 3. *Gamma-field map of Adrasman tailing dump.*

3. Results and Discussion

The average values of the ambient dose rate (ADR) of gamma radiation in areas that are not affected by the Adrasman tailing dump are about 0.15 µSv/h. SA NRN in the soil are given in Table 1. No NRNs such as ^{238}U and ^{228}Th were found in the sample compositions.

Table 1. *Activity concentrations (AC) of natural radionuclides in soil of the areas that are most likely not affected by the Adrasman tailing dump.*

Soil sampling points coordinates	**AC of natural radionuclides, Bq/кg**					
	^{40}K	**^{212}Bi**	**^{212}Pb**	**^{214}Bi**	**^{214}Pb**	**^{226}Ra**
69.97594°E, 40.65658°N	1254,7	47,9	58,1	83,5	88,8	-
69.97640°E, 40.65812°N	1284,8	48,3	41,4	84,0	72,8	-
69.97960°E, 40.65233°N	1195,8	53,4	-	845,5	787,4	138,0
69.98312°E, 40.65980°N	1299,9	46,2	44,7	71,0	63,0	-
69.98276°E, 40.64949°N	1021,4	30,8	30,3	60,9	57,1	114,1
69.97587°E, 40.64770°N	1046,6	40,8	37,6	72,6	70,6	146,8

Figure 3 shows the radiation map of the gamma field of the Adrasman tailing dump. The ADR of gamma radiation on the surface is 0.4–1.25 µSv/h, and in the body of the tailing dump it is 0.5–150.0 µSv/h (at a depth of 3 m).

On slopes down the relief, ADR values reach 1.75 µSv/h, which is associated with the transfer of radioactive material from the body of the tailing dump under the influence of atmospheric precipitation. Water flowing over the surface destroys the coating of the tailing dumps on the edges and carries the tailing material down the relief, polluting the environment.

In the lower part of the Adrasman tailing dump's territory, in places, an increased ADR of gamma radiation up to 3.7 µSv/h is detected (Figure 4). At the border of a settlement at a distance of 20-30 meters, these values decrease to 1.4 µSv/h.

To assess the radiation situation and the impact of the Adrasman tailing dump on the environment, a radiation map of the northern part of the Adrasman settlement was created (Figure 5).

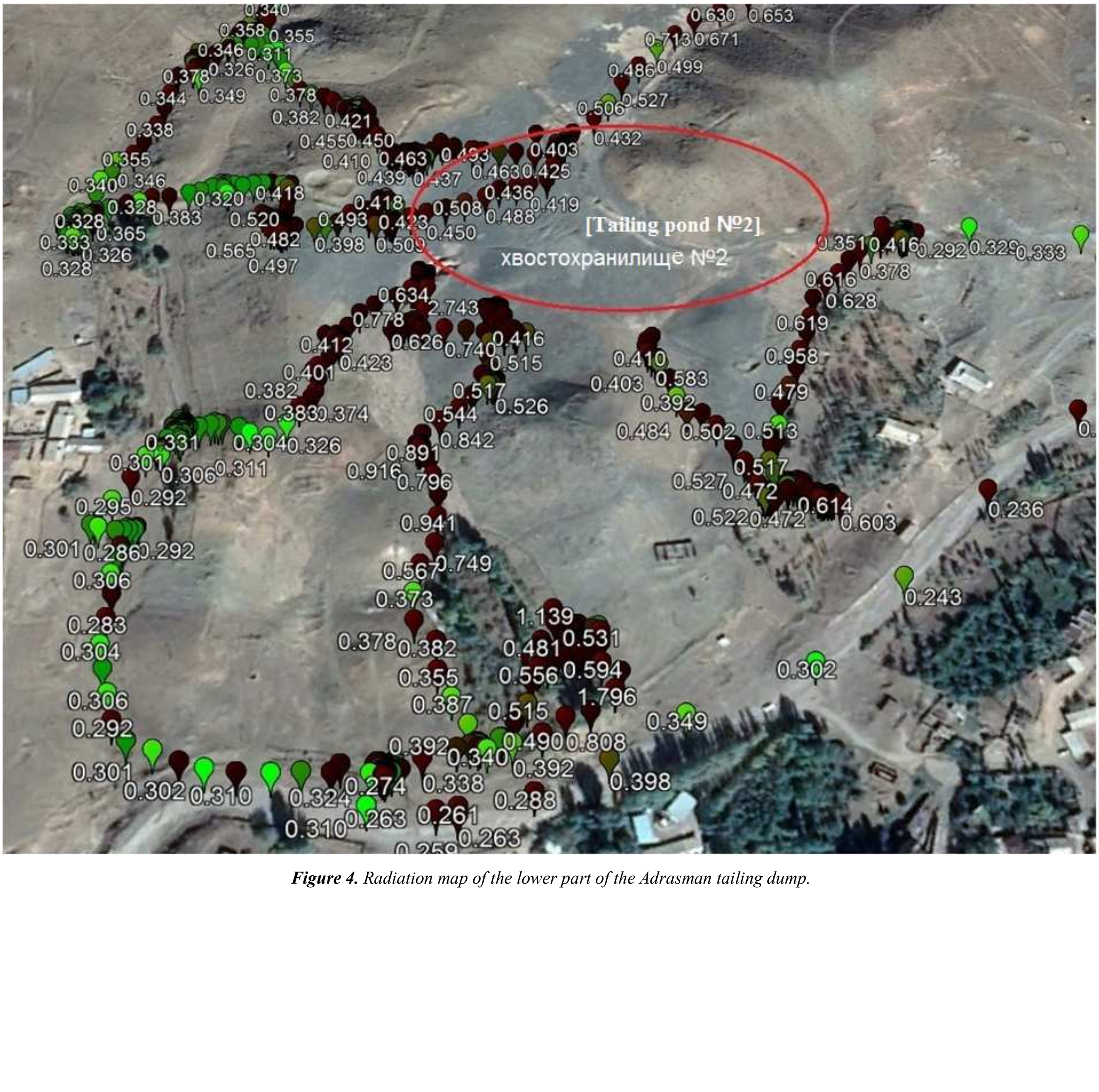

Figure 4. *Radiation map of the lower part of the Adrasman tailing dump.*

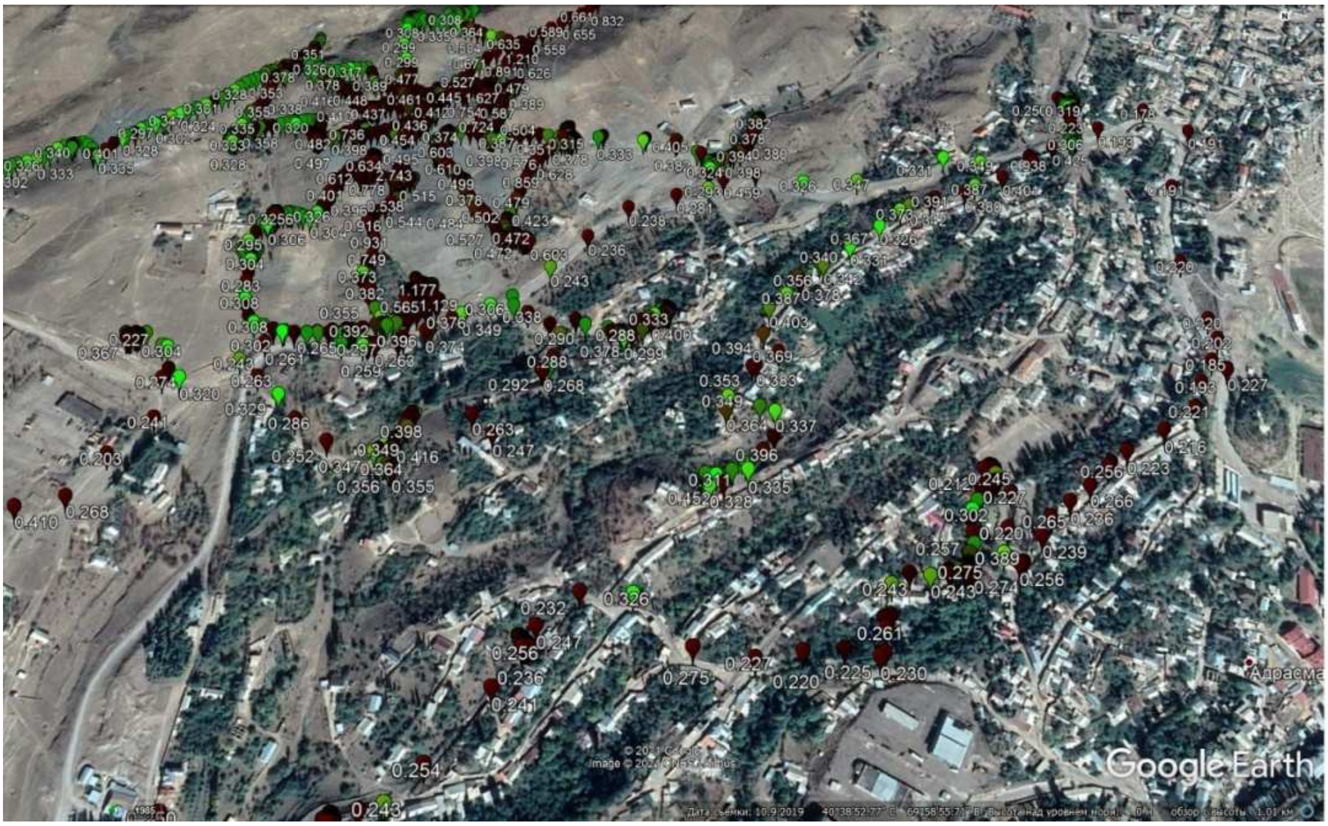

Figure 5. *Radiation map of the northern part of the Adrasman settlement.*

The ADR gamma radiation values within the northern part of the Adrasman village range from 0.1 to 0.3 μSv/h, if local anomalies are not considered, which are up to 30% higher than the natural radiation background. This is presumably due to the use of tailing material by the local population for construction and the transfer of tailing material by water for further irrigation of the sites with this water. The minimum and maximum ADR values of gamma radiation, averaged for each of the two studied areas (settlement and tailing dump) are given in Table 2.

Table 2. *Ambient dose rate (ADR) for the estimated sites around Adrasman tailing dump.*

Site	ADR_{min}, μSv/h	ADR_{max}, μSv/h
Settlement	0,1	0,3
Tailing dump	0,2	3,7

It is known that for the population, the most significant natural source of radioactive radiation is radon and its short-lived decay products (SDPs) [11-14].

Studies were carried out to assess the parameters of radon release into the atmosphere from the surface of the Adrasman tailing dump and the surface of the ravine, where the radioactive material of the tailing dump is carried away by temporary watercourses and its consolidation in the soil layer, as well as the content of radon in residential premises and in the yards of residential buildings closest to the tailing dump.

Previously, using track detectors of the RSKS type, the authors [15] determined the radon content in the air above the surface of the tailing dump No. 2, where the average values of radon VA were 150 Bq/m^3, radon EEVA were 90 Bq/m^3, and in residential buildings of the Adrasman settlement these values were 88 and 35 Bq/m^3, respectively. However, due to the constant washout of tailing material by mudflows, the radiation situation around the tailing dump is constantly changing (Table 3).

According to measurements, the content of radon in indoor air (samples 1–12) exceeds the values recorded in open areas (samples 13–16). However, they fit into the standards established by НРБ-06 [16]. Increased values of radon VA in residential premises are associated with the use of tailing material in the construction of houses, which leads, accordingly, to an increase in the radiation background [17].

The average value of PFD from the surface of the tailing dump (samples 17–20) is estimated at 2.44 Bq/m^2·s.

Content of NRN in soils. To analyze the soil for the content of NRN, 41 samples were taken. The minimum and maximum values of SA of radionuclides in soils (material of the tailing dump and the settlement adjacent to it) are given in Table 4.

Exposure ratings. The following factors and routes of exposure were taken into account in the calculations:

1) external exposure caused by soil contamination;
2) exposure due to inhalation intake of radionuclides with atmospheric air during inhalation, including radon and its SDP.

All calculations were performed for the adult population.

***Table 3.** Indoor and outdoor radon concentrations around the Adrasman tailing dump.*

№	Radon concentration, Bq/m³	Radon exhalation rate, Bq/m²·s	Radon EEC*, Bq/m³	Radon progeny concentration, Bq/m³		
				RaA (^{218}Po)	RaB (^{214}Pb)	RaC (^{214}Bi)
Indoor radon						
1	250	–**	100	52,02	8,55	12,62
2	157	–	62,8	21,02	6,25	8,22
3	161	–	64,4	30,02	7,25	8,82
4	134	–	53,6	48,72	7,76	1,69
5	134	–	53,6	20,02	5,25	8,82
6	129	–	51,6	24,12	5,15	8,72
7	126	–	50,4	18,02	5,55	9,62
8	88	–	35,2	30,02	7,25	8,84
9	157	–	62,8	21,02	6,25	8,22
10	161	–	64,4	30,02	7,25	8,82
11	164	–	65,6	48,72	7,76	1,69
12	134	–	53,6	20,02	5,25	8,82
Outdoor radon						
13	22	0,53	13,2	7,11	1,08	1,14
14	48	0,38	28,8	13,05	4,04	2,19
15	36	0,44	21,6	8,87	2,88	1,57
16	23	0,34	13,8	5,21	2,12	1,88
In the territory of tailing dump No. 2						
17	62	1,25	37,2	16,14	6,22	2,24
18	56	2,36	33,6	12,18	3,92	3,16
19	150	1,48	90	25,05	9,12	7,52
20	65	4,67	39,0	17,25	7,35	4,48

Note: * Radon EEC – radon equilibrium equivalent concentration;
** Radon exhalation rate measurement in dwellings was impossible.

***Table 4.** Activity concentrations (AC) of natural radionuclides in the material of the Adrasman tailing dump and in the soil of the settlement.*

Natural radionuclides	Tailing dump		Settlement	
	AC_{min}, Bq/кg	AC_{max}, Bq/кg	AC_{min}, Bq/кg	AC_{max}, Bq/кg
^{40}K	535	1812	963	1734
^{212}Bi	36	88	30	68
^{212}Pb	36	154	30	87
^{214}Bi	24	8737	60	2868
^{214}Pb	82	8407	57	2460
^{226}Ra	2087	29677	114	4205*
^{228}Th	487	9697	499	2285*
^{232}Th	30	342	-	-
^{238}U	118	1271	-	47

Note: *Abnormal values are related to the tailing material brought from the body of the tailing dump.

When assessing the exposure doses to the population in the Adrasman tailing dump, three hypothetical groups were considered.

Group 1. Village residents, who live relatively far from the tailing dump, and spend most of their time in relatively "clean" places. The buildings are not polluted as no materials from tailing dump were used for their construction.

Group 2. Representatives of this group live relatively close to the tailing dump and spend 10 hours a day in their garden plots, which are also located near the tailing dump. The soil of these sites is contaminated with tailing materials. Livestock also graze in and around the tailing dump.

Group 3. Representatives of this group live relatively close to the tailing dump and live in houses, during the construction of which the tailing material was used as plaster. They spend 14 hours a day in their homes, 10 hours a day in their garden plots, which are also near the tailing dump, and the soils are contaminated with tailing material. Livestock also graze in the area around the tailing dumps.

Table 5 demonstrates data about the duration of stay of various hypothetical groups of the Adrasman village population in the territory of the tailing dump and in the village where they live.

The calculated values of radiation doses for various routes and selected areas of radiological influence of the radioactive tailing dump are given in Table 6.

Estimates of exposure doses for representatives of three hypothetical groups, calculated for the influence area of the Adrasman tailing dump, are given in Table 7. When calculating doses from radon EEVA, the methodology described in the 2000 and 2006 UNSCEAR reports was used (dose coefficient d = $9 \cdot 10^{-6}$ mSv/(Bq·h/m³) was used in calculations) [18].

Table 5. *Duration of stay of different hypothetical groups of population in the sites of potential exposure in the Adrasman settlement.*

Hypothetical group	Outdoors in the vicinity of the tailing dump	Indoors (dwelling or workplace)	Outdoors
	Hours per year		
1	0	3650	5110
2	3650	5110	0
3	3650	5110	0

The values of annual radiation doses are in the range from 3.15 to 21.47 mSv/year. The most significant contribution to irradiation is made by:

1) external gamma radiation;
2) radon on the surface of the tailing dump if people stay on its surface;
3) residents of houses that were built using tailing materials may receive high doses of internal radiation due to radon inhalation.

The given dose estimate up to 21.47 mSv/year is quite high and unacceptable in comparison with the accepted safe dose limit for the population of 1 mSv/year above the natural background (radiation background in the territory of residence and stay of the hypothetical Group 1 is a natural background; the annual dose population exposure is 3.15 mSv/year).

Table 6. *Estimated range values of various radiation factors and possible exposure pathways of the population in the territory of the settlement and the Adrasman tailing dump.*

Exposure site	Exposure pathways	Value		
		min	max	average
Settlement, indoors	Gamma-radiation, µSv/h	0,2	0,8	0,5
	Radon EEC, Bq/m^3	40	100	70
Settlement, outdoors	Gamma-radiation, µSv/h	0,1	0,3	0,2
	Radon EEC, Bq/m^3	13	29	21
Tailing dump	Gamma-radiation, µSv/h	0,2	3,7	1,95
	Radon EEC, Bq/m^3	33	90	61,5

Table 7. *Estimated annual radiation doses to the hypothetical groups of population.*

Hypothetical group	Radiation dose, mSv/year	Contribution of diverse sources of exposure,%	
		Gamma-radiation	Radon
1	3,15	39,4	60,6
2	6,11	46,5	53,5
3	21,47	64,8	35,2

4. Conclusions

At present, under the influence of flood waters and atmospheric precipitation, the pioneer dam is being washed away and radioactive waste is carried out through the gullies and the soil is contaminated in the territory located below the tailing dump. It has been established that at the destroyed boundary of the radioactive Adrasman tailing dump, the gamma radiation ADR values reach 3.7 µSv/h.

ADR of gamma radiation in the village territory is 0.1-0.3 µSv/h. The situation is aggravated by the fact that the contaminated area is used by residents of nearby houses for agricultural production and livestock grazing, as well as the use of tailing material for the construction of residential buildings. This circumstance negatively affects the radiation situation in the area.

Based on the results obtained from the commissioned radioecological monitoring, it is proposed: to stabilize the radiation situation and to prevent the tailing material from being washed away, to build a drainage channel; in the future, in order to actually improve the radiation situation, to carry out a set of reclamation measures in the area of the radioactive Adrasman tailing dump.

5. Recommendations

To install signs of radiation danger on the territory of increased radioactivity to aware the population.

To organize awarening raising meetings with the population living in the risk zone in order to explain about conditions for protect people and the environment from radiation.

The results of the study can be used in planning, remediation of the territories of uranium legacy sites.

Acknowledgements

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