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Current Problems of Radiation-Ecological Monitoring in Penza Region

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***Abstract*—The paper presents the measurement results of construction and finishing materials, agricultural products (honey) on the content of radionuclides in Penza and Penza Region. The obtained dependences allow confirming the dependences between a radon exhalation, type of construction and finishing materials. Seasonal fluctuations of radon release intensity are revealed.**

***Keywords*—radon, radiation safety, radiation environmental monitoring, volume activity.**

I. Introduction

One of the relevant but not sufficiently studied tasks of radiation safety of the Russian population is radon exhalation in industrial, office and social space. The concentration of radon almost in all buildings is much higher than in the atmosphere due to the presence of radium-226 forming radon through decomposition in close proximity to the building or inside it. Radon-222 is the radon isotope with half-life period $T_{½} = 3.82$ days, being part of uranium-238 radioactive family and formed as a result of radium-226 isotope decay. Radon-222 mainly contributes to the radiation dose of the population, such short-lived radon isotopes as ^{220}Rn (thoron, $T_{½} = 54.5$ sec.) and ^{219}Rn (action, $T_{½} = 3.9$ sec.) in total make less than 10% of the radiation dose of all radon isotopes.

The concentration of radon was for the first time recorded and measured in Sweden. The results of these studies were published in the 1950s of the 20th century and showed high level of radon concentration in houses built of concrete containing radium-226. Researchers did not attach significance to it at that time considering it a local Swedish problem. However, this study has driven further research in other countries, which results are presented in UNSCEAR Reports [1], demonstrating that radon exhalation is typical for all European countries.

Traditionally, hydrosphere, lithosphere, recovered minerals that are differently processed, natural construction materials are considered as radon sources. The radon, formed in the soil foundation of buildings and enclosure structures made of materials containing nonmetallic rocks, is able to migrate from the pore space into the open air and accumulate in rooms. Outdoor air and water supplied to buildings from artesian wells belong to other less significant sources of radon. Soil foundation of buildings is considered the main source of indoor radon [2]. Even at standard specific activity of radium-226 the concentration of radon in pore space of the soil foundation makes dozens of kilobecquerels per cubic meter. Construction materials are also considered as a significant source of radon (Figure 1).

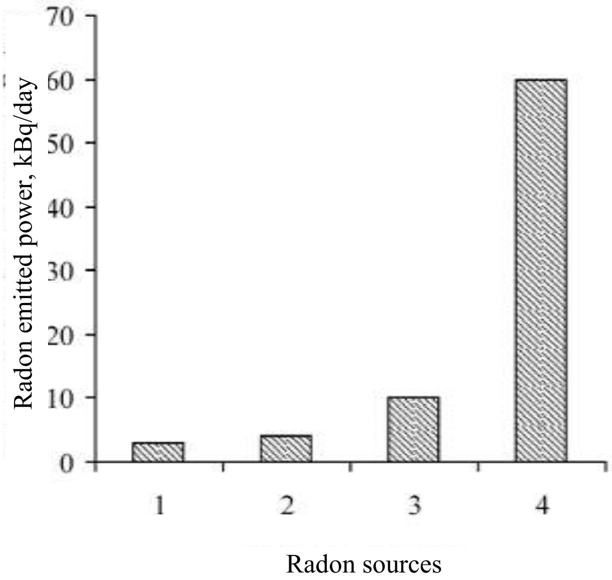

Fig. 1. Radon sources: 1 – natural gas; 2 – water; 3 – outdoor air; 4 – construction materials and soil under the building

Figure 2 shows the distribution of radon exhalation zones in the Russian Federation [3]. It shows that Penza Region is in the area with high radon exhalation rate and therefore urgently needs radiation and environmental monitoring.

Fig. 2. Distribution of radon exhalation zones across the territory of the Russian Federation (areas with high radon exhalation are marked pink) [3]

II. PURPOSE OF THE STUDY

To define the parameters of radon exhalation in Penza and Penza Region depending on the season and used construction and finishing materials. To establish the dependence between radon exhalation and the quality of agricultural goods in Penza Region.

The study was conducted using SKS-07P gamma-spectrometric complex intended to define the specific activity of radioisotopes in samples by three radiation types.

III. RESULTS

The concentration and specific activity of radioisotopes in soil, air, water, food, construction materials were measured, which showed the presence of radionuclides in the studied samples: Cs^{137}, Ra^{226}, Th^{232}, Am^{241}, Rn^{222}. Their quantity in 40% cases exceeded the maximum permissible values [4, 5].

The definition of radon hazard includes the assessment of radon intensity coming from soil under buildings and the forecast of possible radon concentration in the air of both operated and designed buildings [6]. Only the knowledge of dependences of radon exhalation intensity on physical parameters of soil in-situ and external conditions allows designing a model of radon intake from soil under foundation to basements. To forecast the radon hazard of buildings under construction, the report of United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) discusses the possibility of calculating the equilibrium equivalent concentration of radon based on its flux density from soil under foundation of buildings [4].

The radon diffusion and its volumetric activity (VA) in the atmosphere of the studied territory are caused by various factors: size and composition of geological layers causing radiation; optical path length; radiation object size; ventilation in buildings, etc. Statistical laws on data distribution contain the most complete information on the properties of sources. If the radiation results are distributed under the logarithmic normal law, then it is fair to assume that radon exhalation is caused by multiple reasons of different origin. At the same time, the distribution form indicates the existence of diffusion objects of different intensity. In the case where the sources affecting the measurement results are located in the territory, the data tends towards high values. Therefore, there is a need to use the distributions reflecting the shift of measurement results to describe the given data: shifted Weibull-Gnedenko distribution, double exponential distribution, maximum value distribution, etc. [4].

Quite often, the total radiation of a variety of objects having different origin is comparable with the radiation of a single source in the same territory. The logarithmic normal distribution allows approximating the VA results commensurable on intensity and various radon radiation objects. The shifted Weibull-Gnedenko distribution is a good approximation of object radiation defining the activity shift towards higher values in the entire territory. When imposed, the resulting radiation shall be characterized by a mix of two various statistical distributions. Having divided the mixes into initial components, it is possible to obtain the useful information on the radiation sources: character, intensity, power, etc.

The use of known smoothing distributions allows detecting the radon diffusion source only at considerable increase of its intensity over the total intensity of all other sources of diffusion. It shall be noted that even when choosing the most optimum smoothing distribution there is a considerable deviation of its properties from those of initial sampling demonstrated by the deviation of information distribution parameters, such as counterexcess x and entropy coefficient k_e in relation to their optimum values. The mix of distributions allows expanding the possibility of approximation and analysis of asymmetrical data [4].

Over 1000 residential buildings were analyzed in the study of the influence of construction materials on radon concentration in the air of residential and public buildings. Table 1 and Figure 3 show the average and maximum VA of Rn^{222} in the premises of Penza and Penza Region built from wood, concrete, ceramic and lime brick.

The study of the influence of construction materials on radon concentration in the air of residential and public buildings showed that the greatest radon emission is typical for rooms built of a lime brick. These results are confirmed by the study [7]. Radioactivity of a lime brick is bound to radioactive properties of natural materials of which it is made. High concentration of radionuclides is typical for potassium and field spars, clay minerals, etc. from which the lime brick is made.

TABLE I. MEASUREMENT OF RADON VA FROM CONSTRUCTION MATERIALS

No.	Construction material		Average VA, Bq/m³	Mean square deviation, σ, Bq/m³	Maximum VA, Bq/m³
1	Ceramic brick	Winter	110	50	326
		Summer	109	60	330
2	Lime brick	Winter	130	60	331
		Summer	125	60	321
3	Wood	Winter	109	49	340
		Summer	112	50	319
4	Panels	Winter	109	56	340
		Summer	108	51	325

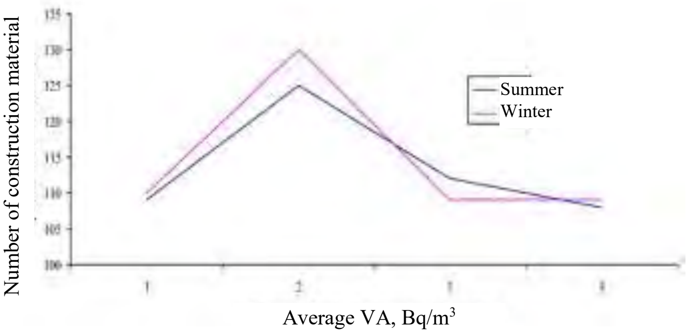

Fig. 3. Dependence of radon average VA on the season and type of construction material (Table 1)

The concentration of radon in rooms mainly depends on the use of finishing materials. Almost all finishing materials reduce radon emission from construction materials. However, there are different indicators indicating the decrease of radon concentration when using different types of finishing materials.

The study of radon concentration in rooms showed technical and economic feasibility of different types of finishing to decrease radon exhalation. Different types of finishing materials were applied on surfaces with further measurement of radon exhalation.

Table 2 and Figure 4 show that almost all finishing materials have high radon insulating properties. Finishing tiles, irrespective of their composition, are also radon protective [8, 9]. It is explained by lacquer coating or melted frit on ceramics applied on a tile surface. However, some finishing materials have high effective specific activity (for example, ceramic tiles), therefore their application can considerably improve the gamma background in rooms [9]. Besides, when selecting the construction materials with high density and low effective specific activity it is not only possible to reduce the radon emission from structural materials, but also the gamma background in rooms [9].

There is direct dependence between the pollution of soils with radionuclides and specific radioactivity of plants.

At present, in most cases the radioactivity of plants is defined by strontium and cesium radioisotopes. It is established that radionuclides mainly accumulate in needles (leaves), then in bark, branches, and the least – in wood [2].

The grassy plants making the cover above surface are actively involved in the circulation of radionuclides within natural and vegetable complexes. In fact, radionuclides are accumulated in those organs and tissues of plants, which are characterized by active metabolism. Then, radionuclides from plants get into the organism of animals, into honey products, etc.

Currently, the requirements to the quality of honey products, namely to their ecological cleanness and safety, are becoming ever more tough.

TABLE II. DECREASE OF RADON CONCENTRATION WHEN USING DIFFERENT TYPES OF FINISHING COATINGS

No.	**Type of finishing coating**	**k_{sh}, %**		
		Q_H=5 mBq/(м²·s)	**Q_H=10 mBq/(m²·s)**	**Q_H=20 mBq/(m²·s)**
1	Whiting	14.3	16.7	21.9
2	Paper wallpaper	36.9	40.3	41.4
3	Water paint	65.9	72.3	78.1
4	Oil paint (1 layer)	76.8	87.1	89.3
5	Oil paint (2 layers)	86.1	92.5	95.4
6	Epoxy-based paint	89.8	94.1	96.3
7	Enamel	89.9	91.4	94.3
8	Oil paint (3 layers)	93.9	96.8	97.1
9	Polymeric wallpaper	94.2	96.3	97.8
10	Finishing tiles with lacquer coatings (regardless composition)	96.5	97.9	98.7

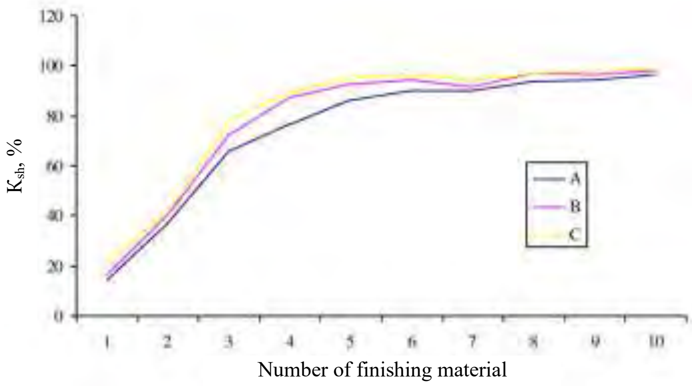

Fig. 4. Dependence of radon reduction coefficient on the type of finishing coating (Table 2): A – at q_H=5 mBq/(m^2·s); B – at q_H=10 mBq/(m^2·s); C – at q_{H}=20 mBq/(m^2·s)

To reduce radioactive and toxic materials received by the human body with honey products, technical rules and regulation, as well as sanitary and epidemiologic rules and norms of our country regulate their maximum permissible concentration (MPC). The maximum permissible concentration of ^{137}Cs makes 80 Bq/kg.

Honey samples taken in the territory of Penza Region were measured in the laboratory of radiation control (Table 3 and Figure 5).

^{137}Cs is formed in nuclear reactors, its half-life period makes 30 years. Cesium is an alkaline metal since it forms alkalis when interacting with water, it is a strong reducer.

IV. Discussion

Main objective of monitoring is to define the general regularities of radionuclide behavior in the environment with further forecasting for a certain period. The gained experience in measurements and statistical processing of multiple long-term monitoring data showed that the identification of temporary trends and hence, the forecasting of radiation dosage on the environment and the population required a careful study.

It was established that radon exhalation is subject to fluctuations with accurately expressed frequency. First of all, these are seasonal fluctuations that increase for ceramic and lime brick in winter and decrease in summer. The inverse relation is established for wood.

The dependence of isolating ability of finishing materials on their density was established through the decrease coefficient of radon intake. The higher the density or the more layers of a finishing material are placed, the more the reduction coefficient of radon intake.

A relatively small period of observations allows noting the presence of seasonal fluctuations of radionuclide content in used samples, but it is possible to assume that long-period fluctuations may also be typical for them.

TABLE III. The radiation control results of honey products in Penza Region

Residential area and area of Penza Region	^{40}K, Bq/kg	^{226}Ra, Bq/kg	No on Fig. 5	^{137}Cs, Bq/kg	^{232}Th, Bq/kg
Kuchki village, Penza Region	2430	82.8	-	-	-
Grabovo village, Bessonovsky district	345.6	32.33	-	-	181.1
Michurino village, Penza Region	2162	45.31	1	38.47	71.06
Pyrkinskiye Dachi	2699	109.3	-	-	68.19
Teplichny village	621.2	104.7	-	-	170.8
Sosnovoborsky district	2759	70.71	-	-	-
Bolshaya Elan	643.7	-	2	27.36	878
Akhuny, Khopr sources	3073	-	-	-	140.9
Akhuny, Khopr sources	4262	34.35	-	-	-
Akhuny, Khopr sources	4305	114.7	-	-	-
Baksheevka village, Bessonovsky district	2744	52.25	-	-	106.7
Umet village, Kondolsky district	4243	23.54	-	-	-
Umet village, Kondolsky district	1898	-	-	-	84.57
Shemysheisky district	2371	-	-	-	-
Shemysheisky district	4310	-	-	-	143.9
Vazerki village, Bessonovsky district	4345	176.6	3	88.56	-
Mikhailovka village, Penza Region	4853	-	-	-	82.19
Ramzai village	1946	-	-	-	187.7
Honey 1-19 0.016 kg	1278	-	-	-	138.3
Zasechnoye village, Penza Region	198	196.9	-	-	-
Varypaevo village, Penza Region	1619	-	-	-	91.19
Alekseevka village, Kolyshleisky district	4265	287.8	4	81.98	66.03
Bessonovka village, Penza Region	546.1	-	5	91.59	210.3
Tonyar village, Nikolsky district	3056	-	-	-	47.25
Vorobievka village, Shemysheisky district	2405	-	6	69.47	106.1
Malaya Serdoba, Penza Region	2239	99.25	-	-	-
Zolotarevka village, Kamensky district	645.8	-	-	-	139.1
Zolotarevka village, Kamensky district	2319	18.28	-	-	71.46
Kalancha, Arbekovo, Penza	629.4	-	7	38.65	249.6
Neftyanik village, Penza	748.9	245.7	-	-	-
Mastinovka village	941.6		8	62.97	144.2
Vazerki village, Bessonovsky district	467	145.4	9	59	223.1
Vazerki village, Bessonovsky district	4708	-	10	98.28	139.3
Grabovo village, Bessonovsky district	2787	16.76	-	-	100.8

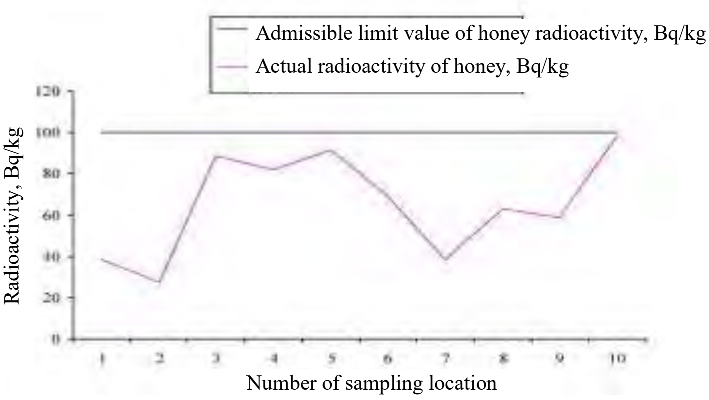

Fig. 5. Dependence of honey radioactivity on sampling place (Table 4).

Thus, to protect rooms against radon it is necessary to ensure radon isolation of walls, floors, ceilings, which prevents the penetration of gas from soil into rooms. It is rational to combine radon isolation with waterproofing of underground and basement parts of a building since the waterproofing materials serve a barrier for radon.

Besides, the special ventilation of basements will help to reduce the radon concentration in social, office and production rooms by dozens of times. Ventilation reduces radon concentration on diffusion boundary before it gets into rooms (Figure 6).

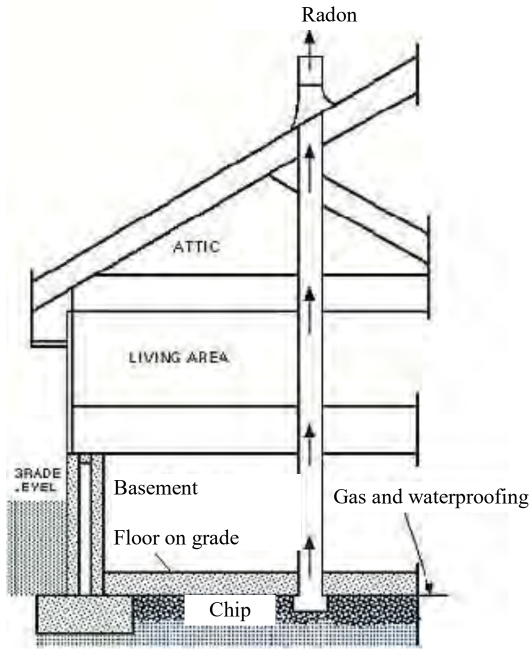

Fig. 6. Special ventilation from radon (on soil).

Such ventilation intercepts the major part (up to 60%) of radon on the way to a protected room before radon isolation barrier. In space before radon isolation barrier, the gas pressure decreases or even the discharge zone is created thus reducing its concentration in the protected room. Such ventilation system capturing radon is also required since the ordinary exhaust ventilation in protected rooms draws in air from the outside increasing radon intake from soil in case of gas-isolation failure. Exhaust ventilation of space under floor concrete bedding is installed to protect the operated cellars or the first floors on grade against radon.

V. Conclusions

The study and analysis allow confirming that the construction department shall consider the results of radiation environmental monitoring for the qualified decision in the field of radiation safety of the population. The projects of civil and industrial engineering shall contain sections ensuring radon safety based on monitoring of radon exhalation in the place of a designed project.

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