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# INFLUENCE OF NATURAL ATMOSPHERIC FACTORS ON RADON EMISSION

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**Abstract**: In recent decades, the problem of exceeding the critical level of radon gas concentration has become very urgent. According to some estimates, radon ($^{222}$Rn) and its decay products can make up 50-70% of the radiation dose received by the population from all natural sources of radiation. One of the factors that makes radon gas dangerous is that it leaks through cracks and crevices in foundations, accumulates in living spaces, and enters the human body through inhalation. It is believed that 10-14% of all lung cancer cases are due to elevated radon concentrations in the air of residential buildings (Kiselev S.M., 2016). Radon emission is more pronounced in mountainous and seismically active regions of the planet, and due to this property, it is used as a criterion for warning about earthquakes in many seismically active countries of the world. The article presents a project for a radioecological station that measures radon levels in an automated mode. In addition, abnormal changes in the concentration of Rn gas in underground waters (in the “Surakhany” and “Shikhov-2” wells) were observed on the eve of earthquakes.

**Key words**: radiation, radon emanation, earthquake, radon concentration.

## Introduction

Radon is a decay product of radioactive uranium-238 and its amount in the Earth's crust reaches at least 4.5%. This gas, which easily enters the human body through air, water, and dust particles and can cause serious problems in the body, is colourless and odorless. It is easily soluble in water and in the human body, especially in fatty tissues. Radon is present in almost all rocks, and the decrease in its concentration due to both decay and migration into the air is compensated by the continuous formation of this gas again as a radioactive decay product. Therefore, radon is always present in the soil and its concentration can decrease or increase from season to season, year to year. The most likely sources of radon gas formation in the atmosphere include soil, plants, groundwater, volcanic eruptions, natural gas and coal combustion, and mining and processing of minerals. The reason for the release of radon into the atmosphere is the migration process in the soil as a result of diffusion and advection processes. The concentration of radon in the atmosphere at ground level can vary significantly depending on the time of day (due to solar radiation during the day; temperature inversion at night and in the morning) and the time of year (due to changes in humidity) (Sakharov, 2006). Humidity also has a significant effect on the emanation process. Since radon is highly soluble in water, as a rule, the absorption of radon atoms by water leads to a decrease in this coefficient, and therefore in coastal areas it may also depend on the direction and strength of the wind. The rate of radon emission varies depending on the composition, moisture, porosity and permeability of the soil (Sapozhnikov, Aliev, Kalmykov, 2006).

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The highest concentration of radon is observed in soil and groundwater sources. The highest level of radioactivity is observed in groundwater in contact with radioactive crystalline fractured rocks - granites, gneisses, schists, diorites, clays.

Unlike many elements, the history of radon gas began long before its discovery. Thus, the harmful effects of Rn gas on the human body were known long after silver mining began in Schneeberg, Germany, around 1470. In Schneeberg, silver was mined from great depths (some mines reached a depth of even 400 m), and at that time the conditions of workers working in the mines of the Schneeberg region differed significantly from other mining regions in Europe. Already at the beginning of the 16th century, an unusually high mortality rate from lung diseases was noted among local mine workers, especially among young workers. The incidence of miners in Schneeberg was compared with data from similar mines in Sweden, Hungary, Tyrol and Joachimstal. It turned out that the health of workers working in these mines is much better than in Schneeberg, and the incidence of lung cancer is much lower. It took researchers about five centuries to conclude that not only "ore dust containing various metals", as Paracelsus wrote, but also the invisible gas radon, an intermediate link in the decay chain of radioactive uranium and thorium, can affect the development of lung diseases (Kiselev S.M., 2016). This fact proves that underground workplaces (mines, tunnels, basements) often increase the effect of radon gas due to geological conditions or limited ventilation.

Exposure of the population to natural sources is one of the main factors of the radioactive impact of the environment on humans. Radon and its decay products account for about half of the total radiation dose of the population. According to the World Health Organization, radon is one of the most toxic and radioactive gases (Radon and health…, 2014). An analysis of the health risk assessment of exposure to radon radiation by UNSCEAR showed that 10-14% of lung cancer cases are associated with exposure to radon decay products in homes. After smoking, radon radiation is the next leading cause of this serious disease (Kiselev S.M. 2016).

The negative impact of radon on human health has been studied since the early 1980s. According to the International Organization for Radiation Protection, radon and its decay products account for 40-75% of the total radiation dose of the population from natural sources. In 1987, radon and its decay products were included in the group of carcinogenic elements for the human body by experts of the International Agency for the Study of Malignant Formations (Aliyev, Mahmudova, 2018). Radonometry studies are actively conducted in many countries of the world (Belgium, Great Britain, Germany, Italy, Russia, USA, Czech Republic, Sweden, etc.). In world practice, radon risk or radon potential mapping of the territory is used to control the danger of radon gas.

In Azerbaijan, in 2010, the Institute of Geology and Geophysics of ANAS, with the support of the Swiss Science Foundation, began implementing a grant project entitled "Creation of a radon cadastre and radon distribution map in Azerbaijan using Swiss methodology and experience". As a result of the research work carried out, a radon cadastre was created for the first time for the territory of Azerbaijan, a map of the distribution of radon volume activity was compiled, and regions where anomalous radon concentrations were observed were identified (Aliyev, Feyzullayev, Baghirli, Mahmudova, 2017). In addition, indicators of radon volume activity in Azerbaijan were included in the European radon map. According to existing regulatory documents, the permissible limit of radon volume activity in enclosed spaces is 200 Bk/m$^3$ for old buildings and 100 Bk/m$^3$ for new buildings (Mahmudova, 2018).

According to the authors, the concentration of radon is higher in the Shamakhi-Ismayilli, Guba, Zagatala-Balakan and Sheki regions, which are active seismic zones and radon gas also comes to the surface from faults. At the same time, there are some places in the Gazakh-Tovuz, Ganja, and Talysh Mountains zones where the concentration of radon gas is high and should be under control.

High radon concentrations can also occur in factories, shops, schools, museums and in most common workplaces such as offices, due to the fact that the building's foundation is above ground, poor ventilation systems or activities related to the processing of raw materials. In addition, people can be exposed to radon gas in houses and sanatoriums that use natural groundwater with high radon levels in geological areas rich in granite rocks.

According to the state program of the Republic of Azerbaijan, after its liberation from the Armenian occupation, industrial zones began to be created in the western regions. Since the creation and development of industrial facilities is directly related to the increase in industrial waste, including radioactive waste, and at the same time, these regions are seismically active, radon gas exhalation in these areas must be constantly monitored.

An automated radioecological station has been established in the western zone of Azerbaijan to study the problems of industrial waste in seismically active areas and to measure radon exhalation from the soil (Bayramov A.A. 2025). The conventional layout of the station is shown in the diagram below (Figure 1).

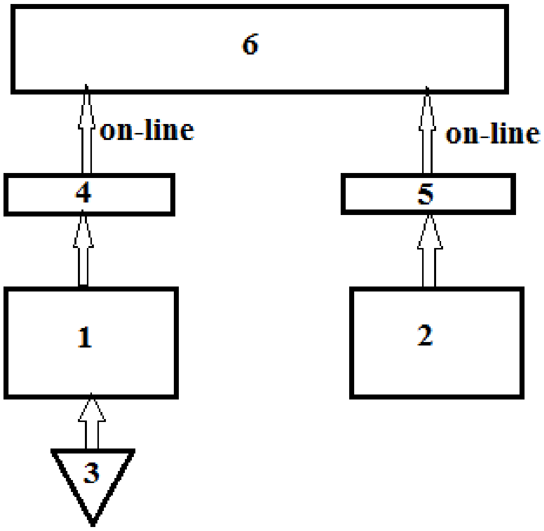

*Figure 1. Scheme of measuring radon emission in soil and surface*
*1,3 - Radon radiometer measuring radon emission in soil*
*2 - Radon radiometer measuring radon on the soil surface*
*4,5 - Interface blocks for online transmission of measurement data*
*6 - Computer for receiving and processing data*

As a result of studies conducted in seismically active regions of various countries, it has been found that radon, a radioactive gas that is released from geological rock layers and penetrates the air, is also considered one of the informative seismic forecast parameters as an indicator of rock changes during tectonic earthquakes. Due to its radioactive properties, radon is the most suitable for this type of research, since its volume activity level (Q) is quite easily determined in the environment. The migration of radon in mountainous areas and its separation from the soil surface is determined by the macroscopic diffusion coefficient, which largely depends on the porosity, permeability and fracturing of the massif. The permeability of the massif, the presence of associated pores and cracks in it, significantly depends on the stress-strain state of the massif. It is obvious that when the massif is compressed, its permeability decreases, and during tension, it increases, and the diffusion coefficient changes accordingly. Consequently, changes in radon concentration in the soil layer near the earth's surface can significantly reflect dynamic changes in the stress-strain state of the mountain range (Utkin, 2000).

Data were also obtained by recording the dynamic changes in the concentration of radon dissolved in groundwater as a short-term precursor of seismic events. The solubility of radon gas in water at room temperature is 460 ml/l, which is higher than the solubility of lighter inert gases. Self-flowing wells are usually used for these purposes. The processes associated with the preparatory period of an earthquake (deformation, changes in various geophysical fields, etc.) affect the rocks, disrupting the balance of the rock-water system, thereby creating conditions for radon to enter the water from the rocks. The time of manifestation of radon anomalies detected during earthquakes in seismically active regions is closely related to the energy and epicentral distance of the earthquakes. These factors were the basis for the study of radon gas as a short-term precursor of seismic events. The goal was achieved by solving the following problems: organization of detailed regime observations of radon gas in the groundwater of the Absheron Peninsula; analysis of radon variations in the taken water sample; justification of the selection of the most significant earthquakes for 2023 (analysis of the spatial position of the seismic source relative to the sampled objects and the magnitude of the earthquake); determination of the emanation responses of the radon field to earthquakes.

Radon (Rn) gas analysis was conducted in the groundwater of the Absheron seismic zone (Shikhov-2, Surakhani facilities) at the Bibi-Heybat gk/st. Water samples were taken once a day, 5 days a week. The measuring equipment used is the “Alpharad Plus” radiometer, included in the list of devices in the state register (database 49013-12). The radiometer is characterized by a relative error limit of ±30%.

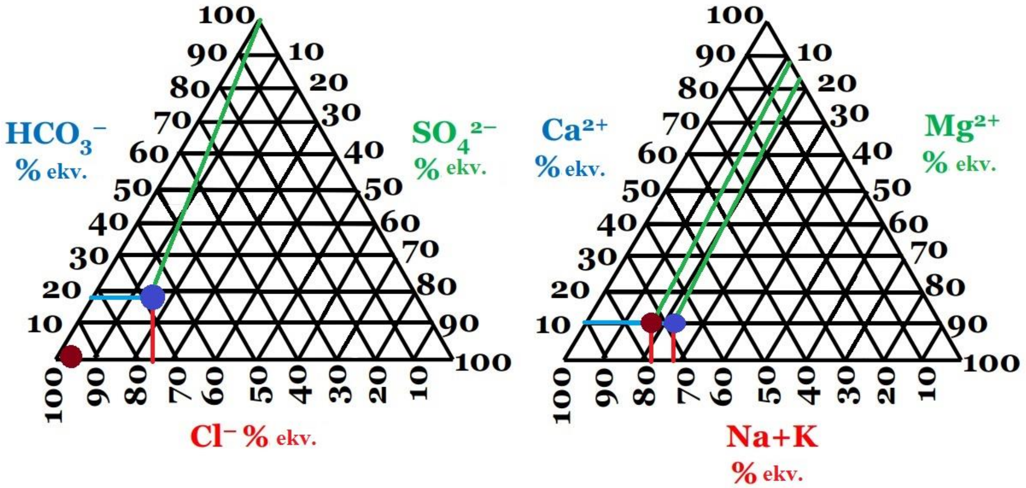

*Figure 2. Chemical composition of “Shikhov-2” and “Surakhani” well water*

*Symbols:*
*- "Shikhov-2" well water*
*- "Surakhani" well water*

The subthermal (T°C =18÷24) waters of the Shikhov-2 and Surakhani wells are located outside the oil fields. However, they differ significantly in all hydrogeochemical parameters (migration conditions, genesis, mineralization, ion-salt and gas composition).

In particular, the well water "Shikhov-2" is highly mineralized saline (M=260÷280 g/l), has a neutral (pH=7.1÷7.2) alkaline-acid reaction of the migration medium, has a sodium-magnesium chloride composition, belongs to the nitrogenous waters of the fracture-vein type. Despite the significant depth of the well h≥800 m, the water migrating to the surface comes into contact with the sea water of the Caspian Sea. This is due to the oxidizing properties of the water indicates high price (Eh=+140÷+170) and proximity to the seashore (Δ=100÷140 m).

The formation of the "Surakhani" water well occurs in a sharply reducing environment (Eh=-300÷-270). According to the migration conditions, the layer belongs to the subartesian type and is the water behind the contour of the oil field (h=24÷60 m). This water has a chloride-bicarbonate, sodium-magnesium-calcium ion-salt composition and belongs to slightly acidic (pH=6.6÷6.7), moderately mineralized (M=5÷6 g/l) waters. The gas composition is hydrosulfide-hydrogen sulfide-methane-radon (Керамова, 2003).

The composition of both waters is shown below with the Fere graph.

Both waters contain dissolved Rn gas, albeit in small amounts. Graphs of changes in the volume activity of radon for 2023 have been constructed (Figures 4,5). Measurements began at the end of February. Initially, it should be noted that during 2023, the volume activity of radon varied between 10 - 30 Bk/m$^3$ (depending on the season, there may be a 5-10% change). As can be seen from the variation, the radon concentration in the Shikhov-2 well water has the highest concentration during the year (the radon concentration increased approximately 6 times). It was observed on 01.03.2024 that three days after this event, on 04.03.2023 local time, an earthquake was recorded in Hajigabul, which repeated 5 times (ml=3.1-3.7). (Figure 3)

*Figure 3. Changes in the concentration of Rn gas in water before the Hajigabul earthquakes of 03.04.23*

An increase in the gas concentration was also observed in the “Surakhani” water 6 days before the seismic event, and the gas concentration was 0 the day before the event.

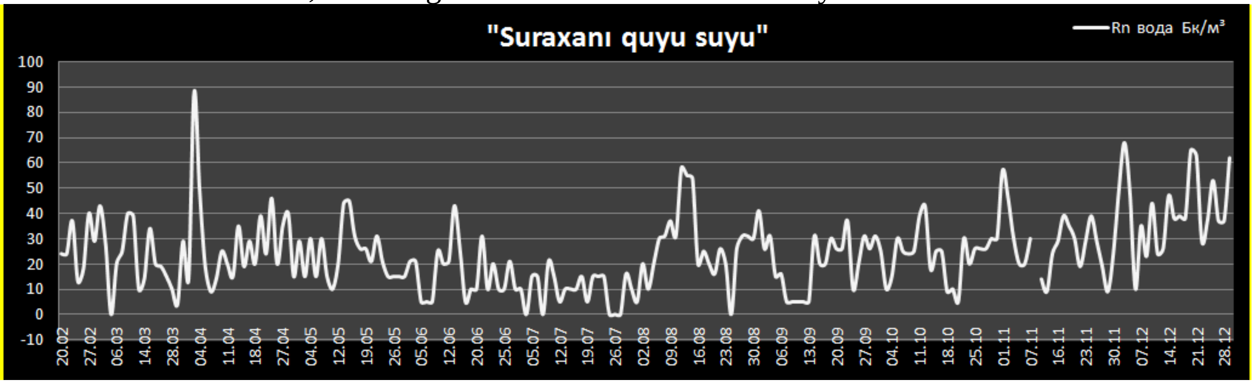

*Figure 4. Rn gas concentration in “Surakhani” well water*

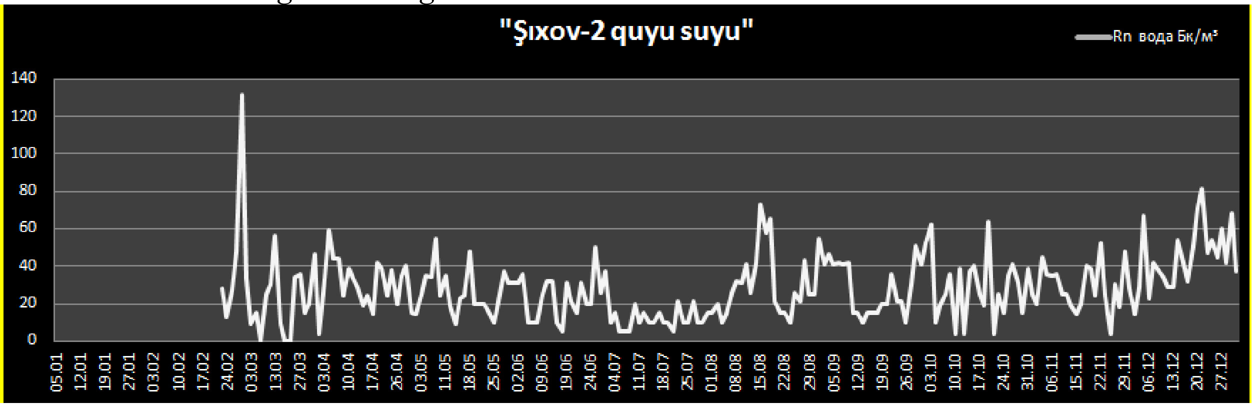

*Figure 5. Rn gas concentration in “Shikhov-2” well water*

A noticeable change in the Rn gas concentration began in early August and continued almost until the end of October. During this time, due to the high seismicity in the territory of the republic, it was not possible to say whether the change in gas concentration was related to a specific earthquake (Table 1, Figure 6).

*Figure 6. Changes observed in the concentration of Rn gas during the earthquakes that occurred between 08.08.23 and 22.10.23*

In general, since the number of earthquakes above ml=3.5 was high in March and April, more mobility was observed in the graph in these months. In May and June, since seismic events were at the background level, there was relative stability in the concentration of Rn. If we look at the variation, we can see that at the end of June, an increase in the concentration of Rn gas was observed again. As we know, on 03.07.2023, an earthquake with a magnitude of ml=5.6 occurred in the Middle Caspian, which was felt in a number of regions of Azerbaijan, including Baku. In general, with the exception of the earthquakes that occurred in the Middle Caspian on July 3 with a magnitude of ml=5.6 and in Lankaran on July 26, 2023 with a magnitude of ml=4.8, there was also relative calm in the hydrogeochemical fields, mainly due to seismic calm (Figure 4-5).

*Table 1.*

| ***Date*** | ***ml*** | ***h, km*** | ***Source location*** |
|---|---|---|---|
| 08.08 | 3.2 | 62 | South Caspian |
| 09.08 | 3.9 | 53 | Saatly district |
| 13.08 | 3.1 | 47 | Guba district |
| 22.08 | 4.9 | 35 | Masally district |
| 31.08 | 3.0 | 26 | Sheki district |
| 03.09 | 5.2 | 52 | Kurdemir district |
| 03.09 | 3.2 | 53 | Kurdemir district |
| 03.09 | 3.0 | 52 | Kurdemir district |
| 16.09 | 3.2 | 42 | Guba district |
| 16.09 | 4.6 | 62 | South Caspian |
| 19.09 | 3.8 | 62 | Middle Caspian |
| 19.09 | 3.5 | 52 | South Caspian |
| 12.10 | 3.2 | 9 | Lenkeran district |
| 15.10 | 3.6 | 19 | Lerik district |
| 16.10 | 3.1 | 3 | Gobustan district |
| 19.10 | 4.4 | 44 | Middle Caspian |
| 21.10 | 3.5 | 18 | Masally district |
| 22.10 | 3.3 | 62 | South Caspian |

If we look at the subsequent change in the concentration of Rn, mobility is observed in October and the first half of November, during which several earthquakes occurred in the Caspian and the Southern region.

Two days before the earthquake (ml=5.6) in the Caspian Sea on 07.12.2023, an increase in the concentration of Rn was observed in both waters (Fig. 7).

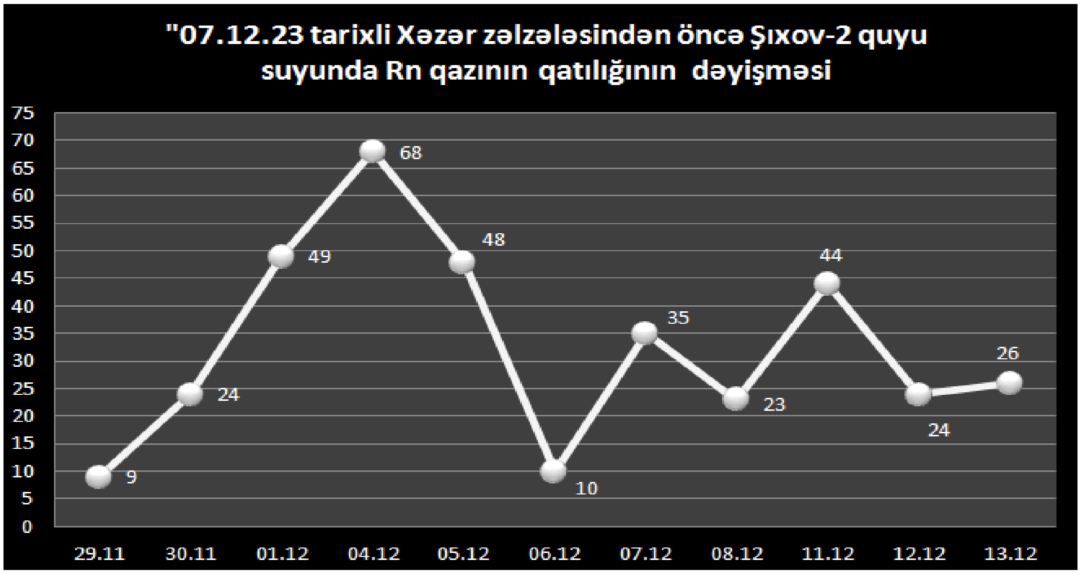

*Figure 7. Changes in the concentration of Rn gas in the water of the Shikhov-2 well before the Caspian earthquake of 07.12.23*

In general, several factors should be taken into account to determine the warning effect of radon emission before strong earthquakes in the region: the magnitude of the earthquake, the depth of the focus, and the distance between the object and the seismic focus.

## Conclusion

The conducted pilot studies allow to obtain results such as preparation of mobile stations for measuring radon concentration; development of a software-hardware complex for conducting analysis at a central point; creation of a database for monitoring radon emission based on a number of geodynamic factors; preparation of a digital map of radon distribution in selected areas; assessment of the seismic risk of selected areas.

Some regions of the territory of the Republic of Azerbaijan are famous for their world-famous mineral water sources due to the peculiarities of geological and geochemical conditions. Conducting seismohydrogeochemical monitoring can be important not only from a seismic point of view, but also from a human safety point of view. Because we know that groundwater (artesian, subartesian, self-flowing springs, etc.) is also used in everyday life.

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