Determination of radon levels in dwellings and social objects and evaluation annual effective dose from inhalation of radon in Stepnogorsk area Northern Kazakhstan

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Radon is a noble gas that is one of the natural radioactive decay products of radium resulting from the disintegration of uranium. Humans are exposed to sources of natural radiation activity, being radon and its progeny breathing air responsible for more than 50% of the annual dose received from natural radiation. The aim of this study was to determine the radon concentration in the air in settlements' dwellings and social objects and calculate the annual effective dose of population from radon on the territory mining activities in Stepnogorsk area. The study has shown that activity concentrations of indoor radon in the buildings ranged from 8 to 870 Bq $\cdot$ m^{-3} in Aqsu, 3-540 Bq $\cdot$ m^{-3} in Kvartsitka located close to former gold mining sites. The E_{inh} corresponding to the activity concentrations ranged from 1-27 mSv $\cdot$ y^{-1} received by the settlements' public. The highest value of E_{inh} in Aqsu School reaches up to 68 mSv $\cdot$ y^{-1} received by the critical group of public was found at the territory of former mining the Stepnogorsk area. The results of this study show significant radiation hazards in Aqsu School which located at the territory of former mining site, and there is evidence of radon health risk to the members of the public.

Keywords: radon concentration, gamma exposure, annual effective dose, mining activity.

Introduction

Radiation comes from the cosmogenic, anthropogenic and primordial sources. Contribution of anthropogenic sources to the total environmental radioactivity is negligible. Level of primal radioactivity is widespread in the earth environment and their concentration depends on local geological conditions and geographical location of the area [1].

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The Republic of Kazakhstan has a long history of mining activities, viz., gold and uranium. The dozens of uranium deposits discovered on the territory of Kazakhstan were various in terms of formation conditions and practical value [5-6]. About 12% of world reserves of uranium were concentrated in Kazakhstan, mainly in the Northern Kazakhstan uranium ore province [7]. In addition to uranium, the gold mining was conducted in this territory. One of the operating mines was the Aqsu gold mine. The Aqsu gold mine has been operating since 1932 and produces and processes gold ore.

Mining and ore processing activities are associated with changes in the surrounding environment and may pose a risk to human health, if adequate safety measures are not taken [8].

The aim of this study was to determine the radon concentration in the air in settlements' dwellings and social objects and calculate the annual effective dose of population from radon on the territory mining activities in Stepnogorsk area, Northern Kazakhstan.

Materials and methods

Study area

The study area is located in the Northern Kazakhstan of Akmola region, where the Stepnogorsk city is located. Stepnogorsk, which was founded in 1959, is located 180 km to the northeast of Nur - Sultan city (Capital of Kazakhstan). The settlements Zavodskoy, Aqsu and Kvartsitka located in territory of uranium ore province and former gold mining sites (Figure 1). Some houses and premises of Aqsu and Kvartsitka were constructed at the former gold mining territory. Mines and the industrial platform practically adjoin residential quarters. Settlements of Zavodskoy, Aqsu and Kvartsitka are known for mines and mines on mining such as: gold, palladium, molybdenum.

The surrounding environment of settlements up to 5-10 km from the uranium mining complex is not regularly monitored for external gamma radiation, outdoor and indoor radon. Samples were collected from houses of nearby settlements to estimate the ingestion of radionuclides. According to international standards, in each settlement, five points along the main geographical directions were selected
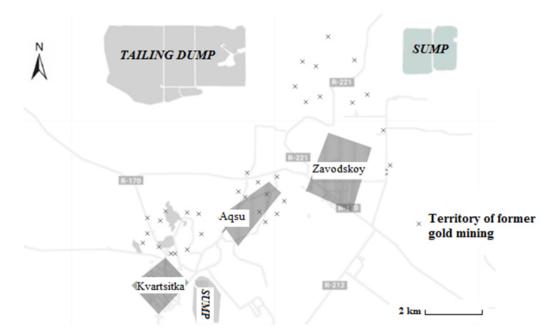
Figure 1. Scheme of settlements location near the tailing dump of the Stepnogorsk mining and processing plant and former gold mining territory.

randomly and about 20 readings were taken at different points in each settlement. The measurements were accomplished during daylight from September to October.

Gamma fields

External gamma radiation levels of settlements' houses in studied area adjacent uranium mining complex were measured using environmental gamma survey dosimeters DKS-AT-1123 and RKS-01-SOLO. According to IAEA Guidelines outdoor and indoor measurements were done at 1m above the soil surface and the floor [9]. Outdoor gamma fields were measured in terms of ambient equivalent dose rates (H(10)).

Radon measurement

Equivalent equilibrium volume activity (EEVA) of radon concentration in the air was measured by automatic compact radiometers of radon and thoron Ramon-02 and Ramon-02A. Measurements were done in accordance to ASTM D6327-10 (2016) [10]. The results were then used to estimate the annual effective dose due to inhalation of radon gas.

Annual effective dose from inhalation of radon

The annual effective dose (E_{inh}) from the inhalation of indoor radon was calculated from the measurements. The calculation was determined using an expression suggested by UNSCEAR:

$$E_{inh} = DCF_{Rn} \times F_{Rn} \times A_{Rn} \times T_{exp} \times 10^{-6}, \tag{1}$$

where DCF_{Rn} - the dose conversion factor of radon via inhalation (assumed to be 9 nSv/Bq$\cdot$h$\cdot$m^3);

F_{Rn} - the indoor equilibrium factor between radon and its progeny (assumed to be 0.4);

A_{Rn} - the radon activity concentration in $Bq \cdot m^{-3}$;

T_{exp} - the exposure time to this concentration (assumed to be 8760 hours in one year).

Results and discussion

The reading was taken at 1 m above soil surface. Dose rates at 1m above the ground reflect only the presence of gamma emitters. Table 1 demonstrates of H(10) measured in studied area.

Measurements of activity concentrations of indoor radon taken from selected studied settlements are recorded in Table 1. The table also shows calculated values for the corresponding annual effective dose from the inhalation to which members of the public are exposed. According to ICRP 103, the international limit of radon concentration in the air is 200 $Bq \cdot m^{-3}$.

Table 1.
Measurements of H(10), radon concentrations and the corresponding E_{inh} in studied area.

Settlements	H(10), µSv/h at 1 m above soil surface	Radon in the indoor air (EEVA), Bq·m^{-3}	E_{inh}, mSv·y^{-1}
	Min-max		
Zavodskoy	0.1-0.3	40	1
Aqsu	0.1-3	870	27
Kvartsitka	0.1-0.25	540	16
Worldwide range*	0.1	200	3-10

*UNSCEAR, 2000

As it can be seen from Table 1 maximum values of both settlement average and local pick were found in Aqsu (exceeding the worldwide range by an order of magnitude). The H(10) exceed the worldwide level not higher than 2.5 times in Zavodskoy and Kvartsitka.

In 27 buildings from the 45 measured buildings radon concentrations of more than 200 $Bq \cdot m^{-3}$ were detected in Aqsu (Figure 2). The results obtained from measurements EEVA of radon in Aqsu dwellings range from 8 to 870 $Bq \cdot m^{-3}$. In Kvartsitka EEVA of radon reaches the values up to 3-540 $Bq \cdot m^{-3}$ and Zavodskoy 25-40 $Bq \cdot m^{-3}$. This high radon concentration in Kvartsitka dwelling was attributed for by the radon emanation in the basement of the house and being close to sump of former gold mining quarries which may give out reasonable amount of radon.

Particular emphasis was payed to school premises in studied settlements. The EEVA radon at School building in Zavodskoy was lower the international limit of radon. In contrast, the data on EEVA in the school of Aqsu were extremely diverse and range in classrooms - from 153 to 2162 $Bq \cdot m^{-3}$, in basements and cellars - from 130 to 5870 $Bq \cdot m^{-3}$, exceeding the permissive level according to ICRP by an order of magnitude. A survey of underground premises (such
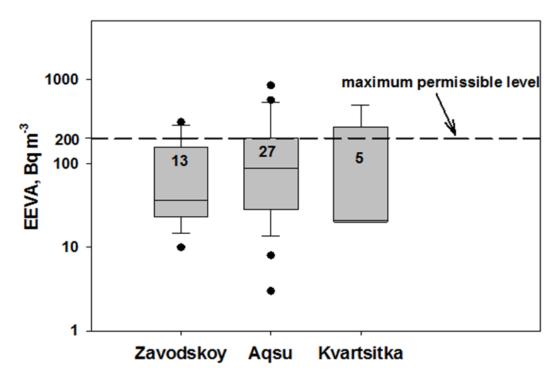
Figure 2. Results of measurement of EEVA of radon in inhabited premises of settlements Aqsu, Zavodskoy, Kvartsitka and Akkol, Bq/m ^{3} . Upper and lower borders of boxes correspond to 25%-75% of EEVA; whiskers border 90% confidence interval. Horizontal lines in the boxes are the median values. Numbers in the boxes reflects the number of measurements in the datasets. Dotes are outliers.

as cellars) shows that rural houses are poorly protected from radon; soil radon enters through vents and cracks in the floor.

One of characteristics of a radiation situation in classrooms is the increased high content of radon in air and H(10) value of 0.18-0.32 $\mu Sv \cdot h^{-1}$ at norm for this area 0.2+ background respectively. It is explained by high concentration daughter products of disintegration of radon in air. In the Figure 3 it is shown that increase of activity of radon is followed by immediate increase in H(10) and vice versa, decreases of the activity of radon leads to immediate reduction of H(10).

Among all sources of natural radioactivity the main contribution to an annual effective dose is made by radioactive gas-radon. It can be noticed from Table 1 that, the highest value of E_{inh} was found in Aqsu, exceeding the worldwide range by an order of magnitude, while the lowest value of E_{inh} was found in Zavodskoy, which is less than the recommended worldwide range. The highest value of E_{inh} in Aqsu School building reaches up to 68 $mSv \cdot y^{-1}$. The main dose burden was determined by indoor radon.

The reason of abnormally high radon contamination is the fact that in 1930s on the places of school there was gold-mining site and perhaps at construction of these building did not meet the requirements of radiation safety or did not monitored before. Generally classrooms (about 60%) with the exceeded value of radon are on the ground floor that also does not exclude influence of the possible remains of ore materials in the thickness of the earth under school.
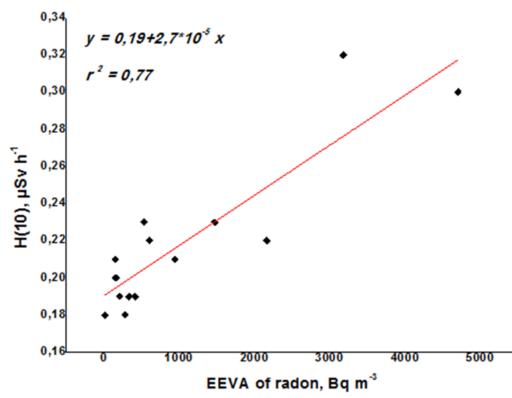
Figure 3. Correlation between H(10) gamma exposure and radon concentrations in Aqsu School.

Conclusion

In this article, indoor radon concentration level in studied settlements was determined in a total of fourty five houses.

The H(10) in Aqsu reaches up to 3 μSv/h exceeding the worldwide level. The study has shown that activity concentrations of indoor radon ranged from 8 to 870 $Bq \cdot m^{-3}$ in Aqsu, 3-540 $Bq \cdot m^{-3}$ in Kvartsitka, exceeding the permissive level by an order of magnitude in the buildings located close to former gold mining sites. The E_{inh} corresponding to the activity concentrations ranged from 1-27 $mSv \cdot y^{-1}$, exceeding the worldwide range values. The highest value of E_{inh} in Aqsu School reaches up to 68 $mSv \cdot y^{-1}$ received by the critical group of public was found at the territory of former gold mining the Stepnogorsk area. The main dose burden was determined by indoor radon.

Overall, radon concentration levels and effective doses measured in Aqsu and Kvartsitka were found higher. Hence results of this study show significant radiation hazards in Aqsu school which located at the territory of former gold mining site, and there is evidence of radon health risk to the members of the public since most of the values of annual effective doses determined are higher than 3-10 $mSv \cdot y^{-1}$ as recommended by UNSCEAR and ICRP [11, 12].

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