STUDYING OF THE GEOLOGICAL FACTORS CONTROLLING THE DISTRIBUTION OF RADON ON THE TERRITORY OF AZERBAIJAN

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The article describes methodology and results of the first measurements of indoor and outdoor radon concentrations in Azerbaijan, including statistical processing of obtained results. Measured indoor radon concentrations varied in a wide range: from almost radon free houses to 1109 Bq/m3, only 7% of all measurements exceeding maximum permissible limit in Azerbaijan (200 Bq/m3). Based on obtained data maps of distribution of volumetric activity and elevated indoor radon concentrations in Azerbaijan were created for the first time. These maps reflect mosaic character of distribution of radon and enhanced values of which are confined to fractured seismically active mountain areas. Results of later carried out radon measurements in soil indicates a good correlate with indoor data. Indoor and outdoor data are well correlated with each other and have shown on its essential fluctuations both in space and in time, being controlled by the geological structure of the region, fault tectonics and seismic processes. All of this allows assertions about the natural character of excess radon values in dwellings.

Introduction. According to the WHO (Fact sheet N°291) radon is one of the most toxic and radioactive gases. According to data of the International Commission on Radiological Protection 50-90% of collective radiation exposure comes from radon and its decay products. Radon and its decay products enter into the human body from the air and may cause lung cancer.

In many countries the radon problem is being studied for a long time. People’s protection from exposure to radioactive natural gas – radon and its decay products is a national problem and demands studying a number of questions related to radon source and radon availability in the buildings. Due to the lack of the necessary analytical techniques in Azerbaijan investigations dedicated to the studying of indoor and outdoor radon concentrations had not been carried out until 2010.

Azerbaijan is located on the western shore of the Caspian Sea, at the southeast extremity of the Caucasus and has a population of about 10 million people. Three physical features dominate Azerbaijan: the Caspian Sea, whose coastline forms a natural boundary to the east; the Greater Caucasus mountain - in the north; Lesser Caucasus and Talysh mountains ranges - in the south and the extensive flatlands (Kura valley) at the country's center. Azerbaijan has a total land area of approximately 86,600 square kilometers.

Azerbaijan is bordered on the north by Russia, on the west by Armenia, on the northwest by Georgia, on the south by Turkey and Iran (fig. 1).

The sedimentary, metamorphic and magmatic formations of a wide stratigraphic range take part in the geological structure of a land of Azerbaijan. The Greater and Lesser Caucasus are represented by sedimentary and volcanic-sedimentary formations of Jurassic, Cretaceous and Paleogene ages. Within the Kur intermountain depression younger Neogene-Quarternary rocks are developed (fig.1).

Results of radiometric studies carried out in Azerbaijan since 1949, showed that natural radiation field on the territory of Azerbaijan is in the range typical for rocks and soils of the Earth and is about 60- 80 ηSv/h. At the same time a relationship between natural radiation fields and the geological structure of the territory has been determined [1].

Indoor radon studies in Azerbaijan were carried out for the first time in 2010-2011 [2]. These studies were conducted with the financial support of the Swiss National Science Foundation (SNSF) under the grant “Creation of Cadaster and Map of Distribution of Radon in Azerbaijan Using the Swiss Methodology and Experience”. The studies were carried jointly by the Radon Competence Centre (RCC) of the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and Institute of Geology and Geophysics (IGG) of Azerbaijan National Academy of Sciences (ANAS).

In 2014-2015 the investigation of radon problem in Azerbaijan has been continued in the framework of Azerbaijan State Program (2014-2018). Measurement of indoor and outdoor (in soil, mineral and thermal waters and mud volcanoes) radon levels, medical examination of population, development of actions for reducing radon risk, creation of regulatory acts, public education, etc. are the main objectives of this program. The results of indoor and outdoor investigations are reported in this paper.

Material and methods. Dosimetry. For indoor radon measurements about 2500 radon detectors of type Gammadata-Landauer were delivered to IGG with the support of the SNSF and the RCC. These dosimeters were placed in different regions of the country, mainly in residential and in some cases in industrial buildings, during the period of November-December 2010. The exposure time was not less than two months. Several dosimeters (around 50 pcs.) were installed in oil fields of the Absheron Peninsula and kept there from March to April 2011. An allocation map of dosimeters on the territory of Azerbaijan for different administrative regions is shown in figure 2.

Additional indoor and outdoor (in soil and water) measurements are carried out by Radon Scout analyzers and RAD7 analyser.

Sampling of data. During the installation of the detectors the special forms were filled in which the detector installation place, floor, building materials and etc. have been indicated. The uncertainty for each single dosimeter is around 1% (provided by the supplier) and 1% error for the transport. In previous indoor studies the total uncertainty was about 12%.

Results. Indoor radon. Measured indoor radon concentrations varied in a wide range: from almost radon free houses to 1109 Bq/m3. The obtained data were processed by using statistical methods. The distribution of the measured radon concentrations is shown on figure 3. Figure 3 shows a lognormal character of radon distribution with a median of 58 Bq/m^3 and a mean of 84 Bq/m^3. To facilitate the graph, all values above 240 Bq/m^3 have been cumulated in the last bin. Upper background limit calculated as 2 median amounted to around 116 Bq/m^3. All values above this limit can be considered as statistically elevated. However, only the buildings with radon concentrations exceeding the given maximum allowable concentration (MAC) for radon in Azerbaijan of 200 Bq/m^3 are regarded as relevant from the health hazard point of view.

The created map shows that a heterogeneous distribution of indoor radon in Azerbaijan (fig. 4).

The areas with elevated radon concentration are confined to mountainous and folded massifs of Great and Lesser Caucasus and the Talysh ranges. The lower concentrations are confined to the Kur lowland which is mostly composed of semi-desert and riverbed areas. Based on these results it is likely to suggest that high concentrations are associated with relatively ancient and faulted rocks.

The results showed differences between the values for first and upper floors (table 1).

Table 1

Radon concentration at different floors in buildings

Floor	Number of detectors	%	Radon concentration, Bq/m^3		
			Max	Min	Mean
1	1561	76,9	1109,02	0,32	90,24
2	439	21,8	546,96	0,71	68,96
3	15	0,8	68,24	0,32	24,87
4	6	0,4	44,83	0,32	23,50
5	1	0,1	19,30	19,30	19,30

Outdoor radon. Radon in soil. Radon content in soil measured within Greater Caucasus varied in the rangeof 28 to 11000 Bq/m^3 (average 946 Bq/m^3). High concentrations of radon were predominately detected in Shamakhy area, where enhanced radon values were also measured indoors.

Radon in mineral/thermal waters. Investigation of 9 natural emergences of water in 7 thermal springs provided a wide range of concentrations - from 3.73 to 93.3 Bq/l (fig. 5). The mineral waters are classified as a weak radon waters. According to the sanitary-hygienic norms radon thermal waters of Talysh are not considered hazardous to human health neither bathing nor drinking, except Bulyudyul spring. Radon levels in the latter exceed the maximum permissible concentration for the drinking water more than 1.5 times (fig.5).

Radon on mud volcanoes. Azerbaijan hosts the world's largest mud volcanoes and most dense mud volcano development. There are about 190 onshore and 160 offshore mud volcanoes (MVs) in Azerbaijan. Onshore MVs are sufficiently well studied. The integral radioactivity of the solid products of their activity varies within the limits 60 - 160 ηSv/h (table 2).

Table 2

Radon in breccia on mud volcanoes

Mud volcano	Integral radioactivity, ηSv/h	Radon, Bq /m^3
Akhtarma-Pashaly	100-110	224
Akhtarma-Ardy	70-80	161
Gushchu	120-130	160
Shikhzagirli	150-160	105
Madrasa	60-70	30

As a rule, excess values of radioactivity have a ring (semi-ring) type of spatial distribution (fig.6) [3].

Radon content in breccia on some MVs has been studied only during last 2-3 years (table 3). As it is showed on example Dashgil MV radon values changes in wide limits (from 76 to 12 400 Bq/m3) and an integral radioactivity has also a ring (semi-ring) type distribution in space (table 3).

Table 3

Peculiarities of spatial distribution of radon in breccia on Dashgil mud volcano

Measurement points	Integral radioactivity, ηSv/h	Radon in breccia, Bq/m^3
Western margin (foot) of MV	80 – 90	12400
Western margin (slope) of MV	100 – 110	1450
Within MV plateau	90 – 100	76
Within MV plateau	80– 90	161
Eastern margin (slope) of MV	70 – 80	1140

Correlation between indoor and soil radon. On the basis of obtained results the comparison of the indoor and outdoor (in soil) radon measurements were carried out. On graph of correlation of these data we can see two trends (fig.7a). The same type of correlation was established between soil radon and soil radioactivity (fig.7b). Such kind correlation between studied parameters is possible because of the different permeability of migration pathways.

Furthermore, we have studied the spatial change of the radon content in the soil along the regional profile on southern slope of G. Caucasus. Comparison of these results with indoor radon measurements in some dwellings located close to this profile has allowed revealing their good correlation (fig.8).

Geological control of radon distribution. Analysis of the compiled maps has showed that the high levels of radon concentrations are characteristic for mountain systems (fig.9). The age of rocks also controls this pattern (fig. 10).

Considering the impact of other geological factors on distribution of radon it is necessary to note that radon is an admixture-component and delivered from the subsoil to the surface in stream of dominant gases of Earth (hydrocarbons, nitrogen and carbon dioxide). It is well known that most favorable pathways for vertical migrations of gases (including radon) are high permeable zones: active faults systems, volcano channels etc.

This proposition has been again confirmed by carried out measurements of radon in the soil within fault and outside (table 4), as well as by comparing concentrations of radon in hydrocarbon gases freely discharging from crater of mud volcano and near in breccia (figure 11 and table 5).

Table 4

Radon in soil within and out of faults

Measurement points	Integral radioactivity, ηSv/h	Radon in soil, Bk/m^3
Shamakhy region		
Within fault	90 – 100	>5000*
Out of fault	80 – 90	340**
Lower Kur lowland**		
Within fault	90 – 100	1330
Out of fault	80 – 90	189
Out of fault	70 – 80	218

** Marcus10 Detector;** RAD7 Radon Detector*

Table 5

Comparison of radon content in free gas emanation from crater and in breccia on mud volcanoes (at RAD7 Radon Detector)

Mud volcano	Radon, Bq/m^3		Radioactivity, ηSv/h
	In gas emanation	In breccia	
Uch-Tepe	2020	170	89
Kichik Maraza	1260	42	100
Bahar	2633	241	67

Seismic activization of the earth subsurface periodically increases gas flow (including radon) [4]. Figure 12 shows the increasing impulse of radon in dwellings as results of seismic events.

Conclusion. Indoor and outdoor measurements of radon in Azerbaijan have shown its essential fluctuations both in space and time:

- regional variations in space are controlled with the geological structure of region – the raised values of radon are characteristic for the highlands composed by the relatively older rocks;
- local variations of radon in space are conditioned by fault tectonics forming the linearly-extended abnormal zones;
- variations of radon in time are predominantly controlled by the seismotectonic processes.

Correlation between indoor and outdoor radon levels, their dependence on a geological structure, fault tectonics and seismotectonic processes allows to approve about the natural character of excess radon values in dwellings.

Acknowledgments. The authors express their thanks to the Swiss National Foundation (SNSF) for the financial support for implementation of above-mentioned investigations, allowing for the first time compiling the map of the distribution of indoor radon in Azerbaijan and reviling of the radon risk zones. The authors also express their appreciation to the Science Development Foundation under the President of the Republic of Azerbaijan for financial support to continuing investigations dedicated to radon problem (project EİF-2013-9(15)-46/24/2-M-33).

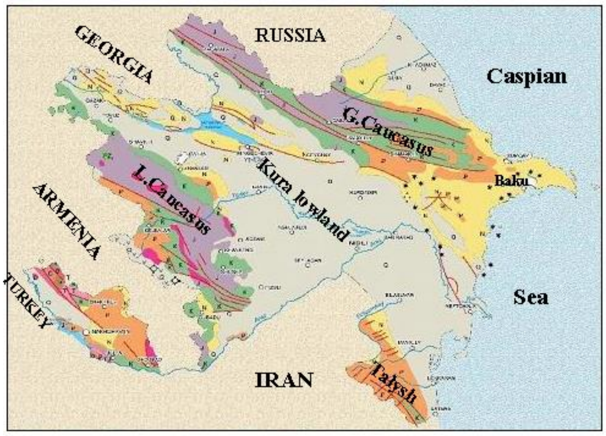

Figure 1. Geological map of Azerbaijan

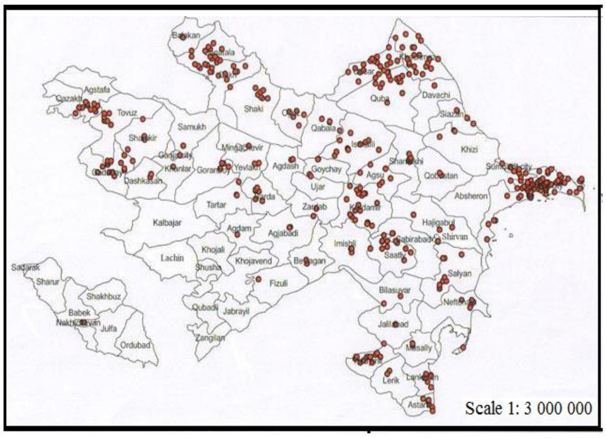

Figure 2. Map of indoor radon measurements points in Azerbaijan

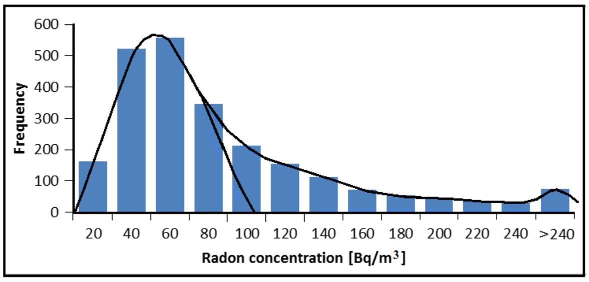

Figure 3. The log-notmal distribution of indoor radon in the investigated houses

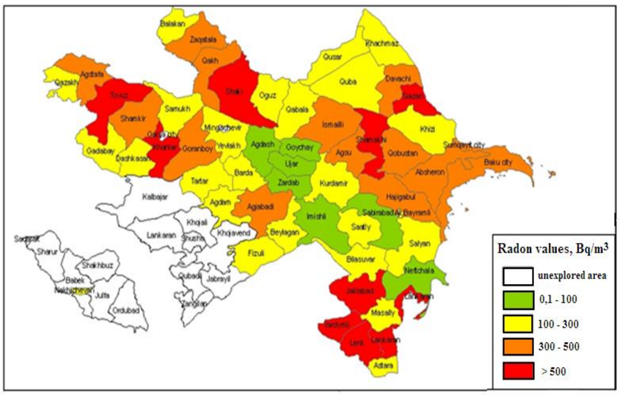

Figure 4. Indoor radon distribution in the surveyed areas

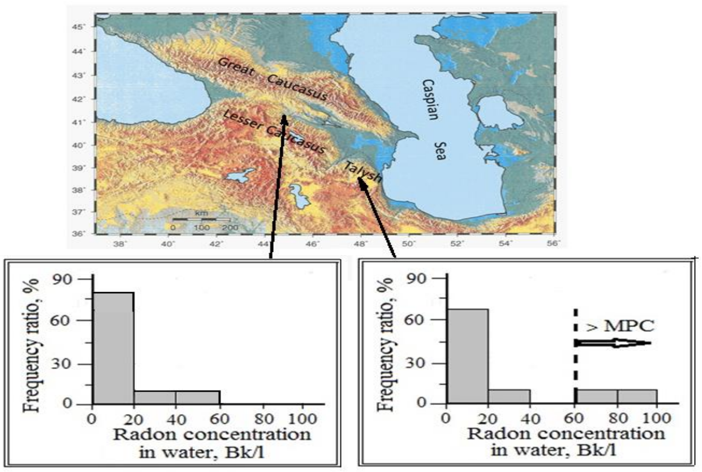

Figure 5. Histogram of the distribution of radon values in the thermal waters of Lesser Caucasus and Talysh mountains. MPC - Maximum Permissible Concentration of radon in drinking water adopted for Russian

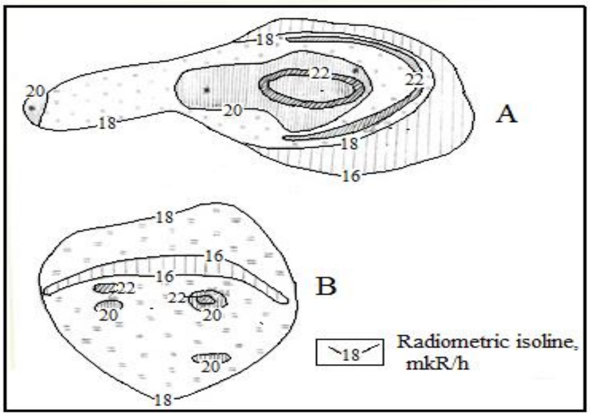

Figure 6. Spatial change of integral radioactivity on some mud volcanoes:
A – Lokbatan MV; B – Bozdaq-Gobu MV

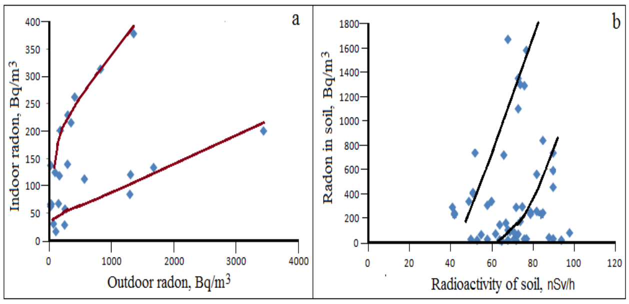

Figure 7. Correlation between indoor, soil radon and soil radioactivity: (a) indoor (at RadonScout Plus) vs. outdoor radon - in soil (at RAD7 Radon Detector); (b) radon in soil (at RAD7 Radon Detector) vs. radioactivity (at dosimeter-radiometer MKC-AT1125) of soil

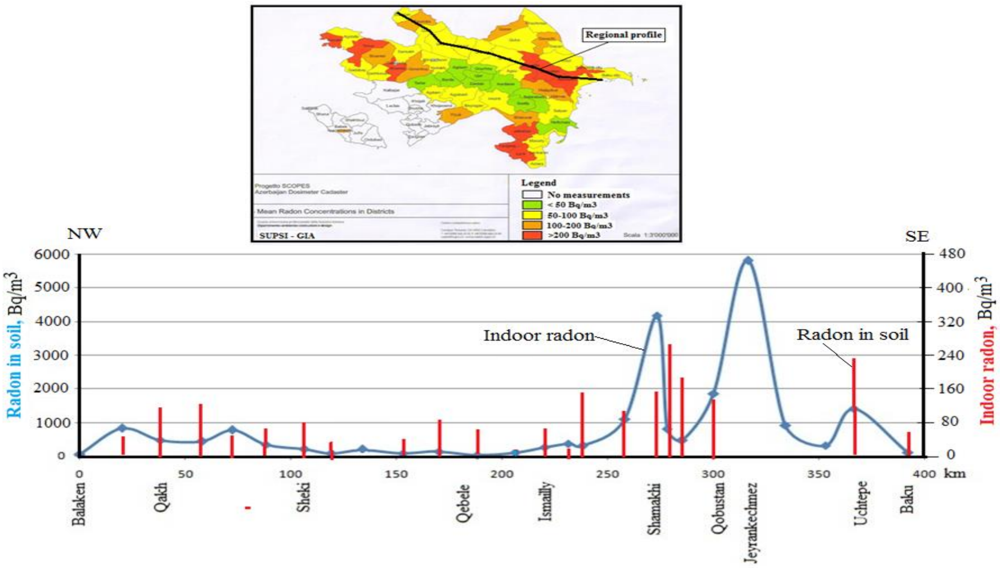

Figure 8. Results of outdoor (in soil) measurements of radon along the regional profile on southern slope of Great Caucasus, extended for a about four hundred kilometers (in comparison with indoor radon)

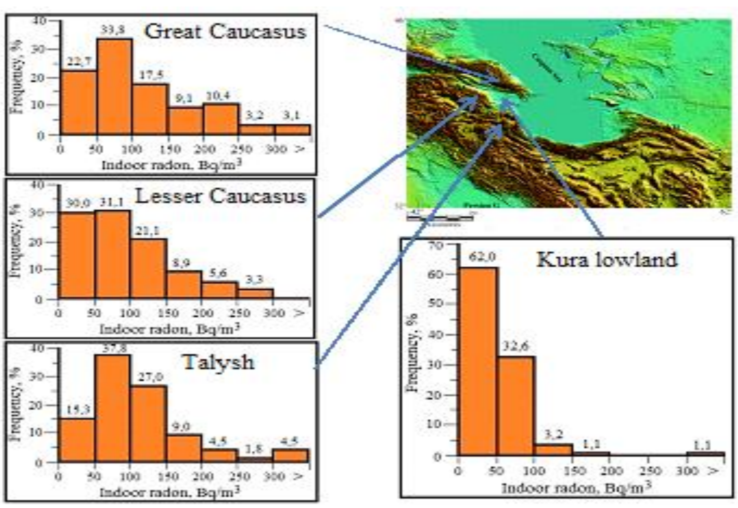

Figure 9. Histograms of distribution of average values of indoor radon in mountain systems (Great and Lesser Caucasus and Talysh) and in Kur lowland (at passive measurements)

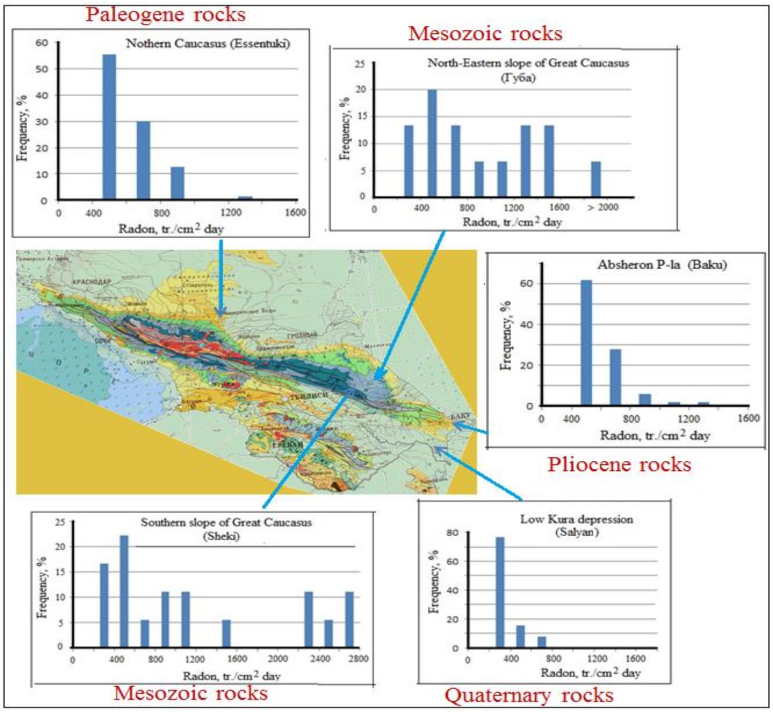

Figure 10. Histograms of distribution of values of radon flow in soil (in tr/cm²day) within the Caucasus region (at alpha-track method)

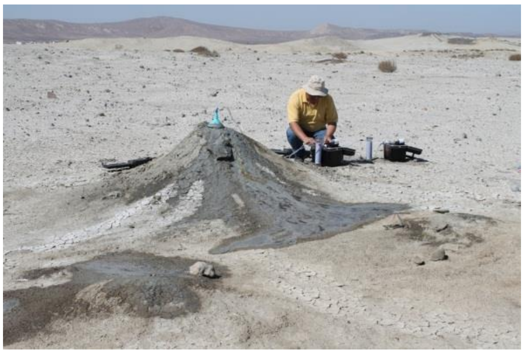

Figure 11. Measurements of radon gas emanation and radon in breccia on mud volcanoes (at RAD7 Radon Detector)

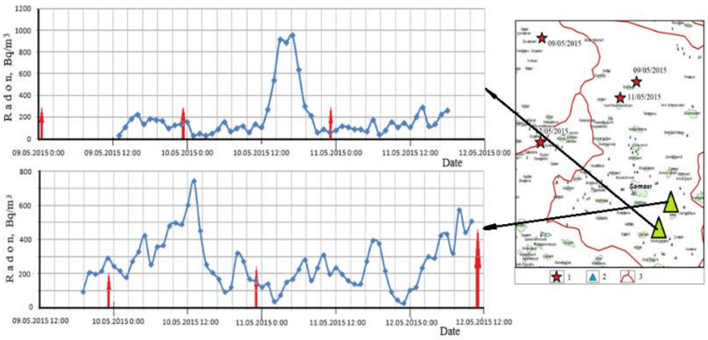

Figure 12. Indoor radon (Radon-Scout monitor) changes in two points in the most seismoactive Shamakhy region of Azerbaijan (southern slope of Great Caucasus) and location of epicenters of earthquakes

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AZƏRBAYCAN ƏRAZİSİNDƏ RADONUN PAYLANMASINA TƏSİR EDƏN GEOLOJİ AMİLLƏRİN TƏDQİQİ

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Məqalədə Azərbaycan ərazisində (yaşayış yerləri və sənaye müəssisələri, torpaq, termal sular və palçıq vulkanlarında) radon konsentrasiyasının ölçülməsinin metodika və nəticələri göstərilmişdir. Qapalı məkanlarda radonun qeydə alınmış konsentrasiyaları geniş sərhədlərdə dəyişir: 20- 1109 Bq/m³. Yalnız 7 % hallarda nəticələr Azərbaycan üçün müəyyən olunmuş yol verilən həddi (200 Bq/m³) keçir. Alınmış nəticələr əsasında ilk dəfə olaraq Azərbaycan ərazisi üçün radonun həcmi aktivliyinin yayılmasının xəritəsi tərtib olunmuşdur. Həmçinin Böyük və Kiçik Qafqaz, o cümlədən Talışın dağlıq massivlərində yüksək radon konsentrasiyaları müşahidə

olunmuşdur. Bundan başqa, torpaqda və qapalı məkanlarda müəyyən olunmuş radon konsentrasiyaları arasında asılılıq müəyyən olunmuşdur. Talış regionunda yerləşən termal mənbədən başqa, bütün mineral mənbələrdə radonun miqdarı içməli su üçün müəyyən olunmuş normalar daxilində dəyişir. Palçıq vulkanlarının brekçiyalarında da yüksək radon konsentrasiyaları müşahidə olunmuşdur. Alınmış nəticələrin kompleks analizi nəticəsində yaşayış məntəqələrində yüksək radon konsentrasiyasının təbiəti haqqında nəticəyə gəlinmişdir.

ИССЛЕДОВАНИЕ ГЕОЛОГИЧЕСКИХ ФАКТОРОВ ВЛИЯНИЯ НА РАСПРЕДЕЛЕНИЕ РАДОНА ПО ТЕРРИТОРИИ АЗЕРБАЙДЖАНА

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В статье описана методика и результаты измерений концентраций радона в Азербайджане (внутри жилых и производственных помещений, в почве, термальных водах и грязевых вулканах). Замеренные концентрации радона внутри помещений изменяются в широких пределах: от 20 до 1109 Бк/м3. Лишь около 7% от общего числа замеров превышают предельно допустимые нормы в Азербайджане (200 Бк/м3). На основе полученных данных впервые были построены карты распределения объемной активности радона на территории Азербайджана. Установлена приуроченность повышенных концентраций радона к горно-складчатым массивам: Большого и Малого Кавказа и Талыша. Результаты измерений радона в почве хорошо согласуются с данными о содержании радона в воздухе помещений. Содержание радона в термальных водах в целом не высокое, за исключением углекислого источника на Талыше, где его концентрации выше предельно-допустимого уровня, принятого для питьевой воды. Выявлены повышенные концентрации радона в брекчии грязевых вулканов, которые имеют характерную кольцевую природу. Особенно высокие концентрации радона установлены в газах, выделяющихся из сальз и грифонов грязевых вулканов. На основании комплексной обработки полученных данных сделан вывод об естественной природе увеличенных значений радона в жилых помещениях.