RADIOECOLOGICAL MONITORING OF ATMOSPHERIC AIR DURING MILITARY OPERATIONS

Kostiantyn Grygoriev, Liudmyla Grygorieva*, Anna Aleksieieva
Petro Mohyla Black Sea National University, Mykolaiv, Ukraine
*Corresponding author: ludmila.grygorieva@chmnu.edu.ua

The relevance of the presented research is related to the objective need for organizational improvement of radiation and radioecological monitoring in Ukraine under a full-scale war that began in February 2022. This is due to the increased risks of radioecological accidents, the threat of changes in the radiation situation, and the release of radionuclides into the air as a result of constant shelling of the territories near Nuclear Power Plants (NNPs) by Russian missiles and drones.

The study purpose is to provide a comprehensive radioecological assessment of the radiation state of atmospheric air and atmospheric fallout in the Nikolaev city and the Nikolaev region, as well as to develop, based on this assessment, proposals for optimizing radioecological monitoring of atmospheric air in Ukraine during military operations. The research methods were an analysis of the current system of radiation monitoring of atmospheric air in Ukraine, analysis of cases of recording changes in the radionuclide composition of atmospheric air due to the movement of the radioactive cloud, results of own observations of the effective dose rate and radiometry of atmospheric deposition samples.

The article presents research materials on the radioactive state of the atmospheric air, the content of radionuclides in atmospheric deposition in the city of Mykolaiv in 2023, and a comparative analysis with the indicators of previous years and in the settlements of the Mykolaiv region. To fully assess the effectiveness and efficiency of the current system of radioecological monitoring of atmospheric air, the results of radiometry of atmospheric air samples in the Mykolaiv region during the movement of the radioactive cloud with ruthenium-106 in autumn 2017 are presented. The scientific novelty is to expand the understanding of the tasks of radioecological monitoring of atmospheric air during military operations. The practical significance of the presented results is to obtain field research data for dosimetry of the population of Mykolaiv and Mykolaiv region during military operations of the Russian Federation, for cartographic modelling of the current formation of individual and collective external dose of the population in certain areas.

Keywords: atmospheric deposition, radionuclides, effective dose rate, radioactive cloud, dosimetry

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Introduction

The issue of bringing the air monitoring system in Ukraine closer to the requirements of the EU Directives continues to occupy a key place among the issues of environmental monitoring in our country. According to the research in the field of radiation safety (Vitko, Kartashov, Khabarova 2020), radiation-ecological (radiation) environmental monitoring is a comprehensive information and technical system of regular observations of the radiation state of the environment, processes of migration and accumulation of radionuclides, potentially hazardous phenomena, etc. implemented with the help of special equipment (systems, complexes or individual devices) for assessing and predicting the radiation state of the environment. Radioecological observations of individual enterprises, especially nuclear fuel cycle enterprises and others that are sources of radioactive substances emissions into the environment, are practiced (Vitko, Goncharova, Kartashev, Kovalenko, Khabarova, 2019). During the Russian aggression against Ukraine, due to the constant shelling of the territory by missiles and unmanned aerial vehicles, attention to radiation safety in Ukraine has increased (Vitko, 2022), and especially near NPPs (Vitko, Goncharova, Kartashev, Kovalenko, Khabarova, 2019). Scientists are raising the issue of transboundary transfer of radiation exposure in case of probabilistic emergencies at NPPs during military operations (Alekseeva, 2022).

The objective is to conduct radioecological studies to assess the radiation state of the atmospheric air, atmospheric deposition in the territory of Mykolaiv and Mykolaiv region in different years and to develop proposals for optimizing radioecological monitoring of the atmospheric air during military operations.

Materials and Methods

Measurements of gamma radiation dose rate were performed using SaveDnipro indicative measurement stations and the MKC-05 TERRA dosimeter at a level not lower than 1 m from the ground surface. Measurements with the MKC-05 TERRA dosimeter were performed two to three times a week. Observations of the effective dose rate in Mykolaiv were carried out at two locations: point 1 – 5, Lazurna Street; point 2 – 10, 68 Desantnykiv Street.

The materials used in the study are the observations of the external dosimetry laboratory of the South Ukrainian NPP (SUNPP) for effective dose rate at the control posts of the 30-km SUNPP zone in the Mykolaiv region, as well as the materials obtained during the zero-background survey around the SUNPP.

The atmospheric deposition was collected by the sedimentation method with subsequent burning of the sample to ash and radiometry of the ash sample on the radiometric unit and on the gamma spectrometric unit SBS-50M with a semiconductor detector DGDK-125. Atmospheric deposition in the city was collected in an open area. The tablet for collecting atmospheric deposition had dimensions of 1x1 m^2. The exposure of precipitation collection was 1-3 months. The atmospheric deposition activity was calculated in units Bq/(month×m^2).

The analysis used data from monthly measurements of the radionuclide composition of atmospheric deposition at observation points around SUNPP during the pre-launch period (Tomilin, Yu., 1980, Tomilin, Yu., 2001) and in 2017 (during the ruthenium-106 radioactive cloud). The latest results were obtained at the SUNPP External Dosimetry Laboratory.

Results and Discussion

The results of observations of the effective dose rate in Mykolaiv at two observation points are shown in Table 1.

The measurement results show that the average value of the effective dose rate in Mykolaiv in 2023 was 0.12±0.02 μSv/hour.

The calculation results were used to create the EDRA_Myko map (Effective dose rate of atmospheric air, Mykolaiv) based on the QGIS geographic information system (Figure 1).

Table 1. Average monthly values of effective dose rate in Mykolaiv in 2023, $\bar{X} \pm 2\sigma$, μSv/hour

Month	Point 1	Point 2
January	0.12±0.03	0.12±0,02
February	0,10±0.03	0.10±0,03
March	0.12±0.03	0.10±0,03
April	0.11±0.02	0.12±0,03
May	0.12±0.03	0.09±0,02
June	0.11±0.02	0.12±0,03
July	0.10±0.02	0.11±0,03
August	0.10±0.03	0.10±0,03
September	0.11±0.03	0.12±0,03
October	0.12±0.01	0.11±0,03
November	0.11±0.01	0.10±0,03
December	0.12±0.02	0.12±0,01
Average	0.11±0.02	0.12±0,03

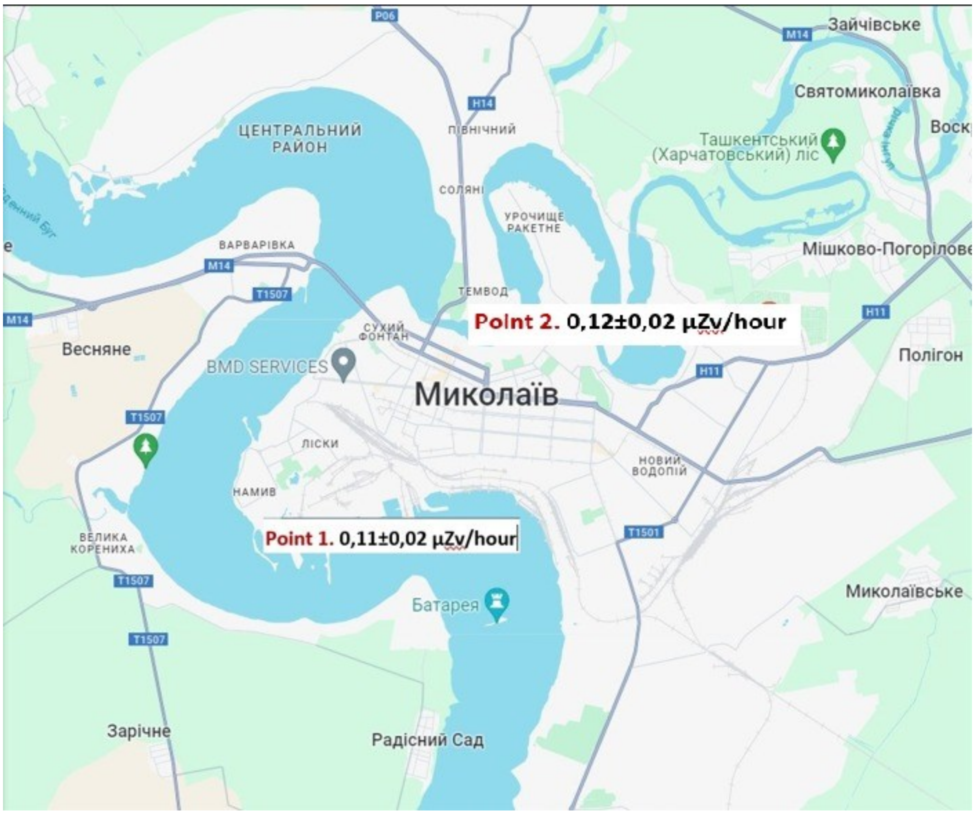

Figure 1. EDRA_Myko map fragment (Effective dose rate of atmospheric air, Mykolaiv)

For comparison, the data on the radiation background in the 30-km area of the SUNPP zone were analyzed (Table 2).

Table 2. Average monthly values of effective dose rate in settlements of the 30-km SUNPP zone in 2022, 2023

Observation point	$\bar{X} \pm 2\sigma$, μSv×/hour	
	2022 year	2023 year
At the SUNPP industrial site	0.11±0.02	0.12±0.02
Arbuzinka village	0.13±0.03	0.15±0.03
Buzke village	0.13±0.03	0.14±0.03
Agronomiya village	0.14±0.03	0.14±0.02
Kostiantynivka village	0.10±0.02	0.11±0.02
Ivanivka village	0.12±0.02	0.11±0.02
Blagodatne village	0.13±0.02	0.13±0.02
Voznesensk	0.10±0.02	0.10±0.02
Olexandrivka village	0.13±0.02	0.12±0.02
Domanivka village	0.11±0.02	0.11±0.02
Bogdanivka village	0.12±0.03	0.13±0.03
Yuzhnoukrainsk	0.10±0.02	0.11±0.02

As can be seen from Table 2, the average values of the effective dose rate of atmospheric air at the control posts ranged from 0.09 to 0.15 μSv/h. As is known, the variation of these values is due to the geological features of Mykolaiv region and the presence of faults with crystalline rocks (characterized by a higher content of natural radionuclides of the uranium-radium and thorium series) coming to the surface in the center in the north of the region.

These indicators almost did not differ from the monitoring data during the zero-background in the SUNPP area in 1979-80 (Tomilin, Yu.,1980). Thus, the highest values of effective dose rate were typical for areas where rocks of pink-grey granite came to the surface: these are areas along the banks of the Southern Bug River. In these places, the effective dose rate was in the range of 0.25-0.35 μSv/hour. At a distance of 5-10 km away from the riverbed, the granite massifs are partially covered with sedimentary rocks, so here the gamma radiation dose rate of the open area decreased to 0.10-0.11 μSv/hour.

This comparative analysis showed that in the city of Mykolaiv and in the settlements of the Mykolaiv region during the military operations in recent years, the effective dose rate of atmospheric air did not exceed the fluctuations of the natural radiation background.

The results of radiometry of atmospheric deposition samples in Mykolaiv are presented in Table 3. The total beta activity of fallout averaged 12.1±2.4 Bq/(month×m^2). The ^{137}Cs content in these fallouts was 1.2±0.4 Bq/(month×m^2).

The total beta activity of atmospheric deposition in Mykolaiv averaged 12.7±3.1 Bq/(month×m^2). The ^{137}Cs content in these depositions averaged 1.2±0.3 Bq/(month×m^2). According to the continuous radiation monitoring of atmospheric deposition in Mykolaiv (Tomilin, 2001), the total beta activity of atmospheric deposition in 1990-2000 varied between 11 and 25 Bq/(month×m^2), and the ^{137}Cs content did not exceed 2.2 Bq/(month×m^2).

Table 3. Results of radiometry of atmospheric deposition samples in Mykolaiv in 2023 year

Exposition	Total beta activity, Bq/(month×m^2)	The ^{137}Cs content, Bq/(month×m^2)
1st quarter	12.0±3,0	1.0±0.2
2nd quarter	12.9±3.5	0.9±0.1
3rd quarter	13.4±2.6	1.4±0.2
4th quarter	14.0±3.0	1.3±0.3

According to the materials of the zero-background assessment around the SUNPP, the total beta activity of atmospheric air in Yuzhnoukrainsk and Voznesensk was 0.200-0.700 Bq/l, ^{137}Cs content did not exceed 2.5 mBq/l, and ^{90}Sr content did not exceed 2.0 mBq/l.

The following tables (Tables 4, 5) show data indicating that during the movement of a radioactive cloud with ruthenium-106 in the Ukrainian atmosphere in September 2017 (due to an accidental leak at the Russian nuclear fuel processing plant Mayak), ^{106}Ru was recorded in samples of atmospheric air and atmospheric precipitation in elevated amounts. Ruthenium-106 is beta radioactive. Therefore, its presence in the air will not lead to an increase in the level of effective/exposure dose rate, which, as shown above, is used to monitor the state of the atmospheric air.

Table 4. Results of radiometry of atmospheric air samples in certain settlements of Mykolaiv oblast during the transfer of the ruthenium-106 radioactive cloud in September 2017

Observation point	^{106}Ru content, Bq/m^3
Yuzhnoukrainsk	1.6×10^{-2}
Buzke village	2.4×10^{-2}
Arbuzinka village	2.9×10^{-2}
Kostiantynivka village	2.3×10^{-2}

Table 5. Results of radiometry of atmospheric deposition samples in certain settlements of Mykolaiv region during the transfer of the ruthenium-106 radioactive cloud in September 2017

Observation point	Total beta activity, Bq/(month×m^2)	^{137}Cs content, Bq/(month×m^2)	^{106}Ru content, Bq/(month×m^2)
Yuzhnoukrainsk	13.8±3.0	1.1±0.2	4.1±0.2
Buzke village	12.9±3.5	0.9±0.1	3.9±0.1
Arbuzinka village	13.4±2.6	1.1±0.2	4.1±0.2
Kostiantynivka village	14.7±3.0	1.3±0.3	4.3±0.3

The results of radiometry of atmospheric air samples in certain settlements showed that the ^{106}Ru content increased significantly, reaching 0.03 Bq/m^3. This radionuclide with β-radiation was also detected in atmospheric deposition in the above-mentioned settlements of the Mykolaiv region. The ^{106}Ru content in atmospheric deposition was 4.1±0.2 Bq/(month×m^2). The presence of ruthenium-106 in the atmospheric air and atmospheric deposition was recorded by the external dosimetry laboratory of the SUNPP during the planned systematic radiometric surveys of atmospheric air samples at control points of the 30-km zone around the SUNPP. Such monitoring was not performed in Mykolaiv, so there is no information on the ^{106}Ru content in the air and in atmospheric deposition. We believe that this is indicative of the fact that radioecological monitoring of atmospheric air during increased risks of an emergency at NPPs, as is the case during military operations, should be expanded to include mandatory radiometry of atmospheric deposition samples and, if possible, radiometry of atmospheric air samples.

Conclusions

The research results are important for the implementation of Ukraine's state policy regarding the following: strengthening security for Ukrainian citizens under martial law; improvement of response to technogenic and environmental emergency situations; minimization of the negative socio-economic and ecological consequences of a full-scale war on Ukrainian territories.

In the city of Mykolaiv and in the settlements of the Mykolaiv region during the period of military actions in 2022-2023, the effective dose rate of atmospheric air did not exceed the limits of fluctuations in the natural radiation background and amounted to 0.12±0.02 μSv/hour. The total beta activity of atmospheric deposition in Mykolaiv in 2023 averaged 12.1±2.4 Bq/(month×m^2). The content of ^{137}Cs in these depositions was 1.2±0.4 Bq/(month×m^2). These values did not exceed the levels of natural atmospheric deposition.

The average values of the effective dose rate of atmospheric air in the settlements of Mykolaiv oblast – control posts around the SUNPP – ranged from 0.09 to 0.15 μSv/hour. This variation is due to geological features of Mykolaiv region with crystalline rocks (characterized by higher content of natural radionuclides of uranium-radium and thorium series) coming to the surface in the center of the region in the north. It is desirable to expand the area of use of stations for indicative measurements of radiation background (effective/exposure dose rate) throughout Mykolaiv region.

Background values of total beta activity in the air in Yuzhnoukrainsk and Voznesensk are 0.200-0.700 Bq/l, ^{137}Cs content is 2.5 mBq/l, ^{90}Sr content is 2.0 mBq/l.

During military operations, when the risk of emergencies increases due to missile and drone attacks by the Russian Federation, we believe it is desirable to expand radiation monitoring of the atmospheric air with continuous measurement of not only effective/exposure dose rate, but also radiometry of atmospheric fallout samples and, if possible, radiometry of atmospheric air samples. Using the example of the movement of a radioactive cloud with ruthenium-106 in the Ukrainian airspace in September 2017 (due to an accidental leakage at the Russian nuclear fuel processing plant Mayak), it is shown that the effective dose rate of atmospheric air did not increase, although ^{106}Ru was recorded in increased amounts in atmospheric air and atmospheric deposition samples. Measurement of the effective/exposure dose rate of atmospheric air together with radiometry of atmospheric deposition and atmospheric air samples will allow timely response to possible changes in the radionuclide composition of atmospheric air from both gamma-emitting radionuclides and pure beta-emitting radionuclides.

Conflict of interest

The authors state no conflict of interest.

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