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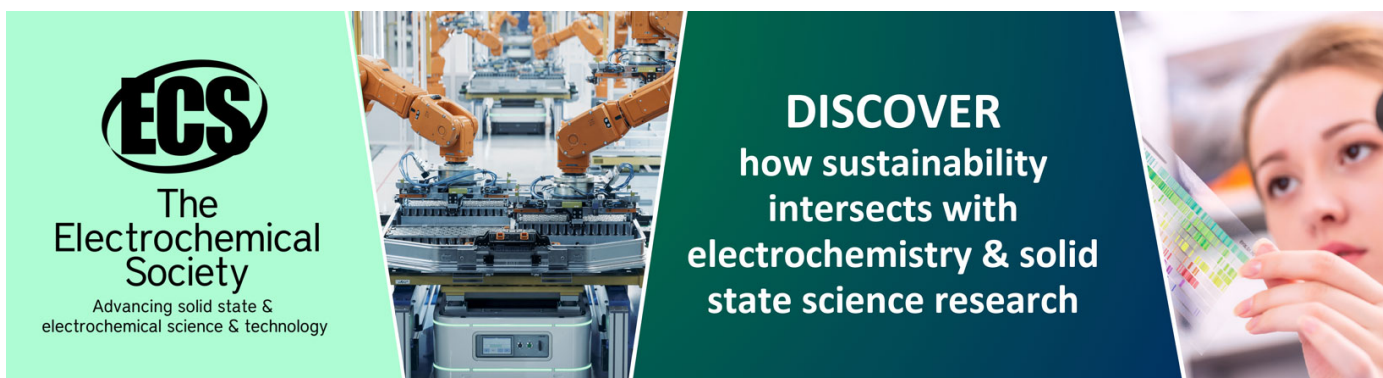
Radon Hazard Assessment in Region with Intense Coal Mining Industry

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Radon Hazard Assessment in Region with Intense Coal Mining Industry

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Abstract. This paper of the assessment of indoor radon volume activity (VAR) in Leninsk-Kuznetskiy region and its environs is presented. Average VAR was obtained during this study is 294 ± 22 Bq/m³. Areal and linear anomalies of the VAR were found in this territory with epicenters values 1840-1042 Bq/m³. It confirmed in this study that it needs to consider the geological environment of the Kuznetsk coal basin during the construction of low-story buildings. It is providing a basis for study of the underground mining effect on the residential radiological parameters.

1. Introduction

Radon is a product of consequent radioactive decay of isotopes series, starting with natural ²³⁸U and ²³²Th and ²³⁵U disperse in the earth's crust. Relatively long-lived isotope of Rn is ²²²Rn (radon), the daughter of ²³⁸U series, (immediate precursor is radium) with $\lambda=3.82$ days, which can accumulate in buildings in significant concentrations and represents main radiological hazard [1]. Two others radon isotopes is ²²⁰Rn (thoron) with $\lambda=56$ s, and ²¹⁹Rn (action) with $\lambda=4$ s, that generates from Thorium and Uran-235 (Actinon) respectively, this two isotopes is mostly decaying before it comes airborne. At the same time even ²²²Rn has a relatively short lifetime and its containing in outdoor air is very low, that makes radon specific indoor type pollutant. Radon is an alpha emitter and its decay is accompanied with formation of radon progeny (RP) – short-lived isotopes Po, Bi, Pb which are also dangerous when inhaled.

In some researches concerning with large groups of people, it was shown that there is a relationship between exposure in domestic conditions (residential exposure) and the additional risk of lung cancer [2]. For the European population, the average additional risk of lung cancer was evaluated as 8% (95% CI 3-16) for every additional 100 Bq/m³ VAR in indoor air. This risk was independent of the samples features, gender, age, or smoking of the subjects. At the same time, analysis based on a long-term average concentration of radon showed a double risk value of 16%. The overall risk assessment of mortality from exposure to radon was 9% of all lung cancer deaths in the European population [3]. Such a significant assessment of the additional risk of exposure to radon makes us consider the problems of resident exposure to radon as one of the most important hygienic and medical problems [4]. Today, many countries recognize the lack of efforts to reduce the concentration of radon in residential buildings, as well as the need for relevant measures, including legislative regulation and some steps to inform peoples about radon threat [5].

According to specific inhalation route of radon intake into organism, the greatest influence belongs to the incidence of lung cancer, trachea and bronchus (TBL cancer). In an extensive study included an analysis of articles from 1980 to 2016, it was made an assessment was of total burden of additional lung cancer incidence caused by the influence of radon. As a quantitative indicator, the indicator “disability - adjusted life years, DALY” was used. The total DALY estimate in 2013 was 32,405,000, while the share of radon resident exposure was estimated as 1979,000 for 2013. The average number of years of



life lost as a result of residential radon calculated for Canada was 0.066 years for non-smokers and 0.198 years for past/current smokers [6].

Radon indoor concentration is determined by a large number of factors described previously which can be combined into the following groups:

1) Construction and material features. Certain materials may be characterized by high radon emission (granite, phosphorites, etc.), which determines the entry of radon and its isotopes into a dwellings [7], however, same study showed that decorative materials are not able to provide a high VAR in normally ventilated rooms. Also isolation of living rooms from the ground is very important, because this factor determines the amount of radon that entry into the building. Another factor is the degree of isolation of living rooms from microcirculation processes between indoor and outdoor air. All these design features can reduce VAR in residential conditions [8].

2) Indoor activities. High ventilation level can reduce indoor radon level as evidenced by the decrease in residential VAR in spring and summer periods and its increase in autumn and winter according to decrease of ventilation, especially in cold climate territories.

3) Geological structure. The heterogeneity of soils, by content of radon parent element (U, Th, Ra), determines a different amount of radon and its progeny entering indoors [9–11]. Also, according to some studies [12,13], anomalies of high radon concentrations are confined to zones of fault lines and fracture rock. Water saturation, porosity, and the temperature of loose soils also have an influence for radon transport into buildings [14,15].

A study of radon indoor level on platform areas showed lower values compared to mountain ranges, which is determined by a significant degree of tectonic disturbance of the rock complexes of orogen and the frequent confinement of uranium and thorium deposits to the mountain ranges in Russia [16]. In addition, there are studies that show that the transporting ability of tectonic destruction with respect to radon and its progeny is determined by the activity of the fault or its development and its genetic type [12]. So, on continuing fault line have higher values of radon emanations. Tectonic destruction associated with spreading zones (dip-slip fault) are associated with higher VAR values than associated with the compression zone (reverse fault), and the slip fault in this case were intermediate [12,13,17]. It is obvious that confinement of radon emanations to fault line predetermines further expression of this effect in the form of linearly elongated areal anomalies of high and low residential radon level perpendicular to the direction of compression.

The high radon level in certain objects (mines, adits, residential buildings, etc.) can be determined by the clark of radon parents elements in coal. The secondary danger is associated with the formation of underground mine during coal mining, which can be areas for radon accumulation. For some mines in Kuzbass region, the VAR values were previously determined up to 6000 Bq / m³.

The study of indoor VAR at building placed in the territory of active underground mining of coal is an urgent task to assess the impact of mining on the environmental functions of the lithosphere and facilities located above or near mine fields. In addition, active coal mining leads to the formation of cracks and tectonic disturbances of anthropogenic origin, and the activity of tectonic blocks on the site is confirmed by a significant number of rock burst and earthquakes of low energy, which can lead to the formation of new transport channels for radon and its progeny.

2. Objects, methods and materials of research.

The object of research was Leninsk-Kuznetsk city and its environs. The tectonic structure of the research site is represented mainly by the eastern wing of the Lenin synclinal. The rock are represented by the Ilya subseries and the Lenin suite formation, composed of a series of interbedded siltstones, sandstones, argillites, and coals. The main faults of the study area with complex kinematics are the fault line of Kilchigz and Zhurinsky (Sokolovsky), which are also accompanied by a concomitant zone of tectonic disturbance, of varying length along strike. The tectonic disturbance of the region determines the presence of transporting channels for radon and its progeny formed as a result of the decay of radium and uranium in rock. The presence of mine fields, which cover a significant territory of the city of Leninsk-Kuznetsk (Fig. 1) and its environs, and active mining, can form new potential routes of radon entry to the surface.

The houses built on the study area belong to different years from 1924 to 2013, which excludes the possibility of a same effect of the engineering and construction features on radon-accumulating properties of buildings.

The studies were carried out from November 2018 to February 2019. The radon level was studied by Camera-01 device (STC Niton, Russia), using a passive adsorption method with SK-13 charcoal sorption columns. Two absorber-columns were installed in the room at a height of 0.7-1.3 m above the floor for 6-7 days to obtain an integral indicator of VAR, which provide to eliminate the effect of short-term changes in the VAR, for example, ventilation before and during research. Each absorber-columns was installed in the rooms where inhabitants spent a longer time (usually, bedroom and kitchen room). VAR level was considered as average obtained by two absorbers to exclude the influence of microcirculation processes in buildings.

The results were processed in MS Office Excel using the add-on “analysis package”. In ArcGIS 10.3.1, were constructed maps of the geological structure of the study area, the location of mine fields, and large tectonic disturbances. The spatial location of the studied residential buildings according with VAR was identified using Landsat 8 satellite imagery data. Interpolation was carried out using the method of the nearest neighborhoods in the ArcGIS program. The construction of spatial interpolation models of the distribution of indoor VAR was carried out separately for two areas of accumulation of the studied rooms, due to the uneven network of observations between these areas.

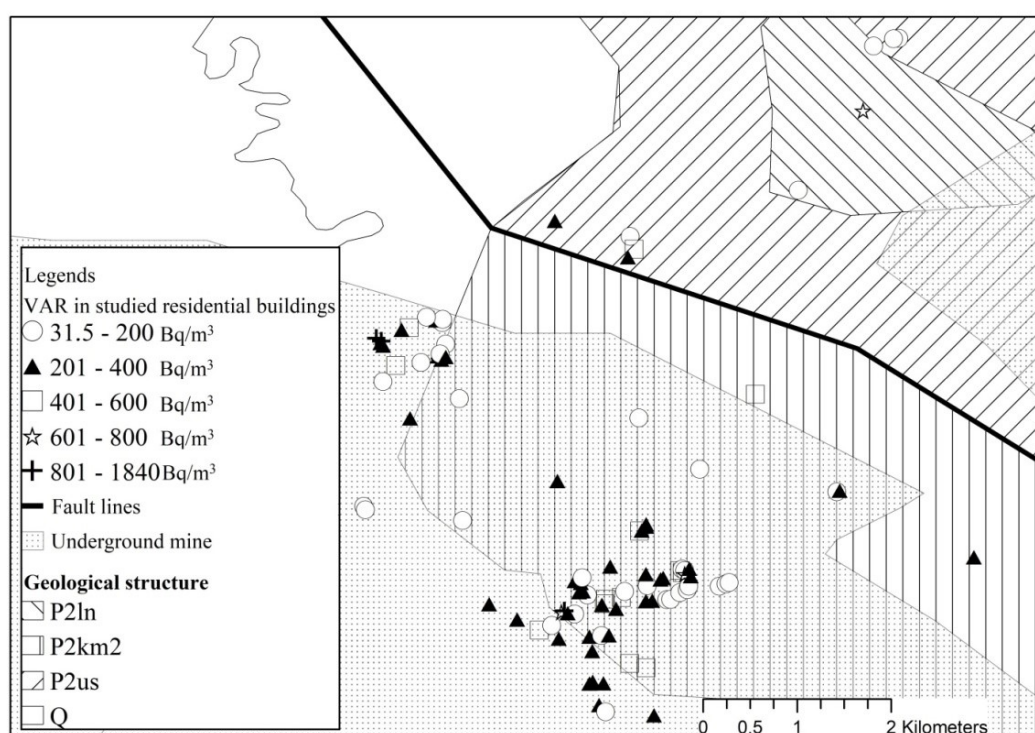


Figure1. Research area map

Note: P2ln - Lenin suite formation, P2km2 - Kazankovo-Markin suite formation. P2us - Uskat suite formation, Q-Quaternary geological system.

3. Results and discussion

Volume radon activity varies significantly within the study area from 31.5 Bq/m³ to 1840 Bq/m³. Arithmetic means for all examined buildings was 294 ± 22 Bq/m³. The frequency of high radon level cases presented in table 1.

Table 1. VAR in studied residential buildings in Leninsk-Kuznetsk

	VAR indoor, Bq/m ³				
	0-200	201-400	401-600	601-800	>800
Number of object (%) from all objects)	44 (38.60%)	49 (42.98%)	14 (12.28%)	3 (2.63%)	4 (3.51%)
Mean $\pm$ st. error	134 $\pm$ 6	288 $\pm$ 9	474 $\pm$ 14	652 $\pm$ 36	1216 $\pm$ 29

A significant number of houses with excessive according to radiation safety standards (NRB) VAR values, belongs to the interval from 3 to 5 groups, overall there are 21 residential buildings or 18.42%. At the same time, houses with high values form linearly elongated areal anomalies, and with a more detailed examination these patterns can change. The degree of influence of all factors leading to high residential VAR values is rather difficult to determine. At the same time, spatial analysis, in the presence of linearly elongated areal anomalies of high VAR values, allows us to evaluate the structural and tectonic conditions of the geological environment and the degree of their influence on the structures. The primary revealed point anomalies of the VAR during a further study of the surrounding structures acquired a linearly elongated areal character or often oval in shape. The compiled schematic diagrams (figure 2. and figure 3.) for two territories (A and B, respectively) with the largest number of studied residential buildings in the city of Leninsk-Kuznetskiy allow us to distinguish linearly elongated areal and oval patterns of the location of houses with high and low VAR.

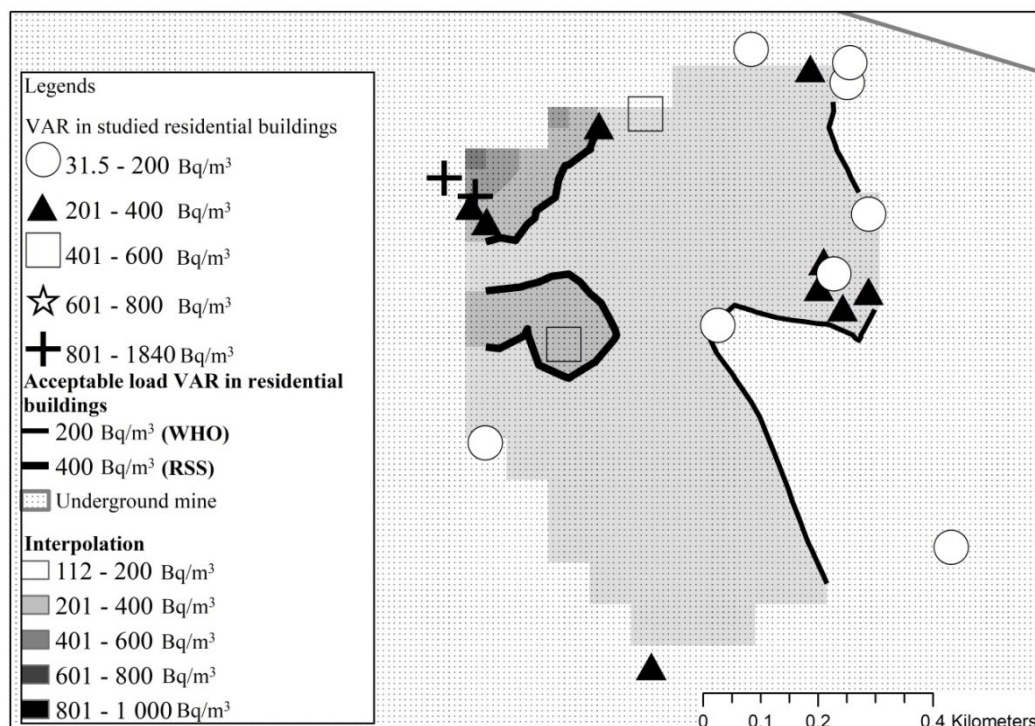


Figure 2. Map of spatial differences of the VAR in dwellings, territory A

Zone A is characterized by 3 clusters with high VAR values in residential buildings. One of the epicenters corresponds to a value of 1840 Bq/m³, and in its vicinity there are buildings with values from 333 to 723 Bq/m³. A field containing 5 buildings with values 376-555 Bq/m³ was also found. In the northeastern part, a linear anomaly of houses with values of 445-624 Bq/m³ was found. A survey of house materials showed that they are all built of wooden beams on a strip foundation, which excludes the influence of the engineering features.

Zone B is characterized by one VAR anomaly with a value of 1042 Bq/m³ at the epicenter and a value of 940 Bq/m³ was found along the line to the northwest. Also found is a house with values of 540-570 Bq/m³, not lying on the line with the first anomaly. In the rest of the territory outside the anomaly, the rooms have a relatively low radon background.

In this connection also it's very interesting are the areas of sharp differences in the VAR in neighboring buildings, which may indicate the attenuation of radon transport to buildings outside of tectonic disturbances. In the absence of faults, the area of the surface exhaling radon will be equal to house area and low concentrations of radon parent's isotopes will not lead to high VAR. In the presence of tectonic disturbances or underground cavities (mine workings), the area of radon collection further release indoor increases significantly due to additional fracturing. As consequence in the case of incomplete soil freezing, a greater amount of gas will flow to indoor.

Negative anomalies of the radon content also form linearly elongated areas and, these areas can be attributed to solid rock masses or compression zones, like it was described previously [12,13], in studies of radon emanation from the zone of disjunctive disorders of various types.

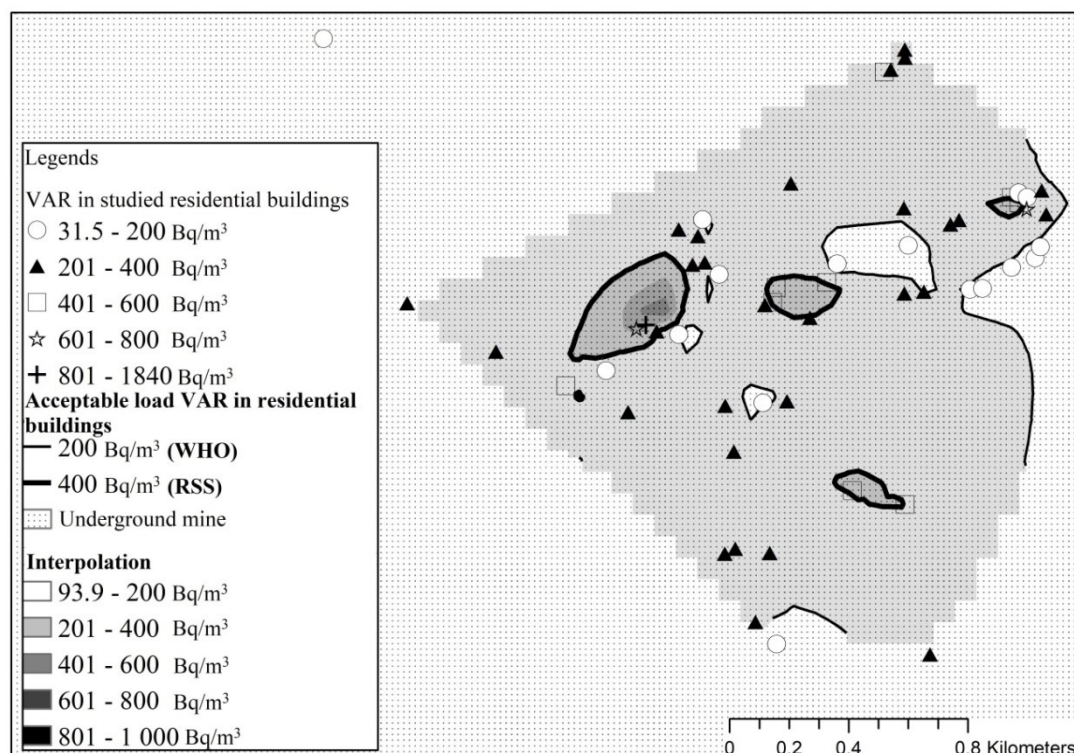


Figure 3. Map of spatial differences of the VAR in dwellings, territory B

Since geologically the whole studied territory belongs to complexes with a low content of U, Th, Ra, the exhalation of radon from the sheet surface is not enough to form the observed VAR values, in this case, significant concentrations of radon will correspond to tectonic disturbances, or indoor radioactive i.e. decorative materials. At the same time, formation of linearly elongated area anomalies with high indoor VAR values in buildings with different construction times and materials, internal furniture and ventilation, independently of the structural and tectonic features of the territory is looks extremely unlikely. Another proof of this statement is the presence of areal negative anomalies within the studied field, and not their random location on the territory.

4. Conclusions

1. Observed low-rise houses on the territory of Leninsk-Kuznetsk city are characterized by high VAR value in winter period, comparable with the territories of the mountains regions, which causes additional radiation exposure for population here;
2. The obtained data confirm the influence of fault line, both previously existing and probably newly formed as a result of mining activities, on the residential radiological safety, especially low-rise houses in the Kuznetsk coal basin, which must be taken into account during urban planning;
3. The transporting effect of tectonic disturbances is often expressed in linearly elongated areal anomalies of high VAR values;
4. The radon hazard of the geological environment in the Leninsk-Kuznetsk region is mainly associated with tectonic disturbances, because according to the petrographic characteristics of the complexes, they are composed of weakly radioactive rocks.

5. Acknowledgement

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