Radon release rate from soil into the surface atmosphere specifics

G. A. Yakovlev¹, V. S. Yakovleva²

¹ Tomsk State University, 36 Lenina ave., Tomsk 634050 Russia

² Tomsk Polytechnic University, 30 Lenina ave., Tomsk 634050 Russia

E-mail: vsyakovleva@tpu.ru

The paper presents the results of the analysis of long-term series of monitoring data on the radon flux density. They were produced using a accumulation chamber of our own design, which allows, in terms of the readings of alpha radiation counters, to obtain the values of the radon flux density. The main results and the most illustrative examples of the behavior of the investigated characteristic of radon are present in the work. As a result, conclusions were drawn about the features of radon release rate from the soil into the surface atmosphere at different time scales and under different meteorological conditions, which can be used in the future to monitor the radon flux density using ionizing radiation detectors, and is also fundamental for the development new models.

Keywords: radon, flux density, surface atmosphere, soil, alpha radiation, accumulation chamber, dynamics

DOI: 10.26117/2079-6641-2021-35-2-150-158

Original article submitted: 15.05.2021

Revision submitted: 21.06.2021

For citation. Yakovlev G. A., Yakovleva V. S. Radon release rate from soil into the surface atmosphere specifics. *Vestnik KRAUNC. Fiz.-mat. nauki.* 2021, **35**: 2, 150-158. DOI: 10.26117/2079-6641-2021-35-2-150-158

The content is published under the terms of the Creative Commons Attribution 4.0 International License (<https://creativecommons.org/licenses/by/4.0/deed.ru>)

© Yakovlev G. A., Yakovleva V. S., 2021

INTRODUCTION

The radon flux density in Russia is monitored to assess the radon hazard of territories for the further construction of residential and public buildings. The value of the radon flux density from the earth's surface determines the total concentration of radon and its daughter decay products in the atmosphere. In geophysics, radon, due to its indicator properties, is a more sensitive precursor of earthquakes or changes in the stress-strain state of the earth's crust. A number of studies have found a significant correlation between the value of the radon flux density and the radiation gamma background in the surface atmosphere [1]. At the same time, the diurnal variations in the gamma background during the non-rainy period were explained precisely by the influence of radon escaping from the soil into the atmosphere. Despite numerous studies of the magnitude and dynamics of the radon flux density, the features of the dynamics of this magnitude and the main influencing factors characteristic of the Siberian region with a sharply continental climate are still insufficiently studied.

Funding. The study was carried out without financial support from foundations.

MATERIALS AND METHODS

Research was carried out on an experimental site Tomsk Observatory of Radioactivity and Ionizing Radiation (TPU-IMCES). Radon flux density (RFD) monitoring was carried out using scintillation detectors of alpha and beta radiation and a dynamic accumulation chamber (AC) of our own design with a 10-min and 1 min cycle, respectively (Fig. 1.).

Fig. 1. Accumulation chamber

The method based on dynamic AC allows to measure the density of the undisturbed radon flux from the soil surface [2]. The method consists in registering alpha (or beta) radiation of radon decay products accumulated inside a chamber installed on the ground surface, in the body of which there are holes for a partial release of soil gas.

Advantages:

- 1) There is no need to automate the process of opening and closing the storage chamber during long-term control in the monitoring mode;
- 2) The design of the storage chamber is greatly simplified, since complex mechanisms are not needed for opening-closing the AC;
- 3) Work in a wide range of changes in meteorological conditions;
- 4) Profitability, the possibility of mass research.

Calibration of the complex for monitoring RFD

It is especially necessary to approach the calibration of the complex for RFD monitoring. The calibration procedure is rather complicated and requires additional radon radiometers or alpha spectrometers. Works have been published regarding this topic [3]. The procedure for determining the correction factor that we used includes the following steps:

- 1) before installing the AC on the soil surface, the RFD is measured using a radiometer, for example, RTM 2200 (SARAD GmbH, Germany);
- 2) at the same place, the number of pulses from the thoron and alpha-emitting daughter products of its decay is determined for the duration of one measurement τ using an alpha spectrometer;

3) with the BDPA-01 (ATOMTEX, Belarus) alpha-radiation scintillation detector (or its analogue), combined with the AC, the total number of pulses from radon, thoron and alpha-emitting daughter products of their decay is measured during the time τ ;

4) determine the correction factor for converting the count rate of pulses from radon and alpha-emitting daughter products of its decay into units of measurement of the radon flux density from the expression:

$$K_{Rn} = \frac{q_{Rn} \cdot \tau}{N_{Rn+Tn} - N_{Tn}}, \quad (\text{Bq} \cdot \text{m}^{-2} \cdot \text{s}^{-1}) / (\text{imp.}/\text{s}) \quad (1)$$

RESULTS AND DISCUSSION

Consider the results of long-term monitoring over the past 9 years. Revealed patterns on the annual and daily scales. The annual trend shows anomalies at the end of April. The minimum values are observed in the spring-winter period, the maximum in the warm period. The radon hazard of the territory is characterized precisely by the summer period. On Figure 2 and 3 RFD monitoring data is shown for alpha 5 cm and 10 cm off the ground respectively for years 2011 through 2018. Values of RFD are present in imp./s that then can be converted to RFD ($\text{Bq} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$).

Fig. 2. RFD alpha 5 cm

Fig. 3. RFD alpha 10 cm

First that can be seen on both figures are the anomalies that vary from year to year of measurements. Strong anomalies were observed in 2013 and 2018, perhaps this is due to the rather rapid melting of snow cover that let to release of the radon (Fig. 4).

Also the autumn to winter transition season shows different reaction in different years, sometimes we can see obvious decrease that is due to the snow coverage of the soil surface and in some cases there are small to no changes in measurements. Further observation is needed for more detailed conclusions.

Fig. 4. RFD dynamics, snow layer depth and atmosphere temperature

Although 5 cm having higher values and sometimes amplitude, which can be useful for some situations but generally has more noise, generally the dynamics of 5 cm and 10 cm is the same with modest variations around value of 0.1 imp./s. Only exceptions is anomalies at the end of April that are associated with the snow cover melting, which causes an anomalous increase in RFD up to 10 times.

In some periods of the year, such as winter shown on Figure 5, there is a significant negative correlation between RFD and atmospheric pressure.

Fig. 5. RFD dynamics negative correlation to atmospheric pressure (mmHg)

Well-pronounced diurnal variations are observed mainly during periods of good weather and significantly correlate with atmospheric temperature (negative correlation).

Figure 6 shows variations that can be frequently observed, such as those with cases of rain, which disturb the well-defined variations. Figure 7 shows clear weather period that shows clear daily variations that correlate with temperature.

In contrast to other characteristics of the radon field, such as radon VA in the atmosphere or in the ground for RFD, the daily dynamics is characterized by 2 maxima - during the day (12 hours) and at night (00 hours). Due to the fallout of low-intensity precipitation, the characteristic diurnal variation is disrupted and only 1 maximum is observed, as can be seen from Figures 6 and 7.

Fig. 6. Urinal variations of RFD with cases of rain

Fig. 7. Urinal variations of RFD in good weather conditions

Our previous results show that daily variations of the RFD also have good convergence with the results of RFD measurements by different methods, as well as a significant negative correlation with the temperature in the soil layer up to 20 cm.

Next, we will consider the influence of precipitation of different intensity on the dynamics of the RFD. Both isolated cases of precipitation of medium and high intensity, and prolonged rains for more than a day lead to an anomalous increase in RFD up to 2 times.

The daily variation of the RFD is poorly expressed or absent altogether on rainy days or in periods with frequent precipitations which are not single peaks (Figure 8).

Single cases of precipitation with an intensity of 15 mm violate the standard daily dynamics of the RFD.

Fig. 8. Variations of RFD with very frequent and long precipitations

Fig. 9. Variations of RFD with frequent but short precipitations and one clear weather period

On the other hand precipitation of low and medium intensity, no more than 15 mm, has a different effect on the magnitude and dynamics of RFD (Figure 9). That means in case of single short rain change in dynamics is not strong and it goes back to usual form in couple of days.

Precipitation with an intensity of 40 mm or more leads to an anomalous increase in RFD up to 2 times, as shown on the Figure 10.

Fig. 10. Another case of RFD variations in clear weather

Similar results were obtained in Beijing in 2012 [4] when studying the effect of precipitation of different intensity on the RFD. They had precipitation that only leads to a violation of the diurnal variation, but does not cause anomalies.

Pronounced diurnal variations in the RFD are observed only in different periods of the year without precipitation. During such periods, RFD significantly correlate with changes in air temperature. In the diurnal cycle, the maximum RFD values are observed in the evening (about 00:00), and the minimum - in the early morning (about 06:00).

CONCLUSIONS

1. The features of the long-term annual behavior of the RFD have been studied.
2. Following seasonal and daily patterns in the dynamics of RFD were revealed:
 - anomalies appear during periods of melting snow cover, as well as during precipitation of medium and high intensity;
 - during periods of good weather and pronounced daily variations in atmospheric temperature, the radon flux density shows two maxima. The rest of the time, there is either 1 maximum per day or the absence of pronounced diurnal variations;
 - the RFD maxima appear at a different time than the radon VA maxima in the atmosphere.
3. Influencing factors:
 - pressure affects the dynamics of the RFD, mainly in the winter;
 - atmospheric temperature, soil temperature affect the daily course of the RFD.

Acknowledgment. The authors express their gratitude to Doctor of Physics and Mathematics, Chief Researcher of Institute of Monitoring of Climatic and Ecological Systems Nagorskiy Petr Mikhailovich, and Doctor of Physics and Mathematics, Senior Researcher of Institute of Monitoring of Climatic and Ecological Systems Smirnov Sergey Vasilyevich, for valuable advices and productive discussion of the results of the article.

Competing interests. The authors declare that there are no conflicts of interest regarding authorship and publication.

Contribution and Responsibility. All authors contributed to this article. Authors are solely responsible for providing the final version of the article in print. The final version of the manuscript was approved by all authors.

References

- [1] Tchorz-Trzeciakiewicz D.E., Solecki A.T., “Variations of radon concentration in the atmosphere. Gamma dose rate”, *Atmospheric Environment*, **174** (2018), 54–65.
- [2] Yakovleva V. S., P.M. Nagorskiy, Yakovlev G. A., “Method of monitoring of undisturbed radon flux density from the soil surface”, *Vestnik KRAUNC. Fiz.-mat. nauki.*, **12**:1 (2016), 85–93.
- [3] Onishchenko A., Zhukovsky M., Bastrikov V., “Calibration system for measuring the radon flux density”, *Radiation Protection Dosimetry*, **164**:4 (2015), 582–586.
- [4] Zhang, L., Guo, Q. & Sun, K., “Continuous measurement of radon exhalation rate of soil in Beijing”, *J Radioanal Nucl Chem*, **303** (2015), 1623–1627.

УДК 550.35

Научная статья

Особенности скорости выхода радона из грунта в приземную атмосферу

Г. А. Яковлев¹, В. С. Яковлева²

¹ Томский государственный университет, 634050, Россия, г. Томск, пр. Ленина, 36

² Томский политехнический университет, 634050, Россия, г. Томск, пр. Ленина, 30

E-mail: vsyakovleva@tpu.ru

В работе представлены результаты анализа многолетних рядов данных мониторинга плотности потока радона. Они производились с помощью накопительной камеры собственной разработки позволяющей в пересчете с показаний счетчиков альфа излучения получить значения плотности потока радона. В работе освещены основные результаты и наиболее показательные примеры поведения исследованной характеристики радона. В результате были сделаны выводы об особенностях скорости выхода радона из грунта в приземную атмосферу на различных масштабах времени и при различных метеорологических условиях, что может быть использовано в дальнейшем с целью мониторинга плотности потока радона при помощи детекторов ионизирующего излучения, а также несет фундаментальный характер для разработки новых моделей.

Ключевые слова: радон, плотность потока, приземная атмосфера, почва, альфа-излучение, накопительная камера, динамика

DOI: 10.26117/2079-6641-2021-35-2-150-158

Поступила в редакцию: 15.05.2021

В окончательном варианте: 21.06.2021

Для цитирования. Yakovlev G. A., Yakovleva V. S. Radon release rate from soil into the surface atmosphere specifics // *Вестник КРАУНЦ. Физ.-мат. науки.* 2021. Т. 35. № 2. С. 150-158. DOI: 10.26117/2079-6641-2021-35-2-150-158

Конкурирующие интересы. Авторы заявляют, что конфликтов интересов в отношении авторства и публикации нет.

Авторский вклад и ответственность. Все авторы участвовали в написании статьи и полностью несут ответственность за предоставление окончательной версии статьи в печать. Окончательная версия рукописи была одобрена всеми авторами.

Контент публикуется на условиях лицензии Creative Commons Attribution 4.0 International (<https://creativecommons.org/licenses/by/4.0/deed.ru>)

© Яковлев Г. А., Яковлева В. С., 2021

Финансирование. Исследование выполнялось без финансовой поддержки фондов.