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# ASSESSMENT OF RADIATION INDICATORS OF ATMOSPHERIC AIR IN SOIL LAYERS OF ECOSYSTEM OBJECTS USING RADIOMETRIC METHODS

In this research, radiation indicators such as the specific activity of radon in the air and the effective dose rates were determined in various soil layers of technogenic areas. The study objects were selected from territories where uranium mine tailings are stored. Differences between soil layers and sampling sites were comparatively analyzed and evaluated based on graphs generated using the Python programming language.

Radiation in the atmosphere originates from numerous natural and artificial sources. Radionuclides such as uranium, thorium, and potassium are present in all ecosystem components. Approximately 82% of the total natural radiation dose that affects humans comes from natural sources. Among these, radon and its radioactive decay products account for about 55% of the total dose [1].

Radon ($^{222}Rn$) is a naturally occurring radioactive inert gas formed as a result of the decay of radium ($^{226}Ra$) in the uranium ($^{238}U$) decay series. Considering that uranium is present to some extent in all types of rocks and soils, radon is continuously produced in the natural environment and is released from soil particles into pores through the emanation coefficient. The release of radon from soil occurs via diffusion and convection processes. Soil porosity, moisture content, and the presence of fractures influence radon mobility. Radon moves more rapidly in dry, porous, and fractured soils. High moisture content causes radon to dissolve in water, thereby slowing its movement [2–4]. Radon is emitted from the soil surface into the atmosphere in gaseous form. Its release is often pronounced in geological fractures, volcanic regions, and especially in areas containing uranium ore deposits. Wind and temperature differences accelerate the dispersion of radon in the air. Once in the atmosphere, radon decays into short-lived progeny (polonium, bismuth, and lead isotopes), which can attach to aerosol particles and, when inhaled, reach the lungs, posing a significant health risk.

The aim of this study is to assess potential radiation hazards to the local population by evaluating gamma radiation levels and radon concentrations in technogenic areas.

The equilibrium equivalent volumetric activity (EEVA) of radon refers to the sum of the volumetric activities of radon progeny with short half-lives - $^{218}Po$, $^{214}Pb$, $^{214}Bi$, $^{212}Pb$, and $^{212}Bi$. EEVA is an indicator developed to evaluate the alpha energy of radon in the air and its short-lived progeny, assuming a state of radioactive equilibrium between radon and its decay products. The measured values were compared with safety limits established by international regulatory bodies, including the International Commission on Radiological Protection (ICRP), in order to identify areas with elevated radiation risk [5–6].

The research was conducted at sites storing uranium mining residues (tailings storage facilities). Although these areas are not located in close proximity to residential settlements, many radionuclides can easily migrate through dust and aerosols transported by wind. The highest migration rates are observed during the spring and summer seasons, while the accumulation of radionuclides tends to occur in areas where wind speeds are lower (depressions, mounds, slopes) as well as in zones inhabited by local populations [7].

**Measurement Instruments and Research Methods**

**Measurement of the Effective Dose Rate (EDR) of Gamma Radiation** The effective dose rate of gamma radiation, H*(10), was measured using the ДКС-96 radiometer-dosimeter, manufactured by the Russian company "DOZA". This portable device is specifically designed to detect and quantitatively assess ionizing radiation, particularly gamma radiation. Equipped with a scintillation detector, the ДКС-96 dosimeter measures radiation dose rates over a specified time interval (1–60 s) within a range of approximately 0.1 μSv/h to 10 Sv/h. The measurement uncertainty of the dosimeter is ±12%.

**Measurement of Radon Specific Activity in Atmospheric Air**

The equilibrium equivalent volumetric activity (EEVA) of radon in atmospheric air was measured using the "Alpharad Plus" automatic compact radiometer (manufacturer: DOZA SPZ, Russian Federation). The Alpharad Plus operates based on a semiconductor silicon detector and is specifically designed to accurately record the energy of alpha particles emitted from radon and its decay products. This allows for a highly precise assessment of radon concentrations in the air [9].

Measurements were carried out at four points (A, B, C, and D) within the study area, at soil depths of 0 cm (surface), 25 cm, 50 cm, and 100 cm. At each point, repeated measurements were performed three times to reduce statistical fluctuations and increase the reliability of the data. The arithmetic mean of these three results was calculated and recorded as the dose indicator for the respective point.

**Results and Analysis**

The measurement results of the equilibrium equivalent volumetric activity (EEVA) of radon in the air and the effective dose rate (EDR) at tailings storage sites in areas with uranium deposits, presented by soil depth, are summarized in Table 1.

**Table 1. Measured EEVA and EDR values at different soil depths in the study areas**

| № | Soil Depth | EEVA (mBq/m$^3$) | EDR (µSv/h) | Air Temperature (°C) | Humidity (%) | Pressure (mmHg) |
|---|---|---|---|---|---|---|
| **Site A** | | | | | | |
| 1 | 0 см | 1025±410 | 5.40 | 14 | 31 | 734 |
| 2 | 25 см | 923±369 | 8.20 | 14 | 31 | 734 |
| 3 | 50 см | 8778±3511 | 9.52 | 14 | 31 | 734 |
| 4 | 100 см | 11329±4531 | 6.50 | 14 | 31 | 734 |
| **Site B** | | | | | | |
| 1 | 0 см | 5320±2128 | 5.20 | 13 | 29 | 737 |
| 2 | 25 см | 17975±7190 | 7.75 | 12 | 39 | 737 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | 50 см | 37304±14921 | 12.3 | 16 | 38 | 737 |
| 4 | 100 см | 27747±11098 | 9.27 | 17 | 38 | 737 |
| **Site C** | | | | | | |
| 1 | 0 см | 3295±1318 | 6.12 | 11 | 34 | 737 |
| 2 | 25 см | 19049±7619 | 10.26 | 14 | 41 | 737 |
| 3 | 50 см | 27338±10935 | 10.1 | 14 | 42 | 737 |
| 4 | 100 см | 41995±1679 | 12,2 | 14 | 42 | 737 |
| **Site D** | | | | | | |
| 1 | 0 см | 22335±8934 | 4.46 | 18 | 39 | 736 |
| 2 | 25 см | 11989±4795 | 6.50 | 16 | 37 | 736 |
| 3 | 50 см | 18489±7395 | 7.33 | 10 | 32 | 736 |
| 4 | 100 см | 41544±16617 | 8.90 | 6 | 46 | 734 |

The measured EEVA values in the uranium-bearing study areas ranged from 923 to 41.995 mBq/m³, while the EDR values ranged from 4.46 to 12.2 µSv/h. These values are not considered high when compared with uranium regions in other countries of Central Asia and several other nations. Specifically:

**Radon concentrations in air:**

- Kurday, Kazakhstan – outdoor: 20 to 90 Bq/m³;
- Taboshar, Tajikistan – indoor: 15 to 330 Bq/m³;
- Digmai, Tajikistan – outdoor: 16 to 1500 Bq/m³.

**Equivalent dose rates of gamma radiation:**

- Kaji-Say, Kyrgyzstan – outdoor (tailings area): 0.3 to 15 µSv/h; at uranium ore points: 100 µSv/h;
- Taboshar, Tajikistan – outdoor, around the lake quarry: 0.3 to 3.9 µSv/h;
- Digmai tailings area, Tajikistan – outdoor: 0.12 to 22 µSv/h.

These values were obtained from the general reports of the NATO SfP RESCA project and the JNKKT (Joint Norwegian–Kazakhstan–Kyrgyzstan–Tajikistan) project [8].

The average values and comparative analysis of the equivalent equilibrium volumetric activity (EEVA) of radon and the effective dose rate (EDR) in the study sites were performed using a grouped bar chart created with Python programming libraries (Figure 1).

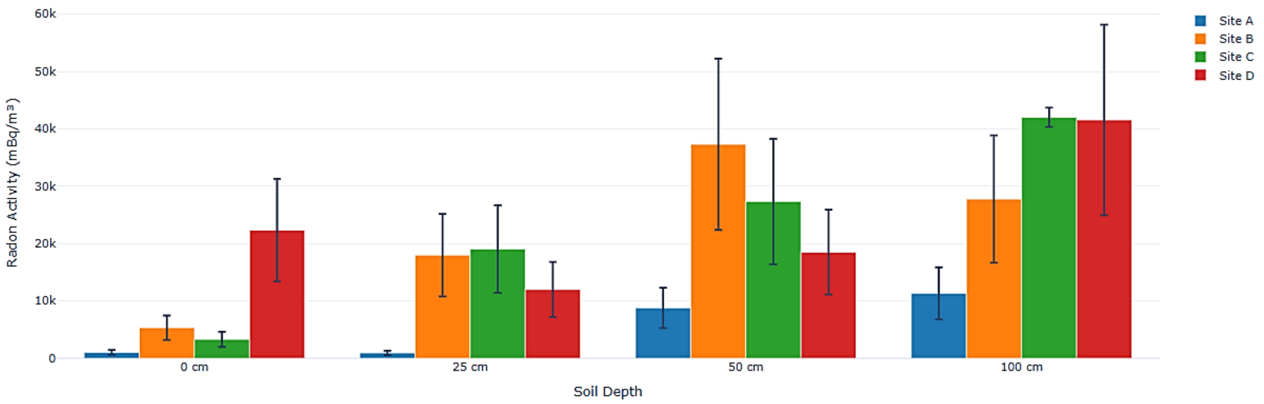


*Figure 1. Variation of radon activity with soil depth and location.*

In all study sites, radon activity increased with soil depth (from 0 cm to 100 cm), confirming the natural process of radon diffusion from the subsurface layers to the surface. Site A (blue) exhibited the lowest radon activity, while Site D (red) showed very high activity at 0 cm depth, indicating intensive radon exhalation through the ground surface. The highest values were recorded at 100 cm depth (in Sites C and D), where radon activity reached up to 40–50 thousand mBq/m³. These results suggest the possible influence of radioactive waste or enhanced radon emanation in those areas.

The variation of radon volumetric activity and effective dose with soil depth (Dual-Axis Line Plot) is presented in Figure 2. In the uranium-bearing sites (A, B, C, and D), the radon volumetric activity in the atmospheric air (left axis) is represented by continuous lines, while the effective dose values (right axis) are shown by dashed lines.

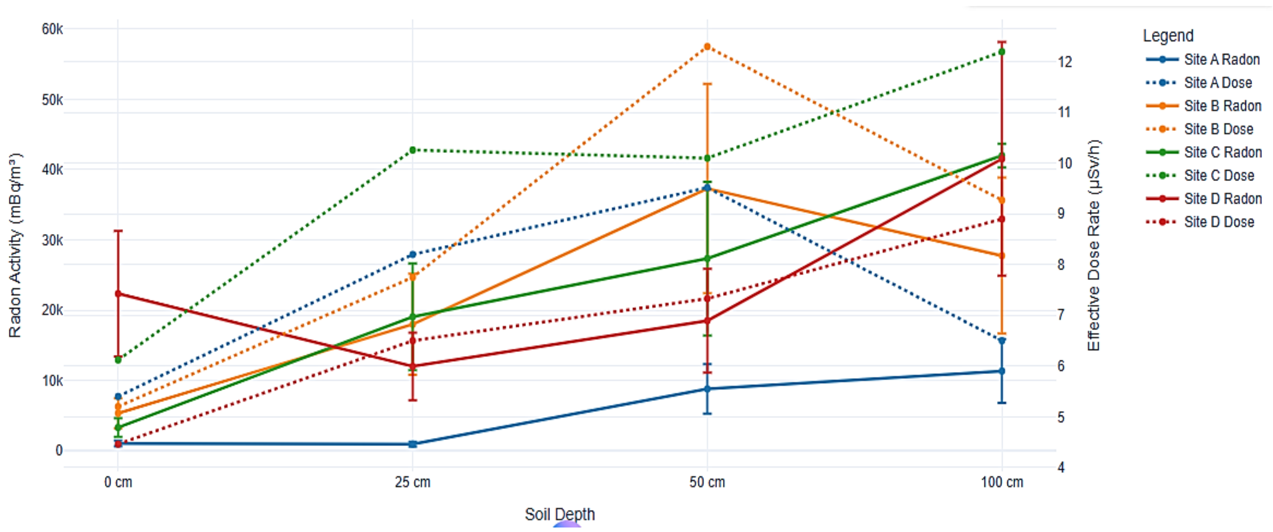


*Figure 2. Radon volumetric activity (continuous lines) and effective dose rate (dashed lines) by soil depth in the four uranium sites (A–D).*

As can also be seen from Figure 2, the specific activity of radon increases sharply with soil depth. The effective dose rate reaches its maximum at 50 cm and then decreases. The highest radon activity was recorded at Site D (41.544 ± 16.617 mBq/m³), while the highest effective dose rate was observed at Site B (12.3 µSv/h).

**Conclusion**

In this study, the volumetric activity of radon and the effective dose rate were determined in soils storing uranium residues at four sites (A–D) at depths of 0, 25, 50, and 100 cm. Field measurements were analyzed using the results presented in Figures 1 and 2. The analysis showed a significant increase in radon volumetric activity with soil depth. The correlation coefficient between depth and radon activity was found to be $R^2 = 0.43$, indicating that soil depth explains 43% of the variability in radon activity. The remaining 57% of the variability is associated with local geological parameters, including uranium distribution and soil characteristics.

The Pearson correlation between radon volumetric activity and effective dose rate was $r = 0.67$, $p = 0.004$, confirming a radiological relationship. The annual effective dose in all sites remained below 1 mSv/y (below the ICRP limit); however, in Sites B, C, and D at depths of 50–100 cm, local dose levels exceeded recommended limits. In future studies, radon transport in these areas is planned to be analyzed in greater detail through modeling using the HYDRUS-1D simulation software.

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