REPUBLIC OF AZERBAIJAN

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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

PECULIARITIES OF THE FORMATION OF THE RADON FIELD AND ITS POSSIBLE PATHOGENIC INFLUENCE (THE TERRITORY OF AZERBAIJAN AS THE CASE STUDY)

Speciality: 2508.01 – Geoecology

Field of science: Earth sciences

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GENERAL CHARACTERISATION OF THE WORK

Relevance of the work. The radiation safety of the population is a global and important problem of our time. The main radiation background of the Earth is formed due to natural radiation sources. Numerous exploration conducted abroad convincingly proved that radon and its short-lived daughter decay products that create about 40-75% of summary doze that human gets from all natural sources ionizing radiation. Currently, the protection of the population from radon, the natural radioactive gas, is an important problem, necessitating a number of research works to identify the sources of this gas, to determine its amount in residential areas. With an indoor increase of volumetric activity of radon, there is an increase of patients' number with malignant lung neoplasms. In 1987, experts of the International Agency of Cancer Study classified radon and its daughter decay products as a group of elements definitely carcinogenic to humans. In many developed countries of the world, national and regional programs are working to estimate and map the radon situation. The results of radiometric exploration, taken in Azerbaijan since 1970, showed that the natural radiation background on the territory of Azerbaijan is located within places typical for rocks and soil and accounts for about 4-12 mR/h. At the same time, it was determined a link between natural radiation field and the geological structure of the territory.

However, certain works in our country on radon problem had been done since 2000, the problem demanded a comprehensive and complex study with consideration of specialty of the geological structure of the explored territory, allocation of radon volumetric activity and factors, that affect its changes, the role of radon radiation in the incidence degree of malignant lung neoplasms among population.

The work was carried out as part of a project of the Swiss National Science Foundation "Creation of cadaster and radon spread map in Azerbaijan using Swiss methodology and experience" and

with the financial support of the Foundation for the Development of Science under the President of the Azerbaijan Republic within the framework of the grant project №EİF-2013-9 (15) - 46/24/2-M-33 and the State program "Study of radon hazard in Azerbaijan and measures to reduce it" for 2014-2018.

Object and subject of research.

The object of the study is the territory of Azerbaijan, the ubject - the study of radon status in the territory of Azerbaijan and the detection of the degree of pathogenicity of radon radiation for the population of the republic.

Purpose of the work. The purpose of the dissertation work is a comprehensive assessment of the radon situation in Azerbaijan, the determination of critical areas of radon hazard and the identification of the degree of pathogenicity of radon radiation for the population of various regions.

The next tasks were solved in order to achieve set of goals:

- Identification of zones with relatively high concentrations of volumetric activity of radon;
- Identification of the main sources of radon indoor permeability in certain regions;
- Analysis of statistical data on the incidence of malignant respiratory neoplasms among population for the period of 2005-2015;
- Identification of link between average radon volumetric activity and index of incidence of patients' with lung malignances.

Research methods. For measuring and monitoring of the volumetric activity of radon were used express (with the help of radometer radon RAD7, RadonScout and RadonScoutPlus) and integrated methods (with the help of track detectors Radtrak2 radiative activity of the Swedish firm Radtrak2).

When considering the biological effects of radon exposure, a model approach was used based on the correlation method.

Main defending statements:

1. Pathogenic zones with high intensity of radon radiation exceeding the level of maximum permissible norms in Azerbaijan;

2. The link between the volumetric activity of radon and the incidence of the population of malignant lung neoplasms living in pathogenic zones of Azerbaijan.

Scientific novelty of the work:

- Zones with relatively high radon concentrations were identified and the territory of Azerbaijan was divided into districts according to the degree of radon hazard;
- Main sources of radon radiation have been identified;
- High incidence of malignant lung neoplasms were identified within the mountain-fold zone of the Greater and Lesser Caucasus and Talysh, where increased values of the volumetric activity of radon had been recorded;
- A high level of malignant lung neoplasms patients' incidence number dependency of the level of radon volumetric activity for certain regions was determined based on correlation analysis.

Practical relevance of the results:

- Zoned indicators of volumetric activity of radon for the territory of Azerbaijan were determined;
- Persons, living in conditions of increased radon concentration, were given appropriate recommendations on ensuring radiation safety, there was determined a set of additional researches and measures necessary to reduce the danger of radon exposure to the population.

Publications of the work:

There were published 20 scientific articles and 11 abstracts of conference reports on the topic of the dissertation. The main results and provisions of the dissertation work were reported at republican and international conferences:

1. The Eleventh International Workshop on the Geological Aspects of Radon Risk mapping. Prague, 2012.

2. Integrated Approach for Unlocking Hydrocarbon Resources. 3-5 October 2012. Baku, Azerbaijan.

3. Seismoforecasting researches carried out in the Azerbaijan territory. 7-12 October 2012. Baku, Azerbaijan.

4. The Fifht international conference of young scientists and students. Baku, Azerbaijan 2013.

5. The first Kiev International Scientific Conference "Scientific and Methodological Foundations of Medical Geology". Kiev, 2013.

6. The Twelfth International Workshop on the Geological Aspects of Radon Risk mapping. Prague, 2014.

7. IGCP 610 Second Plenary Meeting and Field Trip, Baku, Azerbaijan, 12-20 October, 2014.

8. The Second International Conference "Radon in the environment", 2015, Krakow, Poland.

9. The Third International Conference on Radiation and Applications in Various Fields of Research, 2015, Budva, Montenegro.

10. RAD 2017, Fifth International Conference on Radiation and Applications in Various Fields of Research, Budva, Montenegro.

11. The Eighth International Conference on Medical Geology. August 12-15th, 2019. Guiyang, China.

Name of the organization where the dissertation was performed.

The work was performed at the Institute of Geology and Geophysics of ANAS.

Structure and volume of work. The dissertation work consists of an introduction (6950 characters), 5 chapters (1st chapter - 40560 characters; 2nd chapter - 35420 characters; 3rd chapter - 30165 characters; 4th chapter - 25634 characters; 5th chapter - 31019 characters), conclusions (2570 characters), a list of cited literature, including 93 titles. The total volume of work is 145 pages, including 30 figures and 30 tables.

Acknowledgment. The dissertation work was carried out under the scientific supervision of the member-corr. ANAS, the

Doctor of Geological and Mineralogical Sciences, Professor C.S. Aliyev, to whom the author expresses his gratitude for the scientific guidance, full support and assistance in performing the work. The author expresses deep gratitude to the Director of the Institute of Geology and Geophysics of the National Academy of Sciences of Azerbaijan, Academician A.A. Alizada for his constant attention to the research. The author expresses deep gratitude to the academician of the National Academy of Sciences I.S. Guliev for his great support and attention to the work, the academician of the National Academy of Sciences A.A. Feizullayev for his help and support at all stages of the work. The author is very grateful to her colleagues for their assistance in the measurement work.

BRIEF SUMMARY OF WORK

The introduction considers the relevance of the topic of the dissertation, the purpose and tasks of the dissertation work, the provisions put forward for protection, scientific novelty and the practical subsidiaries significance of the data obtained, as well as data on publications and testing of the work.

The first chapter provides a detailed overview of the status of radon-induced environmental radiation background researches. This part of the work provides an overview of recent epidemiological researches of the risk of lung cancer associated with radiation from radon and its daughter products. Particular attention is paid to the results of the combined analysis of case-control researches of exposure in dwellings and cohort investigations of mineworkers exposed to relatively low levels of volumetric activity of radon. Epidemiological researches in dwellings provide a reliable and consistent assessment of the risk of malignant lung neoplasms, statistically significant with an average annual volumetric activity of radon of about 200 Bq/m³.

The European United study, published by Darby[1] and other scientists, is the largest of all such researches. This study included 7,148 lung cancer cases and 14,208 controls from 13 European Residential Radon Concentration Control Studies. The observation period was 23 years. Individual radon exposure was calculated as a time-weighted mean of radon concentrations in all houses over the last 5-34 years. There was developed a statistical model in which the additional risk of lung cancer was proportional to the measured radon concentration. In addition, it was categorization of radon irradiation and the relative risk by category of measured radon concentrations was plotted according to the average level in these categories. In both models, detailed stratification was performed to examine the role of age, gender and region of residence.

According to the results of the generalized analysis, the relative excess risk of lung cancer for the level of 100 Bq/m^3 of radon concentration was 8%. This proportional increase was observed regardless of age, gender and smoking history. Relevant risk estimates for non-smokers, former smokers, and smokers were 7%, 8%, and 11%, respectively. The link between radon exposure and cancer risk turned out to be approximately linear. People, living in houses with volumetric radon activity concentrations of 100-199 Bq/m^3, had a considerably higher risk of lung cancer than patients who lived with concentrations of < 100 Bq/m^3.

Darby[2] and others detailed the results of the European Joint Research Program on the combined effects of smoking and radon. Regardless of smoking status, they took excess relative risk in

[1] Darby S, et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies // British Medical Journal. 2005; 330: 223–227

[2] Darby S, et al. Residential radon and lung cancer: detailed results of a collaborative analysis of individual data on 7, 148 subjects with lung cancer and 14,208 subjects without lung cancer from 13 epidemiological studies in Europe // Scandinavian Journal of Work, Environment and Health. 2006; 32 (Suppl. 1): 1–83

calculations as 16% per 100 Bq/m^3 long-term mean radon volume activity concentration. For those who stopped smoking, the risks connected with radon are significantly lower than for those who continue to smoke, however, they are significantly higher than the risks for lifelong non-smokers.

Next, the chapter presents the main results of radiometric researches conducted in Azerbaijan. Natural radioactivity on the territory of Azerbaijan varies about 4-12 μR/h, rising in some places to 20-30 μR/h. Spacial variations in radioactivity are random and respond to normal law.

Since 2010, a new scientific direction has been developing at the Institute of Geology - medical geology, which is a new, strategically significant direction in geology, studying the link between the features of the geological environment and the incidence of the population, the state of the animal and plant world. The target of medical geology is to identify harmful geological factors and their conditions of impact that contribute to the deterioration of health, as well as to develop rational principles, strategies, programs and approaches necessary to eliminate or minimize health risks.

The second chapter considers the types of sources of ionizing radiation and their effect on human body, permissible levels of exposure to natural radiation sources, reveals the essence of the radon problem and identifies the main sources of radon entry into the buildings.

Isotopes of uranium-238, uranium-235 and thorium 232 give rise to natural radioactive families, which include secondary radioactive elements. The decay half-lives of these maternal nuclides are for thorium $14 \cdot 10^9$ years, uranium-238 $4{,}5 \cdot 10^9$ years, uranium-235 $0{,}7 \cdot 10^9$ years. The final elements of these families are stable lead isotopes with mass numbers 206, 207 and 208.

Radon is the only gaseous product formed during the decay of all radioactive families. In nature, radon occurs in three main forms: in the form of ^{222}Rn, half-life T = 3,8 days, formed in the radioactive

family of uranium-238; ^{220}Rn (side), half-life T = 55 seconds, member of thorium-232 radioactive series; 219Rn (actinone), decay period T = 4 seconds, is formed in the radioactive family of actinium. Radon-222 gives the greatest contribution to the total radiation dose.

The long half-life and chemical inertness of ^{222}Rn, located in the decay chain of uranium-238, increases its content in the air of the areas. Most of the radiation comes from short-lived daughter products of radon decay. Short-lived daughter decay products of radon-222 (isotopes Ro-218 and Ro-214) actively irradiate internal human organs with alpha particles.

The concentration of volumetric activity of radon in closed areas is on average about 8 times higher than in the outside air. And the volumetric activity of radon in the outside air varies significantly at different points of the earth's surface. Radon accumulates inside residential and other areas quite isolated from the external environment. Soil and building materials are the main sources of radon entry into residential areas.

Content of radionuclides of radium-226 and thorium-228, structure and moisture content of soil determine concentration of volumetric activity of radon in soil. There is a direct link between the migration of radon atoms and soil moisture. And the emission of radon from the soil is seasonal. During the summer period, an increase in temperature leads to an expansion of the pores in the soil, and, therefore, increases the release of radon into the atmosphere. And there is a strong inverse link between atmospheric pressure and radon concentration, since an increase in atmospheric pressure leads to a drop in radon concentration in the outside air. During the period of reduced atmospheric pressure, in contrast, we can observe increased concentrations of radon in the air.

Construction materials are also a source of radon in residential areas. According to the results of researches, the average speed of radon entrance into residential buildings in the United States is 20 Bq/m³, while only 20% of this value comes directly from building

materials[3]. Wood, brick and concrete, used as building materials, excrete relatively little radon. Granite, pumice, blocks of phosphogypsum, alum clay shale, alumina, calcium silicate slag have a particularly high specific radioactivity[4].

Next, the chapter gives the main technical characteristics of the devices used to measure and monitor the volumetric activity of radon and its daughter decay products, and also describes express, integral and quasi-integral methods for measuring the volumetric activity of radon. There also are described methods of express measurement of volumetric activity of radon in air and underground air using radon radiometers RAD7, RAD Scout. Using integral methods, the average value of the volumetric activity of radon is determined over a long period (weeks, months). The use of track detectors is the most widely used integral method. The track detector method is widely used in indoor surveys. Insensitivity to gamma and beta radiation, long-term storage of information and the possibility of simultaneous exposure of a large number of detectors are the main advantages of this method. Employment of track detectors Radtrak2 the Swedish company Landauer Nordic carried out measurements of indoor radon volumetric activity.

This chapter also considers the main models of radiation risk assessment - additive (absolute risk model) and multiplicative (relative risk model). Here are given the models of lung cancer risk assessment used in ICRH Publication No. 50 (International Radiation Protection Committee) and proposed by the US National Committee on Biological Effects of Ionizing Radiation (BEIR).

A model approach based on the correlation method is used in this work considering the biological effects of radon irradiation.

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[3] Koltover V.K. Radon radiation: sources, doses, biological effects // Bulletin of the Russian Academy of Sciences 1996 E.66 №2. pp. 114-128

[4] Radiation. Doses, effects, risks. Mir.1990 - 79 pp.

The third chapter considers the regularities of the formation process of the radon field of Azerbaijan. In particular, within the framework of the first protected statement, a detailed description of the carried out researches is given. Measurements of the volumetric activity of radon in the areas were carried out using 2500 track radon detectors Radtrack2. Track radon detectors were located mainly on the first floors of residential and industrial buildings in various regions of the Republic of Azerbaijan. After that the special film-packed detectors were sent to Sweden for processing.

Based on the obtained data, a map of the distribution of volumetric activity and maximum volumetric activity of radon was constructed.

It was found that the measured concentrations of the volumetric activity of radon indoors vary within a wide range: from 2 to 1110 Bq/m³. In 169 of the 2407 houses where measurements were made, the concentration of radon above 200 Bq/m ³ was recorded, in 418 the concentration was between 100 and 200 Bq/m³, in the rest - less than 100 Bq/m³. The data obtained were processed using statistical methods (Figure 1).

Figure 2 shows the allocation of the measured volumetric activity of radon. As you can see, it is logarithmic-normal with a modal value of 58 Bq/m³ and an average value of 84 Bq/m³. At the same time, the upper limit of the background values is 116 Bq/m³. All values above can be considered statistically elevated[5]. In terms of hazard to human health, special attention should be paid to residential areas where the volumetric activity of radon exceeds the maximum permissible norms in Azerbaijan (200 Bq/m³). The number of such houses is about 7% of the total number of objects surveyed.

[5] Veliyeva F.F., Aliyev Ch.S., Feyzullayev A.A., Baghirli R.J., Pampuri L., Hoffmann M., Valsangiacomo C. Indoor Radon Mapping in Azerbaijan. 11th International Workshop on the Geological Aspects of Radon Risk Mapping / Czech Geological Survey. Prague, 2012. pp. 260-268

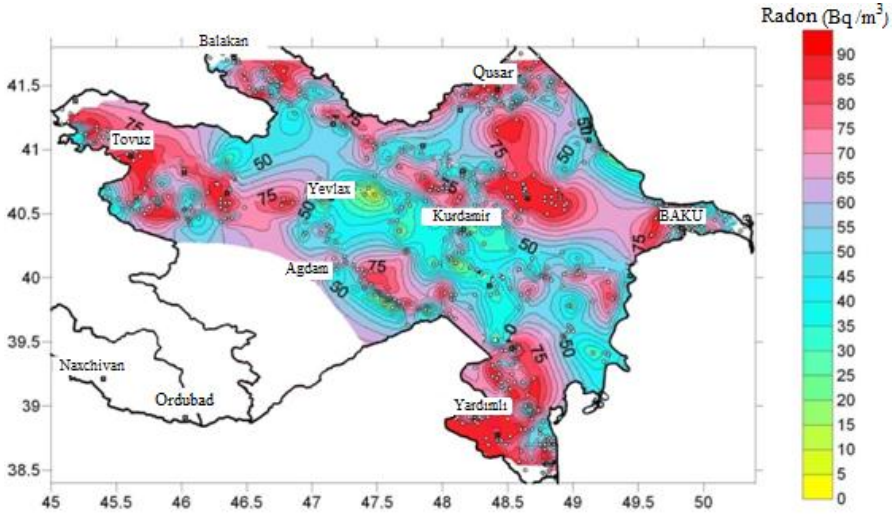

Fig. 1. Allocation of the content of indoor radon volumetric activity in Azerbaijan

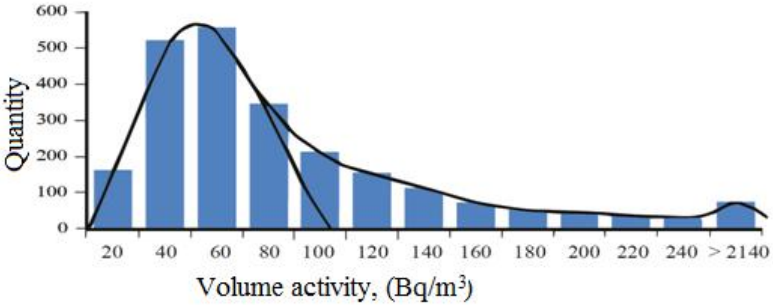

Fig. 2. Histogram of allocation of indoor radon volumetric activity values in Azerbaijan

The results of researches in Azerbaijan conducted to identify the amount of radon gas were included in the "European Indoor Radon Map." The electronic map compiled by the European Commission shows the allocation of the above-mentioned gas in our country (figure 3).

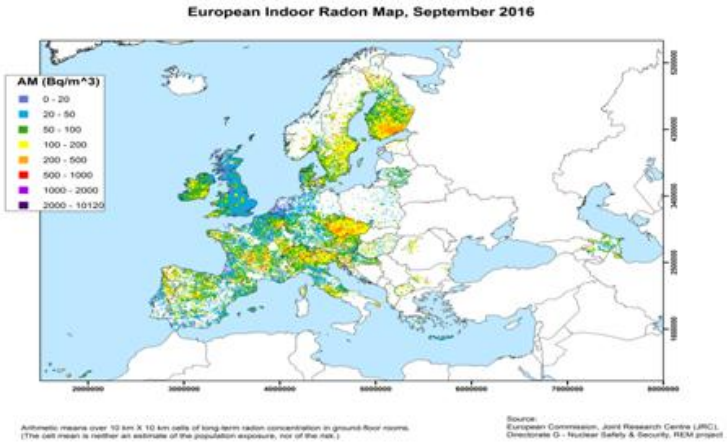

Fig.3. The map of distribution of radon volumetric activity in residential areas on the territory of Europe[6]

The map shows average volumetric activity of radon in residential areas. Each square on the map is a square area equal to 10x10 km. Each square corresponds to an average of 2 to 12 detectors (fig.4).

Analysis of the obtained data shows that the distribution of volumetric activity of radon in the territory of Azerbaijan is significantly non-homogeneous. Increased values of concentration of radon volumetric activity are characteristic of the mountain-folded regions of the Greater and Lesser Caucasus, Talysh, composed of more ancient and deployed rocks, and relatively low values of radon volumetric activity are confined to the Kura and Caspian-Cuban depression zones represented on the surface of the earth by rocks of quaternary age. As a result of research, the territory of Azerbaijan was divided into 4 zones by the degree of radon hazard (indoor radon volumetric activity): dangerous (200-400 Bk/m^3), moderately dangerous (100-200 Bk/m^3), conditionally safe (50-100 Bk/m^3) and safe (<50 Bk/m^3).

[6] Hoffmann M., C.S. Aliyev, A.A. Feyzullayev, R.J. Baghirli, F.F.Veliyeva, L. Pampuri, C.Valsangiacomo, T. Tollefsen, G. Cinelli. First map Residential Indoor Radon Measurements in Azerbaijan // Radiation Protection Dosimetry, 2016. pp.1-8

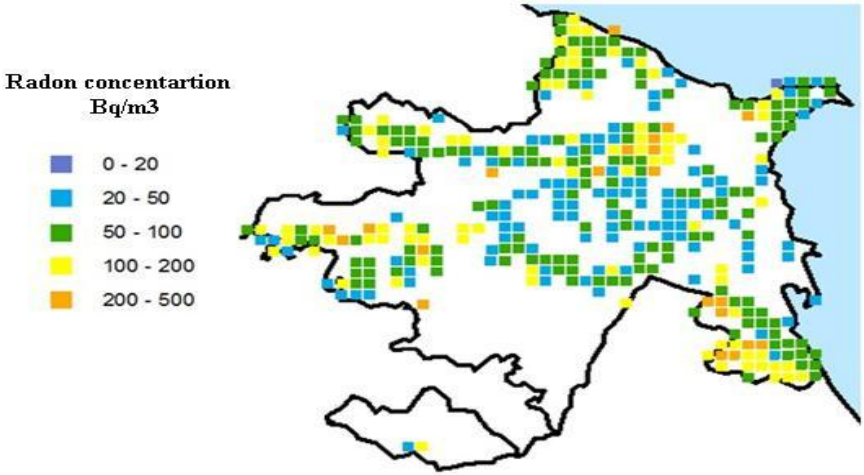

Fig.4. The map of distribution of radon volumetric activity in residential areas on the territory of Azerbaijan

Next, the author provides the results of studies conducted in 155 settlements of nine administrative districts of Shamakhy-Ismailly and Sheki-Zagatala zones. When measuring the volumetric activity of radon indoors, the Swiss research method was used. Measurements were taken on the first floors of residential (where the highest level of radon concentration is usually observed) using radiometers RadonScout and RadonScoutPlus. The radiometer RadonScoutPlus (RGA-1100 Plus) was installed in various residential rooms of the same house for three days. Depending on the number of rooms, the total working time of the device in one house was 7-12 days. At the same time, in the room where the device was installed, during its work they tried to reduce the influence of ventilation (the windows and doors remained closed). The data obtained were processed using statistical methods.

Measured concentrations of indoor radon volumetric activity vary widely: on average, from 20 to 520 Bq/m^3. The distribution of radon volumetric activity in the studied area is uneven: there is an alternation of zones with low and high concentrations of volumetric activity of radon in residential premises. Based on these data, maps

of the volumetric activity of radon were built in the residential areas of Shamakhy-Ismailly (Fig. 5) and Sheki-Zagatala.

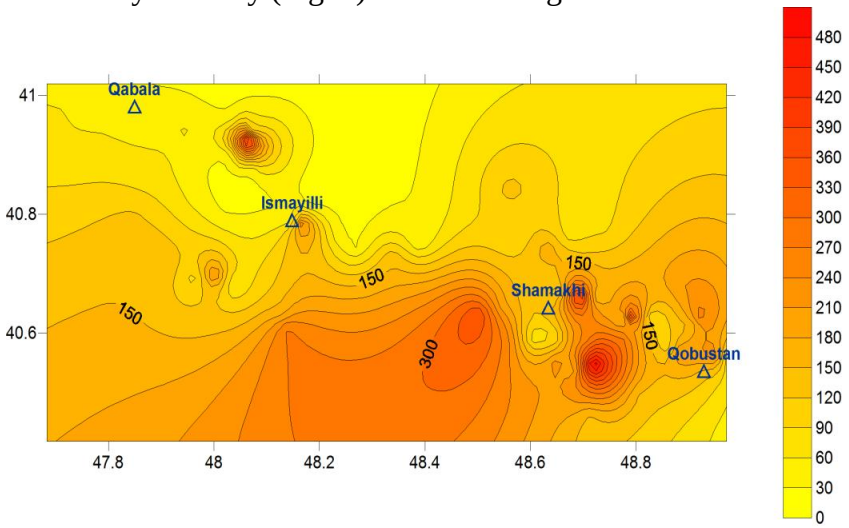

Fig. 5. Map of distribution of radon volumetric activity (Bq/m^3) in residential areas in Shamakhy-Ismailly zone

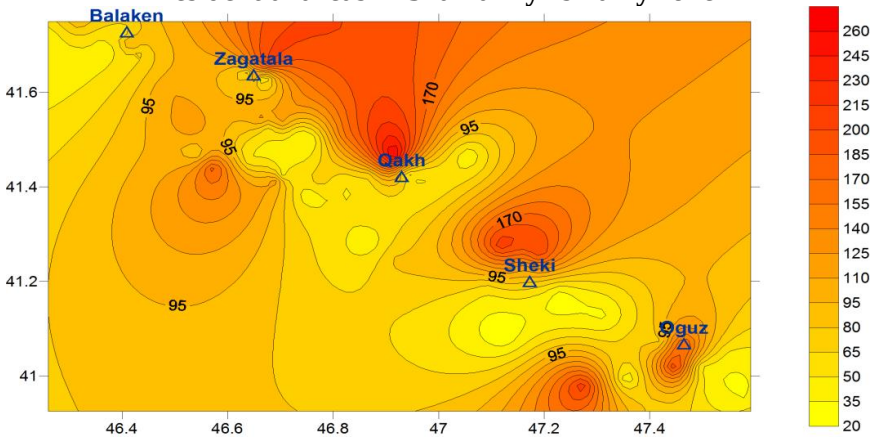

Fig.6. Map of distribution of radon volumetric activity (Bq/m^3) in residential areas in Shaki-Zagatala zone

The results of the mapping of the content of indoor radon volumetric activity in Azerbaijan showed the localization of its increased concentrations mainly in buildings located in mountainous

areas (Fig. 7). As seen from the data presented, one of the factors controlling this type of distribution of radon may be the age of the rocks[7].

The results of measurements of the concentration of radon volumetric activity in the air of the buildings are well consistent with the data on the content of radon in the soil air. The volumetric activity of radon in the soil air, measured within the southern slope of the Greater Caucasus, varies from 30 to 11000 Bq/m³ (an average of 946 Bq/m³). High concentrations of volumetric activity of radon in the soil air were observed mainly in the seismically active Shamakhy region, where increased values of volumetric activity of radon were also noted indoors.

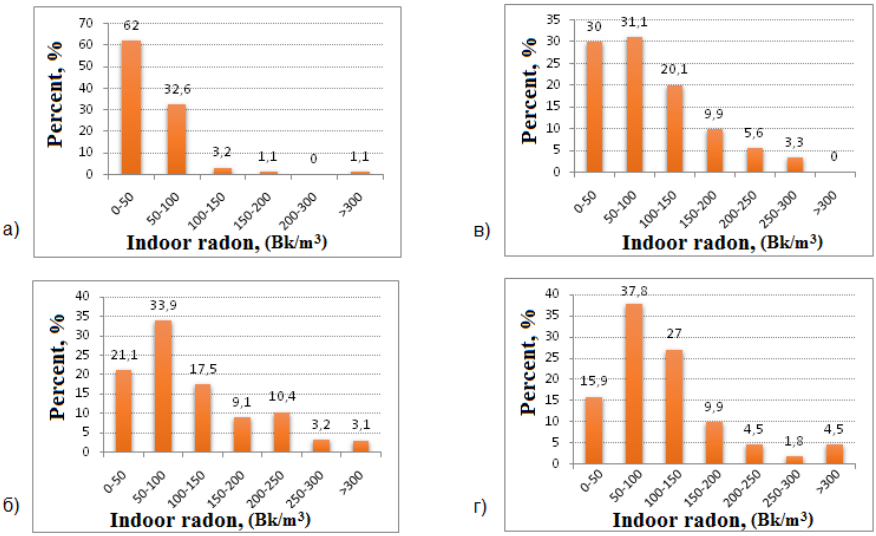

Fig. 7. Histograms of the distribution of average values of the volumetric activity of radon in rooms depending on the geomorphological features of the territory of Azerbaijan: a) Kura Lowland; b) Greater Caucasus; c) Lesser Caucasus; d) Talysh

[7] Алиев Ч.С., Фейзуллаев А.А., Багирли Р.Дж., Махмудова Ф.Ф. Закономерности распределения радона в Азербайджане и контролирующие их факторы // Научно-технический журнал Евро-Азийское геофизическое общество. Геофизика 1.2017. Москва, 2017. С. 72-77

Studying the influence of building materials on the volumetric activity of radon in the air of residential and public buildings, more than 2,400 residential buildings were investigated. A relatively high concentration of radon volumetric activity was observed in houses built of natural and dark stone. The rate of radon excalation from building materials depends on the product of the specific activity of radium on the coefficient of radon emanation (effective specific activity of radium), as well as on the length of radon diffusion in building materials[8].

A comparison of the concentration of radon volumetric activity in premises located on different floors showed that the higher the floor - the lower the concentration of radon volumetric activity. The highest concentrations of volumetric activity of radon are characteristic of the first two floors of the investigated houses.

The fourth chapter considers the second protected position and presents the characteristic results of correlation analysis between the incidence rates of the population with malignant lung formations and the distribution of volumetric activity of radon.

Based on the results of large-scale researches, the increased content of radon and its decay products in the air of residential buildings was assigned by experts of the International Agency For Research on Cancer to the first group of carcinogenic substances. The main hazard to living organisms is not as much radon itself (because of its relatively small half-life (3,825 days)), as its daughter decay products, which are sorbed by dust and moisture, forming α-radioactive aerosol particles. Submicron-sized aerosols are the most dangerous, which can penetrate and settle into the upper respiratory tract, creating local sources of α-irradiation of cells.

According to existing standards, maximum permissible emissions of air pollutants In the United States should not increase the mortality rate of the population by more than 0,001 %. But

[8] Krampit I.A. On measuring the coefficient of emanation of soil // ANRI 2004 №3. pp. 51-52

calculations show that radon radiation causes 20 thousand additional deaths from lung cancer annually, exceeding the permissible mortality rate by 300 times. For the same reason, the risk of non-cancer diseases of the respiratory tract (e.g., lung emphysema and cardiovascular diseases) is significantly increased.

According to the Ministry of Healthcare of the Republic of Azerbaijan, the number of sick men is 8 times more than women. According to experts, the main cause of respiratory diseases is smoking. Radiation ecology experts claim that radon aerosol particles that sorb radionuclides and transport them to the bronchi and lungs. As in result, the local level of cell irradiation rises dramatically.

The results show that people of mature age are exposed to malignant respiratory formations. Radon negatively affects human health due to the accumulative effect, expressed in the gradual accumulation of radiation-related damage.

It was revealed that the incidence with malignancies is especially high within the mountain-folded zone of the Greater, Lesser Caucasus, and Talysh, where increased values of the volumetric activity of radon are recorded. The highest incidence rates with respiratory malignancies were recorded in dangerous and moderately dangerous areas of radon exposure.

Correlation coefficients for 2012-2015 indicate a quite high causal link between the radon activity of the area and the number of patients with lung malignancies.

In addition, in order to analyze the link between the development of lung malignancies and the population living in radon-hazardous zones, relative risk indicators were determined (Table 1). At the same time, the indicator of relative risk made it possible to assess how many times living in conditions of radon-hazardous zones increased the likelihood of getting malignant lung neoplasms.

In order to calculate the relative risk score (RR), each of the observed individuals was categorized into one of four categories:

a) patients with lung malignancies from radon-hazardous zones over the period of 2005-2015;

b) patients with malignant lung neoplasms from non-radioactive zones;
c) persons without detected malignancies from radon-hazardous zones;
d) individuals without detected malignancies from non-radioactive zones.

Table 1

Distribution of patients with malignancies of lungs and other persons depending on residence in radon active and non-radon active zones

Presence of lung malignancies (LM)	Groups		Summary	RR	p
	Basic	Control			
Patients with cases of LM	716	323	1039	1,915 (CI 2,183-1,679)	<0,05
Persons without cases of LM	575 634	497 477	1 073 711		
Total	576 350	497 800	1 074 150		

The RR calculated from Table 1 was RR = 1,915 (CI 2,183-1,679), r< 0,05. Thus, with a probability of 95%, we can claim that there is a significantly pronounced and statistically reliable link between the development of lung malignancies and living in the conditions of radon-hazardous zones of Azerbaijan.

The obtained results confirm the role of radon as a dominant factor leading to a high risk of lung cancer, which should be taken into account in the development and implementation of appropriate preventive social and health measures, construction standards, especially for certain regions of Azerbaijan with a high level of natural radon radiation.

The fifth chapter provides information on preventive measures to be taken to prevent possible radon distribution in residential areas and gives recommendations for reducing radon hazard. Currently, there is a number of methods of anti-radon protection in residential buildings with increased concentrations of volumetric activity of radon. Reducing radon volumetric activity in the air of rooms can be achieved due to the following technical solutions:

- Selection of a site for construction on the territory with a minimum yield of natural radon from the soil;

- Application of various design solutions that prevent radon entering from the soil into the building;

- Forced and natural ventilation to remove radon from indoor air.

The first and the second versions are used at the stage of design and construction of structures in areas with increased emanations of radon from soils. For houses under construction, at the design stage, a comprehensive environmental and geophysical control should be carried out, including the study of the natural radiation background, the identification of active tectonic zones, the distribution of the radon volumetric activity when choosing sites for the construction of residential and industrial buildings.

As the character of the regional radon field of Azerbaijan is determined according to a limited number of residential objects, to identify a more real picture, detailed work must be done in anomalous zones in order to measure radon in residential objects without previous researches. It is recommended to carry out comprehensive work, including a selective medical examination of people who have long lived in houses with abnormal concentrations of radon.

CONCLUSION

Summarizing of research results allows making following main conclusions:

1. It was revealed that regional changes in the radon volumetric activity are due to the geological features of the structure of the region: increased values of the radon concentration are characteristic of the mountain-folded regions of the Greater and Lesser Caucasus, Talysh, composed of rocks of Mesozoic-Cenozoic age, and relatively low values of the volumetric activity of radon are confined to the Kura and Caspian-Cuba depression zones, represented on the surface;

2. Based on performed researches, the territory of Azerbaijan was divided into 4 zones according to the degree of radon hazard (indoor radon volumetric activity): dangerous (200-400 Bk/m^3), moderately dangerous (100-200 Bk/m^3), conditionally safe (50-100 Bk/m^3) and safe (<50 Bk/m^3);
3. Naturalness of increased radon volumetric activity on the territory of Azerbaijan was detected according to correlation analysis of the link between indoor and environmental volumetric activity of radon with geological conditions;
4. A link was established indicating the connection between the average volumetric activity of radon and the floor of the building and it was revealed that in multi-stored buildings the volumetric activity of radon on the first floor is much higher than on the upper floors;
5. Obtained results identified the greatest contribution of construction materials to radon radiation during the construction of residential and industrial buildings;
6. It was detected that the incidence with malignancies is especially high within the mountain-folded zone of the Greater, Lesser Caucasus, and Talysh, where increased values of the volumetric activity of radon are recorded. The highest incidence rates with respiratory malignancies were recorded in dangerous and moderately dangerous areas of radon exposure;
7. Based on correlation analysis, a high degree of dependence of the number of patients with lung malignancies on the level of volumetric activity of radon for various regions was established. Correlation coefficients for 2012-2015 indicate a fairly high causal association between the radon activity of the area and the number of patients with lung malignancies;
8. Indicators of relative risk of malignant lung neoplasms in conditions of radon-hazardous zones of Azerbaijan are determined. Relative risk indicators demonstrate a direct link between the development of lung malignancies and living in radon-hazardous zones of Azerbaijan;

9. Measures were developed to prevent the possible accumulation of radon in residential areas, appropriate recommendations were made to reduce radon hazard, and a set of additional researches and measures was identified to reduce the risk of radon exposure to the population.

The main provisions of the dissertation are published in the following works (articles and extended theses of conferences and seminars)

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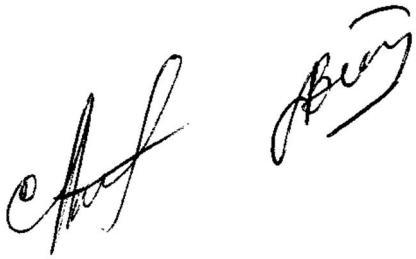
Personal contribution of the applicant

The works [1, 11, 27, 30] were independently performed; in works [2-10, 12-26, 28-31] participation in setting of objective, performing of laboratory investigations and in summarizing the results.



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