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Indoor Radon Survey in Aksu School and Kindergarten Located near Radioactive Waste Storage Facilities and Gold Mines in Northern Kazakhstan (Akmola Region)

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Abstract: Northern Kazakhstan is considered a field of uranium, gold mining, copper–molybdenum ore, and other metals. The aims of the current work were to monitor the indoor radon levels in a school and a kindergarten and to determine the levels of teacher and student exposure to radon. High radon concentrations were detected in the school on the first floor at ca. 9600 Bq/m^3, on the second floor at ca. 6800 Bq/m^3, on the third floor at ca. 4900 Bq/m^3, and in the kindergarten, the concentration was ca. 9500 Bq/m^3. The annual effective dose of the students and teachers of the school and kindergarten varied from 4 mSv/y to 9 mSv/y, which is an order of magnitude higher than the upper annual dose limit. The excess lifetime cancer risk was 14–20% for students, 31.1% for school and kindergarten staff, and 34.9% for kindergarten children. The indoor radon concentrations varied with weather conditions, and it was evident that ventilation had a significant effect on the reduction in the concentration. At these premises, positive correlations between the radon concentrations, outside temperature, and relative humidity were obtained, showing that the concentration of radon is influenced by meteorological parameters. This study will help to identify buildings where continuous monitoring is needed in order to reduce indoor radon levels.

Keywords: radon concentration; school; weather conditions; students; ELCR

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Citation: Kashkinbayev, Y.; Kazymbet, P.; Bakhtin, M.; Khazipova, A.; Hoshi, M.; Sakaguchi, A.; Ibrayeva, D. Indoor Radon Survey in Aksu School and Kindergarten Located near Radioactive Waste Storage Facilities and Gold Mines in Northern Kazakhstan (Akmola Region). *Atmosphere* **2023**, *14*, 1133. https://doi.org/10.3390/atmos14071133

Academic Editor: Antoaneta Ene

Received: 3 May 2023
Revised: 20 June 2023
Accepted: 26 June 2023
Published: 10 July 2023

1. Introduction

Uranium is a naturally occurring radioelement, providing a continuous source of radon. Indoor radon and its decay products are the primary sources of population exposure [1–3]. Worldwide, indoor radon concentrations are higher in the winter season than in the summer season [4,5]. Radon travels through soil and enters buildings through cracks and openings in the foundation. This can occur in buildings or homes of any age and structural type (e.g., with or without basements). Eventually, radon decays into radioactive particles (decay products) that can be trapped in the lungs. As these particles decay, they become sources of further radiation. This radiation can damage lung tissue and lead to lung cancer over the course of a lifetime [6,7].

Indoor radon concentrations in different countries and even individual buildings can vary depending on the climate, building technology, available ventilation methods, living habits, and, most importantly, geological conditions. Outdoor radon concentrations do not pose a risk to human health, as they drop rapidly to very low levels when exposed to the air. During winter, the lower pressure and higher temperature inside than outside a building can cause radon to escape from the soil and enter a building through any openings in the foundation where it is in contact with the ground. Studies conducted in many countries have shown that the maximum concentration of radon is recorded in the heating season, and the minimum concentration of radon is recorded in the summer season [4,5]. The accumulation of radon is aggravated by insulation works, tightly closed windows, and poor ventilation systems. Indoors, radon does not dissipate as quickly as outside, and when it accumulates in enclosed spaces, it can pose a serious health risk to people [8–12].

According to the World Health Organization (WHO), radon is the main risk factor for developing lung cancer after smoking, and prolonged exposure to high concentrations of radon in buildings that may be visited frequently, such as homes, schools, hospitals, and workplaces, increases this risk [13]. Lung cancer occupies one of the leading places in the structure of oncological morbidity and mortality among men and women worldwide. According to the WHO, lung cancer is the leading cause of cancer death in men and the second cause of death after breast cancer in women [14]. In epidemiological studies, the effect of radon in residential buildings on the increased risk of developing lung cancer in the population has been confirmed [3,15–17]. Exposure of the population to radon in residential premises in some cases may exceed the annual value of the effective dose above the dose limit for persons professionally working with ionizing radiation [18]. According to publications by the International Atomic Energy Agency (IAEA) (2012) and the European Commission (2013), radon exposure must constantly be monitored and controlled by experts for the population in residential premises [19].

The monitoring and control of radon concentrations in residential premises, childcare facilities, and workplaces are very important problems worldwide. The International Commission on Radiological Protection (ICRP) publication recommends in terms of action to pay attention to all buildings with public access, especially buildings that may be visited frequently and/or for long periods, such as schools, kindergartens, and hospitals [10]. Children are at an increased risk due to their reduced body resistance to radiation, and children spend more time indoors [20,21]. As a result of child exposure to radon, the risk of developing lung cancer can be up to three times higher than in adults exposed to the same amount of radon concentration. This is explained as being due to morphometric differences between the lungs of children and those of adults, the higher average respiratory rate in children compared to adults [22].

Most epidemiological studies on the effects of radon on human health have focused on radon exposure at work sites and in indoor living environments, and too few studies have been conducted to compare the effects of radon independently. A compelling body of research across different areas of study shows that early childhood is a particularly sensitive time in which anthropogenic activity or environmental issues can have important long-term consequences for adult chronic disease risk [23–25]. The impact of long-term radiation exposure at an early age is not fully understood. According to the results of the epidemiological study by Ilbekova et al., 2020, there is increasing somatic morbidity (cardiovascular system) among the population that has lived in settlements of the Stepnogorsk area since childhood [26]. The Stepnogorsk area in Northern Kazakhstan has a long history of mining activities. Mining activities have many environmental and health impacts in this area [27].

Northern Kazakhstan is considered interesting in the field of geology because it consists of a variety of rocks and minerals. The present study is based on the pilot study of Ibrayeva et al., 2020, in which it was shown that the Stepnogorsk area of Northern Kazakhstan represents a source of potential contamination of the living environment, i.e., gamma radiation, radon exposure, and the NORM concentration in soil sources. The outdoor gamma dose rates (0.13–2.87 μSv/h) were found to be higher than the indoor gamma dose rates (0.15–0.3 μSv/h) in schools, and the indoor radon concentrations of houses were 313–858 Bq/m^3, while the outdoor radon concentrations were 23–39 Bq/m^3 [28]. The values of the outdoor gamma dose rates and the indoor and outdoor radon concentrations are considerably higher than the average worldwide range of corresponding values [8].

The aims of the current work were to monitor the indoor radon levels in a school and in a kindergarten and to determine the levels of teacher and student exposure to radon.

2. Materials and Methods

2.1. Description of the Study Area

The outskirts of the Stepnogorsk area are rich in minerals. The mining of gold and copper–molybdenum ore and other metals in the Stepnogorsk area dates back to the 1930s. In several regions of the country, there are different levels of radon in the indoor air [29,30]. A study of the radiological impact of radon on the populations in the following areas showed increased radon levels in residential buildings and drinking water from underground sources: the Aiyrtau district of the North Kazakhstan region; the Shchuchinsky and Zerenda districts of the Akmola region; the villages Arykbalyk, Saumalkol (formerly Volodarskoe), Novoukrainka, Aiyrtau, Simferopolskoe, Kvartsytka, and Aksu; and Kokshetau and Makinka [31]. In the basement of one of the surveyed houses in Aiyrtau, covered with crushed granite, the radon level was about 12,000 Bq/m^3, exceeding the permissive level. At least 700–1000 people live in the Kokshetau region of Northern Kazakhstan, which has a radon concentration of 1000 Bq/m^3 to 10,000 Bq/m^3 [32].

The school we observed in this study is located in the settlement of Aksu, the Akmola region, in the northern part of the Republic of Kazakhstan (52.4627° N and 71.9808° E) (Figure 1). At a distance of 4 km from Aksu, there is a uranium tailings dump of radioactive waste from the Stepnogorsk Mining and Chemical Combine (Figure 1B), where liquid radioactive waste from the Hydrometallurgical Plant accumulates [28,33]. In the vicinity of the school, there are mothballed, abandoned gold mines.

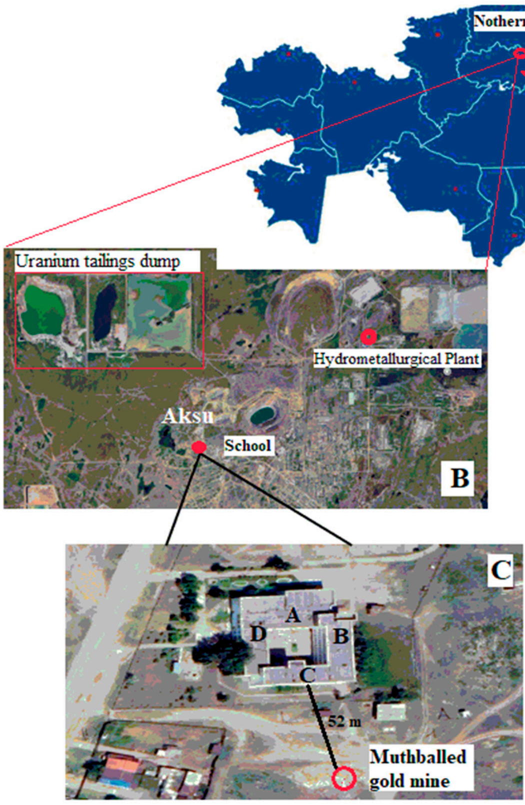

Figure 1. (**A**)—Kazakhstan map and Northern Kazakhstan location; (**B**)—scheme of Aksu school location near the uranium tailings dump of the Hydrometallurgical Plant; (**C**)—Aksu school location near the mothballed mine.

The Aksu school was built in 1987; it consists of four combined blocks (A, B, C, and D), where blocks A and D consist of two floors, blocks B and C consist of three floors, and there is a basement adjacent to the corridor of the first floor (Figure 1). Only a natural supply and exhaust ventilation system is used, as well as periodic short-term openings of the windows in warm weather, especially in the morning.

On the first floor in block A, there is a dining room, a gym, and a dressing room; in block B, there is the director's office, classrooms 1 and 2, bedrooms 1 and 2, and kindergarten playroom 1; in block C, there is playroom 2 and a music room; and in block D, there is a workshop for labor lessons.

2.2. Method of Measurement

2.2.1. Short-Term Radon Measurements Inside of Premises

^{222}Rn measurements were carried out in winter (December) 2021, spring (May), and autumn (October and November) 2022 in 10 classrooms, the library, the gym, three teachers' offices, and on the premises of the kindergarten (bedroom and playing room). The total number of measurements was 13,112.

The indoor and outdoor radon investigations were carried out in Aksu school using a RAMON-02A radon radiometer (SOLO LLP, Republic of Kazakhstan, Almaty) with a semiconductor alpha detector. The device measures radon concentrations in the range from 4 Bq/m^3 to 5×10^5 Bq/m^3. It uses the alpha-spectrometric method (semiconductor detector) of measurement, and an absorbent tape designed for at least three thousand measurements is installed as a filter material [34]. All measurements were conducted according to standard ASTM D6327-10 [35]. For indoor readings, all measurements were made at 1 m above the ground in the middle of the room. The outdoor readings were taken at 1 m above the ground at about 10 m to 15 m away from the buildings. At each location, >10 measurements were taken, and then the data were averaged. A full measurement cycle took 4 min [35].

2.2.2. Indoor Radon Measurements

Radon monitoring measurements were carried out using a RadonScout Professional radiometer manufactured in Germany (SARAD GmbH, Dresden, Germany).

In comparison with other passive radon radiometers, RadonScout Professional radiometers are highly sensitive, so any changes in the radon content are accurately recorded, even at low-temperature radon concentrations. RadonScout Professional radiometers operate in diffusion mode, which eliminates the influence of thoron on the measurement results. The measuring chamber, with a semiconductor detector and high-voltage electrodes, is immune to fluctuations in air humidity. The integration time for 1 unit of data was 240 min.

If the radon concentration results are in the reference level range of 200 Bq/m^3 or below, a 60 min interval should be used (e.g., when measuring outdoors). The measurement results were copied into MS Excel (Microsoft Office Excel 2013, MSO (15.0.5563.1000) 64-bit) using the special professional software "Radon Vision 7.0" [36]. The measurements were carried out in 2021 in the autumn–winter time in classrooms where high levels of radon were found: room 2 on the first floor, room 24 on the second floor, and room 36 on the third floor. Based on the data from earlier studies conducted by D. Ibrayeva and co-authors, we established measurement points [28]. To measure the average annual radon concentration, we installed the Radon Scout Professional radiometer on the ground floor in room 2 from May 2022 to February 2023. During the warm period (May–September), the air temperature varies during the day from +3 °C to +35 °C degrees and at night from −1 °C to + 30 °C. During the cold period (October–February), the daytime air temperature varies from +17 °C to −35 °C and at night from 0 to 35 °C. The height of the school building is 11 m, and the measurement was carried out at the height of 1 m from the roof of the school.

2.2.3. Gamma Dose Rate Measurements

The outdoor gamma dose rate was measured in terms of the ambient equivalent dose rates ($\dot{H}(10)$). The measurements were performed at a height of 1 m above ground: the indoor-outdoor measurements were conducted in the morning and the evening of the same day, and the indoor measurements were conducted during the day. Four measurements were made at one measuring point, and the average value was calculated. For all locations, elevations, and materials of the building construction were noted.

The measurement was performed with the dosimeter–radiometer DKS-96. The exposure dose rate measurement range is from 0.05 μSv/h to 2×10^2 μSv/h. The limit of the permissible basic relative error is ±20%. A pedestrian gamma survey of the territory was carried out on a network of 500m × 500 m, with detailing in areas of radioactive contamination. All measurements were carried out according to the IAEA (2003) Guidelines [37].

2.3. Calculation of Annual Effective Dose and Cancer Risk

2.3.1. Calculation of Annual Effective Dose

Calculations of the average annual effective dose (in mSv y^{-1}) for students, teachers, kindergarten teachers, and kindergarten children were carried out according to the following formula [38]:

$$E = C \times F \times T \times D \tag{1}$$

where C is the average radon concentration in the school and kindergarten (in Bq/m^3), F is the equilibrium coefficient between radon and its decay products (taken to be equal to 0.4) [39], T is the time spent, and D is the dose conversion factor for radon decay products adopted by ICRP 9×10^{-6} nSv/h/Bq m^3 [40].

2.3.2. Calculation of Time Spent on the Premises of the School and Kindergarten

According to clause 36 of the State Compulsory Standard secondary education (primary, basic secondary, and general secondary education) of the Republic of Kazakhstan, "The maximum volume of the weekly teaching load of students, including all types of classroom and extracurricular (optional, individual and circle classes) educational work, should not exceed 24 h for grade 1 (6–7 years old), in grade 2 (7–8 years old)—25 h, in grades 3 and 4 (9–10 years old)—29 h, in grade 5 (10–11 years old)—32 h, in grade 6 (11–12 years old)—33 h, in grade 7 (12–13 years old)—34 h, in grade 8 (13–14 years old)—36 h, in grade 9 (15–16 years old)—38 h, in 10th and 11th grade (17–18 years old)—39 h":

- Teachers—8 h a day (working time);
- Kindergarten teachers and children—9 h a day (working time).

According to the calendar of holidays and weekends of the Republic of Kazakhstan, students are at school for 173 days and rest for 192, and school teachers, kindergarten teachers, and kindergarten children are at school for 245 days.

The average values of annual stay on the premises of the school and kindergarten are as follows:

- Primary school students (grades 1–4)—1040 h;
- Students from grades 5 to 8—1350 h;
- Students from grades 9 to 11—1546 h.

2.4. Calculation of the Excess Lifetime Cancer Risk

The excess lifetime cancer risk (ELCR) was estimated using the following Equation (2):

$$ELCR = E \times DL \times RF \tag{2}$$

where E is the average annual effective dose; DL is the average life expectancy, estimated at 70 years; and RF is the fatal risk factor per Sievert (5.5×10^{-2} Sv^{-1}) [11].

2.5. Statistical Analysis

Statistical analysis was carried out using StatTech v. 3.0.9 (developer—Stattech LLC, Kazan, Russia).

Quantitative indicators were assessed for compliance with the normal distribution using the Shapiro–Wilk test (with the number of subjects being less than 50) or the Kolmogorov–Smirnov criterion (with the number of subjects being more than 50).

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.

A predictive model characterizing the dependence of a quantitative variable on factors was developed using the linear regression method [41].

3. Results

3.1. Radiation Situation in the Territory and on Premises of the School in Aksu

3.1.1. Results of Short-Term Measurements of Radon Concentration

Indoor radon concentration values can vary on a daily basis, depending on several factors, namely, thermo-hygrometric conditions, the time of the season, soil types, the strength of the radon source in the underlying bedrock, and pressure changes created by the building; the level of ventilation and occupancy itself also contribute significantly. Since indoor radon concentrations vary with diurnal and seasonal variations, we considered these when performing the short-term radon measurements. Figure 2 shows the indoor and outdoor radon concentrations on the three floors of Aksu School. The measurement was carried out six times a day every 240 min, but in Figure 2, the radon value is averaged per day. Figure 2 shows the results of the first set of monitoring measurements to identify points for further radon measurements. The measurements were taken before the ventilation system was cleaned.

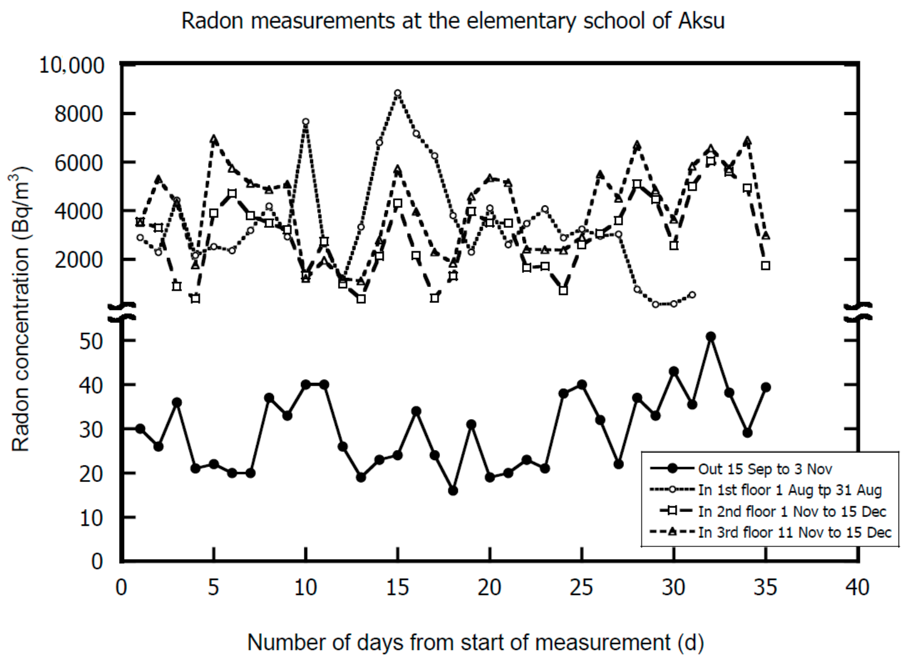

Figure 2. The indoor and outdoor radon concentrations on the three floors of Aksu school at different periods.

As can be seen in Figure 2, the maximum radon concentrations in the kindergarten were 9520 Bq/m^3, 9634 Bq/m^3 in the classrooms on the first floor, 6800 Bq/m^3 on the second floor, and 4853 Bq/m^3 on the third floor, exceeding the permissive level 200 Bq/m^3.

In the autumn period, the outdoor radon concentration on the roof of Aksu school was 43 Bq/m^3.

After cleaning the ventilation shaft of the school, the radon concentrations decreased, but during the cold period, they still exceeded the permissive level.

In the warm period of May and September, the radon concentration varied from 3 Bq/m^3 to 112 Bq/m^3 and did not exceed the permissive value, as the school administration conducted frequent natural ventilation of the school premises.

In November 2022, short-term measurements of the radon concentration were carried out before and after the natural ventilation (the opening of windows) of the school classrooms. The radon concentration on the first floor ranged from 367 Bq/m^3 to 802 Bq/m^3, on the second floor from 253 Bq/m^3 to 367 Bq/m^3, on the third floor from 300 Bq/m^3 up to 708 Bq/m^3, and in the gym from 545 to 791 Bq/m^3; measurements were not carried out in the mini-garden due to repair work on the installation of a ventilation controlling system (Table 1).

Table 1. Comparative analysis of average radon concentrations in the classrooms of Aksu School before and after natural ventilation.

No.	Place of Measurement	The Number of Measurements	Measurement Period	Radon Concentration before Airing, Bq/m^3	Radon Concentration after Airing, Bq/m^3
1	First floor	5	November 2022	550 ± 200	191 ± 58
3	Gym	5		640 ± 92	119 ± 80
4	Second floor	5		308 ± 44	175 ± 47
5	Third floor	5		470 ± 110	188 ± 45

As can be seen in Table 1, the decrease in the radon concentration in the school classrooms reached up to three times, and in the gym, because the windows and doors were open, the decrease in the radon concentration reached up to six times. The airing of the classrooms was carried out during a break of 30 min.

3.1.2. Effect of Meteorological Conditions on Radon Concentrations

From December 2021 to December 2022, RadonScout Professional radon radiometers were installed on the first, second, and third floors of the school.

According to the results of the statistical analysis shown in Section 2.5 (Table 2), it was found that the radon concentration varied from 0 to 15,606 Bq/m^3, the temperature in the room varied from 3 °C to 30 °C, and the relative humidity of the air varied from 10% to 77%.

Table 2. Descriptive statistics of quantitative variables.

Indicators	n	Me	Q_1–Q_3
Radon concentration (Bq/m^3)	1692	185	69–1109
Air temperature at the premises (°C)	1692	20	16–22
The relative humidity of the air (%)	1692	34	20–45

The total number of measurements of the volumetric activity of radon, temperature, and relative humidity of the indoor air in the cold and warm periods was 1692 measurements, of which 839 were conducted in the warm period, and 853 were conducted in the cold period.

The radon concentration, air temperature, and relative humidity of the indoor air, depending on weather conditions, were analyzed using the statistics program Stattech (Figures 3–5).

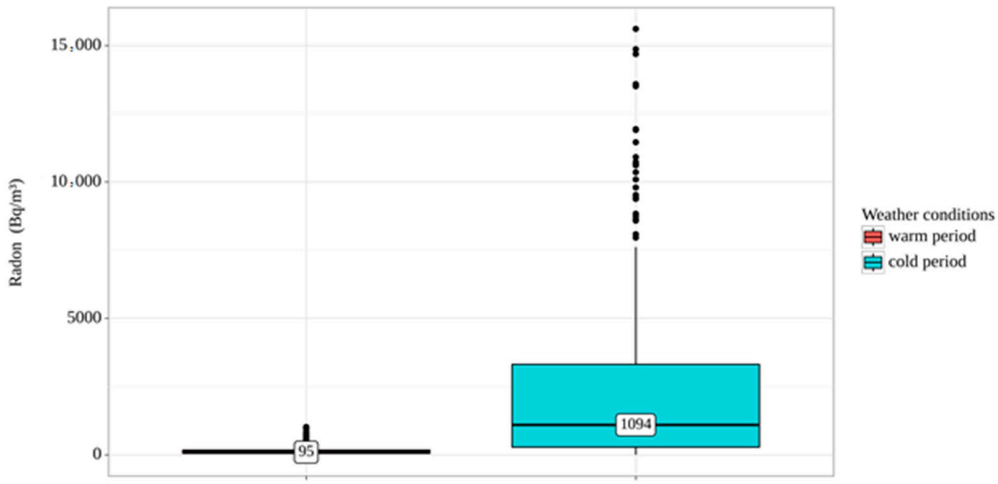

Figure 3. Comparative analysis of radon concentration depending on weather conditions.

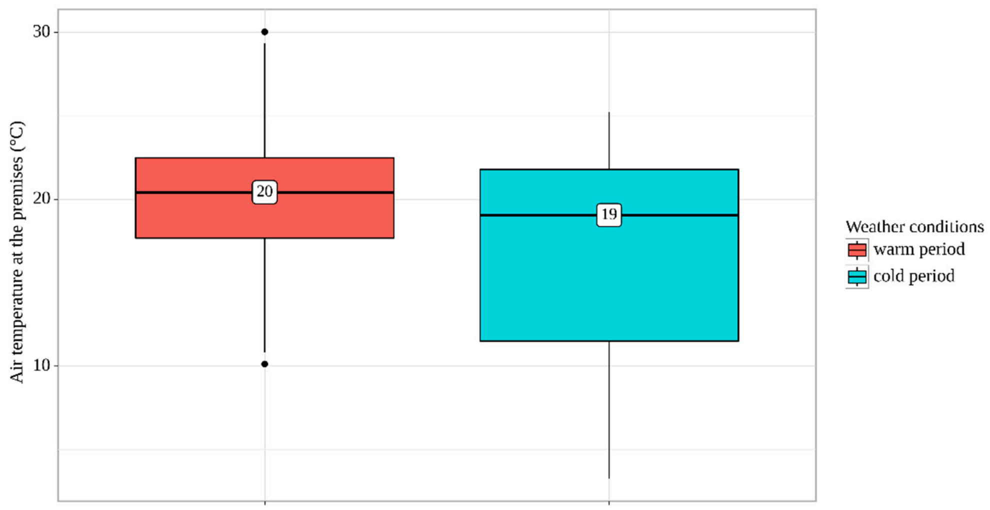

Figure 4. Comparative analysis of the air temperature at the premises depending on weather conditions.

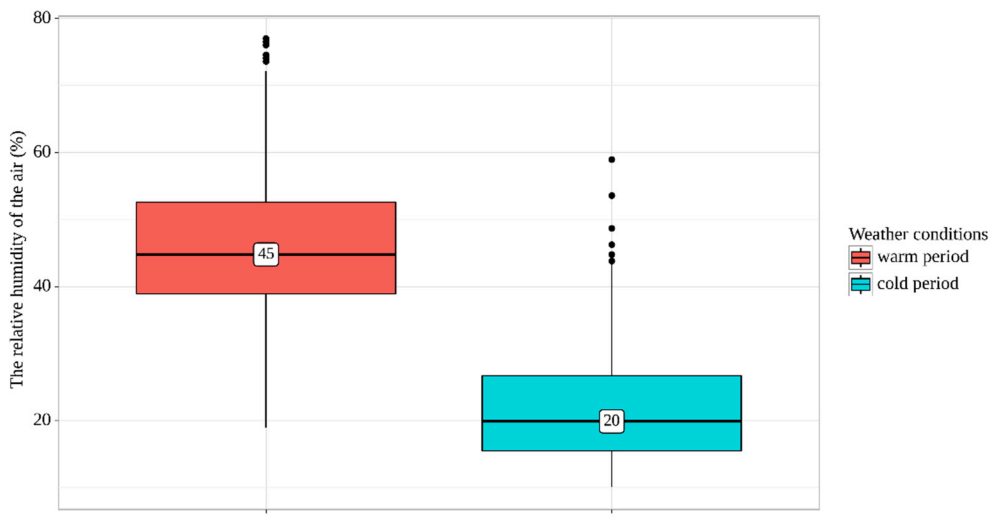

Figure 5. Comparative analysis of relative air humidity depending on weather conditions.

During the warm period, the volumetric activity of radon varied from 1 to 1017 Bq/m^3, the room temperature varied from 3.3 °C to 25.2 °C, and the relative humidity varied from 10.1% to 58.9%.

During the cold period, the volumetric activity of radon varied from 5.5 Bq/m^3 to 15,606 Bq/m^3, the room temperature varied from 10.1 °C to 30 °C, and the relative humidity varied from 18.9% to 77.0%. During the cold period, on the recommendations of the local regulatory authority (Department of Sanitary Epidemiological Control), the school administration carried out natural ventilation during the break to reduce the volumetric activity of radon. In this regard, during the cold period, the device recorded low radon, temperature, and relative humidity levels in the rooms, which led to a large scatter of the obtained data.

According to the presented table, when comparing the radon concentrations, the indoor air temperature, and the relative air humidity, depending on weather conditions, significant differences were found ($p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively) (methods used: the Mann–Whitney U-test).

In connection with the monitoring measurements of the radon concentration throughout the year, a comparative analysis of the radon concentration was performed depending on weekends and holidays (Figures 6–8).

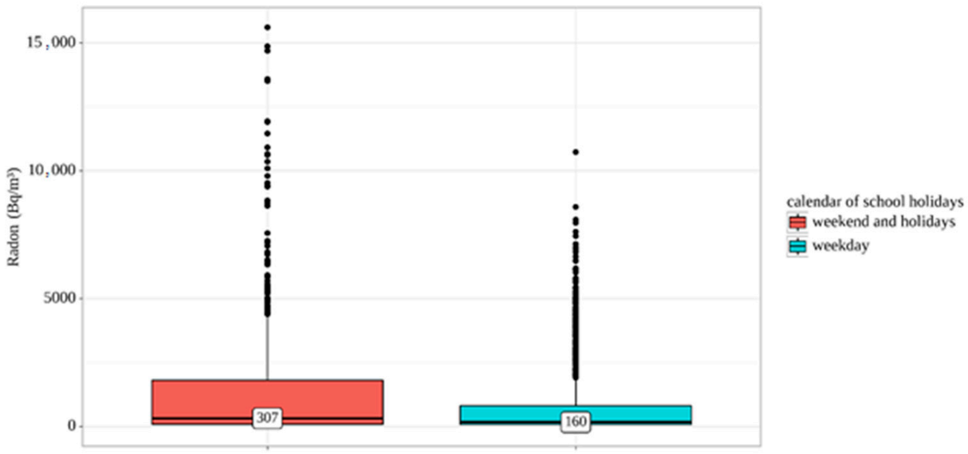

Figure 6. Comparative analysis of radon concentration depending on weekends and holidays.

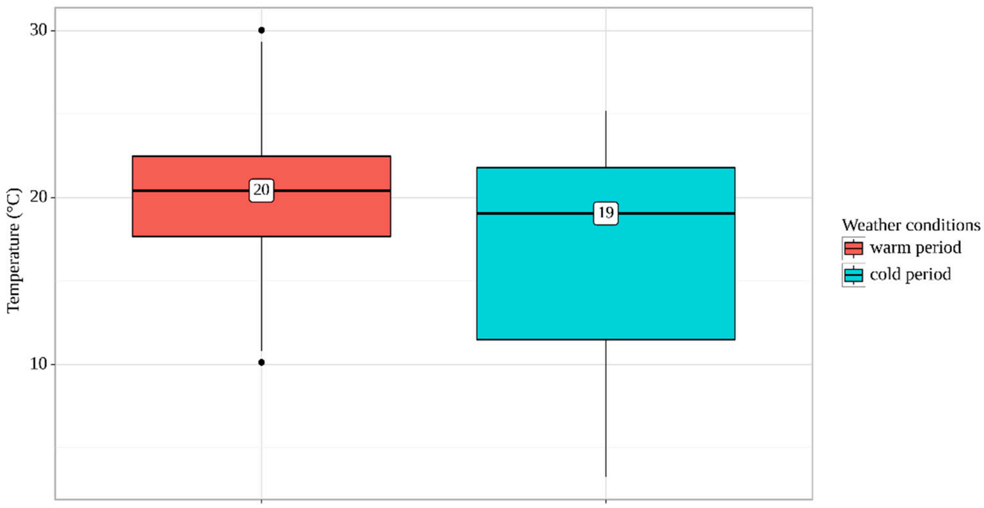

Figure 7. Comparative analysis of the air temperature at the premises depending on weekends and holidays.

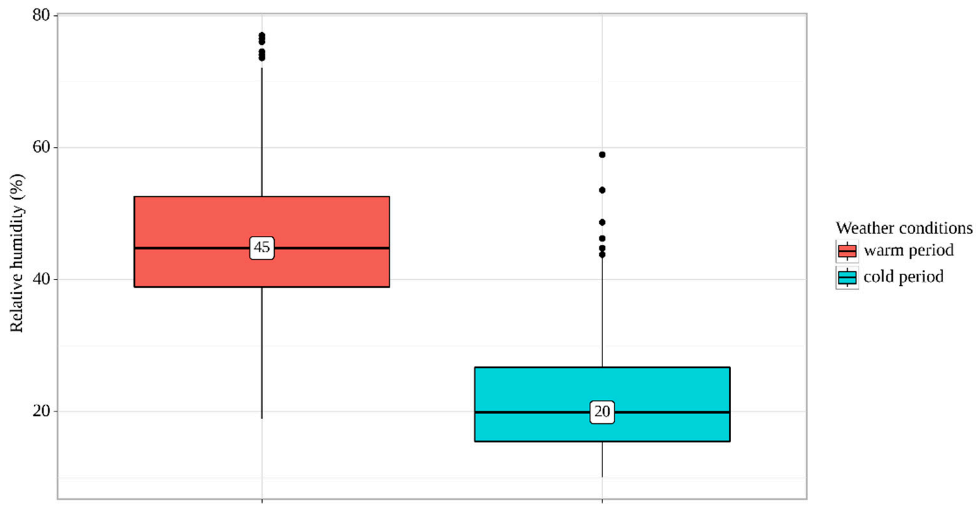

Figure 8. Comparative analysis of relative air humidity depending on weekends and holidays.

According to the results of the comparative analysis of the dependence of the results of radon concentration, air temperature, and relative humidity on weekends and holidays, it can be noted that, on weekends and holidays, the concentration of radon and the air temperature in the room are higher than those on working days, which is due to the fact that, on working days, the school administration rooms are naturally ventilated. When calculating the annual effective dose, we took into account the results of the radon concentration only on working days.

Figure 9 shows the correlation between temperature and radon on the school premises in Aksu.

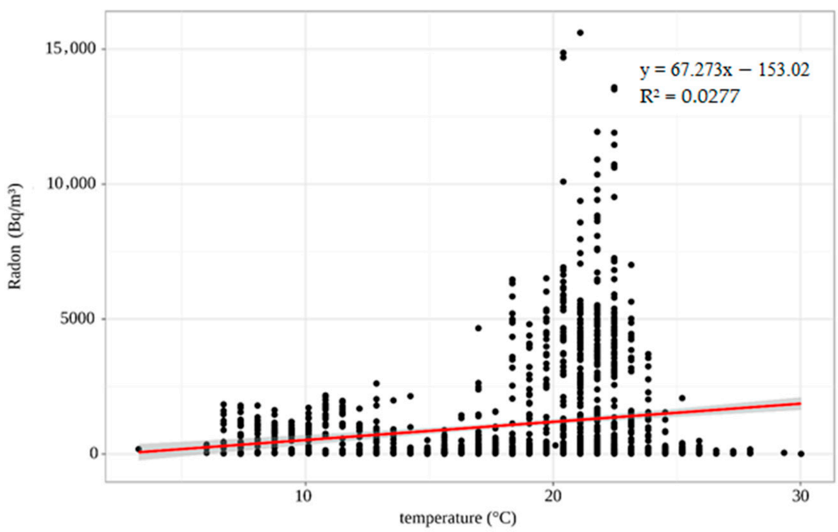

Figure 9. Regression line characterizing the dependence of radon on temperature.

As can be seen in Figure 9, with a 1 °C increase in temperature, a 67.3 Bq/m^3 change in the radon concentration should be expected; however, there was no correlation. According to the coefficient of determination R^2 of the resulting model, 2.8% of the observed variance of radon was explained.

Figure 10 shows the correlation between the relative humidity and radon on the school premises in Aksu.

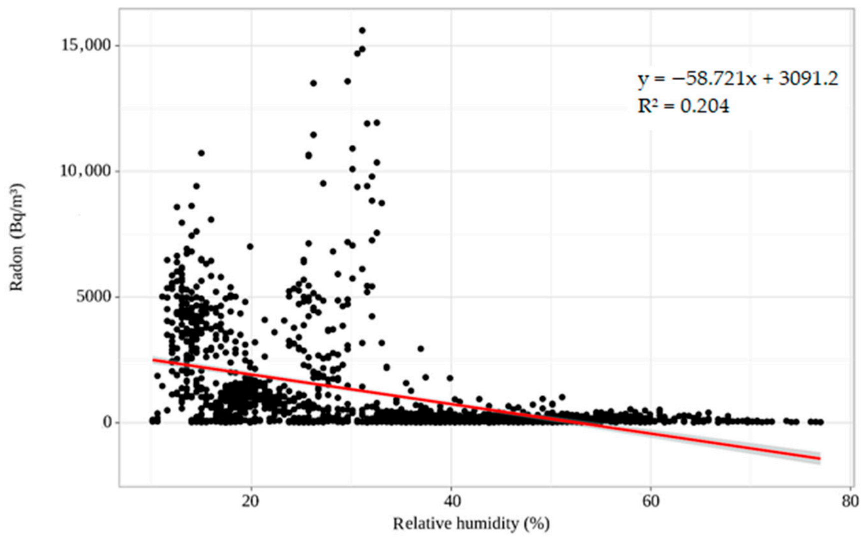

Figure 10. Regression line characterizing the dependence of radon on relative humidity.

As can be seen in Figure 10, with a 1% decrease in the relative humidity, a 58.721 Bq/m^3 change in the radon concentration should be expected; the correlation on the Chaddock scale was average. According to the coefficient of determination R^2 of the resulting model, 20.4% of the observed variance of radon was explained.

3.1.3. The Results of Measuring the Ambient Dose Equivalent H^* (10) of the School's Territory and Premises

In November 2021, $H^*(10)$ measurements were carried out in the territory and on the premises of Aksu School. According to the measurement results, the $H^*(10)$ in the territory varied from 0.13 µSv/h to 0.3 µSv/h, and the gamma background of the territory of the settlement varied from 0.13 µSv/h to 0.16 µSv/h. On the school premises, the capacity of the subscriber dose equivalent varied from 0.18 µSv/h to 0.4 µSv/h (Table 3). The maximum value of 0.40 µSv/h was detected in the kindergarten's playroom. According to the hygienic standard for radiation safety, a territory is considered contaminated if it exceeds the background value by 0.2 µSv/h [41].

Table 3. Results measurement of ambient equivalent dose rate of gamma radiation in the territory and inside the school.

Place of Measurements	H^*(10), µSv/h		
	Min	Max	Mean
First floor	0.18	0.4	0.24 ± 0.06
Second floor	0.18	0.21	0.21 ± 0.05
Third floor	0.20	0.25	0.22 ± 0.05
The school's territory	0.13	0.3	0.18 ± 0.04
Background value for a given locality = 0.13–0.16 µSv/h			

3.2. Annual Effective Dose of Students and Staff of the Aksu School

The average concentration of radon volume activity on the premises exceeded the control level by 1776 Bq/m^3. To calculate the average radon concentration, measurement data from September 2022 to February 2023 were used, with the exception of weekends and holidays according to the calendar of weekends of the Republic of Kazakhstan.

The calculation of the annual effective dose was carried out depending on the average annual concentration of radon and the time spent on the premises by students and staff of Aksu School and the kindergarten (teachers, educators, and administrative and economic staff) (Table 4). The annual effective dose varied from 4 mSv/y to 9 mSv/y, which exceeds the dose values of the average per capita annual effective dose from natural radiation sources of 2.4 mSv/y; this can vary from 1 mSv/y to 10 mSv/y [38].

Table 4. Annual effective dose and cancer risks among students and school and kindergarten staff.

	Students of Grades				School Staff	Kindergarten	
	1–4	5–6	7–8	9–11		Staff	Children
Occupancy time school/kindergarten (hour)	552	621	690	828	1264	1422	1264
Annual effective dose (mSv/y)	3.53	3.97	4.41	5.29	8.08	9.09	8.08
ELCR (%)	13.5	15.3	16.9	20.4	31.1	34.9	31.1

3.3. Risk Assessment for the Health of Students and Staff of Aksu School

According to the WHO, radon causes from 3% to 14% of all lung cancer cases, depending on the national average level of radon concentration and the prevalence of smoking [41].

Using Equation (1), the average annual effective dose received by students and staff of the school and kindergarten varied from 4 mSv/y to 9 mSv/y. In addition, assuming that the average life expectancy is estimated at 70 years, and the fatal risk of cancer on Sievert is 5.5×10^{-2} Sv^{-1}, as recommended by ICRP 103, the average ELCR was 13.5–20.4% for students, 31.1% for school and kindergarten staff, and 34.9% for kindergarten children [11]. The obtained data for ELCR exceed the permissive level by an order of magnitude.

4. Discussion

In Kazakhstan, the problems surrounding the radiation safety of the population and workers are dealt with by the regulatory body, the Committee of State Sanitary Epidemiological Supervision, and national regulatory documents exist [42]. The regulatory document establishes a reference level of the radon concentration of 200 Bq/m^3 for residential buildings. Concentration control is carried out only before the commissioning of the building, and thereafter, the concentrations of radon in schools, residential buildings, and public buildings are not controlled. The absence of mandatory monitoring in homes and public buildings, such as schools, kindergartens, and hospitals, where the population is unintentionally indoors, can lead to overexposure and increase the risk of oncological morbidity in the population.

According to the Ministry of Health of the Republic of Kazakhstan, more than 37 thousand new cases of cancer are detected annually. The structure of morbidity is as follows: in first place is breast cancer (13.2%), in second place is lung cancer (10%), and in third place is colorectal cancer (9.3%). Every year, more than 13 thousand people die from cancer in the country. Among the main causes of overall mortality, malignant neoplasms occupy second place. In the structure of mortality, lung cancer takes first place at 16.3%, stomach cancer takes second place at 12%, and colon cancer takes third place at 10.6%. According to the results of the work for 2022, the Kostanay, Akmola, Aktobe, and Mangystau regions were classified as unfavorable regions for oncological morbidity, where three out of five indicators are higher than international ones [43–46].

The reason for the abnormally high radon level in the school premises is assumed to be that a gold mine used to pass under the school, as there is a mothballed mine at a distance of 52 m from the school. The entrance to the mine is filled with household waste, which prevents the natural ventilation of the mine. Furthermore, perhaps during the construction of this building, the regulatory data differed from the current ones. Essentially, the classrooms (about 60%) that were found to exceed the radon value are located on the ground floor, thus also not excluding the influence of possible remnants of ore bodies in the ground under the school [24].

According to the measurements carried out before and after the natural ventilation of the classrooms of the school, the concentration of radon was reduced by six times;

in connection with this, the school administration gave recommendations on airing the classrooms in the morning before the start of the educational process, as well as after each big change, which lasts 15 min. Airing was scheduled from 7: 30 to 8:30, from 11:05 to 11:20, from 13:00 to 14:00, from 15:35 to 15:50, and in the evening at 19:00.

The obtained data were sent to a regulatory body in the field of sanitary well-being of the population. Employees of the local committees of Sanitary and Epidemiological Control offered to clean the ventilation system of the school and ventilate during the break.

In our results, no correlation was found between the temperature of the room and the radon concentration, but the relative humidity and radon concentration displayed an average correlation. The obtained data indicate the need for monitoring measurements of the radon concentration in children's educational institutions, taking into account the meteorological factors indoors and outdoors and the season of the year [47–49].

Thus, the results of the analysis revealed a relationship between changes in weather conditions, room temperature, relative humidity, and the radon concentration in the rooms. During the cold period, when the room was ventilated, the air temperature decreased, and the relative humidity of the rooms increased, which led to a decrease in the radon concentration in the room.

We recommend approving the national radon safety program, conducting radon monitoring studies in schools and children's educational institutions throughout Kazakhstan, and drawing radon maps. The monitoring studies of the radon concentration, taking into account the season of the year and the meteorological parameters on the premises of the school and kindergarten, as shown by the results of our data in the northern regions of Kazakhstan, indicate that due to weather conditions, it is not possible to ventilate the premises in the winter time. If an increase in the radon concentration is detected on the school premises, the ventilation system should be reviewed, and the inflow and exhaust of indoor air should be increased. According to our recommendations, the school administration is installing an artificial ventilation system. At the moment, the study is continuing. In the future, we will conduct repeated monitoring measurements of the radon concentration to study the effectiveness of the artificial ventilation system and perhaps investigate the hydro-insulation of the ground.

5. Conclusions

1. The H^* (10) in the kindergarten was found to be 0.4 µSv/h, which exceeds the regional average level by two times;
2. During short-term measurements of the radon concentration in the classrooms of Aksu School, an excess of up to 45 times that of the established standard value of 200 Bq/m^3 was detected;
3. According to the results of the monitoring studies of radon, no relationship was found between the temperature of the room and the radon concentration. However, an average correlation was observed between the relative humidity and radon concentration;
4. According to the results of a comparative analysis of the dependence of the results of the radon concentration, air temperature, and relative humidity on weekends and holidays, it could be noted that, on weekends and holidays, the radon concentration and indoor air temperature are higher than those on working days. This is because, on working days, the school administration airs the classrooms naturally;
5. The annual effective dose of students and teachers of the school and kindergarten varied from 4 mSv/y to 9 mSv/y. The worldwide annual effective dose ranges from 0.2 to 10 mSv, with an average value of 1.26 mSv (radon 1.15 mSv, UNSCEAR 2000);
6. The ELCR rates were 14–20% for students, 31.1% for school and kindergarten staff, and 34.9% for kindergarten children.

Author Contributions: Conceptualization, Y.K. and P.K.; data curation, M.B.; formal analysis, Y.K. and D.I.; funding acquisition, Y.K. and M.H.; methodology, Y.K., M.B., D.I., A.K., P.K. and M.H.; writing—original draft preparation, Y.K., M.B., D.I., M.H., A.S. and A.K.; writing—review and editing, Y.K., M.B. and D.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, grant number IRN AR13268875, "Assessment of the radon safety of the Aksu village school located near the radioactive waste storage facility and development of measures to reduce the risk of irradiation of students" (2022–2024). This research was supported by JSPS KAKENHI grant no. 19H01149 and by the Environmental Radioactivity Research Network Center (ERAN) (F-22-14 and F-23-14). This research was supported by grant no. 248/30-22-24 of the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan and grant number IRN AR14871503 "Assessment of the dose load and epidemiological study of the population living near preserved uranium mines, development of measures to minimize negative technogenic factors" (2022–2024).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data sets created and/or analyzed during the current study are available from the author of the scientific project, Kashkinbaev Yerlan, and they can be provided upon reasonable request.

Acknowledgments: The author expresses gratitude to M. Hoshi of Hiroshima University for providing the radon monitoring device Radon Scout Professional manufactured in Germany (SARAD GmbH, Wiesbadener Str.10, 01159 Dresden, Germany) and to scientific supervisor Kazymbet P.K. for the opportunity to work based on the Institute of Radiobiology and Radiation Protection and for advice in carrying out the work.

Conflicts of Interest: The authors declare no conflict of interest.

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