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Preliminary assessment of radiation in territory of uranium industry, the Republic of Kazakhstan

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ABSTRACT
In this study, the existing radioecological state of the Mothballed uranium mine was assessed. The levels of radon concentration in the air of residential premises were determined and dose loads on the population were calculated using the example of Saumalkol village, Kazakhstan located in the zone of potential influence of a mothballed uranium mine. Radon concentrations were measured in living rooms and bedrooms on the ground floor. The contribution of indoor radon to the annual effective inhalation dose for the residents of the village ranged from 9.3 mSv to 145 mSv in winter and from 1.8 mSv to 18.7 mSv in the warm season. The estimated average annual dose for adults in Saumalkol was higher than the world average annual effective dose of 1.2 mSv due to indoor radon inhalation.

Keywords: Uranium, Radon, Mothballed uranium mines, Republic of Kazakhstan.
Article type: Research Article.

INTRODUCTION
The difficult radioecological situation in the Republic of Kazakhstan is mainly associated with radioactive waste from non-operating enterprises of the uranium mining and uranium processing industries (dumps of uranium mines, tailings, dismantled equipment of technological lines), as well as the activities of the former Semipalatinsk nuclear test site. These contaminated materials are poisonous, while they cause dangerous diseases such as rattan and chronic diseases, as well as contamination of plants and terrestrial and marine organisms (Talbi *et al*. 2021; Sweaf & Oudah 2024). Kazakhstan has six large uranium-bearing geological provinces, many small deposits and uranium occurrences, which cause an increased level of natural radioactivity (Hosseini *et al*. 2023). In these areas, there is a potential for increased release of natural radioactive gas, i.e., radon, which poses a danger to population health. Permanent stay in poorly ventilated premises and using groundwater with a higher content of natural radionuclides for drinking purposes can lead to a significant increase in the level of public exposure due to natural radiation (Violeta Hansen *et al*. 2023; Gert *et al*. 2023). According to the International Commission on Radiation Protection (ICRP), radon, whose average volumetric activity in living quarters in different countries of the world averages 40 Bq m^{-3}, causes 10% lung cancer cases annually registered in the world (Protection Against Radon, 1995). According to experts of the UN Scientific Committee on the Effects of Atomic Radiation, 20% of all lung cancers are caused by radon (Sources and effects of ionizing radiation, 2002). The results of several

epidemiological studies have confirmed the effect of increased radon concentrations in residential buildings on rising the risk of lung cancer in the population (Lantz *et al*. 2013; Coretchi *et al*. 2021). According to the WHO, an indoor radon elevation of 100 Bq m^{-3} grows the risk of lung cancer by 16% (Clement *et al*. 2010). In 1996, the World Health Organization (WHO) published a report containing recommendations for risk management from radon (Lantz *et al*. 2013). Further, in 2005, WHO formed a network of key partner agencies from 40 Member States to implement the International Radon Project, whose tasks are to assess radon hazard and its impact on public health, followed by the creation of a database and development of practical recommendations to reduce the negative impact of radon. Based on research results, WHO suggests that the public take action when radon levels exceed 2.7 pCi L^{-1}, the previously used standard of 4.0 pCi L^{-1} has become invalid. The United States of America has developed and published Standards and Protocols for measuring and mitigating human health exposure to radon. In 2010, a document was created in the United States: the National Strategy for Saving Lives (A Strategy for Saving Lives), which is based on four approaches: (i) testing and implementing measures to reduce radon levels with the help of professional services; (ii) providing financial incentives and direct support in situations where radon reduction measures are needed; (iii) introduction of construction practices using approaches aimed at preventing radon risks; and (iv) increasing awareness (information and educational component; WHO 2021).
To date, a significant amount of work has been carried out in the Republic of Kazakhstan to study the radiation situation, as well as to inventory the sources of radioactive contamination of territories. In relation to the study of radon hazard, notably, full-scale studies were carried out only in 1985 to 1990 by various organizations in the Akchatau village of Central Kazakhstan, close to which there is a tungsten - molybdenum deposit. In 44% of the surveyed premises, an excess of the normative value of radon (200 Bq m^{-3}) was found, the annual effective exposure dose for the population was up to 43 mSv/year, with a norm of 1 mSv/year. The morbidity of the respiratory organs, the nervous system, and the circulatory system in the population was 2.9 times higher than the average for the region, which probably indicates the impact of radon on the health of the population of the village. At the same time, the child population was not considered separately. It was decided to close the settlement and resettle people (Educational and methodological guide, 2002). Notably, such studies, unfortunately, are exceptional in Kazakhstan and detailed studies of radon are not carried out.
The purpose of this work is to study the radioecological situation in the uranium mining regions of Northern Kazakhstan and its impact on the environment.
To achieve this goal, it was planned to solve the following tasks:
- a preliminary examination of the area;
- identification of sources of radon;
- assessment of dose loads on the population on the example of Saumalkol village.

Characteristics of the objects of study

The object of the uranium industry, subject to priority inspection, was the Mothballed Mining Department No. 5 of the former Tselinny Mining and Chemical Combine, which is located 5 km from Saumalkol village in the Aiyrtau district of the North Kazakhstan region, where 9480 people live (Fig. 1). Before the liquidation of the mining departments, the extraction of uranium ore was carried out by underground mining. The mining department included endogenous uranium deposits Grachevskoye (complex, uranium phosphorus, 238U concentration - less than 0.3%), Kosachinskoye (monoelement, uranium ores, uranium content - 0.1 - 0.3%) and February, which belong to the North-Kazakhstan uranium ore province. In accordance with the program 008 "Mothballing of inactive uranium mining enterprises and liquidation of the consequences of the development of uranium deposits for 2001-2010", approved by the Decree of the Government of the Republic of Kazakhstan No. 1006 dated July 25, 2001, this facility was mothballed, the worked out quarries were covered wit.

MATERIALS AND METHODS

In 2022, in the autumn season (since November 17), on the territory of the Saumalkol settlement in Northern Kazakhstan and the mothballed mine, pedestrian measurements of the gamma background and radonometry were carried out in 11 premises of Saumalkol settlement. During the study, the air temperature outside varied from -12 °C to -14 °C, with a feeling of -19 °C. Notably, the climate of this region is mainly sharply continental. It belongs to the West Siberian climatic zone. Winter is cold and long (up to 6 months). Summer is moderately warm. The average temperature of the coldest month (January) is about -22 °C, the hottest month (July) is +21 °C. The average amount of rainfall is from 300 mm rainfall in the south of the region and up to 600-700 mm in the north of the region. The territory of Northern Kazakhstan extends from 49° N. up to 55° N. (http://ru.wikipedia.org/wiki/Климат_Казахстана). In November, in the private sector of Saumalkol village, the windows of houses are tightly closed, they are not ventilated, and solid fuel (coal and firewood) is mainly used for heating.

Fig. 1. Objects of study: mothballed mine administration and Saumalkol village.

Pedestrian measurements of the gamma background were carried out using dosimeters "DKS-96" and "RKS-01-SOLO". At each examination point, measurements were made of the ambient dose equivalent rate of gamma radiation [H^*(10)] on the soil surface and at a height of 1 m. The range of dose rate measurements is from 5 to 2×10^4 μR × h^{-1}. The limits of permissible basic relative error are ± 30%. Pedestrian gamma examination of the territory was carried out on a network of 500 × 500 m with detailing in areas of radioactive contamination (Guidelines 2003). At each of the identified sites, a detailed pedestrian gamma examination was also carried out using a 1 × 1 m network with a measurement of the gamma background. To reduce the error at each specific point, 5 measurements were carried out. Measurement of the equivalent equilibrium volumetric activity (EEVA) of radon inside residential and industrial premises was carried out using radon monitors "Ramon-02" and "Ramon-02A" which consisted in the selection of aerosols of the products of the decay of radon and thoron on aerosol filters, measuring the activity of α-emitters (RaA, RaC^1) and (ThC^1), where RaA is the decay product of radon ^{218}Po, RaC^1 is the decay product of radon ^{214}Po, ThC^1 is the decay product of thoron ^{212}Po. The capture of the dispersed phase of aerosols was carried out by filters of the AFA-RSP-20 type. Registration of impulses of alpha particles from the decay products contained on the filter was carried out using a semiconductor detector of alpha particles with an area of 20 cm^2. The device measures radon EEVA in the range from 4 to 5×10^5 Bq m^{-3}. It uses the alpha-spectrometric measurement method, and an absorbent tape is installed as a filter material, designed for at least 3000 measurements (Methodical guidelines, 2015). The average effective annual dose (in mSv/year) for pupils, teachers, kindergarten teachers and kindergarten children of the school examined was calculated using the following formula (ICRP 2018):

$$E=C \times F \times T \times D \quad (1)$$

where C is the average concentration of radon in school and kindergarten (in Bq m^{-3}), F is the equilibrium coefficient between radon and its decay products (assumed to be 0.4 according to UNSCEAR, 2006), T is indoor exposure (assumed to be 7000 h $year^{-1}$), and D is the dose conversion factor for radon decay products adopted by the ICRP 9×10^{-6} nSv per h Bq m^{-3} (Gert 2023). Statistical analysis was carried out using the StatTech v. 3.0.9 (StatTech 2020). Quantitative indicators were assessed for compliance with the normal distribution using the Shapiro-Wilk or the Kolmogorov-Smirnov tests. In the absence of a normal distribution, quantitative data were described using the median (Me) and the lower and upper quartiles (Q1 - Q3). The direction and closeness of the correlation between two quantitative indicators were assessed using the Spearman rank correlation coefficient (with the distribution of indicators other than normal).

RESULTS AND DISCUSSION

The average radiation background of the territory of Saumalkol village in terms of gamma radiation, excluding the areas of granite outcrops on the day surface, for the period of the survey was 11-16 μR h^{-1}. An increased value of gamma radiation from 40 to 50 μR h^{-1} was recorded in the northern part of Saumalkol in the area of a dairy plant and a forest area, where the territories are characterized by granites. There is a crushed stone quarry on Energetikov street in Saumalkol village and studies of the quarry showed that the EDR of gamma radiation varies from 31 to 91 μR h^{-1}, which on average exceeds the background values of the area up to 6 times (15 μR h^{-1}). Crushed stone from this quarry is used by local residents for backfilling household plots, cellars, roads close to the house, etc.

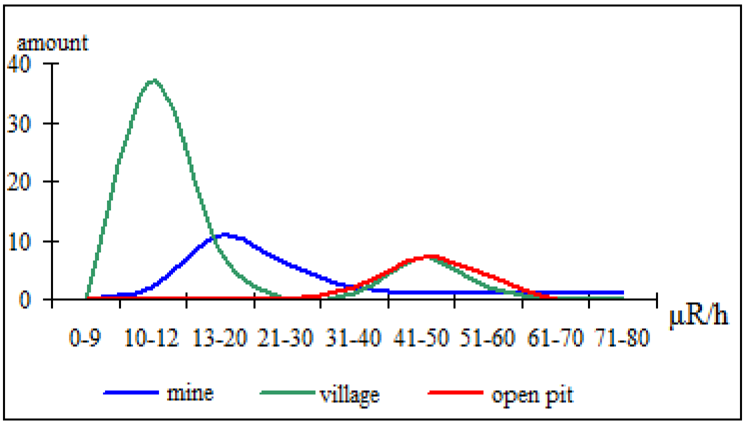

Fig. 2. Distribution of ADER values in the area of Saumalkol village.

It follows from Fig. 2 that the nature of the EDR distribution in the village is bimodal. The left mode corresponds to the background values of the region, and the right one coincides with the mode in the EDR distribution in the crushed stone quarry. The data presented indicate that local spots in the village are due to the employment of crushed stone from a quarry during economic work. The EDR distribution mode outside the sanitary protection zone of a mothballed mine is in the range of 13-20 μR h^{-1}. Within the territory of the mothballed mine, there are areas where the EDR varies from 15-56 μR h^{-1}. Pedestrian gamma survey of the mothballed mine area will continue. For a predictive assessment of the influence of the decay product of the uranium series, radonometry was carried out in the premises of Saumalkol beside the crushed stone quarry and the mothballed mine. Notably from October to March, due to the low temperature in the private sector of the premises, the windows are closed and not ventilated. In March, the air temperature on the street during the day is up to +30 °C, and at night it reaches -16 °C. As a result of the studies, increased values of EEVA of radon were established in premises where its concentration reaches up to 11657 Bq m^{-3} (at a rate of 200 Bq m^{-3}; Table 1).

Table 1. EEVA of radon in residential premises of Saumalkol village (Bq m^{-3})

№	Date and time of measurement	Address, street, house number	Geographical coordinates	ADER of gamma-radiation (μR h^{-1})	EEVA of radon, Bq m^{-3}
1	17.11.2022. 14:54	Energetikov, 1/1	N53°18’15” E68°4’35”	15	844
2	17.11.2022. 15:06	Energetikov, 3/2	N53°18’13” E68°4’34”	15	1294
3	17.11.2022. 15:06	Energetikov, 2/2 Cellar	N53°18’14” E68°4’35”	-	1827
4	17.11.2022. 15:21	Energetikov, 6	N53°18’14” E68°4’39”	18	1084
5	17.11.2022. 15:32	Cellar	-	-	456
6	17.11.2022. 15:44	Energetikov, 9/1	N53°18’10” E68°4’41”	42	11657
7	17.11.2022. 15:50	Energetikov, 9/1 Cellar	-	-	7144
8	17.11.2022. 15:55	Pumping station	-	-	13061
9	18.11.2022. 10:10	Energetikov, 10/2	-	61	9013
10	18.11.2022. 10:35	Ilina, 3/1	N53°18’8” E68°5’15”	25	2044
11	18.11.2022. 10:47	Ilina ,11/2	N53°18’5” E68°5’11”	22	1930
12	18.11.2022. 11:09	Lyudinovo, 8	N53°17’51” E68°5’28”	22	1930
13	18.11.2022. 11:28	Abylaikhan, 29	N53°17’35” E68°5’33”	29	746

A high radon content (13061 Bq m^{-3}) was also detected at the pumping station, where the local population takes drinking water. Apparently, a high concentration of radon comes through drinking water. During the survey of the settlement, it was found that residential buildings with a high concentration of radon are concentrated adjacent to the crushed stone quarry, and within this local zone, the values of EEVA of radon in the air of nearby houses may differ. The building materials of the studied premises were the same (cinder blocks, red and clay bricks); the heating systems and basic structures were also identical. Previously, it was found that in the warm season (April-September) in residential premises, where houses are periodically ventilated, the value of radon EEVA varied from 173 to 1717 Bq m^{-3} (Nygymanova *et al*. 2021). In the premises, we detected a high content of radon in the air and the value of the EDR of gamma radiation from 15 to 61 μR h^{-1}, with a background value of 15 μR h^{-1}, which may be due to the high concentration of gamma-emitting decay products of radon in the air. A predictive model characterizing the dependence of a quantitative variable on factors was developed using the linear regression method (Table 2).

Table 2. Descriptive statistics of quantitative variables.

Indicators	Me	$Q_1 – Q_3$	n	min	max
ADER of gamma-radiation	22	18 – 29	9	15	61
EEVA of radon	1930	1084 – 2044	9	746	11657

We have performed a correlation analysis of the relationship between the indicator "ADER of gamma radiation" and the indicator "EEVA of radon" (Table 3).

Table 3. Results of correlation analysis of the relationship between the indicator "ADER of gamma radiation" and the indicator "EEVA of radon".

Indicator	Correlation characteristic		
	ρ	Bond strength on the Chaddock scale	p
ADER of gamma-radiation – EEVA of radon	0.599	Noticeable	0.088

When evaluating the relationship between the indicator "EEVA of radon" and the indicator "ADER of gamma radiation", a direct relationship of noticeable strength was established. The observed dependence of the indicator "EEVA of radon" on the indicator "ADER of gamma radiation" is described by the equation of paired linear regression:

$Y_{\text{EEVA of radon}} = 223.74 \times X_{\text{ADER of gamma radiation}} - 2796.595$

Once an increase in the indicator "ADER of gamma radiation" by 1, an elevation in the indicator "EEVA of radon" by 223.74 should be expected. The resulting model explains 69.9% of the observed dispersion of the radon EEVA index.

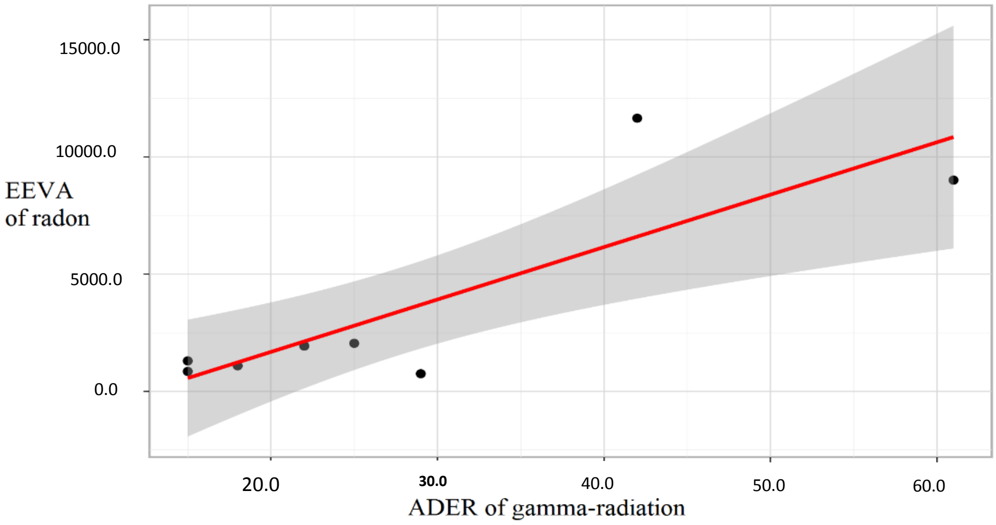

Fig. 3. Graph of the regression function characterizing the dependence of the indicator "EEVA of radon" on the indicator "ADER of gamma radiation".

Previously, comprehensive studies were carried out to assess the radon hazard in residential areas of the settlements of Aksu, Zavodskoy and Kvartsytka, the Republic of Kazakhstan, located beside the storage of radioactive waste in Northern Kazakhstan. The operating repository of radioactive waste is located 3.75 km west of the Stepnogorsk Hydrometallurgical Plant, 3.2-4.7 km north of the villages of Aksu, Zavodskoy and Kvartsytka in the Akmola region, where over 6000 people live. It has been established that in the settlement of Kvartsitka the EEVA of radon fluctuates within 20-500 Bq m^{-3}, Aksu settlement 3-860 Bq m^{-3}, Zavodskoy settlement 30-310 Bq m^{-3}, Akkol town 3-23 Bq m^{-3}, at norm 200 Bq m^{-3}. Measurement of radon EEVA in residential premises of Kvartsytka, Zavodskoy and Aksu villages showed high radon values, up to four times the maximum permitted level. The reason for the abnormally high radon hazard is that earlier there was a gold mine on the territory of the Aksu settlement or it was close to it, and it is possible that during the construction of this building the regulatory data differed from the current ones. Basically, classes (about 60%) with an excess of radon are located on the first floor, which also does not exclude the influence of possible remnants of ore bodies in the earth under the school (Ibrayeva *et al*. 2020). When calculating the total annual effective radiation dose, the ICRP recommends that 80% of the time the population spends in buildings (ICRP 2018). The calculations showed that for residents of Saumalkol village, living beside a crushed stone quarry, the probable effective dose of exposure to residents of this area due to radon isotopes in winter varies from 9.3 mSv to 145 mSv, and in the warm season - 1.8 mSv to 18.7 mSv, with a permitted annual effective dose from radon products of 1.2 mSv/year. The reason may be the presence of areas with an intense flow of radon or the use of prohibited building materials (rubble). For a detailed study, it is necessary to measure the concentration of radon using integral dosimeters throughout the year. Noteworthy in Kazakhstan, the territorial sanitary and epidemiological services, when contacted, carry out radon measurements when choosing land plots for the construction of multi-storey buildings, determine the activity of natural radionuclides in building materials and notify the relevant services. To ensure the radon safety of the population, the regulatory body takes measures mainly in two situations:

1) when radon measurements are taken when selecting specific sites for the construction of new buildings (not carried out in all regions of the country), if they exceed the norm, then construction will be refused;
2) when measuring certain types of building materials, if their concentration of radionuclides many times exceeds the permissible ones, then a ban is imposed on them for use.
Unfortunately, the population does not know about the concentration of radon in the room where they live or work; what is the radiation background of the site where they are going to build a house or buy it; and they do not know about the background when growing agricultural products and grazing animals. The results of radon background measurements are not entered into the technical real estate cadaster. All transactions with real estate are made without taking into account the radon background, and moreover, no one is interested in the radon background.
At the same time, cost-effective methods to reduce the radon content in buildings that are in use and measures to prevent the entry of radon into buildings under construction have already been tried and tested worldwide (Khan *et al*. 2019; WHO, 2009). These activities include:
1) Establishing a national control level for indoor radon concentration (WHO 2009, 2021).
2) Establishing a national reference level for radon concentration in drinking water (WHO 2009).
3) Homeowners are advised to take action when radon concentration levels in dwellings exceed the national reference value. It is recommended to carry out ventilation, concrete the floor and basements.
4) Introduction to the sanitary and construction norms of the requirement that a protocol for its implementation should be attached to the certificate of putting the building into operation Radiation protection before the house is put into operation.
5) Constant monitoring of the radon content in the room air of the operated buildings and residential buildings as well as the water, since building codes and regulations alone cannot guarantee that the radon concentration will be below control levels.

CONCLUSION

Thus, in practice, it turns out that there are regulatory documents that provide for the need to control and monitor the radon background, measures to protect citizens when the radon concentration is exceeded, provide for the legal responsibility of the competent bodies for failure to take appropriate measures. However, in fact the implementation of this strategy is not there. The data obtained indicate the need for urgent work to reduce the impact of radon on population health. So, all available materials on radon phenomena should be collected, taking into account the geological, structural and tectonic features of the territory. In addition, detailed investigations into radon exhalation from soil, indoor radon concentration and water sources are required. Measures to reduce the risk to the population should include both technical solutions and extreme measures, i.e., the relocation of residents from areas prone to radon. The basis for decisions about the need for remedial measures to reduce the consequences of radioactive contamination of the environment are the results of extensive radio-ecological investigations. These investigations should include the determination of the radon concentration in indoor air, drinking water, the content of radionuclides in building materials, the assessment of the dose load and the level of radiation exposure of different population groups. To assess the possible impact of the mothballed mine on the radiation situation in the area of the Saumalkol village, research will be continued. We propose to carry out additional measurements, covering all residential buildings from the side of the uranium mine in Saumalkol village. Measurements will be carried out with CR39 passive detectors during the heating season from October to April in administrative buildings, i.e., workplaces, kindergartens, schools, and public buildings, as well as in residential buildings, especially on the ground floors and in those rooms where residents spend more time in the living room and bedroom. We recommend further research into the radon content, taking into account the geology of the foundation of the house and other indicators, such as the year of construction, type of house, number of floors, floor area, the ceiling height on each floor, type of basement, type of heater used, type of ventilation and its mode of operation, features of opening windows, and tightness of the room. building envelopes, building materials, air replacement time (natural ventilation), etc.

Author contribution

Conceptualization: Meirat Bakhtin and Polat Kazymbet; formal analysis: Yerlan Kashkinbayev, AG, Ainur Pirmnova and Nursulu Altaeva; attraction of financing: Polat Kazymbet; Methodology: Masaharu Hoshi, Meirat

Bakhtin, Ainur Pirmnova, Nursulu Altaeva and Moldir Aumalikova; project administration: NJSC "Astana Medical University"; writing - the original version of Yerlan Kashkinbaev, Meirat Bakhtin, Ainur Pirmanova and Nursulu Altaeva; writing, review and editing: Meirat Bakhtin and Moldir Aumalikova. All authors have read and agreed with the published version of the manuscript.

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Statement of the institutional review board

Not required.

Statement of informed consent

Not required.

Data accessibility statement

The data analyzed in the course of the current study is available from the head of the scientific project Kazymbet P.K. and may be made available upon reasonable request.

Conflict of interest

The authors declare no conflict of interest.

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