DOI 10.52209/2706-977X_2026_1_37 IRSTI 81.09.07 UDC 504.65

Studying Radiation-Radon Safety of Building Materials and Residential Buildings of the Karaganda Region

Pak D. [1], Pak Yu.[1], Ibragimova D.[1], Matonin V.[2], Tebayeva A.[1]
[1]Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan
[2] Ecoexpert LLP, Karaganda, Republic of Kazakhstan

Abstract. The objective of the study is to assess the radiation and radon safety of building materials and structures and to develop material science recommendations to reduce radon hazard. The study included 78 residential buildings in the Akchatau settlement of the Karaganda region that were built in different periods and using various materials: brick, natural stone, cinder blocks, foam blocks and concrete. The methodology included determining specific activity of natural radionuclides (Ra-226, Th-232, K-40) by gamma spectrometry using a high-resolution detector, as well as measuring radon emanation with Alfarad Plus and Ramon-Radon devices. The mineral composition of materials and their porosity that affect radon permeability were analyzed. The results showed that in a number of houses, the equivalent equilibrium concentration of radon in the premises exceeded sanitary and hygienic standards by tens of times, while the maximum values were recorded in buildings made of brick and stone quarried in areas of granite massifs. It was found that increased porosity and cracking of materials, as well as the presence of uranium-containing minerals, significantly increase radon emission. Based on the analysis, measures to reduce radon hazard were proposed: the use of concrete mixtures with low radioactivity, barrier membranes, sealing coatings and effective ventilation.

Keywords: radon, building materials, specific activity, Ra-226, radiation safety, porosity.

Introduction

Radon (222Rn) is a radioactive noble gas formed as a result of the decay of radium-226 in the uranium-238 chain. Radon (Rn222 and Rn220) and their daughter products (isotopes Po, Pb, Bi) make the main contribution to the radionuclide background of residential and industrial premises [1-3]. It is the second leading cause of lung cancer after smoking, according to the World Health Organization (WHO). Radon and its daughter products emit alpha radiation, which, when inhaled, can cause damage to respiratory cells [4, 5]. The main characteristics of radon and its daughter products are shown in Figure 1.

In a number of regions of Kazakhstan, including the Karaganda region, geological conditions contribute to increased radon emissions from soil and building materials. Particular danger are materials made of rocks with high uranium and thorium content, as well as materials with a developed pore structure that promotes gas migration into the premises.

The negative impact of radon on human health has led to the introduction of permissible radon levels in such countries as the United States (148 Bq/m^3), Canada, Norway (100 Bq/m^3), and the EU countries (300 Bq/m^3). In Kazakhstan, the permissible level is 200 Bq/m^3. In addition to the level of radon exposure, countries need to identify areas that are most susceptible to radon, to identify those areas where the predicted radon concentration in most buildings will exceed the permissible level.

Radon is recognized by the World Health Organization and the International Agency for Research on Cancer (IARC) as a class I carcinogen. Experience in foreign countries shows that radon is one of the key threats to radiation safety in residential premises. Many countries have implemented strict building codes (Finland, Czech Republic, Germany), large-scale housing stock inspection programs (USA, UK), engineering protection technologies (under-foundation ventilation systems, sealing) [5, 18, 19]. Differences in radon hazard in some countries are presented in Table 1 [18, 20, 21].

There are a significant number of studies in the world practice that deal with the impact of building materials on the radon level in rooms [7-9]. Work [6] presents a collection of data on radon emanation and exhalation rate of about 2000 samples of building materials used in Europe. Concrete is the most consumed material in the world after water. The authors of [7] measured radon gas in concrete, the concentration of which varied in the range of 100–400 Bqm^{-3} in houses and 100–3700 Bqm^{-3} in workplaces. System analysis of models for describing radon transport inside porous materials and its release from structures showed the importance of taking them into account when transferring and generating radon in building materials [8]. Cement-based materials made of rocks and soils emit radon that is a carcinogen and affects indoor air quality. Alkaline cement-based materials neutralize carbon dioxide in the air with acid gas, reducing its pH value [9]. Being an inert gas, radon can easily penetrate highly porous materials, such as building materials, due to their characteristic microstructure. Table 2 provides a comparative analysis of building materials by radon emanation [10].

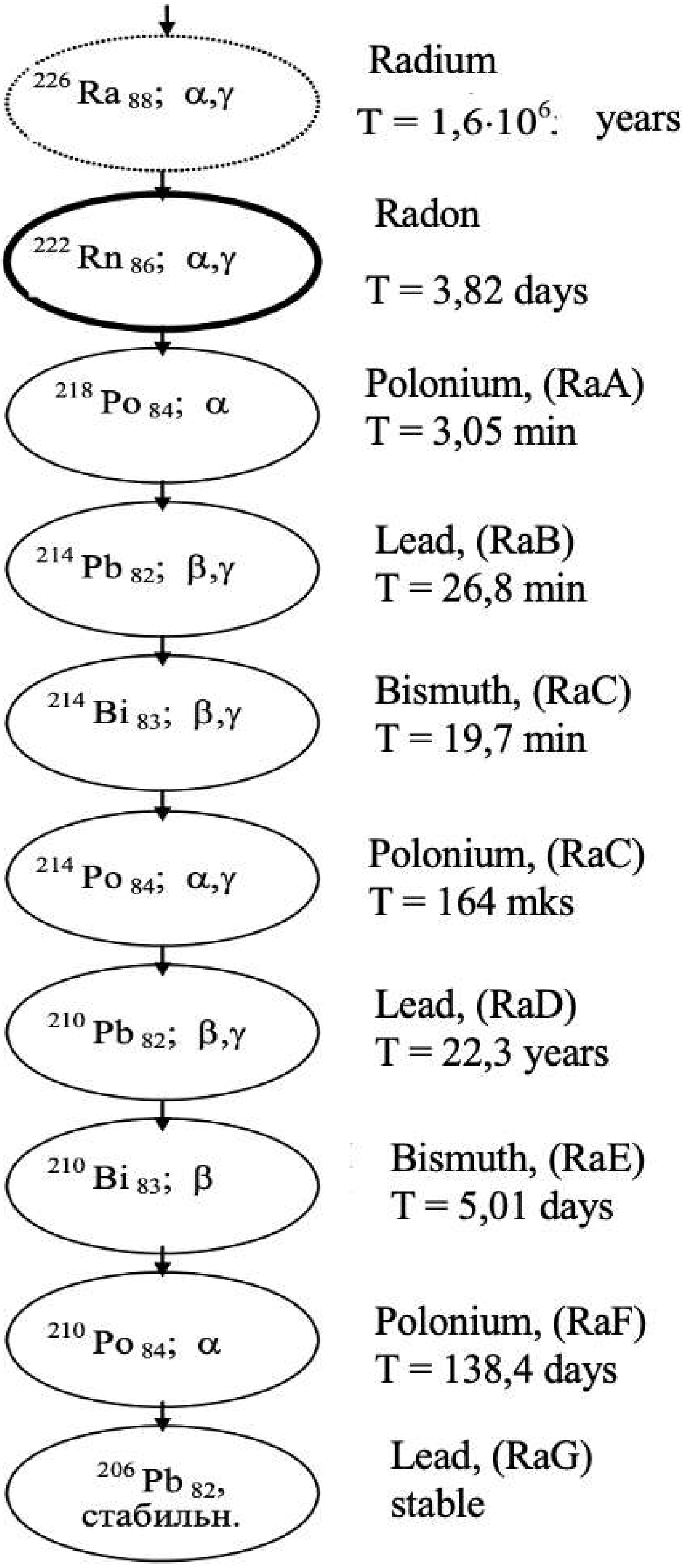

Fig. 1. - Radon isotopes and their daughter products in decay chains (symbol, decay path (α-, β, γ-radiation), name, half-life T) [20]

Table 1. Comparative data on radon in residential buildings in different countries

Country	Average values, Bq/m ^{3}	Maximum values, Bq/m^3	Measures taken
Finland	100–150	to 10 000	Standard ≤200 Bq/m^3 for new buildings; ≤800 Bq/m^3 for old buildings
Sweden	~100	to 10 000	In 10% of houses >100 Bq/m^3, in 1% >400 Bq/m^3; strict control during construction
Great Britain	40–60	to 2000+	Identified >20 thousand houses with high radon; rehabilitation programs
Germany	40	to 600	Federal law StrlSchG (2018), reference level 300 Bq/m^3
USA	55	до 800	Indoor Radon Abatement Act (1988), EPA limit of 150 Bq/m^3
Ukraine	150–250	>1000	High levels in crystalline massif areas; average annual dose of 4.2 mSv
Russia	30–100	to 2500	Standard ≤200 Bq/m^3, radon maps and building material controls

Table 2. Comparative analysis of building materials by radon emanation

Material	Emanation coefficient (%)	Activity Ra-226 (Bq/kg)	Structural features	Source of data
Concrete	10–25	20–50	Low porosity, cement stone, fly ash	Kovler, 2005; Wu et al., 2019
Granite	15–40	80–200	Crystalline structure, quartz, feldspar, biotite	Pillai et al., 2014; Shabek et al., 2024
Brick (ceramic)	5–15	15–40	Porous baked clay, possible feldspar impurities	Chao, 1999; Sabbarese et al., 2022

Continuation of the Table 2

Material	Emanation coefficient (%)	Activity Ra-226 (Bq/kg)	Structural features	Source of data
Marble	1–5	5–20	Dense calcite structure, low porosity	Kuzmanović et al., 2022
Phosphogypsum	20–50	200–800	Fine-grained structure, residual phosphate minerals	Campos et al., 2017; Ferranti et al., 2013
Gas concrete (AAC)	25–60	30–60	High open porosity, autoclaved	Wu et al., 2019

The highest emanation coefficients are characteristic of materials with high open porosity and significant radionuclide content, such as phosphogypsum and aerated concrete. Granite demonstrates moderate emanation but has high Ra-226 activity, which makes it a significant source of radon in rooms. Concrete and ceramic brick have moderate indicators, while marble is characterized by minimal emanation due to its dense structure.

In Serbia, studies have shown that aerated concrete with high porosity requires mandatory sealing before use [11]. In Iran, it has been found that covering walls with travertine significantly reduces radon levels in hospital rooms [12]. In Peru, it has been found that cement with uranium-containing additives can significantly increase radon emanation, which requires the introduction of standards for the content of Ra-226 in cement [13].

In Kazakhstan, the problem of radon hazard remains poorly understood. Despite the presence of geological and material science prerequisites (granitoid massifs, brick housing construction, groundwater), there are no systematic studies and a national program for radon regulation yet. This study is aimed at filling this gap and developing recommendations for reducing the radon load on the population. Studying radon hazard has been conducted, where the main factors causing high radon concentrations in the houses of the village are: high exhalation from the soil surface; radioactivity of building materials; low air exchange in the premises [14].

1. Materials and methods

In 2023–2024, the studies were conducted in different seasons (winter, spring, summer) in residential buildings and educational premises of the Akchatau settlement. The increased concentration of radon in a number of areas is associated with the Akchatau tungsten-molybdenum mine. The geological source of radon is acidic leucocratic granites in the northwestern and southeastern parts of the studied area. All the measurements were carried out in heated rooms at the temperature of 18–25 °C. Both active and passive methods were used to record the volumetric activity (VA) and equivalent equilibrium concentration (EEC) of radon. Active measurements were carried out using the Alfarad-Plus complex (Russia) and the Ramon-Radon radiometer (Kazakhstan) (Figures 2 and 3). The devices are equipped with an electrostatic chamber, a built-in microprocessor and the ALFA AR software, which provides automatic recording, processing and storage of data. Built-in sensors recorded temperature, humidity and atmospheric pressure. The time of one measurement was 20–40 min. The operating principle is based on the deposition of charged daughter products of radon decay on the detector, which allows for the instantaneous assessment of the ERC. Passive measurements were performed using carbon sorption detectors "Kamera-01" (Republic of Kazakhstan) containing sorbent SK-13. These devices were installed indoors for 1–6 days at the temperature of 12–30 °C and a relative humidity of up to 95%. The method is based on the adsorption of radon by activated carbon, followed by measurement of the activity by gamma or beta radiation of short-lived daughter products of decay (Pb-214, Bi-214).

Fig. 2. - Radon radiometer Alpharad Plus

Fig. 3. - Radon radiometer Radon-Ramon

To determine the radionuclide composition of building materials, a gamma-spectrometric complex with a high-purity semiconductor HPG detector manufactured by the NTC Aspect (Russia) with the SpectraLine software was used.

The energy resolution was 1.8 keV (on the 1.33 MeV line), the relative registration efficiency was 21.8%. Measurements were carried out in 1-liter Marinelli vessels, the sample fraction was 0–5 mm, the measurement time was 30–40 min. The detection limit for 226Ra and daughter products was no worse than 2 Bq/kg. The measurement error did not exceed 20%.

The obtained values of specific activity were compared with the sanitary standard of 370 Bq/kg for building materials. The ambient dose equivalent rate (ADER) of gamma radiation was measured using dosimeters DKS-AT1121 and DKS-AT1123 with the relative error of ±15%. The sensors were placed at the height of 1 m from the floor and no closer than 0.5 m from the walls. Integrating methods were used to take into account the effect of ventilation on radon concentration.

In each room, at least four ADER measurements were taken under different air exchange modes: closed windows, slot ventilation, cross ventilation, and typical operating mode.

In the winter season, 10 paired ADER and average radon VA measurements were taken.

To analyze their interrelationship, a linear dependence was constructed, which revealed a weak positive correlation (correlation coefficient of 0.282), indicating a weak positive relationship between these parameters. The equilibrium factor between radon and its decay products was 0.4, which corresponds to typical values for unventilated indoor environments. The reduction factor of the equivalent equilibrium concentration (EEC) of radon during daytime relative to the daily average was 0.705, which is most likely associated with natural ventilation and a decrease in radon concentration during daylight hours. At the same time, the indoor radon concentration is determined not only by the activity of Ra-226, but primarily by emanation and exhalation processes and gas transport conditions, including material porosity and fracturing, moisture content, pressure gradients, temperature regime, and ventilation. Therefore, gamma radiation from walls does not always correspond to the rate of radon release into indoor air: under similar gamma background levels, significantly different radon fluxes may occur, and vice versa.

The calculation of the effective annual dose of radon radiation was carried out according to the methodological guidelines (the Committee of State Sanitary - Epidemiological Supervision of the RK MH (CSSES) order No. 94 dated 09/08/2014) using the conversion factor of 5.1 10^{-9} Sv/(Bq m^{-3} h) and the structure of the time of stay: 0.8 years indoors and 0.2 years outside.

The annual volume of inhaled air for an adult was taken to be 8100 m^3.

$$D_{Rn} = 0.8 \cdot 8100 \cdot 5.1 \cdot 10^{-9} \cdot \text{EEC av. year}\,. \tag{1}$$

Differentiated values of radon concentration were obtained in cases where daily and seasonal observations were carried out. In 43.1% of premises, the effective dose varies from 6.6 mSv/year to 33 mSv/year, and for 9.4% of premises from 33 mSv/year to 680 mSv/year. The increased radon concentration is due to high exhalation from the soil surface, radioactivity of building materials and low air exchange in the surveyed premises. Gamma surveying identified 11 anomalous zones and 12 point anomalies with exposure dose rate (EDR) values exceeding 0.3 μSv/h against a background level of 0.18 μSv/h. In the northwestern part of Akchatau, anomalous zones were found where the exposure dose rate of gamma radiation exceeded 0.6 μSv/hour. The elevated EDR values are attributed to the presence of leucocratic granite outcrops exposed at the surface in the southeastern part of the studied settlement, as well as a closed mine and the occurrence of geological fault zones.

Such an integrated approach made it possible to take into account both the radionuclide characteristics of building materials and the actual operating conditions of the premises. Radiation safety standards must be calculated regardless of whether the irradiation occurs from natural or man-made sources of ionizing radiation. Hence, the systematic monitoring of radon should not only have independent significance but also be part of a complex of rehabilitation measures for surveying areas subject to man-made impacts.

2. Results and discussion

The conducted seasonal studies (winter, spring, summer 2023-2024) showed that the levels of equilibrium equivalent concentration (EEC) of radon in residential buildings of the Karaganda region varied widely. The average annual values of radon EEC in the surveyed buildings ranged from 35 to 380 Bq/m^3, while the maximum concentrations in individual rooms exceeded the permissible level for residential buildings of the Republic of Kazakhstan (200 Bq/m^3) and reached 1200-1900 Bq/m^3.

The highest values of radon EEC were recorded in winter (up to 1200 Bq/m^3), which is associated with a low air exchange rate and the operation of heating systems. In summer, concentrations were significantly lower and decreased by 2-4 times due to natural ventilation. The highest concentrations were noted in the northern part of the region (Figure 4).

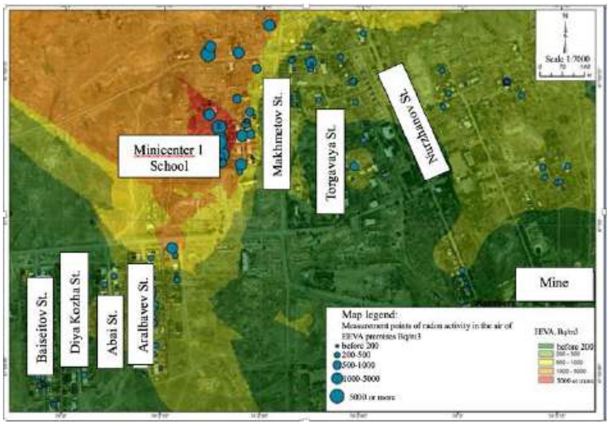

Fig. 4. - Map of the average annual radon EEC values

Additionally, an assessment of the radiation characteristics of the most common building materials (brick, concrete, granite, foam blocks) was carried out. For this, data from gamma-spectrometric studies and literature data were used [15]. The results are presented in Table 3.

Table 3. Radon activity of building materials

Material	Specific activity, Bq/kg (Ra-226)	Volume activity in premises, Bq/m³	Structural features
Brick	50–120	to 19 000	Porosity, clay base
Granite	80–150	to 10 000	High U, Th content
Concrete	30–80	to 1500	Low porosity, cement matrix
Foam block	40–90	to 3000	Increased sorption capacity
Wood	< 30	Lower that 200	Organic structure, low emanation

The highest radon levels are recorded in brick and granite buildings. It is due to the porosity and mineralogical composition, as well as the increased content of Ra-226. Concrete structures and foam blocks are characterized by lower emanation, which makes them preferable from the point of view of radiation hygiene. Wood is practically not a source of radon, which explains the low concentrations in wooden buildings.

It has been established that regular ventilation of premises reduces the radon concentration by 30-50%. The use of waterproofing of floors and walls in basements significantly reduces the ingress of radon from the soil. The use of forced ventilation systems allows maintaining EEC levels below sanitary standards.

In Lithuania and Poland, comparable radon values were recorded in brick and stone buildings (up to 15-20 thousand Bq/m³) [16]. In Finland and the Czech Republic, strict building codes have been introduced limiting the use of granite in residential construction. In Germany, mandatory design of ventilation systems is practiced in areas with increased radon hazard [17].

Thus, the obtained results confirm the importance of taking into account the radiation characteristics of building materials when designing buildings. Materials with low emanation (concrete, wood) are preferable, while the use of brick and granite requires mandatory engineering measures for sealing and ventilation. Under the sharply continental climatic conditions of the Karaganda region, it is advisable to use the following radon protection barriers: polyethylene membranes as a continuous gas-impermeable layer over the soil, and polymer-modified bituminous materials that combine gas impermeability with high adhesion and resistance to temperature-induced deformations and aging. The key condition for their effectiveness is the airtight sealing of overlaps, junctions, and service penetrations, since radon ingress is mainly associated with leakage through cracks and gaps rather than diffusion through the membrane itself.

Conclusions

1. The conducted studies of radon concentrations in residential buildings of the Akchatau settlement of the Karaganda region showed that the values of the equivalent equilibrium concentration (EEC) of radon varied significantly: from minimum values of the order of tens of Bq/m³ to maximum values exceeding the permissible sanitary standard (200 Bq/m³).
2. The highest radon concentrations were recorded in the winter, which is associated with reduced ventilation of the premises and accumulation of radon inside the buildings. In the summer, the values of radon activity are significantly reduced due to ventilation and temperature conditions.
3. A dependence of radon levels on the type of building materials was established: buildings made of brick and natural stone were characterized by increased radon emission, while concrete and foam block structures showed significantly lower values.
4. The results obtained confirm the need to take into account radon hazard in the design and operation of residential buildings. Particularly relevant is the task of developing and implementing building materials with low radon emission potential, as well as the use of engineering solutions (effective ventilation, waterproofing of foundations and walls), which is directly related to the problems of materials science.
5. Methodological recommendations are needed to ensure radiation safety of housing in radon-hazardous areas of Kazakhstan.

Funding: This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant no. AP26199353).

References

1. Fialova E., Otahai P. Determination of the Radon Progeny Activity Size Distribution in Laboratory Conditions //Atmosphere, 2024, 15(11), 1262. https://doi.org/10.3390/atmos15111262

2.Bekman I.N. Ecological radiochemistry and radioecology. Study guide. Volume VI. – M.: Publisher Markhotin P.Yu., 2015. - 400 p. ISBN 978-5-00038-184-7.

3. Leshukov T., Legoshchin K., Larionov A. A Case Study of the Radon Hazard at the Boundary of a Coal Minefield// applied sciences, 2023, 13(24),13188. https://doi.org/10.3390/app132413188.

4. Papaefthymiou H., Mavroudis A., Kritidis P. Indoor radon levels and influencing factors in houses of Patras, Greece// Journal of Environmental Radioactivity, 20036 V. 66(3). - P. 247-260. https://doi.org/10.1016/S0265-931X(02)00110-8.

5. UNSCEAR (United Nation Scientific Committee on the Effects of Atomic Radiation Report), Vol. II: Sources-to-Effects Assessment for Radon in Homes and Workplaces; UNSCEAR, United Nations: New York, NY, USA, 2006.

6. Nuccetelli C., Leonardi F., Trevisi R. Building material radon emanation and exhalation rate: Need of a shared measurement protocol from the european database analysis // Journal of Environmental Radioactivity, 2020, 226:106438. DOI: 10.1016/j.jenvrad.2020.106438

7. Bulut H.A., Şahin R. Radon, concrete, buildings and human health - A Review Study //Buildings, 2023, 14(2), 510. https://doi.org/10.3390/buildings14020510

8. Carlo C. Di, Maiorana A., Ampollini M., Antignani S., Caprio M., Carpentieri C., Bochicchio F. (2023) Models of radon exhalation from building structures: General and case-specific solutions //Science of the Total Environment, V.885(10):163800, 2023 https://doi.org/10.1016/j.scitotenv.2023.163800

9. Yang R., Wang J., Zhang X., Li J., Chen M. Radon exhalation from cement-based materials under accelerated carbonation// Environmental Science and Pollution Research, 30(17):50610-50619, 2023 doi: 10.1007/s11356-023-25831-x

10. Hassan, N. M., Ishikawa, T., Hosoda, M., Iwaoka, K., Sorimachi, A., Sahoo, S. K., et al. The effect of water content on the radon emanation coefficient for some building materials used in Japan//Radiat. Meas., 46(2), 2011. - P.232–237. doi:10.1016/j.radmeas.2010.11.006. https://www-pub.iaea.org/MTCD/Publications/PDF/trs474_webfile.pdf

11. Kuzmanović P., Miljević B., Todorović N., Forkapić S., Čeliković I., Filipović Petrović L., Knežević Radić J. (2022) The influence of building material structure on radon emanation// Journal of Radiological Protection, V. 42, №4. DOI 10.1088/1361-6498/aca59d

12. Pirsaheb M., Najafi F., Haghparast A., Hemati L., Sharafi K., Kurd N. () The Influence of Internal Wall and Floor Covering Materials and Ventilation Type on Indoor Radon and Thoron Levels in Hospitals of Kermanshah, Iran //Iranian Red Crescent Medical Journal (IRCMJ), 18(10):e25292, 2016, doi: 10.5812/ircmj.25292

13. Liza R., Pereyra P., Muñoz D., Viera V., Herrera L.M.E., Rojas J., Palacios D., Díaz,F., Cerna N., Rojas S.; et al. Comprehensive Study of Natural Radioactivity in Building Materials: A Case Study in Ica, Peru //Atmosphere, 2024, 15, 279. https://doi.org/10.3390/atmos15030279

14. Pak Y., Pak D., Matonin V., Ibragimova D., Timoshenko P., Barkov Y., Tebayeva A., Medvedev P. Study of Radon Radiation in the Area of the Akchatau Polymetallic Mine, Republic of Kazakhstan //Atmosphere, 2025, 16, 769. https://doi.org/10.3390/atmos16070769

15. Soroka Yu.N., Molchanov A.I. Survey of the radiation situation in the area of operation of the Kaztungsten Production Association // Non-ferrous Metallurgy, 1992, No. 2. – P. 62-66.

16. Wysocka M. Radon problems in mining and post-mining areas in Upper Silesia region, Poland // Nukleonika, 2016, V. 61(3). DOI:10.1515/nuka-2016-0051

17. Dehnert J., Altendorf D., Trabitzsch R., Grunewald H., Geisenhainer R., Oeser V., Streil T., Weber L., Schonherr B., Thomas J., Forner K., Alisch-Mark M., Weiss H. Radon protection in apartments using a ventilation system wireless-controlled by radon activity concentration// Journal of Radiological Protection, 2021, 41(3) doi: 10.1088/1361-6498/abfc97

18. Protection against Radon-222 at Home and at Work-Annals of the ICRP, № 65. - Oxford: Pergamon, 1994.

19. Schmier H., Koenig K., Schmitt-Hannig A., Schwibach J. Results of radon-measurements in buildings and recommended action in the Federal Republic of Germany/ /High Levels of Natural Radiation, 1993. -Vienna: IAEA. - P. 353-363.

20. Tikhonov M. N. Radon radiation: sources, doses and unresolved issues // Ecology of industrial production, 2008, No. 1. - P. 35-51. EDN JXRIPH.

21. Holmgren O., H. Arvela H., Collignan B., Jira´nek M., Ringer W. Radon remediation and prevention status in 23 European countries //Radiation Protection Dosimetry, 2013. – P. 1-5. doi:10.1093/rpd/nct156

Information of the authors

Pak Dmitri Yuryevich, c.t.s., ass. professor, Abylkas Saginov Karaganda Technical University
e-mail: d.pak@ktu.edu.kz

Pak Yuri Nikolayevich, d.t.s., ass. professor, Abylkas Saginov Karaganda Technical University
e-mail: yu.pak@ktu.edu.kz

Ibragimova Diana Andreevna, PhD, research fellow, Abylkas Saginov Karaganda Technical University
e-mail: podgornaya1992@mail.ru

Matonin Vladimir Viktorovich, director, Ecoexpert LLP
e-mail: matoninvov@mail.ru

Tebayeva Anar Yulayevna, master lecturer, Abylkas Saginov Karaganda Technical University
e-mail: tebaeva@ktu.edu.kz