Electrode Layer Structure Generating Under Radon-222 Transfer across Land-Atmosphere Interface

Olesya Pestova[1*], Dmitriy Pestov[1], Alexander Shishenya[1], Gennady Kupovykh[1], Alexander Redin[1], Alexander Klovo[1]

1. Southern Federal University, Nekrasovsky 44, Taganrog, 347928, the Russian Federation

ABSTRACT. The convective-diffusion model of radon distribution in the soil and in the near-surface layer is developed. The expression of the ionization rate was received on the basis of radon distribution in the atmosphere. The influence of ionization rate on the characteristics of the surface layer at mentioned conditions was studied.

INTRODUCTION

It is well known that electrical characteristics of the atmospheric free of aerosol surface layer are mostly determined by the electrode effect [1, 2]. The presence of radioactive gas emanations of radon and its decay products from soil has the significant influence on the ionization processes near the surface.

Bricard [3] has shown that the average concentration of radon under the dry surface is $158 \cdot 10^{-18}$ *(Ci/sm^3)*. Considering that during one α-decay $2 \cdot 10^5$ *(ion pairs)* are formed, the concentration mentioned above brings to the values of ion formation equal to $11.7 \cdot 10^5$ *(ion pairs/m^{3}s)*. Hoppel [1] has built up the profile of the ionization rate q which relays to the real profile received on the basis of the results of work [4]. It corresponds to the ionization produced by the cosmic rays, γ-, β- and α- rays near the earth surface. As usual the space charge is positive, and its density depends on the turbulent mixing and the ionization rate. It was also shown that in the presence of increased ionization in thin layer near the surface, the negative space charge appears in the electrode layer. Kupovykh et al. [5] have shown that in case of weak turbulent mixing in the surface layer the negative space charge remains the same, thereby its scale distribution rises, but the value of space charge density decreases. The intensification of turbulence mixing or electric field destroys the negative space charge near the surface. Iordanov [6] has provided the solution of the equation of vertical distribution of the radioactive substance in the premise of horizontal homogeneity, absence of sources and with diffusion to find the link between the concentration of radon and the ionization rate. The solution was found analytically with the help of similarity theory.

[*] Contact information: Olesya Pestova, Southern Federal University, Nekrasovsky 44, Taganrog, 347928, Russian Federation; E-mail: olesia.pestova@gmail.com, kupovykh@sfedu.ru

THEORETICAL BACKGROUND

Mathematical model of mass transfer of radon in the soil and in the surface layer

A convective-diffusion model of radon mass transfer in loose sediments and its emanation into the atmospheric surface layer is given by [7]:

$$\begin{cases} \eta \dfrac{\partial N_1(z,t)}{\partial t} + \upsilon\eta \dfrac{\partial N_1(z,t)}{\partial z} = D\dfrac{\partial^2 N_1(z,t)}{\partial z^2} - \lambda\eta N_1(z,t) + Q, \qquad Q = \dfrac{a \cdot Ra \cdot \rho \cdot \lambda}{\eta} \\ \dfrac{\partial N_2(z,t)}{\partial t} = \dfrac{\partial}{\partial z}\left(A(z) \cdot \dfrac{\partial N_2(z,t)}{\partial z} \right) - \lambda N_2(z,t), \end{cases} \tag{1}$$

The main system parameters are presented in Table 1 [8]:

Table 1 – Parameters of system (1)

Parameter	Description	Typical values
η	rock porosity	0.1÷0.4
D	diffusion coefficient (in loose sediments), m^2/s	$(5\div15)\cdot10^{-9}$
λ	emanation disintegration constant, s^{-1}	$2.1\cdot10^{-6}$
v	convective transport velocity, m/s	$7.5\cdot10^{-10}$
Ra	amount of radium in the solid, Bq/kg	0.45
ρ	rock density, kg/m^3	$(1\div3)\cdot10^3$
a	emanation rate	0.2-0.5
$A(z)$	diffusion coefficient of radon in the atmosphere, m^2/s	$4\cdot10^{-6}$

The other parameters are: Q – the velocity of emanation into the soil space in the unit volume of structure, ($Bq/s\cdot m^3$), $N_1(z,t)$ – density of radon distribution in the soil, $N_2(z,t)$ – density of radon distribution in the atmosphere, N_∞ – maximum concentration of radon in the soil.

The first equation of system (1) describes the steady-state diffusion-convective process of radon mass transfer in the soil and the second equation of system (1) is the diffusion mass transfer of radon in the atmosphere.

The initial and boundary conditions for system (1) are the following:

a) equality of flows and correlation of the radon concentration at the boundary of structures is given by the following boundary condition [7]:

$$z = z^0, \quad N_1(z,t) = N_2(z,t), \ \frac{D}{\eta}\frac{\partial N_1}{\partial z} - \upsilon N_1 = A\frac{\partial N_2}{\partial z}, \qquad (2)$$

where z^0 – the boundary of structures soil-atmosphere, z – vertical coordinate;
b) constant concentration of radon while achieving the balance with decay products at the certain depth of loose sediments gives the boundary conditions in the soil:

$$z \to -\infty, \quad N_1 = N_\infty, \quad z \to +\infty, \quad N_2 = 0; \qquad (3)$$

The oriental axe here is directed vertically. Zero level is at the boundary of soil and atmosphere;
c) with the assumption of the fact that the radon concentration at the initial time is maximum the following initial conditions are received:

$$t = 0, \quad N_1 = N_\infty, \ -\infty < z < z_0, \ N_2 = N_\infty, \ z_0 < z < +\infty. \qquad (4)$$

For constructing a function of ion formation with taking into account the received radon distributions calculated with the model (1) the following acquainted formulas are used: one α-decay induces in the total sum $2{\cdot}10^5$ *ion pairs* [3]. By virtue of the fact that 1 *Bq* = 1 *decay/s*, so 1 Bq/m^3 = 1 *decay/* m^3 *s* and 1 Bq/m^3= $2{\cdot}10^5$ *ion pairs/*m^3 *s*. For the summand, describing the score of radon into the process of ion formation, come out to $q_0 = k_0{\cdot}Rn$, where $k_0 = 0.2 = const$, Rn (Bq/m^3) is the concentration of radon near the surface. By this means for the ion formation velocity function we obtained:

$$q = (7 + 0.2 \cdot Rn) \cdot 10^6 \ \ (ion\ pairs/m^3) \qquad (5)$$

The values of q calculated according to (5) are in a good agreement with the experimental facts [2] in particular with measurements of *Radon-222* on the Peak Terskol near Elbrus made in [11].

Surface Layer Electrical State Model

The system of equations of the non-stationary horizontally-homogenous surface layer, describing its state condition in the limit of turbulent electrode effect, is (6) [1, 9, 10]:

$$\begin{cases} \dfrac{\partial \mathrm{n}_{1,2}}{\partial \mathrm{t}} \pm \dfrac{\partial}{\partial \mathrm{z}}\left(\mathrm{b}_{1,2} \cdot \mathrm{E} \cdot \mathrm{n}_{1,2}\right) - \dfrac{\partial}{\partial \mathrm{z}}\left(\mathrm{D_T}(\mathrm{z}) \cdot \dfrac{\partial \mathrm{n}_{1,2}}{\partial \mathrm{z}}\right) = \mathrm{q} - \alpha \cdot \mathrm{n}_1 \cdot \mathrm{n}_2 \\ \dfrac{\partial \mathrm{E}}{\partial \mathrm{z}} = \dfrac{e}{\varepsilon_0}(n_1 - n_2), \end{cases} \qquad (6)$$

The stationary view of air ions turbulent diffusion coefficient $D_T(z) = D_1 \cdot z$ is used. Ionization rate function q, is given by (5). The main characteristics of system (6) are given in Table 2.

Table 2 – Parameters of system (6)

Parameter	Description	Typical values
E	electric field value, $V{\cdot}m^{-1}$	10^2
b_1	positive small ions mobility, $m^2{\cdot}V^{-1}{\cdot}s^{-1}$	$1.2{\cdot}10^{-4}$
b_2	negative small ions mobility, $m^2{\cdot}V^{-1}{\cdot}s^{-1}$	$1.4{\cdot}10^{-4}$
α	small ions recombination, m^3s^{-1}	$1.6{\cdot}10^{-12}$
e	elementary charge, *coulomb*	$1.6{\cdot}10^{-19}$
ε_0	electric constant, *F/m*	$8.85{\cdot}10^{-12}$
z_0	surface roughness parameter, *m*	$2.5{\cdot}10^{-3}$
$n_{1,2}$	small ions space density (positive and negative), m^{-3}	$\sim(10^8\text{-}10^9)$
D_T	multiplier in turbulent diffusion coefficient, $m{\cdot}s^{-1}$	(0.01-0.1)
q	ionization rate, m^3s^{-1}	$\sim(10^6\text{-}10^7)$

Initial and boundary conditions are the following:

- for small ions:

$$\begin{cases} n_{1,2}\big|_{t=0} = \sqrt{\dfrac{q}{\alpha}} \cdot \left(1 - e^{-\frac{(z-z_0)}{l_1}}\right), \\ n_{1,2}\big|_{z=z_0} = 0,\ n_{1,2}\big|_{z=\infty} = \sqrt{\dfrac{q}{\alpha}}, \end{cases} \tag{7}$$

- for electric field:

$$E(t=0) = E_0, E(z=z_0) = E_0 . \tag{8}$$

l_1 – typical scale of turbulent electrode layer.

THEORETICAL RESULTS AND DISCUSSION

The profiles of ionization rate are represented in Figure 1 under the following parameters: η = 0.4,

$\lambda = 2.1 \cdot 10^{-6}$ (s^{-1}), $D = 15 \cdot 10^{-9}$ (m^2/s), $\rho = 1660$ (kg/m^3), $a = 0{,}35$, $A = 4 \cdot 10^{-6}$ (m^2/s). The profiles of ionization rate function are given in Figure 1. The profile Q_1 is the function received on the basis of experimental data which was used earlier in modeling [1]. The profile Q_2 was numerically developed from the radon mass transfer model (1).

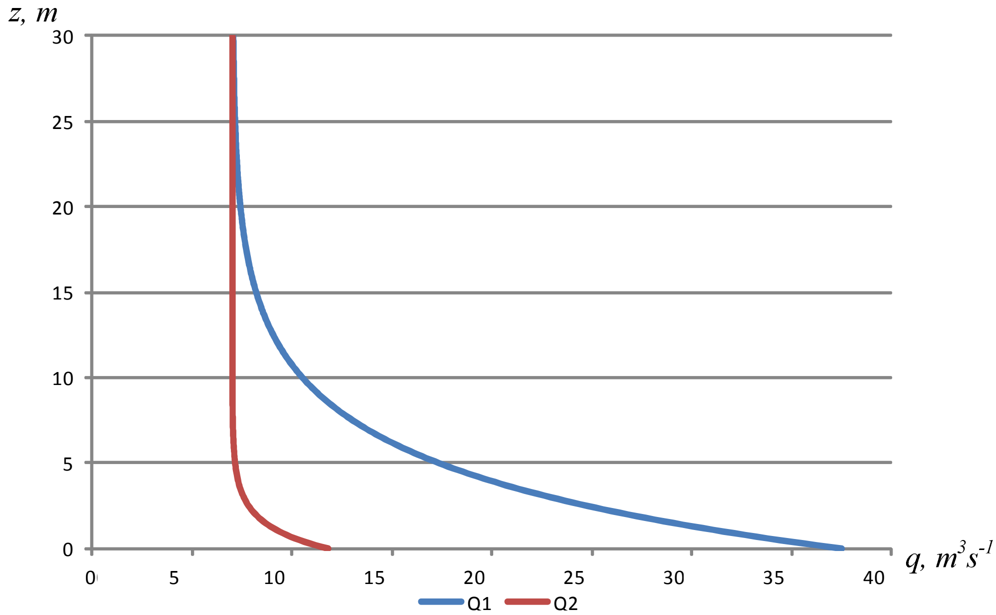


Figure 1 – Ionization rate functions Q_1 (experimental data) and Q_2 (numerically calculated)

As seen from Figure 1 the profiles are similar and aren't in contrast with each other. The received values of ionization rate qualitatively conform to the results of the experiments of radon measuring [11] and direct measuring of ion formation rate conducted by Kupovykh et al. [2].

The profiles of positive and negative charged small ions and electric field under different values of the turbulent mixing coefficient in the atmosphere were considered. The electrode layer structure with $D_T = 0{,}1$ $(m \cdot s^{-1})$ is given in Figure 2. It is similar to the results received in [1, 5].

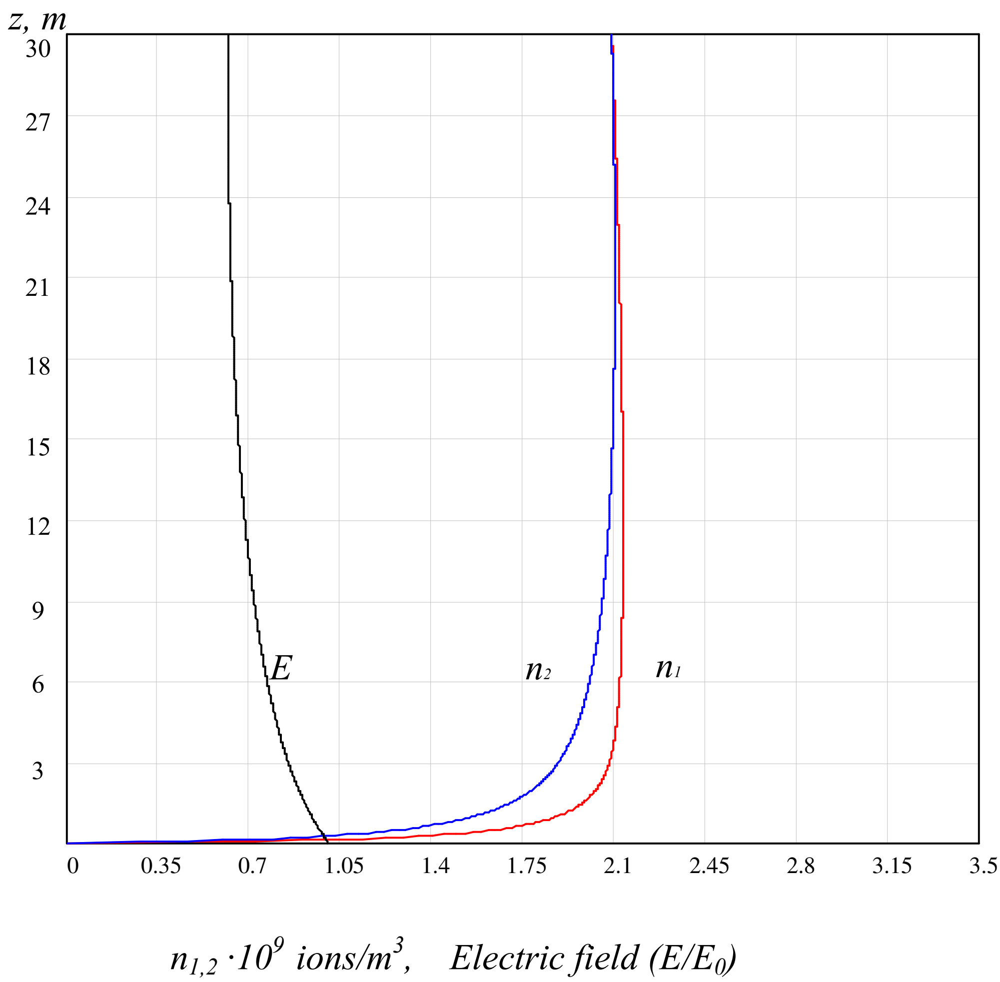
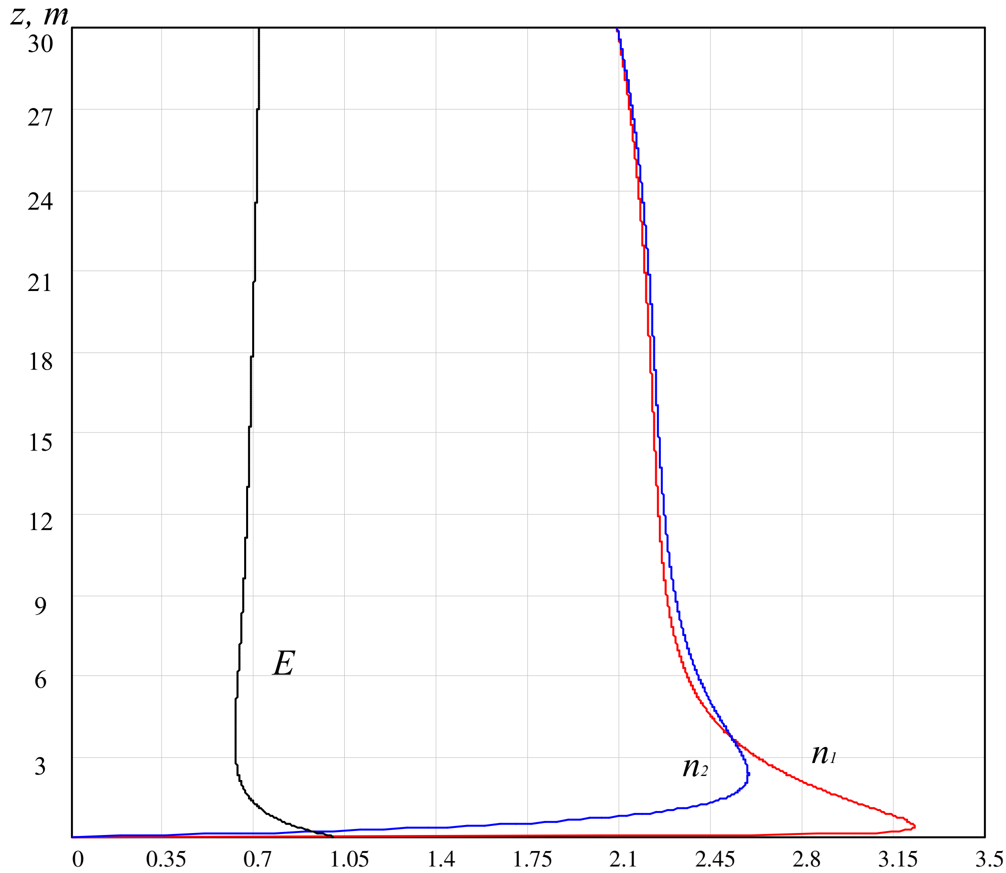


Figure 2. Profiles of positive and negative small ions volume density and electric field with $D_T = 0.1$ ($m \cdot s^{-1}$)

Under weak turbulent mixing ($D_T = 0.01$ ($m \cdot s^{-1}$)) the negative space charge is formed near the earth surface. The results are given in Figure 3



$n_{1,2} \cdot 10^9$ *ions/m*^{3}, *Electric field (E/E*$_0$*)*

Figure 3. Profiles of positive and negative small ions volume density and electric field with $D_T = 0.01$ ($m \cdot s^{-1}$)

CONCLUSIONS. By this means, the combined model of mass radon transfer and the model of electric structure of turbulent surface layer was developed. The aggregation of these models allows to elaborately research the influence of *Radon-222* on the air ionization and as a result to the formation of electrode layer near the surface. The made theoretical calculations don't contradict the known experimental data about the distribution of radon and ionization rate in the alpine conditions.

REFERENCES

1. Hoppel W.A. Theory of the electrode effect // J.Atm.and Terr. Phys..V.29,N.6. 1967. P.709-721.
2. Kupovykh G., Morozov V, Shvartz Ya. Electrode Effect under Alpine Conditions // Proc. 11th

Int. Conf. on Atmosph. Electr.,Versailles, 2003.4p.

3. Bricard J. Action of radioactivity and of pollution upon parameters of atmospheric electricity In:Coroniti S.C. (ed.) Problems of Atmospheric and Space Electricity, Elsevier. 1965.P. 82-116.

4.Dolezalek H. Zur Methodik Luftelektrischer// Messungen Beitraege zur Geophysik.V.71-82,S.77,b3,S.161,b4, 1962.S.242.

5. Kupovykh G.V. Negative space charge in surface layer// Proc. 10th Int. Conf On Atmosp. Electr, Osaka. 1996. P. 164-167

6. Iordanov D. On the stationary electric field in the surface air layer.// Pure and Appl Geophys., 1970, V. 79, NO 1 p. 85-91.

7. Pestova O.V., Pestov D.A., Shishenia A.V. Modelirovanie protsessov perenosa podpochvenogo radona v grunte i ego ekshaliatsia v prisemnii sloi atmosfery // Sovremennie problemi nayki i obrasovania. – 2013. – № 6; URL: http://www.science-education.ru/113-10823 (data obrachenia: 19.11.2013).

8. Parovik R.I., Ilyin I.A., Firstov P.P. Matematicheskay diffusionnaya model massoperenosa radona (^{222}Rn) v grunte I ego ekshaliatsia v prisemniy sloi atmosfery// Vestnic Krauns. Seria nayki o zemle. 2006. №1.Vipusk №7. –S. 110-114

9. Kupovykh G.V. ,Morozov V.N. Modeling of the electrode effect in surface layer // Proc. 9 th Int. Conf. on Atm. El., St.Petersburg,V.2, 1992. P.615-618.

10. Kupovykh G., Redin A., Boldyreff A. Modeling of ionization-recombination processes in the atmospheric surface layer. // Journal of Electrostatics 71. Elsevier B.V. 2013. p. 305-311.

11. Adzhiev A.H., Boldyreff A.S., Dorina A.N., Kudrinskaya T.V., Kupovykh G.V., Novikova O.V., Panchishkina I.N., Pestov D.A., Petrov A.I., Petrova G.G., Redin A.A. «Alpine Atmospheric Electricity Monitoring and Radon-222 Measurement near Elbrus» Proc. 13th International Conference on Atmospheric Electricity, August 07-12, 2011, de Janeiro, Brazil. http://www.icae2011.net.br