UDC 504.064:539.16:004.8:004.94

MODELING AND OPTIMIZATION OF PROCESSING ALGORITHMS BASED ON REAL-TIME MONITORING OF RADIATION AND DUST PARAMETERS

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Abstract: The potential radiation exposure of a person or worker in workshops covered with crushed mining dust mainly comes from two sources: the first is external gamma radiation generated by radionuclides in raw materials and the second is internal radiation resulting from inhalation of radon and its decay products. An assessment model was developed to predict the amount of gamma radiation from the radiation of crushed sand in the workshop and its movement in the air. In this case, internal radiation resulting from inhalation of radon and its decay products was calculated using data on radon emissions.

Keywords: radiation monitoring, dust monitoring, real-time systems, gamma radiation, radon, internal radiation, external radiation, radionuclides, mining industry, airborne dust, modeling, optimization, dose assessment, inhalation exposure, radiation hazard, prediction models, sensor systems

Аннотация: Потенциальное радиационное облучение человека или работника в цехах, покрытых измельченной горнодобывающей пылью, в основном происходит из двух источников: первый — это внешнее гамма-излучение, генерируемое радионуклидами в сырье, а второй — внутреннее излучение, возникающее в результате вдыхания радона и продуктов его распада. Была разработана оценочная модель для прогнозирования количества гамма-излучения от излучения измельченного песка в цехе и его распространения в воздухе. В данном случае внутреннее излучение, возникающее в результате вдыхания радона и продуктов его распада, рассчитывалось с использованием данных об выбросах радона.

Ключевые слова: радиационный мониторинг, мониторинг пыли, системы реального времени, гамма-излучение, радон, внутреннее излучение, внешнее излучение, радионуклиды, горнодобывающая промышленность, пыль в воздухе, моделирование, оптимизация, оценка дозы, ингаляционное облучение, радиационная опасность, прогностические модели, сенсорные системы

The advantages of using the developed computational model are that it allows for the prediction of expected values for reclamation activities. In such cases, given the impossibility of conducting experimental measurements, and the need for experimental measurements to assess the extended spatial distribution of values, the advantage of the computational model is obvious in the context of the need for real-time monitoring in space and time.

The computational model created in this work is written in C++ and is used to calculate the power and intensity of radiation in the air, determined using crushed mining sand. pGr•hour^{-1} The calculation model developed in this work is written in the C++ programming language, and its main purpose is to calculate the amount of airborne dose absorbed as a result of the use of crushed mining sand. (nGy·hour⁻¹) The basic assumptions are rectangular geometry, uniform distribution of activity concentration, and uniform density of the layers.

The basic assumptions made are rectangular geometry, uniform distribution of activity concentration, and uniformity of layer density. Absorbed dose in air (nGy·hour⁻¹) The algorithm used to calculate takes into account the gamma radiation emitted by the coating layer "upper layer" and the layer below it "lower layer", and takes into account the phenomena of self-absorption and accumulation at different densities associated with the different composition of the materials (difference in densities). The radionuclides under consideration ^{40}K and ^{238}U and ^{232}Th The results of the absorbed dose calculation for each wall are Bk•kg⁻¹ in relation to pGr•hour⁻¹ provided by the software.

In a homogeneous medium of infinite length, a beam of a certain energy is emitted by an isotropic point source with a linear extinction coefficient of μm. E_i When photons are emitted, the current density at a distance l is determined as follows.

$$F(E_i)=\frac{1}{4\pi l^2}\; B(E_i,s)\; S\; e^{-\mu_m(E_i)s} \qquad (1)$$

Here $F(E_i)s$ - accumulation coefficient, S — source asset, s - the distance traveled by a photon in the medium.

The method used provides a sufficient level of accuracy in the range of distances considered in the proposed applications, and provides a precise unit value when the penetration distance is zero, avoids uncertainties for small values of the thickness traversed, and is suitable for integration in the case of volumetric sources.

The amount of absorbed air calculated at point P for a given volume of source D [Gy· hour⁻¹] determined by the sum of the contributions from the effects of radionuclides (the standard geometry is illustrated in Figure 1).

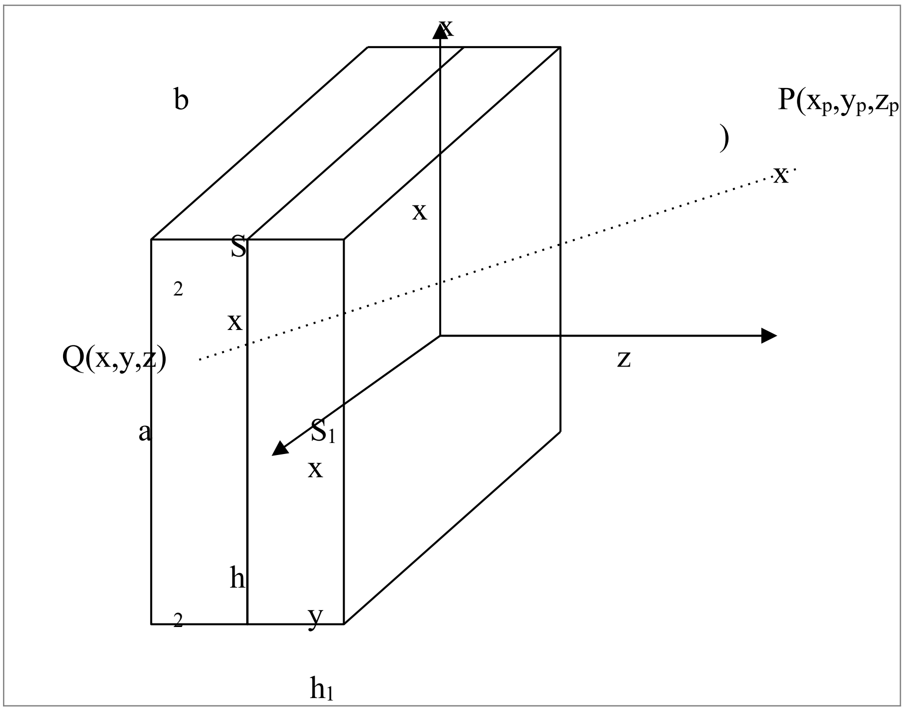


Figure 1. The geometric model was taken into account when calculating the absorbed dose in the air at point P.

The fraction resulting from the coating layer is expressed by the following formulas: (Equation 2), (Equation 3), (Equation 4).

$$D_i = 5{,}77 \ 10^{-7} \ \frac{C_1\rho_1}{4\pi} \ {}_i \ \gamma_i \ \frac{\mu_{en}}{\rho} \ {}_i \ E_i \ \ B_i(l)\frac{e^{-\mu_i(l)s_1}}{l^2}dV \qquad (2)$$

savings rate $B_i(l)$ is evaluated according to the following:

$$B_i(l) = 1 + C(E_i)\mu_i(l)s_1 e^{D(E_i)\mu_i(l)s_1} \qquad (3)$$

va

$$s_1 = \left|\frac{z}{z_p - z}\right| l, \qquad l = \sqrt{(x_p - x)^2 + (y_p - y)^2 + (z_p - z)^2} \qquad (4)$$

C (Ei), D (Ei) -The coefficients and numerical values of the Berger model are presented in the table.

The dose fraction associated with the lower layer is calculated using the following formulas (Equation 5):

$$D_2 = 5{,}77 \ 10^{-7} \ \frac{C_2\rho_2}{4\pi} \ {}_i \ \gamma_i \ \frac{\mu_{en}}{\rho} \ {}_i \ E_i \ \ B_i(2)\frac{e^{-(\mu_1(l)s_1 + \mu_2(l)s_2)}}{l^2}dV \qquad (5)$$

$$s_1 = \left|\frac{h_1}{z_p - z}\right| l \qquad s_2 = \left|\frac{z}{z_p - z}\right| l - s_1 \qquad (6)$$

Here

C_2 - activity concentration in the lower layer, Bk kg^{-1}

s_2 - distance traveled by radiation within the lower layer, cm

To estimate the amount of gamma radiation ^{238}U, ^{232}Th and ^{40}K Radioactive substances consisting of isotopes are considered. ^{238}U and ^{232}Th In such cases, the absorbed amount should be calculated separately for each gamma-decay line and summed up. (Table 1). In order to simplify the calculations ^{238}U only one for, ^{232}Th For the latter, two decay lines were used (the line at 2615 keV was analyzed separately because it accounts for more than 40% of the thorium chain). These new lines were calculated in terms of energy as a weighted average of all gamma-decay lines.

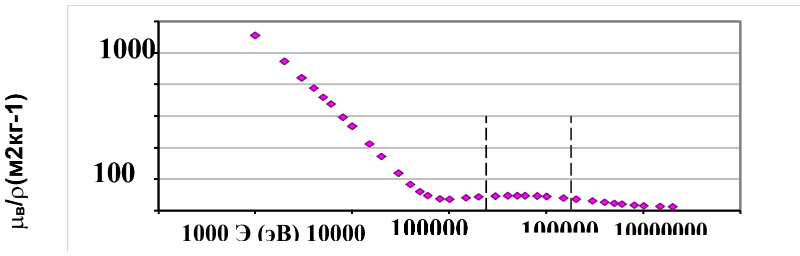


Fig. 2 Extinction coefficient in air

The values calculated and used by the program are given in Table 2. The possibility of such an approximation is that the energy absorption coefficients and extinction coefficients in the range of 240-1800 keV are, respectively, as shown in the figure. $2{,}672*10^{-3}$ m^2kg^{-1} and $2{,}342*10^{-3}$ m^2kg^{-1} up to and 0,272 and 0,113 m^{-1} changes to, and as a result, remains almost unchanged depending on the energy being viewed.

The attenuation coefficients in the "upper" layer material other than the wall:

$$\mu = \frac{\mu_{cem}\rho}{\rho_{cem}} \qquad (7)$$

Table 1

Energy and emission intensity of gamma photons

Basic example	**Energy**	**Emissions**	Basic example	**Energy**	Emissions
	MeV			MeV	**%**
	0,047	0,040		0,040	0,015
	0,053	0,022		0.100	0,023
	0,186	0,040		0,129	0,034
	0,242	0,084		0.209	0,045
	0,273	0,059		0,239	0,450
	0,295	0.207		0,270	0,032
	0,352	0,348		0,289	0,057
	0,395	0,012		0.331	0,190
	0,470	0,021		0,409	0,019
	0,609	0.430		0,463	0,046
	0,666	0,029		0,511	0,086
	0,773	0,077		0,583	0.300
	0,806	0,021		0,727	0,072
	0,934	0,036		0,782	0,091
	1120	0,159		0,860	0,051
	1,246	0,083		0,911	0,260
	1390	0,092		0,969	0,172
	1509	0,037		1,588	0,066
	1661	0,020		1626	0,041
	1760	0.180		2615	0,352
	1,848	0,027			
^{238}U	2118	0,011	^{232}T		
	2204	0,062			
	2435	0,024			
			^{40}K	1460	0.107

Table 2

Values of constants included in the calculation model

Nuclear	**Energy**				**C**	**D**
	keV		cm^{-1}	cm^2g^{-1}		
^{238}U	810	2.12	0,166	0,0285	1,161	0,144
^{232}T	587	2.05	0,193	0,0295	1,279	0,190
^{232}T	2615	0,356	0,0927	0,0217	0,734	0,0234
^{40}K	1461	0.107	0,124	0,0257	0,946	0,0755

As mentioned, one of the main tasks of the calculation program is to assume a rectangular shape of the workshop, in which the walls are assumed to be made of a material with the same density and the same radionuclide concentration. Then the user can enter the dimensions of the workshop to be modeled in the form of length, height and wall thickness. In fact, the model performs a separate calculation for each wall and then sums up the total components. Also, the coordinates of the point P, from which the quantity should be calculated, the density of both thicknesses ("upper layer" and "lower layer"), and the activity concentration of radionuclides present in the two layers ^{238}U, ^{232}Th and ^{40}K is recalculated relative to .

After the initial data is entered, the program checks for the presence of both layers of dust. If only the lower layer is present, the results are displayed immediately. These results are expressed as the amount absorbed in the air per unit of activity concentration of the carrier nuclides. [nGy/hour Bq/kg per head].

If there is also an overlay, the share of each layer is calculated separately according to formulas 2 and 5, and then the results are displayed. The block diagram of the program is shown in the

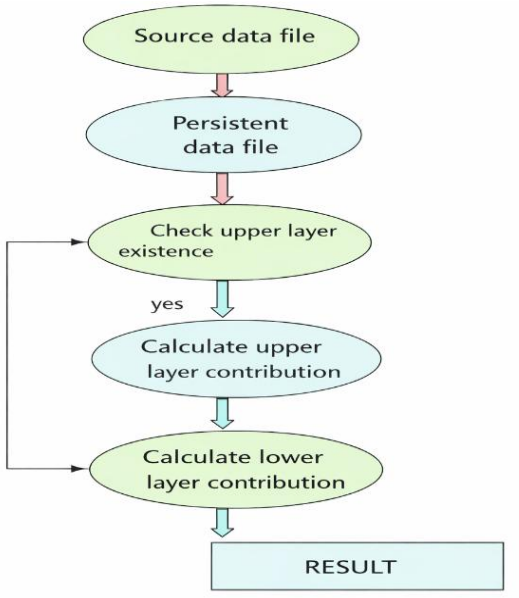


figure.

Figure 4 Block diagram for the airborne dose calculation program

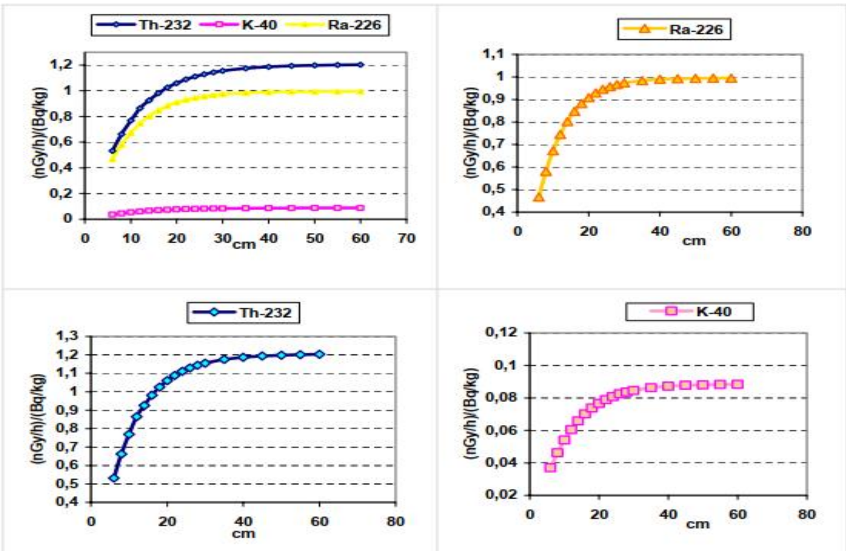
Table 3 presents the studied parameters and their ranges of variation. Range of variation of parameters used in the sensitivity analysis of the program.

Table 3

The range of parameters used in the sensitivity analysis of the program

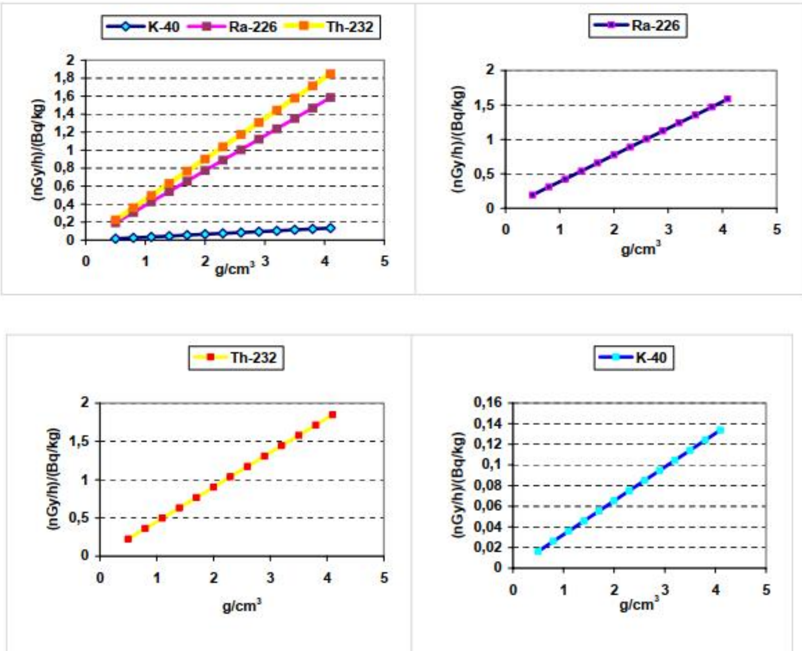
	Thickness (cm)	Density (g/cm⁻³)	Size (m)	Distance from point P to the retaining wall (m)
A	6-60	2.3	5 x 4 x 2,8	Sex center
B	20	0,5-4,1	5 x 4 x 2,8	Sex center
V	20	2.3	5 x 4 x 2,8	

Figure 5 shows the amount absorbed in the air in the center of the room. [nGr•hour^{-1} Bk•kg^{-1}] thickness for each family of radioactive substances The graph of the change in quantity is shown depending on the change in thickness. Figure 6 illustrates the change in quantity depending on the change in thickness.



When we change the wall thickness in the range of 6-60 cm, we observe a rapid increase in the quantity at the point of acceptance P in the center of the shop, and then it tends to the limit value. Starting from a thickness of 40 cm, the quantity, apparently, does not depend on this increase (the value at 60 cm differs from that at 40 cm by only 1%).

INTERNATIONAL MULTI DISCIPLINARY JOURNAL FOR RESEARCH & DEVELOPMENT
eISSN 2394-6334 Impact factor: 8.854 Volume 13, issue 05 (2026)



Dust density 0.5 to 4.1 g/cm³ As the absorption rate increases, the calculated absorption rate at point P always increases linearly. This phenomenon is easily explained by the direct proportionality between rate and density (equations 2 and 5). Table 4 presents the results of the simulations performed by changing the position of the absorption point P relative to the wall, moving it from the center point to a distance of a few centimeters from the wall.

Table 4

The dependence of the amount absorbed on the change in the position of the absorption point P.

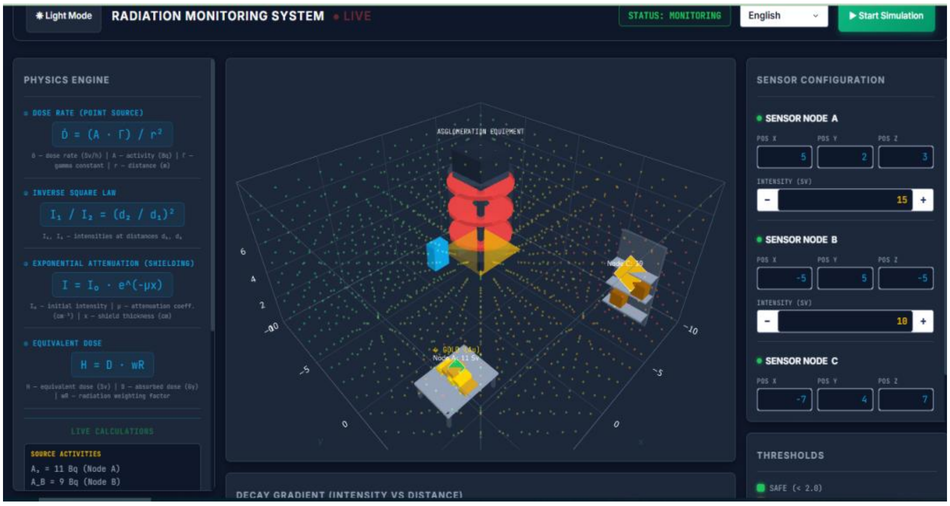
cm	^{226}Pa	^{232}T	^{40}K	Difference %
250	0,91	1.06	0,077	
200	0,92	1.07	0,078	1%
150	0,95	1.11	0,080	5%
100	0,98	1.19	0,086	10%

As can be seen from the data presented in the table, the error in considering the amount of radiation at the center of the workshop is 10 percent. Therefore, the value obtained as a result of modeling should be considered reliable, since it is within the uncertainty limit associated with the experimental measurement (±15 percent).

Within the framework of this study, the issues of real-time monitoring of radiation and dust factors in industrial environments, their mathematical modeling, and assessment under uncertainty were comprehensively studied. Experimental observations and computational experiments were conducted in various production zones (grinding, crushing, and warehouse areas).

As a result of the research, an integrated mathematical model was developed that represents the spatial-temporal distribution of radiation intensity and dust concentration, as well as takes into account uncertainties in the measurement process. The model was formed based on physical laws (inverse square law, exponential decay) and statistical approaches.

- BIn addition, the developed model comprehensively takes into account the following important factors:
- determination and assessment of the contribution of gamma radiation emitted by materials;
- modeling the process of radioactive dust entering the human body through inhalation (breathing);
- taking into account the duration of employees' stay in critical (high-risk) areas and determining the dose load depending on it;
- Increase accuracy by integrating data from different sources;
- Evaluate and reduce measurement uncertainties.



7-Online monitoring of the spread of contaminated dust in the room

The software system, developed based on Model 8, allows for real-time monitoring of radiation and dust parameters, visual display of their distribution in three-dimensional space, and in-depth analysis across production zones

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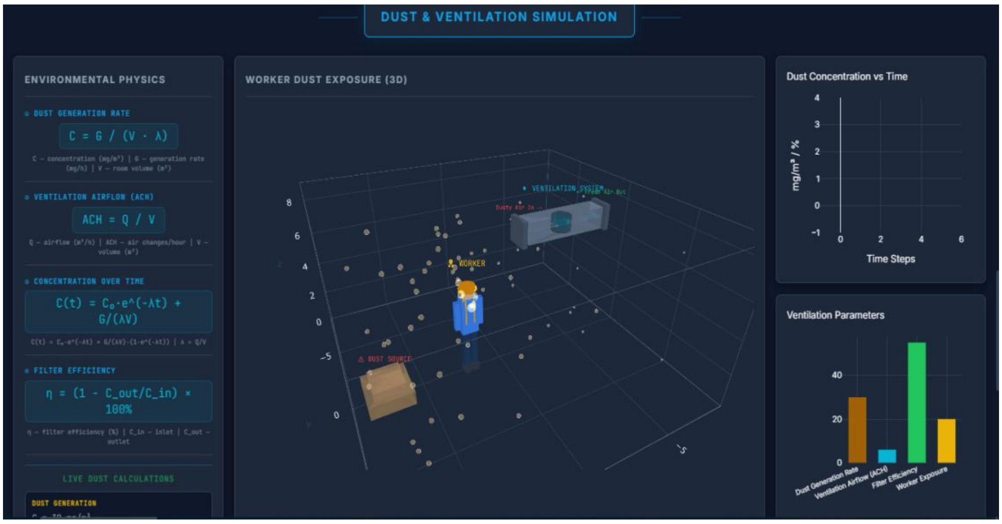

Figure 8: Taking into account the duration of employees' stay in critical (high-risk) areas and determining the dose load depending on it

Conclusion

The results of the study show that the developed model allows for a comprehensive assessment of harmful factors in the industrial environment, minimizing uncertainties and accurately predicting the level of risk.

As a result, the developed model implements scientific and practical solutions that ensure worker safety by monitoring radiation and dust parameters in real time, determining the contribution of gamma radiation, assessing the entry of radioactive dust into the body through inhalation, calculating the dose load depending on the time of employees' stay in critical areas, reducing measurement uncertainties, and conducting a comprehensive analysis of the level of risk in the production areas.

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