УДК [613.648+614.76](98)

DOI: 10.37482/2687-1491-Z114

NATURAL BACKGROUND RADIATION IN RESIDENTIAL AND PUBLIC BUILDINGS LOCATED IN THE VICINITY OF MINING OPERATIONS IN THE ARCTIC = ЕСТЕСТВЕННЫЙ РАДИАЦИОННЫЙ ФОН В ЖИЛЫХ И ОБЩЕСТВЕННЫХ ЗДАНИЯХ В РАЙОНАХ ПРОВЕДЕНИЯ ГОРНЫХ РАБОТ В АРКТИКЕ[1]

*А.Н. Никанов** ORCID: https://orcid.org/0000-0003-3335-4721
*А.Б. Гудков*** ORCID: https://orcid.org/0000-0001-5923-0941
*И. Томассен**** ORCID: https://orcid.org/0000-0001-7334-6385
В.П. Чащин/***** ORCID: https://orcid.org/0000-0002-2600-0522
*О.Н. Попова*** ORCID: https://orcid.org/0000-0002-0135-4594

*Северо-Западный научный центр гигиены и общественного здоровья (Санкт-Петербург)
**Северный государственный медицинский университет (г. Архангельск)
***Норвежский университет естественных наук (Норвегия, Осло)
****Национальный исследовательский университет «Высшая школа экономики» (Москва)

Естественный радиационный фон в значительной степени определяет ингаляционное поступление в организм радионуклидов, образующихся при распаде изотопов ^{238}U, ^{235}U и ^{232}Th. Эта проблема имеет особое значение для здоровья арктического населения в районах повышенной сейсмичности, индуцированной проведением горных работ. **Цель** исследования – оценить воздействие горных работ на естественный

[1]Вклад авторов: А.Н. Никанов – редактирование чернового варианта рукописи, утверждение ее окончательного варианта; И. Томассен и В.П. Чащин – разработка концепции и дизайна исследования, подготовка чернового варианта рукописи; А.Б. Гудков – подготовка раздела «Обсуждение»; О.Н. Попова – анализ и интерпретация данных, подготовка чернового варианта рукописи.

Авторы статьи благодарят сотрудников Кольской научно-исследовательской лаборатории гигиены труда (г. Кировск, Мурманская область) за оказанное содействие в проведении исследования.

Ответственный за переписку: Никанов Александр Николаевич, *адрес:* 191036, Санкт-Петербург, ул. 2-я Советская, д. 4; *e-mail:* a.nikanov@s-znc.ru

Для цитирования: Никанов А.Н., Гудков А.Б., Томассен И., Чащин В.П., Попова О.Н. Natural Background Radiation in Residential and Public Buildings Located in the Vicinity of Mining Operations in the Arctic = Естественный радиационный фон в жилых и общественных зданиях в районах проведения горных работ в Арктике // Журн. мед.-биол. исследований. 2022. Т. 10, № 4. С. 363–371. DOI: 10.37482/2687-1491-Z114

радиационный фон в помещениях жилых и общественных зданий, расположенных в непосредственной близости от предприятий, осуществляющих добычу апатито-нефелиновых руд в Арктике. **Материалы и методы.** Измерения проводились в помещениях жилых и общественных зданий г. Кировска (Мурманская область), расположенных на расстоянии до 3 км от предприятий по добыче полезных ископаемых открытым и подземным способами. Определялись: общая мощность дозы радиоактивного излучения проб рудного сырья и продуктов производства, их спектральные характеристики, а также аэрозольная концентрация продуктов распада радона и его объемная концентрация в подвальных помещениях жилых и общественных зданий, расположенных в районе проведения горных работ. **Результаты.** Радиационная активность руды, добываемой открытым способом, существенно (в 7,3 раза) превышала активность руды из подземных рудников (107 300±9823 и 14 615±1980 Бк/кг соответственно). Однако радиоактивность конечного продукта (апатитового концентрата) не зависела от способа добычи руды (59 792±865 и 61 827±1022 Бк/кг соответственно). В воздухе цокольных этажей зданий, расположенных в пределах 3 км от рудников, концентрация радона линейно увеличивалась в среднем на 0,15 Бк/м^3 на каждую тонну использованных при отбойке руды взрывчатых материалов. Содержание радона и продуктов его распада в воздухе помещений жилых и общественных зданий населенных мест, прилегающих к району проведения горных работ, после осуществления технологических взрывов не превышало 100 Бк/м^3. Таким образом, горно-взрывные работы в условиях напряженно-деформированного состояния рудовмещающих пород могут способствовать повышению интенсивности эмиссий радона и продуктов его распада и их накоплению внутри помещений жилых и общественных зданий в населенных пунктах Арктики, расположенных в районах проведения горных работ по добыче апатит-нефелиновых руд.

Ключевые слова: *горно-обогатительные предприятия, радиационный фон, радон, Арктика, эколого-гигиенический мониторинг среды, риск для здоровья населения.*

The Khibiny massif of the apatite-nepheline ores located in the Kola Peninsula is the largest in the world in terms of reserves of phosphorus-containing raw materials, which are widely used in the production of mineral fertilizers and in other sectors of global economy. These deposits, with an area of 1300 km^2, have a complex tectonic structure and stress-strain state of the ore massif during combined open-underground mining by drilling and blasting. Over the years, 16 mining-induced earthquakes, 20 mountain tectonic faults, and 45 rock bumps and microcracks have been recorded in the area [1]. The ore-forming minerals are apatite, nepheline, feldspar, titanomagnetite, pyroxenes, and sphene (or titanite). Sphene, being a widespread constituent of the Kola apatite ores, often contains terrestrial radionuclides scattered in the rock belonging to the U-238, U-235, Th-232, and K-40 families, which are the primary natural sources of background radiation [2]. Mining and beneficiation of apatite-nepheline ores are accompanied by mechanical damage to landscapes and emission of large volumes of dust from quarries and tailing dumps into the air [3]. These emissions are multicomponent. Along with the pollutants typical of industrial regions (carbon, nitrogen and sulphur oxides), environmental objects of the Kirovsk-Apatity region are also contaminated with specific components of raw ores: phosphorus and aluminium compounds, fluorides and their accompanying elements, including radioactive ones. The technogenic impact of mining enterprises on the environment can significantly affect the radioactive conditions through direct changes in the geological conditions and changes in the factors of exogenous geological processes that form natural background radiation (NBR) [4, 5].

The purpose of this paper was to assess the impact of mining operations on the changes in NBR in residential and public buildings located in proximity to the apatite-nepheline ore mines in the Arctic.

Materials and methods. To measure the dose rate of gamma radiation and the alpha- and beta particles emitted from naturally occurring radionuclides in ores and apatite concentrates, MKS-01A Multirad-M portable spectrometric complex was used. Equivalent equilibrium volumetric activity (EEVA) of radon progeny concentrations in indoor air was measured using RAA-10 aerosol radiometer and POU-04 sampling device. Volumetric radon concentrations were measured using Camera-01 measuring complex for radon monitoring and RRA-01M-03 radon radiometer. The research procedure and assessment of the results were carried out according to the Methodological Guidelines approved by the Chief State Sanitary Doctor of the Russian Federation[2]. We analysed 286 measurements taken on the basement/ground floors of 6 panel, brick, and one-storey wooden residential and public buildings in the city of Kirovsk (in its 3 municipal districts located within 3 km of the underground mine).

Results. Concerning the assessment of NBR, we found that the specific radioactivity of ores, apatite concentrates, and suspended dust at workplaces at ore-beneficiation factories is different and depends on the source of the apatite ore mined. The differences are mainly due to gamma radiation (see Table 1).

It should be noted that Russia's regulation of radiation safety is based on the normalized indoor radon content, i.e. annual average equivalent equilibrium volumetric activity (EEVA) of radon isotopes, which is measured in Bq/m^3. EEVA of radon should not exceed 100 Bq/m^3 in residential and public buildings after construction, overhaul or reconstruction and 200 Bq/m^3 in operated buildings[3]. To assess the effect of the energy

Table 1

RADIATION CHARACTERISTICS OF APATITE ORE MINERAL AND APATITE CONCENTRATE DEPENDING ON THE MINING TECHNIQUE (Khibiny deposits), $\bar{X} \pm SD$

ХАРАКТЕРИСТИКА РАДИОАКТИВНОСТИ АПАТИТОВОЙ РУДЫ И АПАТИТОВОГО КОНЦЕНТРАТА В ЗАВИСИМОСТИ ОТ СПОСОБА ДОБЫЧИ РУДНОГО СЫРЬЯ (Хибинские месторождения), $\bar{X} \pm SD$

Mining technique and products	Radiation spectrum and specific activity of products, Bq/kg		
	α	β	γ
Underground mining: Apatite ore mineral	17.4 ± 3.2	77.7 ± 12.4	51.1 ± 8.7
Apatite concentrate	21.1 ± 4.0	21.8 ± 4.3	555.0 ± 75.9
Open-pit mining: Apatite ore mineral	29.6 ± 5.3	114.7 ± 21.1	928.7 ± 164.6
Apatite concentrate	18.5 ± 3.9	15.2 ± 3.7	584.6 ± 94.5

Note. 17 samples of each product were studied. Underground ore was extracted from Kukisvumchorr mine and open ore, from Koashva mine. *Notation* (*hereinafter*): $\bar{X} \pm SD$ – arithmetic mean and standard deviation.

[2]MU 2.6.1.2838–11. Radiation Monitoring and Sanitary-Epidemiological Assessment of Residential, Public and Industrial Buildings and Facilities After Their Construction, Repair, and Reconstruction According to Radiation Safety Performance. Approved on 28 January 2011 (in Russ.).

[3]Radiation Safety Standards (NRB-99/2009). Russian Sanitary Rules and Norms (SanPiN 2.6.1.2523–09). Approved on 7 July 2009 (in Russ.); Russian Sanitary Rules and Norms (SanPiN 2.6.1.2800–10). Hygienic Requirements for Limiting Public Exposure Through Natural Sources of Ionizing Radiation. Approved on 24 December 2010 (in Russ.).

release due to technological explosions in Kukisvumchorr underground mine on background radiation, measurements of equilibrium equivalent volumetric radon concentration in the air of basement rooms were made (see Table 2).

Table 2

EQUIVALENT EQUILIBRIUM VOLUMETRIC ACTIVITY OF RADON IN THE BASEMENT AIR OF PUBLIC AND RESIDENTIAL BUILDINGS AFTER TECHNOLOGICAL UNDERGROUND EXPLOSIONS OF DIFFERENT ENERGY, KUKISVUMCHORR MINE AREA, $\bar{X} \pm SD$

ЭКВИВАЛЕНТНАЯ РАВНОВЕСНАЯ ОБЪЕМНАЯ АКТИВНОСТЬ РАДОНА В ВОЗДУХЕ ПОДВАЛЬНЫХ ЭТАЖЕЙ ОБЩЕСТВЕННЫХ И ЖИЛЫХ ЗДАНИЙ ПОСЛЕ ТЕХНОЛОГИЧЕСКИХ ПОДЗЕМНЫХ ВЗРЫВОВ РАЗНОЙ МОЩНОСТИ В РАЙОНЕ РУДНИКА КУКИСВУМЧОРР, $\bar{X} \pm SD$

Daily TNT equivalent of explosion energy, t/24h	EEVA, Bq/m^3			
	Before explosion	After explosion		
		in 15 min	in 60 min	in 24 h
10	23.1 ± 2.2	23.1 ± 2.8	23.1 ± 3.1	46.1 ± 4.0
165	15.4 ± 3.5	23.1 ± 3.1	32.2 ± 3.9	54.6 ± 4.5

Note. For each type of explosions 143 measurements were made.

The analysis of the results obtained showed that the estimated total energy of underground explosions expressed in TNT (2,4,6-trinitrotoluene) equivalent (t/24h) has a linear association with the increase in EEVA of radon in the basements of buildings located close to the mining area. Moreover, the increase in EEVA of radon isotopes in basements depends on the energy released due to the explosions and on the time elapsed after the blasting. With a total daily explosion TNT-equivalent of 10 tons, the EEVA of indoor radon isotopes doubled within 24 hours, and with a TNT-equivalent of 165 tons, it increased by the factor of 3.5.

Discussion. Secondary cosmic radiation (solar and galactic) as well as terrestrial radionuclides form the NBR of settlements. Exposure levels of the population due to cosmic radiation depend on the geographical latitude and altitude. Irradiation from radionuclides is determined by their quantity and type [6]. The main terrestrial radioactive isotopes found in rocks are K-40 and Rb-87, as well as two radioactive families originating from U-238 and Th-232, long-lived isotopes that have been part of the Earth since its inception. In turn, out of the products of radioactive U-238, the most considerable contribution to NBR is made by Po-210, Ra-226, Rn-222, and Pb-210. Among the natural sources of radiation, the main one is radon, which, with its progeny, makes up about 75 % of the annual effective dose equivalent received by the population from terrestrial sources of radiation and about 50 % of the dose from all sources of radiation [2, 7].

Radon is a tasteless and odourless gas 7.5 times heavier than air, with a half-life of 3.8 days. It enters the atmosphere from the soil as radium decays. Its concentration in the atmosphere varies with place, time, altitude, and meteorological conditions [8]. Indoors it is noticeably higher than in outdoor air [9]. Soil types and foundation systems that are used in house building (granite, concrete, brick, phosphogypsum, etc.) as well as household natural gas are the main sources of indoor radon exposure [10]. Rn-222 is present inside all buildings and is an unavoidable radiation exposure source, both in homes and workplaces. In some geographical points (underground mines, caves, tunnels, mineral water resorts, and faults in the Earth's crust) elevated radon concentrations can be observed [11, 12].

As a result of mining operations, landscapes are damaged, leading to a technogenic increase in NBR. The study of the residential area in Transbaikalia showed that mining disturbs the relief; in addition, intensive accumulation of radon and its decay products in basements and on the ground floors of buildings in concentrations of up to 1000 Bq/m^3 and more was found [13]. The same problems with radon in residential buildings have been reported in many other mining areas [5]. An even more significant increase in indoor air concentrations of radon isotopes was observed in uranium ore mining regions [14].

The results of our research showed that, although the specific activity of the apatite ores extracted from underground (Kukisvumchorr) and open-pit (Koashva) mines differs by the factor of 18.2, the activity of apatite concentrates from both deposits is almost the same. These are model calculations, which, therefore, should not be taken as a standard. With caution, however, their results can be extended to all types of mining complexes. Ore mining using massive explosions may have an impact on the level of NBR inside the buildings located in the adjacent populated areas.

The seismic events induced by the drilling and blasting methods of mining, especially in the Arctic regions, are associated with an increase in EEVA of radon in residential and public buildings and, thereby, may cause unacceptable carcinogenic risks to public health in the impacted areas [15, 16]. For example, in the basements of 6 buildings located close to the underground mine, EEVA of radon within 24 hours after the explosions increased by 0.15 Bq/m^3 for each ton of explosives used. A linear equation describes this dependence as follows:

$$Cx = 27.6 + 0.15x,$$

where Cx is indoor air radon concentration expressed in Bq/m^3 and x is daily explosion TNT-equivalent expressed in tons of TNT.

It should be emphasized that the maximum air radon concentrations in basements after explosions do not exceed the regulatory limit of 100 Bq/m^3. However, the trend for increasing indoor radon levels in case of planned intensification of explosions used in mining is to be considered to ensure radiation safety of the populated areas adjacent to mining enterprises.

Thus, the analysis of the impact of apatite-nepheline mining on NBR showed that the energy released during technological explosions used in ore extraction may be associated with increased NBR in residential and public buildings located close to large mining companies. This is particularly important in the cold climate regions, especially in the Arctic, where, as we know, indoor accumulation of radon results from commonly used tight thermal insulation of houses and reduced ventilation for the purpose of keeping residential premises warm [15, 17].

Massive explosions related to mining operations performed in the stress-strain state of orebodies may facilitate the intensity of terrestrial radionuclide emissions and, thereby, increase NBR inside residential and public buildings in settlements adjacent to the areas of apatite-nepheline ore mining in the Arctic. Considering that indoor radon concentrations associated with the total mass of explosives used in blasting operations on apatite ore bodies were found to be lower than the permissible exposure limits, further studies using modern measuring instruments are required in areas with higher NBR.

Conflict of interest. The authors declare no conflict of interest.

Authors' contributions. A.N. Nikanov edited the draft version of the manuscript and approved its final version sent to the editor; Y. Thomassen and V.P. Chashchin developed the concept and design of the study and prepared the draft version of the manuscript; A.B. Gudkov prepared the discussion section; O.N. Popova participated in the analysis and interpretation of the data and preparation of the draft version of the manuscript.

Acknowledgments. We would like to thank the staff of Kola Research Laboratory for Occupational Health (Kirovsk, Murmansk Region) for their assistance in the study.

Список литературы

1. *Гурьев А.А.* Устойчивое развитие рудно-сырьевой базы и обогатительных мощностей АО «Апатит» на основе лучших инженерных решений // Зап. Горн. ин-та. 2017. Т. 228. С. 662–673. DOI: 10.25515/PMI.2017.6.662

2. *Кизеев А.Н., Жиров В.К., Ушамова С.Ф., Коклянов Е.Б., Никанов А.Н., Кульнев В.В., Базарский О.В.* Экогеосистемы горнодобывающего класса северо-запада Восточно-Европейской платформы (Мурманская область) // Экологическая геология крупных горнодобывающих районов Северной Евразии (теория и практика): коллект. моногр. / под ред. И.И. Косиновой. Воронеж: ВГУ, 2015. С. 282–326.

3. *Никанов А.Н., Гудков А.Б., Попова О.Н., Чащин В.П., Пешкова А.П., Мироновская А.В.* Условия труда при добыче и переработке редкоземельных металлов в Арктической зоне Российской Федерации // Журн. мед.-биол. исследований. 2019. Т. 7, № 4. С. 444–451. DOI: 10.17238/issn2542-1298.2019.7.4.444

4. *Kizeev A.N.* Accumulation of Radionucklides in Natural Objects in Central Part of Murmansk Region // Eur. J. Nat. Hist. 2015. № 2. P. 67–68.

5. *Mudd G.M.* Radon Sources and Impacts: A Review of Mining and Non-Mining Issues // Rev. Environ. Sci. Biotechnol. 2008. Vol. 7. P. 325–353. DOI: 10.1007/s11157-008-9141-z

6. *Grachev V.A., Arutyunyan R.V., Plyamina O.V.* Radiation in the City: Natural and Artificial Radiation, Reality and Myths // Res. J. Pharm. Biol. Chem. Sci. 2016. Vol. 7, № 4. P. 2337–2344.

7. *Онищенко Г.Г., Попова А.Ю., Романович И.К., Барковский А.Н., Кормановская Т.А., Шевкун И.Г.* Радиационно-гигиеническая паспортизация и ЕСКИД – информационная основа принятия управленческих решений по обеспечению радиационной безопасности населения Российской Федерации. Сообщение 2. Характеристика источников и доз облучения населения Российской Федерации // Радиац. гигиена. 2017. Т. 10, № 3. С. 18–35. DOI: 10.21514/1998-426X-2017-10-3-18-35

8. *Sahu P., Panigrahi D.C., Mishra D.P.* A Comprehensive Review on Sources of Radon and Factors Affecting Radon Concentration in Underground Uranium Mines // Environ. Earth Sci. 2016. Vol. 75, № 7. Art. № 617. DOI: 10.1007/s12665-016-5433-8

9. *Seminsky K.Zh., Bobrov A.A., Demberel S.* Variations in Radon Activity in the Crustal Fault Zones: Spatial Characteristics // Izv. Phys. Solid Earth. 2014. Vol. 50, № 6. P. 795–813. DOI: 10.1134/S1069351314060081

10. *Бакаева Н.В., Калайдо А.В.* Механизмы поступления радона в здания и сооружения // Строительство и реконструкция. 2016. № 5(67). С. 51–59.

11. *Steinitz G., Piatibratova O., Kotlarsky P.* Sub-Daily Periodic Radon Signals in a Confined Radon System // J. Environ. Radioact. 2014. Vol. 134. P. 128–135. DOI: 10.1016/j.jenvrad.2014.03.012

12. *Yarmoshenko I., Onishchenko A., Zhukovsky M.* Establishing a Regional Reference Indoor Radon Level on the Basis of Radon Survey Data // J. Radiol. Prot. 2013. Vol. 33, № 2. P. 329–336. DOI: 10.1088/0952-4746/33/2/329

13. *Савченков М.Ф., Макаров О.А., Ильин В.П.* Гигиеническая оценка опасности радона в жилых помещениях // Гигиена и санитария. 2001. № 3. С. 16–19.

14. *Bersimbaev R.I., Bulgakova O.* The Health Effects of Radon and Uranium on the Population of Kazakhstan // Genes Environ. 2015. Vol. 37. Art. № 18. DOI: 10.1186/s41021-015-0019-3

15. *Nash A.L. Jr., Hamade A.K.* Radon in Alaska – Current Knowledge and Recommendations // State Alsk. Epidemiol. Bull. 2015. № 25. URL: http://www.epi.alaska.gov/bulletins/docs/b2015_25.pdf (дата обращения: 10.08.2020).

16. *Schmid K., Kuwert T., Drexler H.* Radon in Indoor Spaces: An Underestimated Risk Factor for Lung Cancer in Environmental Medicine // Dtsch. Arztebl. Int. 2010. Vol. 107, № 11. P. 181–186. DOI: 10.3238/arztebl.2010.0181

17. *Symonds P., Rees D., Daraktchieva Z., McColl N., Bradley J., Hamilton I., Davies M.* Home Energy Efficiency and Radon: An Observational Study // Indoor Air. 2019. Vol. 29. P. 854–864. DOI: 10.1111/ina.12575

References

1. Guryev A.A. Sustainable Development of Crude Ore Resources and Benefication Facilities of JSC “Apatit” Based on Best Engineering Solutions. *Zapiski Gornogo instituta*, 2017, vol. 228, pp. 662–673 (in Russ.). DOI: 10.25515/PMI.2017.6.662

2. Kizeev A.N., Zhirov V.K., Ushamova S.F., Koklyanov E.B., Nikanov A.N., Kul’nev V.V., Bazarskiy O.V. Ekogeosistemy gornodobyvayushchego klassa Severo-Zapada Vostochno-Evropeyskoy platformy (Murmanskaya oblast’) [Mining Class Ecogeosystems in the North-West of the East European Platform (Murmansk Region)]. Kosinova I.I. (ed.). *Ekologicheskaya geologiya krupnykh gornodobyvayushchikh rayonov Severnoy Evrazii (teoriya i praktika)* [Environmental Geology of Large Mining Regions of Northern Eurasia (Theory and Practice)]. Voronezh, 2015, pp. 282–326.

3. Nikanov A.N., Gudkov A.B., Popova O.N., Chashchin V.P., Peshkova A.P., Mironovskaya A.V. Working Conditions at Mining and Processing of Rare-Earth Metals in the Arctic Zone of the Russian Federation. *J. Med. Biol. Res*., 2019, vol. 7, no. 4, pp. 444–451. DOI: 10.17238/issn2542-1298.2019.7.4.444

4. Kizeev A.N. Accumulation of Radionuclides in Natural Objects in Central Part of Murmansk Region. *Eur. J. Nat. Hist.*, 2015, no. 2, pp. 67–68.

5. Mudd G.M. Radon Sources and Impacts: A Review of Mining and Non-Mining Issues. *Rev. Environ. Sci. Biotechnol.*, 2008, vol. 7, pp. 325–353. DOI: 10.1007/s11157-008-9141-z

6. Grachev V.A., Arutyunyan R.V., Plyamina O.V. Radiation in the City: Natural and Artificial Radiation, Reality and Myths. *Res. J. Pharm. Biol. Chem. Sci.*, 2016, vol. 7, no. 4, pp. 2337–2344.

7. Onishchenko G.G., Popova A.Yu., Romanovich I.K., Barkovsky A.N., Kormanovskaya T.A., Shevkun I.G. Radiation-Hygienic Passportization and USIDC-Information Basis for Management Decision Making for Radiation Safety of the Population of the Russian Federation. Report 2: Characteristics of the Sources and Exposure Doses of the Population of the Russian Federation. *Radiatsionnaya gigiena*, 2017, vol. 10, no. 3, pp. 18–35 (in Russ.). DOI: 10.21514/1998-426X-2017-10-3-18-35

8. Sahu P., Panigrahi D.C., Mishra D.P. A Comprehensive Review on Sources of Radon and Factors Affecting Radon Concentration in Underground Uranium Mines. *Environ. Earth Sci.*, 2016, vol. 75, no. 7. Art. no. 617. DOI: 10.1007/s12665-016-5433-8

9. Seminsky K.Zh., Bobrov A.A., Demberel S. Variations in Radon Activity in the Crustal Fault Zones: Spatial Characteristics. *Izv. Phys. Solid Earth*, 2014, vol. 50, no. 6, pp. 795–813. DOI: 10.1134/S1069351314060081

10. Bakaeva N.V., Kalaydo A.V. Mekhanizmy postupleniya radona v zdaniya i sooruzheniya [About the Radon Transport Mechanisms into the Buildings]. *Stroitel’stvo i rekonstruktsiya*, 2016, no. 5, pp. 51–59.

11. Steinitz G., Piatibratova O., Kotlarsky P. Sub-Daily Periodic Radon Signals in a Confined Radon System. *J. Environ. Radioact.*, 2014, vol. 134, pp. 128–135. DOI: 10.1016/j.jenvrad.2014.03.012

12. Yarmoshenko I., Onishchenko A., Zhukovsky M. Establishing a Regional Reference Indoor Radon Level on the Basis of Radon Survey Data*. J. Radiol. Prot.*, 2013, vol. 33, no. 2, pp. 329–336. DOI: 10.1088/0952-4746/33/2/329

13. Savchenkov M.F., Makarov O.A., Il’in V.P. Gigienicheskaya otsenka opasnosti radona v zhilykh pomeshcheniyakh [Hygienic Assessment of the Danger of Radon on Residential Premises]. *Gigiena i sanitariya*, 2001, no. 3, pp. 16–19.

14. Bersimbaev R.I., Bulgakova O. The Health Effects of Radon and Uranium on the Population of Kazakhstan. *Genes Environ.*, 2015, vol. 37. Art. no. 18. DOI: 10.1186/s41021-015-0019-3

15. Nash A.L. Jr., Hamade A.K. Radon in Alaska – Current Knowledge and Recommendations. *State Alsk. Epidemiol. Bull.*, 2015, no. 25. Available at: http://www.epi.alaska.gov/bulletins/docs/b2015_25.pdf (accessed: 10 August 2020).

16. Schmid K., Kuwert T., Drexler H. Radon in Indoor Spaces: An Underestimated Risk Factor for Lung Cancer in Environmental Medicine. *Dtsch. Arztebl. Int.*, 2010, vol. 107, no. 11, pp. 181–186. DOI: 10.3238/arztebl.2010.0181

17. Symonds P., Rees D., Daraktchieva Z., McColl N., Bradley J., Hamilton I., Davies M. Home Energy Efficiency and Radon: An Observational Study. *Indoor Air*, 2019, vol. 29, pp. 854–864. DOI: 10.1111/ina.12575

DOI: 10.37482/2687-1491-Z114

Aleksandr N. Nikanov* ORCID: https://orcid.org/0000-0003-3335-4721
Andrey B. Gudkov** ORCID: https://orcid.org/0000-0001-5923-0941
Yngvar Thomassen*** ORCID: https://orcid.org/0000-0001-7334-6385
Valeriy P. Chashchin*/**** ORCID: https://orcid.org/0000-0002-2600-0522
Ol'ga N. Popova** ORCID: https://orcid.org/0000-0002-0135-4594

*The Northwest Public Health Research Center
(St. Petersburg, Russian Federation)
**Northern State Medical University
(Arkhangelsk, Russian Federation)
***Norwegian University of Life Sciences
(Oslo, Norway)
****National Research University Higher School of Economics
(Moscow, Russian Federation)

NATURAL BACKGROUND RADIATION IN RESIDENTIAL AND PUBLIC BUILDINGS LOCATED IN THE VICINITY OF MINING OPERATIONS IN THE ARCTIC

Natural background radiation (NBR) largely contributes to the human inhalation of radionuclides originating from the decay of U-238, U-235 and Th-232 isotopes. This problem is of particular importance for public health in the areas with high seismicity induced by mining operations. The **purpose** of this article was to assess the impact of mining activities on NBR in the residential and public buildings located in the immediate vicinity of the apatite-nepheline ore mining operations in the Arctic. **Materials and methods.** The measurements were taken in residential and public buildings of Kirovsk (Murmansk Region) adjacent to open-pit and underground mines. The following were measured: total radioactivity dose of samples of raw ores and their concentrates, their spectral characteristics, as well as the aerosol concentration of radon decay products, and volumetric radon concentration in the basements of residential and public buildings located within 3 km from the mining area. **Results.** The radioactivity of open-pit ore was significantly (7.3 times) higher than that from underground mines (107,300 ± 9823 and 14,615 ± 1980 Bq/kg, respectively). However, the radioactivity of the final product (apatite concentrate) did not depend on the extraction technique (59,792 ± 865 and 61,827 ± 1022 Bq/kg, respectively). Indoor air concentrations of radon in the basements of buildings located up to 3 km from the mines, increased linearly by an average of 0.15 Bq/m^3 for each ton of explosives used in ore breaking. The levels of radon and its decay products in residential and public buildings in areas adjacent to the mining operations did not exceed 100 Bq/m^3. Thus, mining and blasting operations in the stress-strain state of ore-bearing rocks might have an important impact on the intensity of radionuclide emissions and changes in NBR inside residential and public buildings located in Arctic settlements adjacent to the areas of apatite-nepheline ore mining.

Keywords: *ore mining and processing enterprise, background radiation, radon, Arctic, environmental and hygienic monitoring, public health risk.*

Received 11 March 2022
Accepted 21 September 2022
Published 28 November 2022

Поступила 11.03.2022
Принята 21.09.2022
Опубликована 28.11.2022

Corresponding author: Aleksandr Nikanov, *address:* ul. 2-ya Sovetskaya 4, St. Petersburg, 191036, Russian Federation; *e-mail:* a.nikanov@s-znc.ru

For citation: Nikanov A.N., Gudkov A.B., Thomassen Y., Chashchin V.P., Popova O.N. Natural Background Radiation in Residential and Public Buildings Located in the Vicinity of Mining Operations in the Arctic. *Journal of Medical and Biological Research*, 2022, vol. 10, no. 4, pp. 363–370. DOI: 10.37482/2687-1491-Z114