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IMPROVEMENT OF ENVIRONMENTAL STANDARDS FOR RADON-222 EXPOSURE

Radiation safety is ensured by the system of legislative acts, regulatory and technical documents aimed at limiting the occurrence of deterministic (manifestation and severity of which depends on the absorbed dose) and stochastic (probability of which does not depend on the dose, and the frequency of their occurrence depends on the dose) effects in humans from various sources of ionising radiation. Certain areas of southern Ukraine (central and northern territories of Mykolaiv, Odesa, Kherson, and Kirovohrad regions) are characterised by the presence of granitoids in the underlying rock layer, which contributes to the widespread development of granite mining and granite processing industries in the region [5, 8]. Due to this and the planned introduction of uranium mining enterprises in the region in the near future, one of the most pressing issues of radiation safety and radiation hygiene in the region is the issue of radiation safety from man-made enhanced natural radiation background, primarily ^{222}Rn exposure.

The article presents an analysis of the sources of dose load on workers in the granite mining industry. The purpose of the study was to analyse the levels of ^{222}Rn exposure of workers in the granite mining industry to assess the need to adjust existing environmental standards. The materials used were the results of measurements of exposure dose rate, measurements of ^{222}Rn volumetric equivalent equilibrium activity in the air of working premises and at the workplaces of granite quarry workers in Mykolaiv region, and the results of studies of ^{222}Rn content in drinking water.

Keywords: *radon-222, environmental standards, exposure, atmospheric air*

Introduction

Certain territories of southern Ukraine (central and northern territories of Mykolaiv, Odesa, Kherson and Kirovohrad regions) are characterised by the presence of granitoids in the underlying rock layer, which contributes to the widespread development of granite mining and granite processing industries in the region [4, 9]. On the other hand, these rocks are characterised by an increased clarke content of radioactive elements of the uranium-thorium series, and, therefore, are associated with manifestations of 222Rn and its daughter decay products (DDP). According to national authors [4, 6, 8], the total annual dose from natural radionuclides in Ukraine is considerable and amounts to 6.15 mSv/year. According to the UNSCEAR [7], the contribution of radon from DDP to the dose of the world's population from natural sources is 54%. In Ukraine, radon reaches 79% (4.2 mSv) of the specified dose and about 60% of the average effective dose from all sources [8].

Due to the widespread development of granite mining and granite processing industries in these areas of the region, as well as the planned introduction of uranium mining enterprises in the region in the near future, one of the most pressing issues of radiation safety and radiation hygiene in the region is the issue of technogenically enhanced natural radiation background, primarily ^{222}Rn exposure. According to the researchers, the effective dose from ^{222}Rn from the DDP for the population of the northern and central regions of Mykolaiv oblast is 4-5 mSv/year. The purpose of the study was to analyse the levels of ^{222}Rn exposure of workers of granite mining enterprises.

Materials and methods

The materials were the results of measurements of exposure dose rate (EDR), studies of equivalent equilibrium volumetric activity (EEVA) of ^{222}Rn in the air of working premises and at the workplaces of the main groups of workers (crusher operator, perforator driller, stonemason, bulldozer operator, excavator operator) of granite quarries (Pervomaiskyi granite and Pervomaiskyi granite and Crushed Stone Quarries, Oleksandrivskyi, Prybuzkyi, Sofiivskyi, Novo-Danylivskyi granite quarries), results of studies of ^{222}Rn EEVA in the air of residential premises of these workers, results of studies of ^{222}Rn content in drinking water.

Determination of the effective dose of external human exposure from technogenically enhanced radiation background ($E^{ext}_{tecn\_nat}$) was performed based on the results of determining the exposure dose rate (EDR) and taking into account the time spent by a person in the open area of 2000 hour/year, indoors – 4652 hour/year [7]. The effective dose from ^{222}Rn by inhalation ($E^{inhal}_{^{222}Rn,\mathrm{home}}$, $E^{inhal}_{^{222}Rn,work}$) and drinking water ($E^{ing(drink)}_{^{222}Rn,\mathrm{home}}$, $E^{ing(drink)}_{^{222}Rn,work}$) as determined in accordance with mathematical models of the ICRP [1] and the UNSCEAR report [2]. The dose rate of oral intake of ^{222}Rn to humans with drinking water was assumed to be $1\cdot10^{-8}$ mSv/Bq [2]. In the statistical processing of the research results, the following software was used STATISTICA 6.0., MathCard 7.0.

Research results

The average value of exposure dose rate (EDR) at the workplaces of employees of Pervomaisky, Prybuzky, Oleksandrivsky, and Novo-Danylivsky granite quarries was 17 ± 3 μR/hour. EDRs at Sofiyivskyi granite quarry averaged 22 ± 2 μR/hour, with EDRs of 24-28 μR/hour recorded at the workplaces of excavators, crushers, and drillers. In Novo-

Danylivskyi quarry, where granite layers were opened, EDR levels of 35 μR/hour were recorded. The effective dose of external exposure of granite quarry workers at the workplace ($E^{ext}_{tecn-nat}$) was on average 0.32±0.05 mSv/year at Pervomaisky, Prybuzky, Oleksandrivsky, Novo-Danylivsky granite quarries; 0.42±0.04 mSv/year at Sofiyivsky.

Table 1 shows the ^{222}Rn EEVA values for each quarry. Almost all granite quarries were characterised by a wide range of data scatter. At Sofiyivka granite quarry, almost all ^{222}Rn EDR measurements were above 100 Bq/m^3. The coefficient of variation of ^{222}Rn EEVA results in this quarry was also high (~44%) due to the wide range of data scatter. The weighted average value of ^{222}Rn EEVA at workplaces for all open pits was 129±2 Bq/m^3.

Table 1. – ^{222}Rn EEVA values at workplaces of granite quarry workers, Bq/m^3

Employee's workplace granary	$\bar{X} \pm S\bar{x}$	The maximum value	The minimum value
Pervomaisky granite quarry	136±24	220	85
Pervomaisky granite and crushed stone quarry	124±46	190	50
Aleksandrovsky granite quarry	110±34	160	86
Prybuzky granite quarry	156±48	310	84
Sofiyivka granite quarry	196±86	355	58
Novo-Danilovsky granite quarry	110±36	240	58

Table 2 shows the results of studies of ^{222}Rn EEVA in the living quarters of granite quarry workers.

Table 2. – The ^{222}Rn EEVA in the living quarters of granite quarry workers. Bq/m^3

Granite quarry	$\bar{X} \pm S\bar{x}$	The maximum value	The minimum value
Pervomaisky granite quarry	108±30	120	55
Pervomaisky granite and crushed stone quarry	123±12	160	45
Aleksandrovsky granite quarry	88±10	160	45
Prybuzky granite quarry	83±10	120	55
Sofievsky granite quarry	127±34	230	75
Novo-Danilovsky granite quarry	87±19	180	65

Elevated values of ^{222}Rn EEVA are typical for buildings constructed either of concrete structures or mud bricks (adobe), with granite foundations, without ventilated basements, and with either no or insufficient ventilation. In buildings with good ventilation of living quarters, ^{222}Rn EEVA values were low. It should be noted that for the specialists of Pervomaiskyi Granit, Pervomaiskyi Granite and Crushed Stone, and Sofiivskyi Granite quarries, the average radon activity values were at the level of the standards for existing buildings - 100 Bq/m^3 [7]. The average weighted ^{222}Rn EEVA values in residential premises was 96±2 Bq/m^3.

The results of studies of ^{222}Rn content in water consumed by granite quarry workers (wells, boreholes) showed that the content of ^{222}Rn in some drinking water sources exceeded 100 Bq/l (the standard value according to [7]). High values of ^{222}Rn content in drinking water were observed for artesian water from the Sofiyivka granite quarry (345 ± 17 Bq/l) and from the Oleksandrivka granite quarry. The content of ^{222}Rn in drinking water consumed by these specialists at home was 50 ± 18 Bq/l. It should be noted that other Ukrainian researchers [8,9] also note the need to continue studies of the content of radon-222 in underground sources.

Calculated effective doses by inhalation of ^{222}Rn to humans in the workplace ($E^{inhal}_{^{222}Rn,work}$) and at home ($E^{inhal}_{^{222}Rn,home}$) and the total dose from inhalation ^{222}Rn at home and at the quarry ($E^{inhal}_{^{222}Rn-home} + E^{inhal}_{^{222}Rn-work}$) (Table 3). Value $E^{inhal}_{^{222}Rn,home}$ is greater than the value of $E^{inhal}_{^{222}Rn,work}$. Generalisation by quarries shows that the average weighted value of the effective dose $E^{inhal}_{^{222}Rn,work}$ was 2.1±0.2 mSv/year with a range from 0.9 to 5.9 mSv/year; the weighted average effective dose $E^{inhal}_{^{222}Rn,home}$ was 4.1±0.2 mSv/year with a range from 1.8 to 9.7 mSv/year.

Effective dose from ^{222}Rn in drinking water ($E^{ing(drink)}_{^{222}Rn,work}$) was 0.02±0.01 mSv/year in Prybuzkyi and Novo-Danylivskyi granite quarries; about 0.04 mSv/year in Oleksandrivskyi granite quarry; and 0.15 mSv/year in Sofiyivskyi granite quarry. Average value of effective dose from intake of ^{222}Rn in drinking water at home ($E^{ing(drink)}_{^{222}Rn,home}$) was 0,05±0,01 mSv/year.

Adding up all the obtained values of the effective internal dose of granite quarry workers ($E^{inhal}_{222Rn,home}$, $E^{inhal}_{222Rn,work}$, $E^{ing(drink)}_{222Rn,home}$, $E^{ing(drink)}_{222Rn,work}$) we obtain that the total effective exposure dose to granite quarry workers via inhalation and oral routes of ^{222}Rn intake (based on weighted average values) was 6,2±0,6 mSv/year. The maximum values were 15,6 mSv/year.

Table 3. – Effective dose from ^{222}Rn for granite quarry workers, mSv/year

Granite quarry	Effective dose in the workplace $E^{inhal}_{222Rn-work}$			The effective dose at home $E^{inhal}_{222Rn-home}$			Total effective dose $E^{inhal}_{222Rn-home} + E^{inhal}_{222Rn-work}$		
	$\overline{X} \pm S\overline{x}$	The maximum value	The minimum value	$\overline{X} \pm S\overline{x}$	The maximum value	The minimum value	$\overline{X} \pm S\overline{x}$	The maximum value	The minimum value
Pervomaisky granite quarry	2,2±0,3	3,5	1,4	4,5±0,4	5,0	2,3	6,7±0,6	8,5	3,7
Pervomaisky granite and crushed stone quarry	2,0±0,2	2,5	0,8	5,2±0,5	7,0	1,8	7,2±0,7	9,5	2,6
Aleksandrovsky granite quarry	1,8±0,4	2,4	1,1	3,7±0,4	6,7	1,8	5,5±0,5	9,1	2,9
Prybuzky granite quarry	2,5±0,4	5,0	1,1	3,5±0,4	5,0	2,8	6,0±0,6	10,0	3,9
Sofievsky granite quarry	3,2±0,6	5,9	1,8	5,3±1,4	9,7	3,2	8,7±3,4	15,6	5,0
Novo-Danilovsky granite quarry	1,8±0,4	3,8	0,9	3,7±0,8	7,6	2,7	5,5±1,9	11,4	3,8

Conclusions

1. Workers in granite quarries are exposed to a double burden of ^{222}Rn (at work and at home). The weight-average value of the effective dose from inhalation of ^{222}Rn with workplace air was 2.1±0.2 mSv/year (with a range from 0.9 to 5.9 mSv/year). The average weighted value of the effective dose from inhalation of 222Rn with the air of residential premises was 4.1±0.2 mSv/year (with a range from 1.8 to 9.7 mSv/year).
2. The total effective internal dose from ^{222}Rn intake in the air of working and living quarters and in drinking water averaged 6.5±0.2 mSv/year, with maximum values of about 15.6 mSv/year. This allows us to recommend revision of the current radiation safety standards to limit excessive exposure for employees of granite mining enterprises.

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