MODELING OF THE INFLUENCE OF TURBULENCE DIFFUSION COEFFICIENT AND WIND SPEED ON THE VOLUMETRIC ACTIVITY OF THE VERTICAL PROFILE OF RADON AND ITS PROGENY

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The purpose of this work is to study the role of turbulence diffusion coefficient and wind speed on the transfer of radon and its progeny in the atmosphere. Radon is a radioactive noble gas that is widely used as a tracer for the investigation of the processes of transporting and mixing atmospheric phenomena. It is very effective for identifying natural air exchange in underground environments [1]. Radon and its progeny have been used as tracers for investigating vertical diffusivity. This is due to the fact that their source and sink are well defined. Atmospheric advection and vertical turbulence play an important role in the transport of momentum, heat, moisture, and trace gases into the atmosphere. Vertical transport also plays a significant role in the transportation of long-range air pollutants into the atmosphere. This is because wind speed increases with height. Different researchers have studied the vertical distribution of radon [2]. This paper presents a model of the influence of turbulence diffusion coefficient for different cases (where there is a positive wind speed, a negative wind speed, or no wind speed) and the effect of wind speed on the vertical profile of the volumetric activity of radon and its progeny.

Mathematical Model

A one-dimensional study of the steady state of the transfer of radon and its progeny in the atmosphere was used. The mathematical model includes a differential equation for radon and thoron with variable coefficients (where $i = 1{,}2$ represents radon and thoron, respectively) and can be written in the form [3]:

$$0 = \left(D_M + D_T(z)\right)\frac{d^2 A_i(z)}{dz^2} - \upsilon_\omega \frac{dA_i(z)}{dz} - \lambda_i A_i(z) \quad (1)$$

The system of the equation was solved with the initial condition of the absence of radon and thoron with increasing height: $A_i(z \to \infty) = 0 \; for \; i = 1{,}2;$

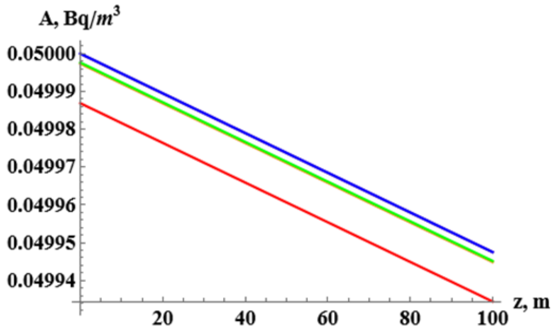
And a boundary condition for both radon and thoron, taking into consideration the output from the surface of the ground, was given as: $\left(D_M + D_T(z)\right)\frac{dA_i(z)}{dz}\Big|_{z=0} - \upsilon_\omega A_i(z)|_{z=0} = -q_i \; for \; i = 1, 2;$

Where D_M is the coefficient of molecular diffusion, m^2/s; $D_T(z)$ is the coefficient of turbulent diffusion, m^2/s; $A_i(z)$ is volumetric activity of radon (i = 1) and thoron (i = 2) with respect to height, Bq/m^3; υ_ω is the wind speed's vertical component, m/s; λ_i is the radioactive decay constant of radon (i = 1) and thoron (i = 2), 1/s; q_i– the radon (i = 1) and thoron (i = 2) flux density from the surface of the ground, Bq/m^{2}s.

The model was carried out for the range of 0.001–5 m^2/s for the turbulence diffusion coefficient (for cases when there is no wind speed, positive, and negative wind speed) and that of the wind speed ranges from –0.2–0.2 m/s. The negative wind speed indicates the direction of the wind towards the earth's surface.

Results and Discussion

Figs. 1 and 2 illustrate how the volumetric activity of both radon and thoron is dependent on height, respectively.



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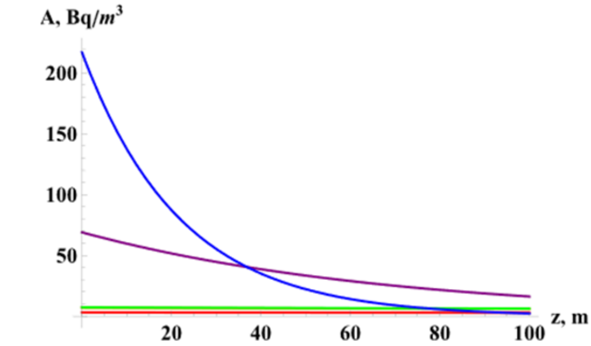

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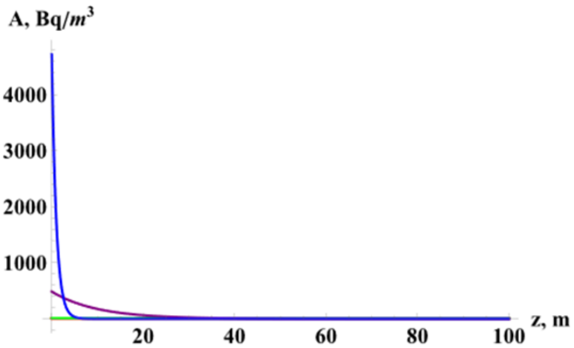

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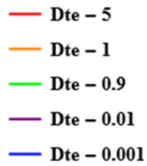
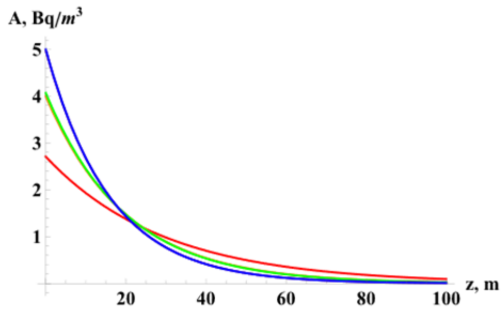


Fig. 1. Dependence of volumetric activity of radon on height for different turbulence diffusion coefficients for cases with (a) positive wind speed, (b) no wind speed, and (c) negative wind speed



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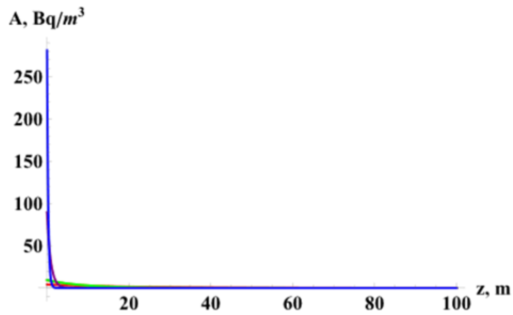

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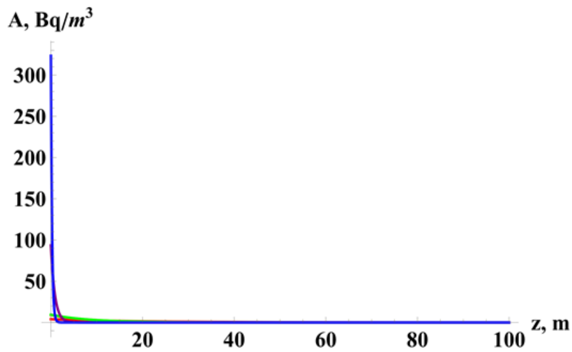
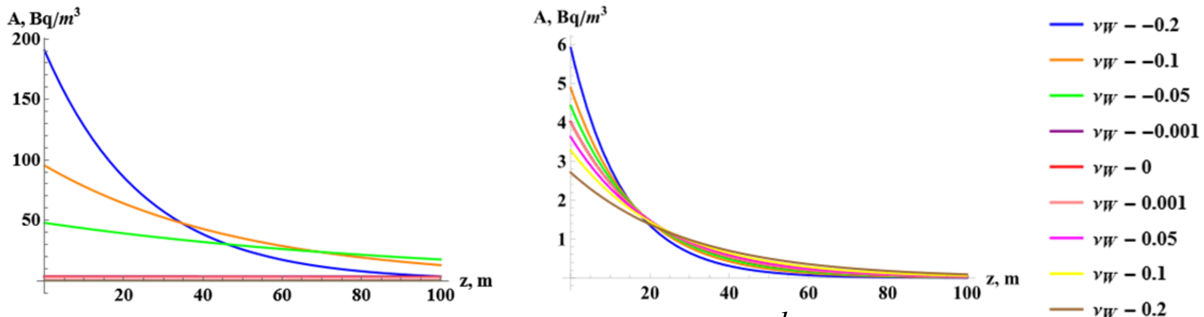


c

Fig. 2. Dependence of thoron volumetric activity on height for different turbulence diffusion coefficients for cases with (a) positive wind speed, (b) no wind speed, and (c) negative wind speed

The results obtained showed that the coefficient of turbulence diffusion changed from exponential to linear dependence for situations in which there was no wind speed or negative wind speed for radon and thoron. This has caused a significant change in the vertical profile of the radon and thoron volumetric activity, particularly near the earth's surface. Additionally, the volumetric activity close to the earth's surface decreased very sharply when there was negative wind speed for radon and when there was no wind speed and negative wind speed for thoron. For the case where there was positive wind speed, the volumetric activity for radon has only linear dependence in the turbulence diffusion coefficient and only exponential dependence change for thoron. It was also noted that when there was a decrease in the turbulence diffusion coefficient of less than 0.01 m^2/s, the volumetric activity of radon and thoron at the earth's surface was high in all cases. However, there was a rapid decrease with increasing height. This shows that turbulence diffusion is efficient in rapidly decreasing the concentration of radon released into the atmosphere. It was observed that the volumetric activity of radon was more than 220 Bq/m^3.

Figure 3 illustrates how the volumetric activity of radon and thoron depends on different values of wind speed. Based on the obtained results, it can be seen that the positive and negative wind speed values coincide with the direction of the z-axis. The wind speed strongly changes the vertical profile of the volumetric activity of both radon and thoron. The volumetric activity of radon and thoron decreased as the wind speed increased from the earth's surface. For radon, radionuclides were transferred to altitudes as high as over 100 m. As wind speed increased, the change in dependence for thoron was only exponential, but that of radon changed from exponential to linear. The wind speed greatly increases the volumetric activity at the surface of the earth and decreases at higher altitudes.



a *b*

Fig. 3. Dependence of the volumetric activity of the vertical profile of (a) radon and (b) thoron for different wind speeds

Conclusion

In this work, we present the model influence of turbulence diffusion coefficient at different wind speeds and the effect of wind speed on the volumetric activity of radon and thoron.

The presented work shows that the vertical variation of atmospheric stability and wind speed affect the variation of the coefficient of turbulence diffusion with height. The turbulence diffusion coefficient increases rapidly with height in the boundary layer close to the earth's surface. For low turbulence diffusion coefficients, the difference between radon and thoron is relatively high at ground level but decreases with increasing height. This is because of their short half-lives.

The wind speed increases the volumetric activity of radon and thoron at the surface of the earth and decreases with increasing height. The results show that turbulence diffusion coefficient and wind speed affect the volumetric activity of the vertical profiles of radon and thoron.

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