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METHOD OF MONITORING OF UNDISTURBED RADON FLUX DENSITY FROM SOIL SURFACE

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The paper presents the results of analysis of measurement methods for radon flux density from the soil surface. A new method of monitoring of undisturbed radon flux density from the soil surface is described. It may be applied within a wide range of meteorological conditions. The method is based on registration of α-radiation of radon decay products collected inside an accumulation chamber installed on the soil surface. The accumulative chamber has some small vent holes for partial soil gas emission. The procedure of calibration and determination of correction coefficients is described. The results of testing of the method and comparison of the monitoring data obtained by different methods are discussed. The new method differs from the analogues in the way that it allows the authors to investigate diurnal variations of radon flux density.

Key words: radon, flux density, undisturbed flux

Introduction

The quantity of radon flux density (RFD) from the soil surface is widely used to solve applied problems in different fields of science. RFD is the key parameter determining an integrated quantity of concentration of radon, thoron and daughter products of their decay in the near surface atmosphere which, in its turn, affects the background radiation [1]-[3]. RFD may be successfully applied as one of the forecast parameters on the basis of which we can make forecasts of change of stress-deformation state of the Earth's crust [4]-[7]. Radon flux density may also be useful in the investigations of radon effect on the electric properties of the near surface layer of the atmosphere since radon and its decay products are air ionizers and according to [8] determine the temporal component of atmospheric electricity dynamics.

First attempts to develop methods to measure the RFD from the soil surface were made in the 1st half of the latest century. During that time, the main principle of determination of RFD by a static accumulation chamber (AC) and the first devices, which were further upgraded and modified, were developed.

At the end of 80-s when electret detectors were developed, the method of an accumulation chamber was changed from a static to a dynamic one [9],[10]. Thus, there appeared an opportunity to measure and to control an undisturbed radon flux.

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Widely spread is the static model, in which a AC is closed from the outer atmosphere for the time of radon accumulation. Then it is ventilated before a new measurement. The main advantage of the static method [3],[11] is the simpler recalculation into RFD quantity in comparison to the dynamic method. Moreover, combination of the static method of accumulation of siol gases with instantaneous methods of measurement of accumulated activity allows us to control time variations of RDF within a day. The disadvantage of the static method is that during the increase of radon concentration inside an AC, concentration gradient decreases, and, consequently, the radon flow from the ground does. That means that during the increase of radon concentration inside an AC to 25% and more from radon concentraition in the soil air, the estimated quantity of radon density may be underestimated [11]. Thus, the AC exposure time should be chosen in dependence to the characteristics of the region under investigations which may significantly make the whole procedure more complicated.

In the dynamic method, the accumulation chamber is "slightly open to the atmospheric air"that means that it has small vent holes for the air-gas mixture to come into the atmosphere (and vice-versa). Thus, this method is intended for "undisturbed"flow measurements. The advantage of the dynamic method is the absence of radon (thoron) background concentration inside an accumulation chamber. One more significant advantage is that there is no need in automation of the process of opening and closing of an accumulation chamber for long monitoring investigations because it significantly complicates the construction of a measuring complex and increases the total method error. The main disadvantage of the dynamic method is complex recalculation of the results of measurements of accumulated volumetric activity (VA) of radon into RFD quantity which requires long calibration.

Other disadvantages of the dynamic method [9],[10] are the following:

- the duration of one measurement depends on the thickness of a teflon disc and is from 2 days to 12 months that does not allow us study the diurnal variations of radon flux density;

- impossibility of application for automated monitoring, that means for continuous consecutive measurements without an operator;

- necessity to change a diffused filter in the basis of an accumulation chamber which results in the change of measurement conditions.

In the result of analysis of the literature on the methods of RFD measurements and patent investigations, we discovered that the present methods are not appropriate for complex radiation monitoring [2],[12]. They do not have the required functions in corpore but realize them partially.

All the above said determined the main aim of the present work, that is development of a method for monitoring of undisturbed radon flux density from the soil surface.

Measurement method of undisturbed radon flux density from the soil surface

In the course of development of a new technique for radiation monitoring [2] at Tomsk observatory of radioactivity and ionizing radiation (TORII), the requirements for the method of monitoring of undisturbed radon flux density from the soil surface were formulated, they are:

a) be simple in operation;

b) provide data of high confidence;

c) be capable of operating continuously, long (one year at least), and reliably in field conditions in a wide range of air pressure change, relative humidity (from 0 to $\sim$ 100%), and temperature (minus 45 °C to 50 °C);

d) have automated system of control and data record;

e) provide data time series with high sampling rate, of not more than 30 min, to investigate diurnal variations of the quantity;

f) be of low cost for mass distribution and equipping the monitoring networks in different regions of RF.

Moreover, the method for RFD monitoring from the soil surface should provide:

a) absence of thoron effect on measurement results;

b) absence of a system of opening and closing of an accumulation chamber which increases the duration of one measurement to 2 hours and more that is non enough to investigate diurnal variations of RFD and decreases significantly the duration of work.

Analysis of the modeling results of atmosphere and lithosphere impact on the dynamics of radon and thoron flux densities from the soil surface [13] showed that thoron flux density from the soil surface (Fig. 1) almost does not change during advection velocity change (not more than 2,6% in a wide range of values $0 < v < 10^{-5}$ m/s) of soil gases. That means that thoron will come out of the soil into an AC with the constant velocity and, consequently, will contribute continually into the total number of pulses recorded by a detector.

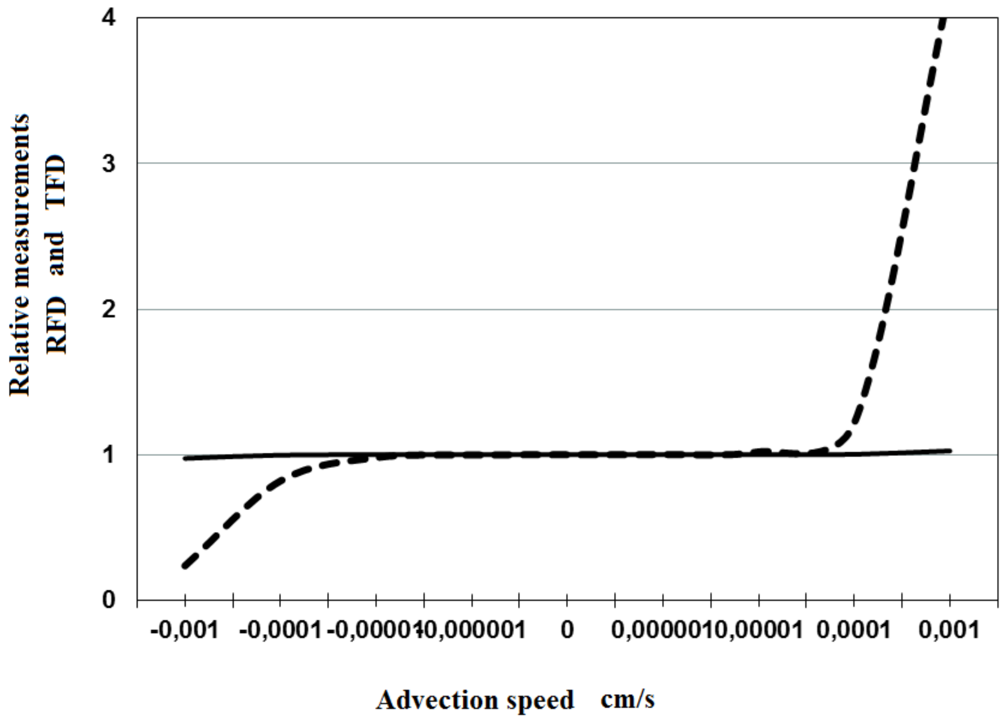

Fig. 1. Dependence of radon (dashed line) and thoron (solid line) flux densities on avection velocity

This result allowed us to develop a simple and low cost method for monitoring of undisturbed radon flux density from soil surface. The method consists in the application of a scintillation (or semiconducting) detector of α-particle and an accumulation chamber (Fig.2). The detector of α-particles is mounted inside an accumulation chamber so that its sensible surface is located not closer than 10 cm from the soil surface. Such limitation allows us to eliminate the "background"which may be determined by registration of α-particles formed in the result of soil radionuclide decay.

The AC has vent holes for partial discharge of soil gas and for conservations of radon semi-equilibrium concentration inside an accumulation chamber. The number and the size of holes is chosen according to the condition that the counting rate of pulses inside an accumulation chamber should be not less than 10 times as much as the counting rate of pulses in the open atmosphere at the same distance of a sensitive surface of a scintillation α-detector from the soil surface. That allows us to decrease the statistic error (mean root square deviation) of measurement results. Radon flux density is determined by the following expression:

$$q_{Rn}(t) = K_{Rn} \frac{N_{Rn+Tn}(t) - N_{Tn}}{\tau}, \quad (1)$$

where q_{Rn} is radon flux density from the soil surface at the instant of time t, Bq m^{-2} s^{-1}; K_{Rn} is the correction coefficient to convert pulse counting rate from radon and α-radiating daughter products of its decay into radon flux density measurement units, (Bq m^{-2} c^{-1})/(pul. s^{-1}); N_{Rn+Tn} is the total number of pulses from radon, thoron and α-radiating daughter products of their decay at the instant of time t registered within one measurement τ, pul.; N_{Tn} is the number of pulses from thoron and α-radiating daughter products of its decay registered during one measurement τ, pul., which, according to [13], is a constant for a definite place of monitoring and does not depend on time. τ is the duration of one measurement, s.

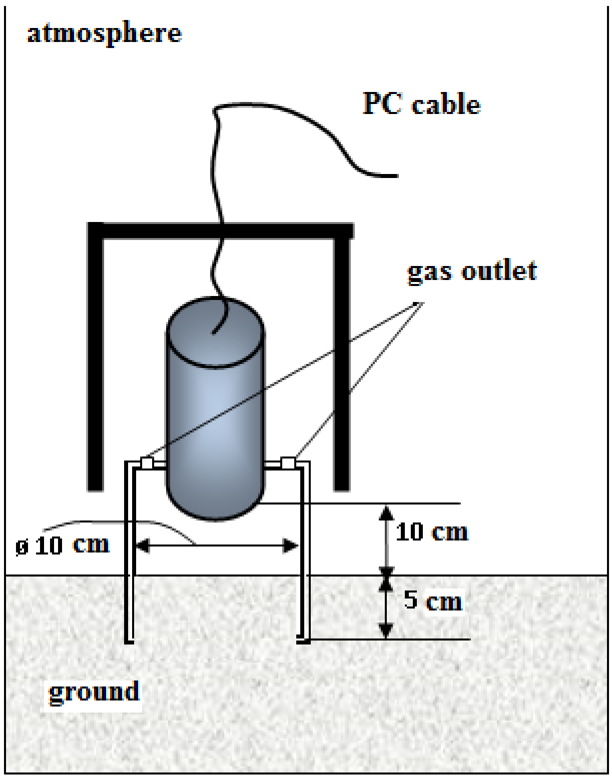

Fig. 2. Scheme of installation of the device to monitor undisturbed radon flux density from the soil surface

The recommended duration of one measurement τ is from 60 to 900 s. It is determined by the requirement to the uncertainty of measurement result. The value τ depends on technical characteristics of the chosen α-particle detector, in particular on the efficiency of registration and radon VA inside an accumulation chamber. If α-radiation detector operates in the counting mode with high sampling rate, it allows us to control the RFD diurnal variations.

The choice of the dynamic accumulation chamber in the developed method was determined by its significant advantage, it does not require automation of the process of opening and closing of an accumulation chamber during long control in monitoring mode. Thus, the accumulation chamber construction becomes significantly simpler because it needs neither complicated mechanisms to open and to close an AC nor the control software for this process and synchronization for AC and the measuring device. Hence, the total method error decreases, the lifetime of the device increases and the total cost of the instrumentation also decreases significantly.

Thus, the developed method for monitoring of radon flux density from the soil surface is:

a) reliable since it measures the density of undisturbed radon flux from the soil surface applying an accumulation chamber with large vent holes;

b) simple and reliable as the accumulation chamber basis need not to be covered by a diffused filter preventing thoron from penetration from soil, application of which could increase method error associated with disturbance of measurement conditions during periodic change of a filter;

c) inexpensive since it does not require application of complex spectrometric instrumentation, techniques to separate signals from thoron and radon;

d) reliable since statistics increases due to the registration of a total signal from radon, thoron and daughter products of their decay inside an accumulation chamber.

Calibration procedure

To monitor the RFD, two devices, RadEx-01 and RadEx-005, were developed at TORII. Their sensitive surfaces of scintillation α-detectors are located at 10 cm and 5 cm above the soil surface, respectively. The accumulation chambers were made of polyvinyl chloride, material impermeable for radon. The diameter of each of 6 vent holes was 4 mm. As a detector, we chose a scintillation detector block BDPA-01 (ATOMTEX, Belarus) controlled by a factory-furnished software. The both devices were installed at TORII experimental field.

Before the accumulation chamber was mounted on the soil surface, radon flux densities $q_{Rn}(t)$ were measured.

Then we determined the number of pulses N_{Tn} from thoron and α-radiating daughter products of its decay within one measurement τ.

After that, pulse counting rate in the accumulation chamber was measured during one measurement τ, being sure that pulse counting rate inside the accumulation chamber satisfied the conditions that it should be not less than 10 times as much as the pulse counting rate in the open atmosphere at the same height from the soil surface.

Then we determined the correction coefficient K_{Rn} for conversion of pulse counting rate from radon and α-radiating daughter products of its decay into the measurement units of radon flux density from the expression:

$$K_{Rn} = \frac{q_{Rn}(t)\,\tau}{N_{Rn+Tn}(t) - N_{Tn}}. \quad (2)$$

To begin the monitoring, the value of K_{Rn} determined from expression (2) was put into the program to calculate radon flux density. The counting start time and the duration of one measurement were also set.

Results of RFD measurements

Analysis of the results of monitoring of radon flux density from the soil surface into the near-surface atmosphere allowed us to discover some features and regularities. It was obtained that RFD changes significantly in time. Seasonal changes of RFD were detected. Weather conditions change considerably the form and the duration of anomalies in RFD series associated with formation and melting of snow cover.

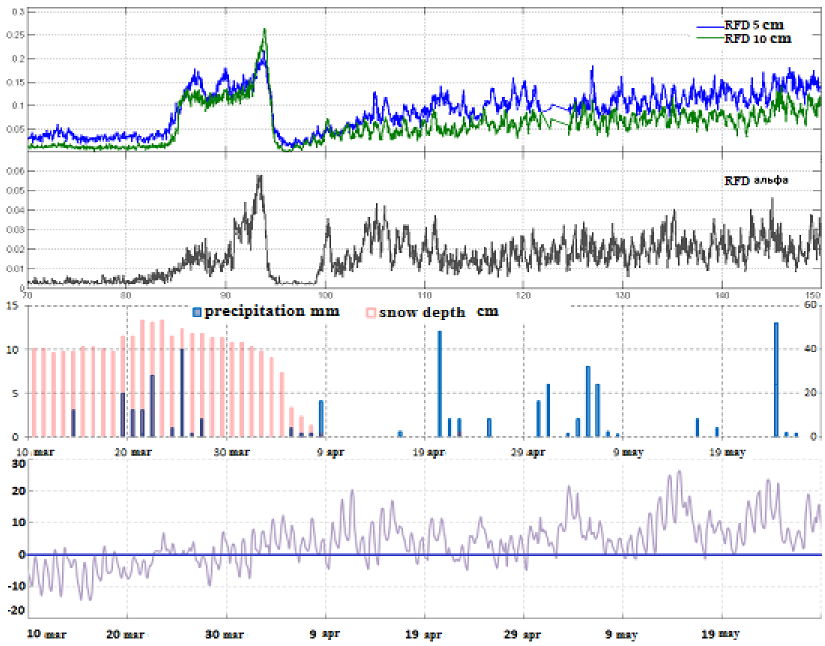

Fig. 3. Dynamics of RFD and of weather parameters in spring 2012.

Fig. 3 shows experimental series of RFD measured by different methods, snow cover thickness, air temperature, precipitation for the period from March 10 to April 28, 2012. The method based on the application of a static AC and a scintillation α-detector (RFD alpha) is described in detail in the paper [14]. The data obtained by RadEx-005 и RadEx-01, are hereafter denoted as «RFD 5 cm» and «RFD 10 cm», respectively.

The three devices based on different methods showed similar dynamics with some differences and anomalous behavior during snow melting. Anomalous increase of RFD began about 2 weeks before complete melting of snow (March 24-25) and ended by a sharp fall of RFD to the minimal registered values at the time of intensive melting of snow.

Such unusual behavior of RFD during snow melting was observed for the first time and has not been described before in scientific literature in spine of a large number of experiments on soil dampness effect on RFD value.

We obtained that maximal values are observed in autumn, at the end of summer and before snow melting (Fig. 3). Minimal values are usually registered in winter. Such a regularity agrees well with the results obtained on the RF territory [15]. It was mentioned in the paper that in the seasonal variation, minimal values of RFD were observed during winter period. Significant temporal variability of RFD at one control point was discovered. It is more than one order of the value within a year.

In fair weather conditions, diurnal variations are clearly seen with the maximum at midnight and minimum at noon. The difference between nighttime and daytime values reaches two times on average. These data agree well with the results of the papers [16]-[18]. The form of RFD diurnal variations may vary from «sawtooth» to «almost stepwise» during different periods. Slow decrease of RFD to the maximal value fallowed by a sharp decrease is more often observed.

Consideration of the features of RFD diurnal variations is important for radiation and health-related inspection of territories intended for building as well as determination of the degree of their potential radon hazard. If we take into account that controlling organizations make measurements of radon flux density during daytime, as a rule, and apply instantaneous methods, but RFD minimal values are minimal by day, the results of measurements may be underestimated significantly. As a result, the conclusions on the degree of radon hazard for a territory may be wrong.

The developed method is usable in the solution of a wide range of applied problems: estimates of territory radon hazard, of atmospheric near ground layer ionization density; investigation of earthquake precursors, processes and mechanisms of gaseous exchange between the soil and the atmosphere, lithosphere-atmosphere relations.

Conclusions

The method for monitoring of undisturbed radon flux density from the soil surface was developed. In comparison to other analogues, this method has a number of advantages, they are: a) enables us to measure the density of undisturbed radon flux in the result of application of a dynamic accumulation chamber; b) is quite simple in operation since it does not need diffused filters for blocking-off thoron and automation of the process of opening and closing of accumulation chambers c) is of low cost, since it does not require application of complex spectrometric instrumentation, techniques for signal separation from thoron and radon.

In the result of method testing it was obtained that RFD changes significantly in time. The maximal values are observed in autumn, at the end of summer, and before snow melting. The minimal values are observed in winter. Anomalous increase of RFD is observed during snow cover melting.

Strong temporal variability of RFD, by more that one order within a year, at one control point was discovered. In fair weather conditions, "standard"diurnal variation with the maximum at midnight and the minimum at noon was set. The difference between nighttime and daytime values reaches 2 times, on average.

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