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Ways to reduce the risk of radioactive contamination at the Digmay tailing pond in Tajikistan

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ABSTRACT

The article presents the results of a study on the selection of materials based on local raw materials to reduce the risk of radioactive contamination in Digmay tailing pond in Republic of Tajikistan. One of problem with long-term storage of uranium production waste is the formation of radon – a radioactive gas that poses a serious threat to public health and the environment. The particular relevance of this problem lies in the fact that the tailings storage facility, as a source of radon, is located in close proximity to populated areas. Analysis of radon monitoring data in the Digmay tailing pond area indicates its state of increased radon hazard. The radon volume activity in different areas of the tailings storage facility varies from 50 to 680 Bq/m³, and the radon flux density ranges from 0.5 to 17 Bq/m²·s. The estimated annual radon emission from the tailings storage facility surface was found to be on the order of 201.52 TBq/year. The paper examines various surface covering models for tailings storage facilities aimed at reducing radon exhalation. Neutral soil and a composite mixture based on local raw materials were used as a protective barrier. The optimal parameters for the protective layer thickness have been determined. It has been established that with a radon barrier thickness of 0.45 m, a tenfold reduction in radon concentration is achieved (from 576 to 56 Bq/m³), while the radon flux density decreases by a factor of 21 compared to the initial values. The proposed model contributes to preventing environmental pollution by radon decay products, highlighting the need for a comprehensive approach to radioactive waste management.

Keywords: tailing pond, radon, flux density, volumetric activity, model, coatings, barrier, composite mixture.

INTRODUCTION

As a result of many years of uranium ore mining and processing in Tajikistan, approximately 55 million tons of radioactive waste have accumulated, which were placed in 10 tailings storage facilities. The total radioactivity of radioactive waste is approximately 240–285 TBq [1–5].

The Digmay tailing pond is located in northern Tajikistan, in the Sughd region, on territory of Bobojon Gafurov district, on the Digmay Upland, 1.5 km from the nearest settlement of Goziyon and 9 km from the regional center of Khujand. In 1963, the tailings storage facility was put into operation, covering an area of 90 hectares and containing approximately 20 million tons of uranium ore waste, about 500 thousand tons of off-balance uranium ore, and 5.7 million tons of waste from the processing of vanadium-containing raw materials, with a total activity of 156 TBq. Since 1963, the tailings storage facility has been filled to approximately 83% of its capacity. The tailing storage facility has not yet been decommissioned and is still active, and the surface of the tailing storage facility remains open. After the hydrometallurgical plant in the city of Chkalov (now Buston) ceased operations in 1996, cracks formed on the surface of the Digmay tailing pond (up to one-meter-wide and more than four meters deep). This was facilitated by the arid climate of the area, meaning the disappearance of the water mirror from the tailing pond (evaporation and drainage down the slope). As a result of the active wind dispersal of dried tailing material containing natural radionuclides and its decay into daughter products, there is a high risk of environmental and public health contamination in the direction of the prevailing winds [1].

One of the problems with the long-term storage of radioactive materials, uranium production waste, is the formation of radon. It poses a serious risk to human health and the environment. Especially if a radioactive tailings storage facility, as a source of radon, is located near populated areas, a detailed examination is required [6–10].

Radon exhalation from the surface depends on the density of the material coating, the pressure gradient, and the air temperature. International practice convincingly demonstrates that when creating radon barriers, it was most rational to use clays as buffer materials, as well as waterproofing layers for underlying and covering screens. In the coming decades, the volume of barrier clay materials used is projected to increase more than fivefold, which will require improvements in the regulatory framework, production technologies, and their application, including the development of solutions for specific sites, taking into account the current state of science and technology [11–15]. The aim of this study is to identify and justify the selection of materials used in creating radon barriers to enhance the safety of long-term storage and disposal facilities for radioactive waste.

Research objectives:
1. Study of the influence of grain size class and thickness of neutral soil on radon exhalation;
2. Studying the influence of the composite mixture on radon exhalation from the surface of the radioactive material.

Measurement method. Instantaneous measurements of radon volumetric activity (VA) were performed using a RRA-01M-03 radon radiometer according to the method described in [16, 17]. To convert the radon volumetric activity to equilibrium equivalent radon activity concentration (EERAC), a radioactive equilibrium factor F_{Rn} value of 0.6 was used for atmospheric air.

Ambient equivalent dose rates of gamma radiation were measured using dosimeters DKS-96 (Doza, Russia), DKS-AT1123 (Atomtech, Belarus) and a PackEye FHT-1377 (Thermo, Germany). Measurement location. Field measurements of radon exhalation were conducted at the Digmay tailing pond in northern Tajikistan in two directions (Profile I – longitudinal profile, Profile II – transverse profile) (Figure 1).

To study the influence of the particle size distribution and thickness of the radon barrier coating on radon exhalation from the surface

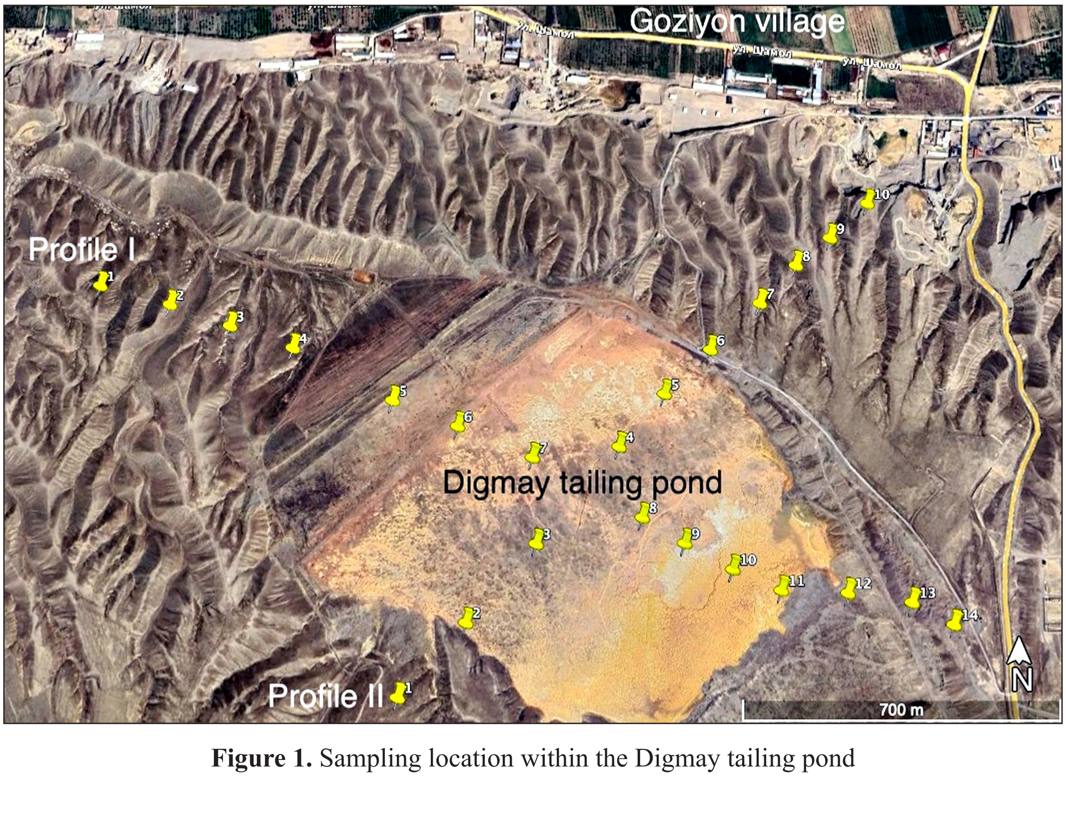

Figure 1. Sampling location within the Digmay tailing pond

of radioactive material under laboratory conditions, a setup was used, the schematic of which is shown in Figure 2.

Research results and discourse

Depending on the weather conditions and atmospheric stability parameters, air masses with high concentrations of radon and its decay products spread up to several kilometers from the Digmay tailing pond. The dose rate of gamma radiation on the surface of the tailings storage facility is within the range of 0.3 to 20 μSv/h. The concentration of radon released from cracks in the dried tailings material reaches 700 Bq/m^3. This value is significantly higher than the background level (20–36 Bq/m^3) of radon in the air for this area. The data obtained from radon monitoring in the area of the radioactive Digmay tailing pond are summarized in Table 1.

The average radon concentration, based on measurements taken above the surface of the Digmay tailing pond (Profile I and Profile II), is 340 Bq/m^3. The estimated radon activity was assessed to be 0.61 GBq in the near-surface layer above the tailing pond. Accordingly, the radon EEVA within the tailing pond (under windy conditions and significant air dilution) also increases. The average radon exhalation rate from the surface of the Digmay tailing pond was determined based on measurements taken at points located on the tailings

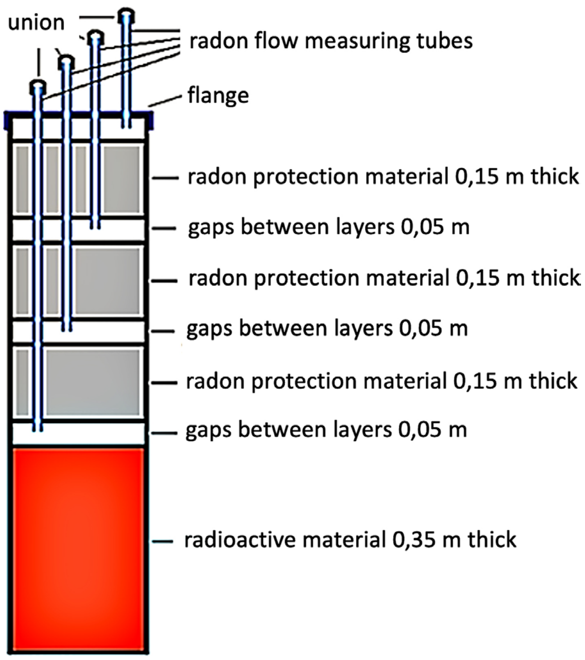

Figure 2. Diagram of the radon exhalation study setup with different coating thicknesses

dam body, ranging from 0.5 to 17 $Bq/m^2 \cdot s$, with an average of 7.1 $Bq/m^2 \cdot s$. Using this data, the annual radon emission was estimated to be $7.1 \times 36 \times 10^2 \times 24 \times 365 \times 90 \times 10^4 = {\sim}201.52$ TBq/year.

The estimated radon flux density (up to 17 $Bq/m^2 \cdot s$) is 17 times higher than the recommended safety level in Tajikistan (1 $Bq/m^2 \cdot s$) [18].

In this regard, we consider it necessary to explore ways to reduce radon exhalation from the surface of the radioactive Digmay tailing pond.

Option No 1

For the study, neutral soil of local origin was chosen as the shielding material. Neutral soil is a hard loamy sand with gravel and coarse-grained material, containing up to 20–25% (by total mass) of fine gravel and pebbles. Key physical properties (based on average values):

- specific gravity – 2540 kg/m^3;
- bulk density – 1720 kg/m^3;
- natural moisture content – 9.8%.

The tank model was used to estimate the actual radon diffusion coefficients in loam. This emitting layer (0.35 m) of radioactive waste from the Digmay tailing pond, with a mass fraction of ^{226}Ra of about $4 \cdot 10^{-10}$ g/g, was placed in installations with a volume of $V=0.03$ m^3. A layer of loam of varying thickness was laid on top.

After a diffusion equilibrium was established after 3 months, air samples were taken using a tube and the radon concentration was determined. Next, the apparent diffusion coefficient (D) was calculated. The results are summarized in Table 2.

As can be seen from Table 2, the average value of D for the model is 0.0146 cm^2/s. Over time, the loam compacts and self-seals, which leads to a decrease in the diffusion coefficient over time and, consequently, a reduction in radon entering the atmosphere.

Additionally, three models were developed, differing from the previous one due to the use of covering material with different particle sizes. In a neutral environment, on the surface of the emitting layer, air intake tubes were installed every 0.15 meters to determine the radon concentration at different levels. The thickness of the neutral soil was 0.45 m in all three models. The dependence of the radio shielding barrier on the coating thickness and the grain size class of the neutral soil is summarized in Table 3.

Analysis of the data presented in Table 3 indicates that after reaching equilibrium concentration

Table 1. Radon emission from the surface of the Digmay tailing pond

No of measurement points (see Figure1)	Coordinates	Radon flux density, Bq/m²·s	Radon VA, Bq/m³	Radon EEVA, Bq/m³
Profile I - longitudinal profile				
1	40°13’55.76”N / 69°36’50.36”E	5.28	680	408
2	40°13’54.33”N / 69°36’57.63”E	6.22	460	276
3	40°13’32.63”N / 69°37’3.84”E	12.66	520	312
4	40°13’50.90”N / 69°37’10.27”E	16.48	450	270
5	40°13’46.71”N / 69°37’20.45”E	5.86	480	288
6	40°13’44.74”N / 69°37’26.90”E	16.24	420	252
7	40°13’42.40”N / 69°37’34.27”E	12.68	484	290
8	40°13’37.93”N / 69°37’44.99”E	16.46	450	270
9	40°13’36.02”N / 69°37’49.11”E	16.89	426	255
10	40°13’34.10”N / 69°37’53.75”E	11.28	457	274
11	40°13’32.56”N / 69°37’58.41”E	11.41	628	377
12	40°13’32.38”N / 69°38’4.80”E	6.16	340	204
13	40°13’31.75”N / 69°38’10.69”E	5.28	680	408
14	40°13’30.10”N / 69°38’14.29”E	6.32	440	264
Profile II - transverse profile				
1	40°13’24.92”N / 69°37’21.02”E	1.18	50	30
2	40°13’30.24”N / 69°37’27.61”E	2.22	350	210
3	40°13’35.39”N / 69°37’3.84”E	3.14	340	204
4	40°13’43.21”N / 69°37’42.84”E	2.18	370	222
5	40°13’47.19”N / 69°37’47.46”E	1.35	160	96
6	40°13’50.53”N / 69°37’52.07”E	1.20	140	84
7	40°13’54.14”N / 69°37’57.23”E	1.13	110	66
8	40°13’57.19”N / 69°38’1.23”E	1.46	90	54
9	40°13’59.33”N / 69°38’4.80”E	1.89	80	48
10	40°14’2.25”N / 69°38’9.09”E	0.48	60	36

Table 2. Calculated diffusion coefficient values

No coating layer	Barrier layer depth, m	Diffusion coefficient (D), sm²/s
Layer I	0.6÷0.45	0.0226
Layer II	0.4÷0.25	0.0127
Layer III	0.2÷0.0	0.0086
Average diffusion coefficient value	0.0146	

of radon, the radon flux density value on the surface of the neutral layer was 1.8, 1.3, and 0.1 Bq/m²·s for the first, second, and third models, respectively. In accordance with the provisions of SP 2.6.1.001-06 (NRB-06), the surface activity of the neutral layer of the radioactive waste tailings storage facility should not exceed 1.0 Bq/m²·s.

Table 3. Characteristics of radiation protection parameters of models by individual layers

No layer and coating thickness	Material name	Model I (class -50+25 mm)			Model II (class -25+10 mm)			Model III (class -10 mm)		
		Radon flux density, Bq/m²·s	Radon VA, Bq/m³	Gamma background, μSv/h	Radon flux density, Bq/m²·s	Radon VA, Bq/m³	Gamma background, μSv/h	Radon flux density, Bq/m²·s	Radon VA, Bq/m³	Gamma background, μSv/h
Original, 0.35 m	Radioactive material	17±4.1	576±97	3.60÷3.70	17±4.1	576±97	3.60÷3.70	17±4.1	576±97	3.60÷3.70
Layer I, 0.15 m	Neutral soil	5.0±3.7	404±76	0.65÷0.70	3.5±2.2	366±42	0.47÷0.50	1.8±2.4	242±46	0.35÷0.40
Layer II, 0.15 m	Neutral soil	3.4±2.1	387±69	0.35÷0.40	2.7±2.7	235±41	0.25÷0.30	0.7±1.2	157±35	0.20÷0.25
Layer III, 0.15 m	Neutral soil	1.8±0.7	177±44	0.15÷0.20	1.3±0.7	152±32	0.15÷0.20	0.1±0.8	68±18	0.15÷0.20

Table 4. Characteristics of radon barriers by individual layers

No layer and coating thickness	Material name	Radon flux density, Bq/m²·s	Radon VA, Bq/m³
Original, 0.35 m	Radioactive material	17±4.1	576±97
Layer I, 0.15 m	Composite mixture	5.3±2.3	180±17
Layer II, 0.15 m	Composite mixture	2.6±0.6	105±43
Layer III, 0.15 m	Composite mixture	0.8±1.2	56±12

The results obtained from the studies on Model III fully meet the regulatory requirement.

Option No 2

The mixture used to cover the surface of the radioactive tailings storage facility includes the following components (wt%): sulfur – 25; bentonite – 15; magnetite – 15; quartz sand – 20; quartz gravel – 25.

The functional purpose of the components is determined by their physicochemical properties: bentonite reduces radon diffusion; magnetite provides gamma radiation attenuation; quartz sand and quartz gravel increase the tailings storage facility surface's resistance to wind erosion; and sulfur gives the mixture water-repellent properties.

At the bottom of the installation (Figure 2), radioactive tailings from the Digmay tailing pond are placed from a layer of 0.35 m, and on top of this, a composite mixture is filled in three layers with a total thickness of 3 × 0.15 m = 0.45 m.

Radon flux measurement tubes were installed at depths of 0.60, 0.40, and 0.20 meters, as well as on the surface of each layer. Once the equilibrium state was reached (after two months), measurements of the radon activity concentration were taken. The results are summarized in Table 4. From the data in Table 4, it can be seen that the intensity of radon exhalation significantly depends on the thickness of the protective barrier. As the coating thickness increases, radon emanation decreases, and at 0.45 meters, a tenfold reduction in radon concentration is achieved (from 576 to 56 Bq/m^3).

At the same time, the radon exhalation rate value decreased 21-fold (compared to the initial value) and showed the ability to protect the environment from radon contamination.

The study showed that using both options for covering the surface of the radioactive Digmay tailing pond is considered acceptable. However, it is necessary to prepare the shielding material (neutral soil and composite mixture) according to the grain size of the proposed options.

CONCLUSIONS

The analysis of the studies conducted indicates that the problem of radon emanation is more significant than previously assumed. The volumetric activity of radon in different areas of the Digmay tailing pond varies from 50 to 680 Bq/m^3, and the radon flux density ranges from 0.5 to 17 Bq/m^2·s. Radon emissions are approximately 201.52 TBq/year. At the same time, the radioactive gas radon accounts for about half of the total radiation dose a person receives annually from natural sources of ionizing radiation.

The studies were aimed at reducing the impact of the radioactive tailing pond on the environment by isolating its surface using neutral soil and a composite material. It has been established that Model III, which involves the use of neutral soil, is the most optimal, as it fully complies with the current regulatory requirements for tailings storage facility covers.

Applying a composite mixture 0.45 meters thick provides a tenfold reduction in radon flux, while its emanation coefficient decreases 21 times compared to the initial values.

Thus, the formation of radon barriers effectively reduces the negative impact on the environment and the health of the population living in the tailing dump's area of influence.

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