Modern Environmental Science and Engineering (ISSN 2333-2581)
February 2020, Volume 6, No. 2, pp. 294-301
Doi: 10.15341/mese(2333-2581)/02.06.2020/014
Academic Star Publishing Company, 2020
www.academicstar.us

Studying the Process of Dispersing Gamma Radiation, Radioactive Gas (Radon, Thoron) in Rare Earth Mines

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Abstract: In order to serve the national industrialization and modernization process, many mineral mines have been promoted and exploited to serve socio-economic development, including mineral deposits. radiation. When the exploration and exploitation process is carried out, it is necessary to have the impact of artificial factors to upset the rock layers, breaking the natural position of the ore bodies, increasing the dispersion process, leaching… makes the process of dispersing radioactive substances into the environment more and more powerful and complicated. Studying theoretical models and empirical surveys shed light on the spread of radionuclides emitting gamma radiation, radioactive radon, thoron on rare earth ore bodies containing radioactivity. Survey results on rare earth ore bodies cause gamma radiation dose rate with amplitude 0.6 ÷ 7.7 μSv/h, radon concentration has amplitude (30 ÷ 45).10^3 Bq/m^3, concentration degree thoron amplitude (45 ÷ 70).10^3 Bq/m^3.

Key words: radon, thoron, gamma radiation, radioactivity, rare earth, dispersal, environment

1. Introduction

Our country has abundant mineral resources, including radioactive ore mines (uranium in sandstone, Trung Nong Son coal) and many types of radioactive minerals (coastal placer, rare earths Nam Xe, Dong Pao, Muong Hum, Sin Quyen copper, uranium phosphate in Binh Duong).

Our country belongs to the tropical region, the climate is hot, humid and rainy, the surface soil is affected by strong weathering and weathering. Therefore, most of the ore mines in general and the radioactive ore mines in particular are in the form of "hidden" ores, the ore bodies are often buried under unconsolidated cover.

In many regions of our country such as Lai Chau, Lao Cai and Yen Bai, there are rare earth mines with large reserves of medium and large mines in the world. In rare earth ores containing radioactive substances Th, U, this is the cause of gamma radiation, high radioactive radiation abnormalities in the area [1].

The mineral mines themselves have high radioactive content causing radioactive anomalies with the radiation dose rate of tens of μSv.h^{-1}, the concentration of radioactive gases hundreds, thousands of Bq.m^{-3} in the area they exist. When exploring, exploiting, people carry out drilling, digging trenches, furnaces, opening fields... making soil cover and vegetation cover removed, ores excavated, collected and enriched. All these activities increase the natural radiation field (increasing gamma radiation, radioactive gas concentration...) at the mine and spreading the content of radioactive substances to the surrounding environment causing harmful impact to the environment and human health.

In the content of the article, the author presents the research results of the process of dispersing radionuclides emitting gamma radiation, radioactive gas from the body of rare earth ores containing

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radioactivity to the environment and proposing solutions to minimize mitigation.

2. Radon Emission to the Environment from Rare Earth Ore Bodies

The rare earth ores of our country are usually in the form of pockets, loaves, vessels or lenses. The content of total rare earth oxides TR_2O_3 ranges from a few percent to over 30%, averaging 10%. The content of roughri in weathered rare earths is 0.0199% to 0.0441% ThO_2, in rare earths original ore is 0.0087% to 0.0204% ThO_2, the uranium content in rare earths is from 0.001% to 0.023% U_3O_8 [1].

The ore body model has a width of tens of meters, a length of hundreds of meters, an average thickness of 3-4 m, a maximum of 7 m can be considered as a horizontal layer of ore lasting indefinitely.

Here we calculate the distribution of radioactive gas concentration in the two layer environment: infinite horizontal, the second layer is the radioactive ore layer below with the parameters: radioactive content q_2, concentration radioactive gas N_2, density ρ_2, pore coefficient η_2, diffusion coefficient D_2, a_{02} - amount of free eman released into $1cm^3$ stone in 1 second, ($Bq/cm^3.s$), emanization coefficient K^{e2} . The first layer is the top layer of thickness h and parameters N_1, ρ_1, η_1, D_1, K_{e1} (Fig. 1).

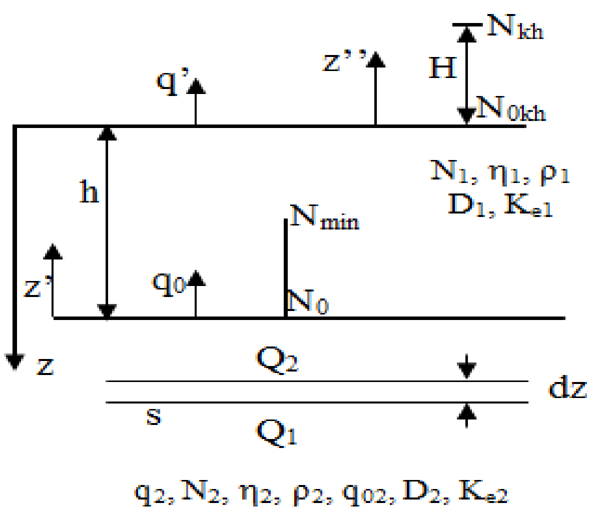


Fig. 1 Model of radioactive gas concentration distribution in the ore layer.

The concentration of radioactive gas N in an environment with pore η varies only in the z-axis direction. The differential equation for equilibrium of radioactive gas in the dx layer has the following form:

$$\frac{\partial}{\partial t}(N\eta Sdz) = Q_1 - Q_2 + a_0 Sdz - \lambda N\eta Sdz \qquad (1)$$

In which: radioactive gas flows through the area S of class dz

$$Q = DSdN/dz + vN\eta S \qquad (2)$$

$$a_0 = N_\infty\lambda = K_e q\rho\lambda.3.7.10^{10}. \qquad (3)$$

The distribution of radioactive gas concentration according to the sampling depth z is determined by solving the differential Eq. (1) [4, 12].

2.1 The Concentration of Radioactive Gas in the Covered Soil (the First Layer When z <h)

$$N_1(h-z) = N_0 e^{m_1(h-z)}\frac{sh(n_1 z)}{sh(n_1 h)} \qquad (4)$$

2.2 The Concentration of Radioactive Gas in the Ore Layer (Second Layer z > h)

$$N_2(z) = N_{2\infty}\left[1 - \frac{e^{-(n_2+m_2)(z-h)}}{1+\frac{D_2(n_2+m_2)}{D_1 n_1[(cth(n_1 h) - \frac{m_1}{n_1})]}}\right] \qquad (5)$$

In which:

$$N_0 = N_{2\infty}\frac{1}{1+\frac{D_1 n_1}{D_2(n_2+m_2)}[cth(n_1 h) - \frac{m_1}{n_1}]}$$

N_0 is the concentration of radioactive gas at the boundary of the first and second layers.

$$m_i = \frac{v\eta_i}{2D_i}\ ;\ n_i = \sqrt{m_i^2 + \frac{\lambda\eta_i}{D_i}}$$

When h → ∞, the formula (4) has the form:

$$N_1(h-z) = N_0 e^{-(n-m)(h-z)} \qquad (6)$$

If r = h - z is the distance that the concentration of radioactive gas decreases from the value N_0 to the value of N_{min} (the minimum value that the radioactive gas device can reliably determine), then we determine:

$$r = 2{,}3\lg\frac{N_0}{N_{\min}}\frac{1}{\sqrt{(\frac{v}{2D^*})^2+\frac{\lambda}{D^*}}-\frac{v}{2D^*}} \qquad (7)$$

In which:

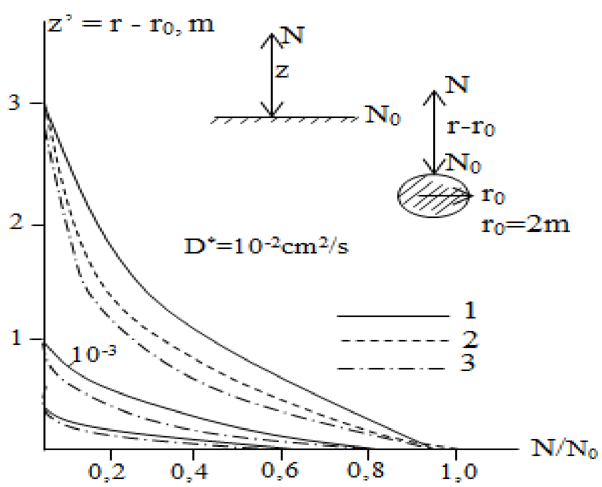
v - convection rate of radioactive gas,

D^* - apparent diffusion coefficient $D^* = D/\eta$.

Eq. (7) is used to assess the depth of the radioactive gas method.

Theoretical calculations indicate that the propagation of radon from the source to the ground and the depth of the radioactive gas method depend on the parameters D* and v.

The results of calculating the radon concentration distribution on the ore bodies of different shapes (Fig. 2) show that the decrease in the value of the concentration when away from the source mainly depends on the diffusion coefficient D* which little depends on the type of ore body, if the coating thickness does not exceed the ore body diameter [4].



1- The infinite ore layer

2. The ore body has a horizontal cylinder shape

3. The ore body is in the form of a sphere

Fig. 2 Rn concentration distribution on different shape ore bodies.

Due to the short half-life ($T_{1/2}$ = 54.5 seconds), the depth of the radioactive gas method for thoron is only about 2-4 cm. This means that the depth of the thoron method corresponds to the depth of gas sampling [4].

2.3 The Concentration of Radioactive Gas in the Air Environment

From the model of ore layers and soil cover as shown in Fig. 1, we can calculate the concentration of radioactive gas in the air above ground $N_{kh}(0)$ and at height H from ground $N_{kh}(H)$.

$$N_{kh}(0) = N_\infty \eta\sqrt{\frac{D^*}{A}} \qquad (8)$$

$$N_{kh}(H) = N_{kh}(0)e^{-\sqrt{\frac{\lambda}{A}}H} \qquad (9)$$

in which: A - ground air stirring coefficient is 10^3 cm^2/s while H = 30-50m then A = 10^4-10^5 cm^2/s.

Theoretically and empirically can determine the concentration of radon in air close to the ground thousands of times smaller than its value N_∞ in rocky environment. In the absence of wind, the radon concentration in the atmosphere decreases slowly with altitude; thoron concentration decreases very quickly and completely eliminates at a distance not exceeding 10cm from the ground [1-4].

3. Emission of Gamma Radiation to the Environment from Rare Earth Ore Bodies

In the process of exploration and exploitation of rare earth ores, it is necessary to carry out the work of drilling, excavating, making roads… All of these processes cause the surface rock to be disturbed, increasing the discovering the ore body, making gamma radiation field from the ore body easily spread into the environment. For gamma radiation field, there are two main emission mechanisms:

- Gamma radiation has a large puncture ability, so in each project, each trenching area, the seams become a source of radioactivity exposed on the surface, gamma radiation field easily penetrates in the atmosphere far away from its source.

- The process of digging, trenching and drilling will bring to the surface a large amount of rocky soil containing radioactive ores, these radioactive substances dissolve on the one hand, and move mechanically on the other topographic conditions go far from their original locations, causing widespread pollution in many places.

To see the level of distribution of gamma radiation in the environment as well as the ability of the influence of gamma radiation to each different position in the air environment. The following gamma radiation theory is calculated on a rare earth ore block model with an average uranium content of 0.01% typical U3O8 [5-8, 11]. The radioactive ore body in this case is considered to be horizontal ore body, finite in size. The intensity of gamma radiation caused on the ore body at each position relative to the ore body boundary is calculated as follows:

The source of gamma radiation here is considered to be a finite disk-shaped source with radius R right on the ground. The medium that determines gamma radiation intensity is the air environment (Fig. 3).

The intensity of gamma radiation emitted by the source is limited in the ground, the radius r is calculated as follows: Considering the intensity of gamma radiation of the source element, the volume dm has the volume dV in the radioactive disk. The source strength of the dI element is calculated as follows:

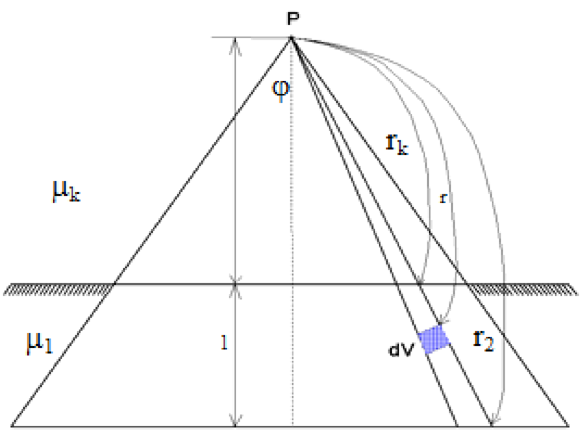


Fig. 3 Gamma radiation field of finite size source.

$$dI = K\frac{dm}{r^2}e^{-\mu_1(r-r_k)-\mu_k r_k} = KQ\rho e^{-\mu_1(r-r_k)-\mu_k r_k}.\sin\psi.d\psi.dr.d\varphi \qquad (8)$$

Calculate the integral by the finite disk volume:

If: r_k = Hsecψ

r_2 = (H+1)secψ.

$$I = KQ\rho\int_0^{2\Pi}\int_{r_k}^{r_2}\int_0^{\psi_0}e^{-\mu_1(r-r_k)-\mu_k r_k}.\sin\psi.d\psi.dr.d\varphi$$
$$= \frac{2\pi KQ\rho}{\mu_1}\int_0^{\psi_0}e^{-\mu_k H\sec\psi}.\sin\psi d\psi.\int_0^{\psi_0}e^{-[\mu_1 l+\mu_k H]\sec\psi}\sin\psi d\psi \qquad (9)$$

$\int_0^{\psi_0}e^{-x\sec\psi}.\sin\psi.d\psi$ is represented by the Kinθ(x) function.

The given Kin function value [4].

$$\int_0^{\psi_0}e^{-x\sec\psi}.\sin\psi.d\psi = \Phi(x)-\cos\psi_0\Phi(x\sec\psi_0) \qquad (10)$$

In which:

$$\Phi(x) = \int_0^{\pi/2}e^{-x\sec\psi}.\sin\psi.d\psi = e^{-x}-x\int_x^{\infty}e^{-u}.u^{-1}.du \quad (u=x.\sec\psi) \qquad (11)$$

Calculated results:

$$I = \frac{2\pi KQ\rho}{\mu_1}\{\Phi(\mu_k\mathrm{H})-\cos\psi_0.\Phi(\mu_k\mathrm{H}.\sec\psi_0)- -\Phi(\mu_1\mathrm{l}+\mu_k\mathrm{H})+\cos\psi_0\Phi[(\mu_1\mathrm{l}+\mu_k\mathrm{H})\sec\psi_0\mathrm{l}]\} \qquad (12)$$

In which: $Cos\psi_0 = \frac{H}{\sqrt{R^2+H^2}}$

Consider the particular cases of formula (12) above.

3.1 Semi-infinite Radiation Space, Intensity Measurement Taken at the Ground

Then we have:

l → ∞; R→ ∞; ψ_0 →π/2; H→0

ψ_0 →π/2; R→∞; l→∞; H→0

Then cosψ_0→ 0; Φ (μ_kH) → l;

$\Phi(\mu_1+\mu_k H) \to 0$

We have: $$I_\infty(0) = \frac{2\pi K Q \rho}{\mu_1} \quad (13)$$

This is the general formula for calculating the gamma radiation dose right on the surface of the ore body, which lasts infinitely long, thick enough to saturate gamma rays.

3.2 When the Intensity Measurement Is Made at Position H

$$I_\infty(H) = \frac{2\pi K Q \rho}{\mu_1}\Phi(\mu_k H) = I_\infty(0).\Phi(\mu_k H) \quad (14)$$

This is the formula for calculating the gamma dose rate in air.

In the above formulas:

I - Gamma radiation dose rate (also called gamma intensity, μR/h);

K - is the gamma radiation constant; $K_{Ra} = 9{,}1.10^9$; $K_U = 3{,}15.10^3$; $K_{Th} = 1{,}35.10^3$ (K's units are μR/h.cm^2/g);

Q - is the content of radioisotope calculated as g/g rock;

ρ - is the source density, g / cm3;

μ -is the weakening coefficient of gamma radiation, cm^{-1}. The weakening factor μ depends on the environment.

Table 1 shows the coefficients that weaken the intensity of gamma radiation by empirical literature [9, 10].

Table 1 Coefficient of weakening gamma intensity of volumetric source.

Ore type	Measurement type	Detector for recording gamma intensity (Ig)	Energy threshold (MeV)	$\mu_m = \mu/\rho$, cm^2/g		
				Rock	Water	Air
Uranium ore	Integral	CU-19Г NaI (Tl)	- 0.035	0.037 0.028	-	- 0.025
	Differential	NaI (Tl)	1.05-1.35 1.35-1.55 1.65-1.85 2.05-2.65	0.034 0.034 0.034 0.035	- 0.036 0.037 0.038	- 0.032 0.033 0.034
Thorium ore	Integral	CU-19Г NaI (Tl)	- 0.035	0.034 0.021	- 0.024	- 0.022
	Differential	NaI (Tl)	1.05-1.35 1.35-1.55 1.65-1.85 2.05-2.65 2.4-2.8	0.032 0.032 0.033 0.035 0.037	- 0.032 0.034 0.035 0.037	- 0.029 0.030 0.031 0.033

From formulas (13) and (14) above, it is possible to see the decrease in gamma dose rate at different locations in the air environment. Calculate the gamma dose rate on the ore-containing rock mass as follows: The device used to measure the gamma dose rate is a device with NaI crystal type detector (Tl), the size of the ore-containing rock mass as specified above, that is enough saturation gamma ray. We calculate the gamma dose rate due to the rare earth uranium-containing rock mass at different locations compared to the ore body boundary. The mass weakening coefficient of gamma dose rate in rocky soil for ore containing U is equal to 0.028; The mass weakening coefficient of the gamma dose rate in the air for ore containing U is equal to 0.025 (according to the above experimental table for NaI crystal type (Tl) for ore containing U), the density of rock in the body the ore is 2.2 g.cm^{-3} and the air density is 0.03 g.cm^{-3}. The values of Kin function are taken in the lookup table in the radioactive exploration curriculum [4]. The result of calculating gamma radiation dose rate at different locations in the air for rock mass is shown in Fig. 4.

The graph in Fig. 4 shows: With the ore body content equivalent to 0.01% U_3O_8, they cause gamma dose rate on the ground 52 μR.h^{-1}. At one metter, the gamma dose rate is about 40 μR.h^{-1} (reduced by 23% compared

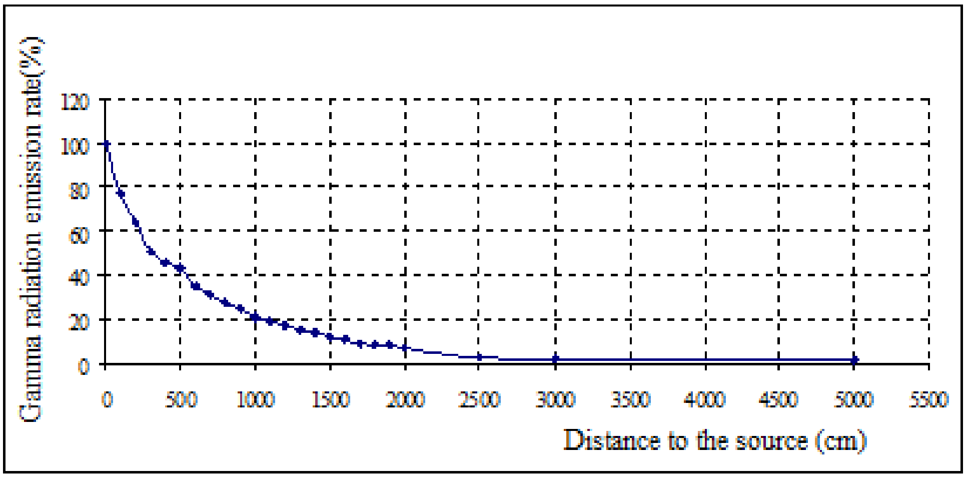


Fig. 4 Gamma radiation dose rate drop on rare earth bodies containing radioactive material.

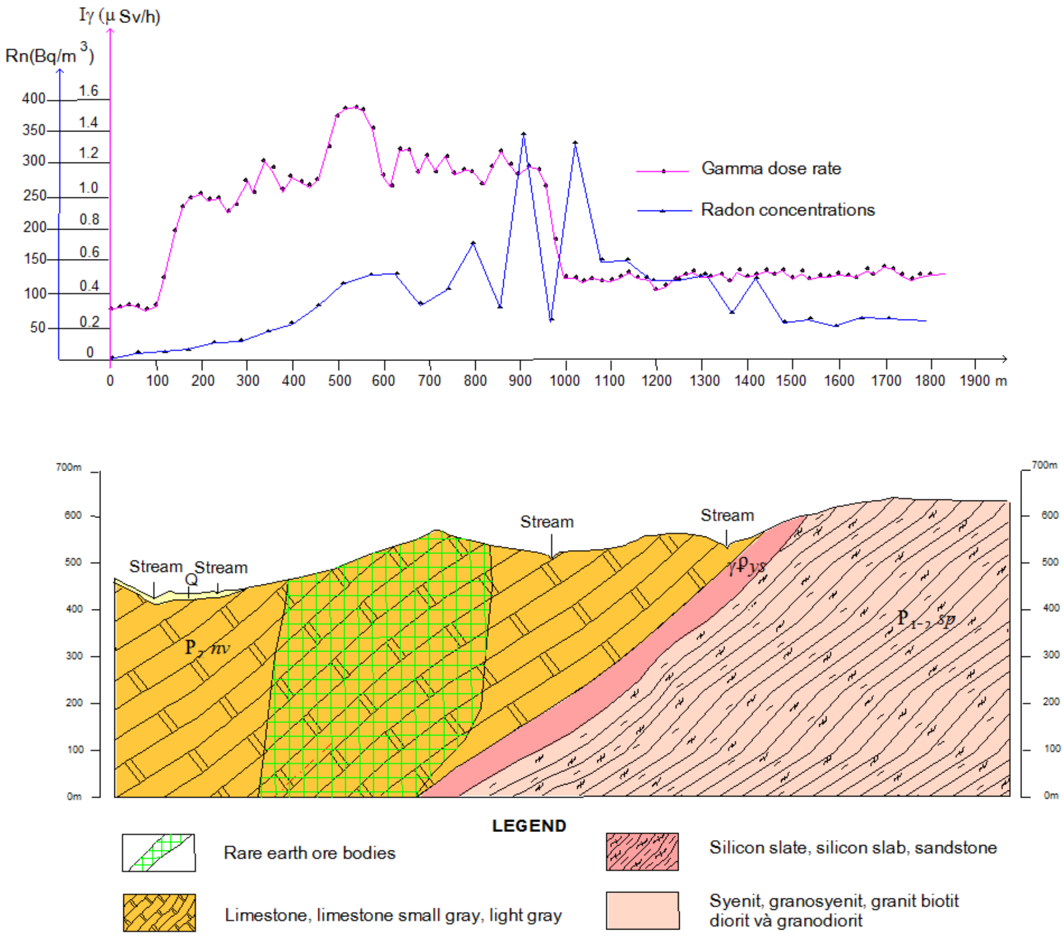


Fig. 5 Gamma dose rate distribution and radon gas on rare earth ore bodies.

to the ground). At 25 m from the ore body boundary, the remaining gamma dose rate is about 1.3 μR.h^{-1} (2.5% of the radiation rate compared to the ore body boundary). When away from the boundary of the ore body 33 m, the gamma dose rate is ~ 1μR.h^{-1} (0.01 μSv.h^{-1}) within the sensitivity range of the current dosimeters. In other words, for ore bodies with a concentration of 0.01% U_3O_8, the effect of gamma dose rate in the air environment is caused by them at a distance of at least 30 m, that is the influence of the source of rock and soil containing ore from the ditch works is raised to about 50 $\mu R.h^{-1}$ (equivalent to the external projection dose of about 5 $mSv.year^{-1}$), far from the area of rocky soil containing ore 30 m, the dose rate is not significantly affected. (0.1 $mSv.year^{-1}$). For ore bodies, the radioactive content is greater than the impact ability will be greater, but far from the ore body, about 50 m, this influence level is considered insignificant.

4. Results and Discussion

The mechanism and level of radioactive nuclear dispersion of gamma radiation and radioactive gas to the environment were studied due to the process of exploration and exploitation of rare earth ores containing radioactivity. Formulating a theoretical model of gamma radiation emission and radioactive gas emission of rare earth ore on the basis of selection of typical parameters, suitable to the actual conditions of exploration and mining rare earth ore mine contains radioactivity. The research results draw the following remarks:

- Gamma radiation field emitted from rocky soil containing radioactive ores that are able to penetrate in the air to several tens of meters (depending on the ore content). The ore body contains radioactive gamma radiation intensity depending on the content of radioactive substances and the materials shielding them.
- When carrying out the work of trenching, seaming or in direct contact with the ore bodies containing high radioactive content, it is necessary to apply mitigation measures by means of shielding or avoiding direct contact with the source (body ore).
- For ore bodies of industrial content, it is necessary to apply a reasonable working regime to workers directly executing excavation works and technicians when collecting data.
- Due to the long lifetime, radon gas has the ability to spread far in the air and is the subject of radiation dose affecting human health and the environment.
- For construction officials who need to pay special attention to the irradiation caused by radon gas, practical measurements should be made to make specific recommendations in each case.
- Before going down to the trenches, the furnace should have ventilation measures to reduce the radon concentration in the works.

5. Conclusion

The article has stated the mechanism of releasing gamma radiation and radioactive gas to the environment in radioactive mineral exploration and mining.

For the model of dispersion of radionuclides emitting gamma radiation in the air environment of rocky soil containing radioactive ore taken from excavation works potentially affected within a radius of < 50 m (according to calculation model), the closer the source is, the greater the level and likelihood of influence, especially in areas where the ore body has industrial content (> 0.05% U_3O_8).

With the theoretical calculation results the decline of radioactive gas in the air has shown that radon concentration decreases slowly in the air environment, on the other hand due to the long half-life, radon gas when released into the air environment usually exists for a long time and moves very far from the source, especially the terrain valleys and the wind blowing in fixed directions. Thoron gas escapes into the environment very quickly, usually very rarely at a height of several meters, on the other hand, the short half-life (54.5 s) should exist not long in the environment and move not far from the transmitter source region.

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