

SCIENTIFIC AND METHODOLOGICAL APPROACH TO THE CREATION OF REMOTE RADIATION MONITORING OF ATMOSPHERIC AIR IN UKRAINE

H.V. Khabarova¹, G.D. Kovalenko², S.V. Barbashev³

¹Scientific Research Institution

“Ukrainian Scientific Research Institute of Ecological Problems”, Kharkiv, Ukraine;

²Institute of High Energy and Nuclear Physics

of National Science Center “Kharkiv Institute of Physics and Technology”, Kharkiv, Ukraine;

³Odesa Polytechnic National University, Odesa, Ukraine

E-mail: anetp@ukr.net

The scientific justification for the creation of a remote component of radiation monitoring of the atmospheric air of Ukraine based on the integration of satellite data, ground-based radiometric and gamma-spectrometric measurements and modeling of radionuclide transfer processes is presented. The need to introduce remote radiation control technologies into the state monitoring system in conditions of military risks, potential accidents at nuclear and radiation-hazardous facilities, as well as transboundary transfer of radionuclides is indicated. An approach and a conceptual algorithm for assessing and predicting the spatiotemporal distribution of radionuclides in the atmospheric air using the theory of advection-diffusion transfer, data assimilation and integration with the European Radiological Data Exchange System (EURDEP) are developed. The system architecture is proposed, which ensures the receipt, pre-processing, harmonization, model interpretation and operational transfer of information in accordance with international standards on radiation safety.

Atmospheric air pollution by radioactive and chemical substances is one of the key risk factors for environmental safety, public health and sustainable development of Ukraine. In the context of full-scale armed aggression of Russia against Ukraine and its subsequent resumption, potential risks become systemic, which is due to damage to industrial, energy and nuclear infrastructure, violation of environmental protection mechanisms and limitations on the possibilities of conducting ground monitoring by traditional means [1].

The state air monitoring system in Ukraine is based mainly on ground-based measurements, which limits its spatial representativeness, efficiency and resilience in crisis conditions. At the same time, international approaches implemented within the framework of the Copernicus Atmosphere Monitoring Service (CAMS) program [2] demonstrate the effectiveness of integrating satellite, ground-based and remote observations with numerical modeling for assessing and forecasting the state of atmospheric air.

In this context, the scientific and practical task of developing a remote component of monitoring atmospheric air pollution by radioactive and chemical substances as an element of the national environmental monitoring system and a component of the Draft Ukraine Recovery Plan [3] is becoming more relevant. In this study, the authors present a justification for the approach to creating a remote component of atmospheric air radiation monitoring in Ukraine.

An important prerequisite for the formation of such an approach is the analysis of the current regulatory and international framework, which determines the framework conditions for the creation and operation of relevant systems in Ukraine.

Previous studies [1, 4, 5] assessed the current state of the monitoring system in Ukraine, presented research on automated radiation monitoring systems, identified

modern approaches to the creation and optimization of a network of automated radiation monitoring points in Ukraine [6], and identified prospects for the integration of remote methods [7]. The study [8, 9] laid the methodological foundation for satellite radiation monitoring in the context of military operations in Ukraine, provided theoretical justification for the need to introduce remote monitoring into the state system [10] and develop a forecasting model with further integration into the European Environmental Information and Observation Network (EIONET) [11], and highlighted the transboundary aspect in accordance with international environmental security [12].

In addition, the authors of the study conducted an analytical review of the regulatory and legal framework in the field of atmospheric air monitoring in Ukraine and the relevant international and methodological framework [1].

The legal framework for state monitoring of atmospheric air is determined by the Law of Ukraine “On Atmospheric Air Protection” [13], which establishes general requirements for monitoring pollutant emissions and atmospheric air quality. However, the aforementioned Law [13] is focused mainly on indicators of pollution by chemical substances, does not take into account the specifics of the radiation component of the atmospheric environment, as well as modern remote observation methods.

Issues of radiation safety of atmospheric air are regulated by the Law of Ukraine “On the Use of Nuclear Energy and Radiation Safety” [14], according to which the principles of radiation protection and control are defined. At the same time, this Law [14] does not contain provisions on the integration of radiation monitoring in accordance with the system of observations of atmospheric air quality and the use of satellite data and data obtained by means of mathematical modeling. The

Law of Ukraine “On Environmental Protection” [15] defines the general framework of environmental monitoring, which is declarative in nature and does not define instrumental and information-analytical mechanisms for the implementation of integrated atmospheric air monitoring.

The Resolution of the Cabinet of Ministers of Ukraine dated August 14, 2019 No. 827 [16] approved the procedure for implementing state monitoring in the field of atmospheric air protection and determined the regulations for the functioning of the network of ground observation posts and data exchange between monitoring entities, however, the use of remote methods and satellite information as a mandatory component of the system is not provided for.

The relevant provisions on the radiation component of atmospheric air monitoring in terms of obtaining operational information on the concentration and dynamics of radionuclide migration in the surrounding natural environment and making decisions in the event of a radiation accident, forecasting the development of the radiation situation are determined by the Strategy for the Development of the Integrated Automated Radiation Monitoring System (IASRM), approved by the Resolution of the Cabinet of Ministers of Ukraine dated April 29, 2022, No. 323-p. [17]. In addition, the Operational Plan for the Implementation of the Strategy for the Integrated Automated Radiation Monitoring System for the Period Until 2024 was approved [17].

It should be noted that this by-law only lays the foundation for automation and international exchange of radiation data, does not cover atmospheric air pollution by chemicals, and does not consider remote monitoring in a larger environmental context.

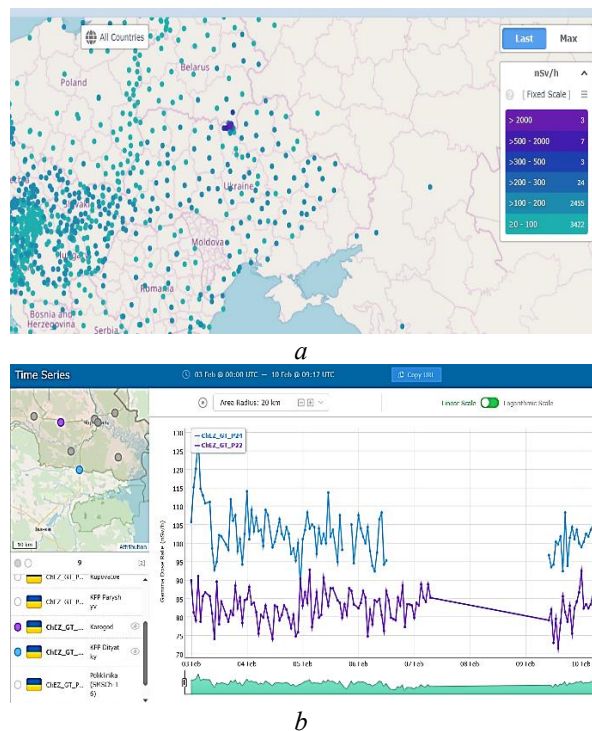
The Cabinet of Ministers of Ukraine of July 7, 2023 No. 610-r. approved the order “On Approval of the Concept of the State Targeted Environmental Program for Environmental Monitoring” [18], which identifies the need to integrate various types of environmental monitoring and implement information and analytical systems, but does not contain clearly defined algorithms, technical solutions, and protocols for integrating remote data.

International practice in the field of atmospheric monitoring is based on integrated approaches that combine ground-based, remote sensing, and data obtained through mathematical modeling. In EU countries, the Copernicus services, in particular the CAMS [2], play a key role, providing regular assessment and forecasting of the state of the atmosphere based on the assimilation of satellite and ground-based observations.

Ukraine, as a future IAEA member state [19], partially fulfills its obligations to provide measurement results to the international radiation monitoring system in the international format for the exchange of radiological data in accordance with the implementation of Directive 2013/59/Euratom [20] and the European Online Radiological Data Exchange Platform (EURDEP) [21], the European Community Radiological Information Exchange Platform (EURIE) [22], and the International Radiation Monitoring Information System (IRMIS) [23]. These platforms provide for the rapid exchange of data in

the event of radiation accidents. These mechanisms form the basis for international compatibility of national monitoring systems, but in Ukraine they require further integration with environmental monitoring systems.

Figure, a shows a demonstration map with the image of observation posts on the territory of Ukraine, radiological indicators of which are already automatically transmitted to EURDEP [21], and Figure, b shows a graph for a week and color-coded values of the background radiation power according to the EURDEP gradation.



Map of observation posts in Ukraine and radiation monitoring results displayed on the EURDEP platform [21]

At the same time, the hydrometeorological observation network of the National Radiological Service of Ukraine is not equipped with an automated radiation monitoring system and makes it impossible to provide data to EURDEP [21] on the state of the radiation situation in a continuous mode in the event of an emergency. In addition, Ukraine does not have an integrated automated monitoring system for detecting, analyzing and predicting possible consequences of radiation accidents. As a result of the analysis, we note that the regulatory and legal framework of Ukraine creates general prerequisites for the functioning of atmospheric air monitoring systems and radiation safety, but is characterized by fragmentation and the absence of a single integrated approach. Remote monitoring and the use of satellite data are currently not established as a mandatory element of the system at the state level, which justifies the need to develop an approach (principles, methods, algorithms) to the creation of a remote monitoring component within the framework of the Draft Ukraine Recovery Plan [3].

The current radiation monitoring system of Ukraine is mainly based on stationary ground-based monitoring stations and local measurements, which limits the

possibility of operational spatial analysis and forecasting of radionuclide distribution at the national level. At the same time, international practice provides for the use of satellite technologies, model data assimilation and integrated information platforms [1, 2, 21–23].

The aim of the study is to scientifically substantiate the approach to the creation of remote radiation monitoring of the atmospheric air of Ukraine and to develop recommendations (algorithm) for the assessment and forecasting of radionuclide distribution based on the integration of satellite observations, ground-based gamma-spectrometric measurements, atmospheric transport models and data exchange mechanisms with the European EURDEP network [21].

The work used a set of theoretical, experimental and model methods, in particular:

- Radiation measurement methods: high-resolution gamma spectrometry, equivalent dose rate radiometry, measurement of the volumetric activity of radionuclides in the air.

- Remote sensing methods: use of satellite data on aerosol loading, meteorological parameters, cloudiness and atmospheric dynamics.

- Mathematical modeling: application of the advection-diffusion transfer equation of radionuclides taking into account radioactive decay and source functions [24].

- Data assimilation methods: integration of ground measurement results into numerical models to refine the forecast.

- System and structural and functional analysis: development of the architecture of the remote monitoring component taking into account the requirements of EURDEP [21] in accordance with the format, time discreteness and spatial representativeness of the data.

- Comparative analysis of international experience: use of CAMS approaches [2] to adapt architectural solutions to the conditions of Ukraine.

The authors of the study propose to assess and predict the state of atmospheric air pollution by radioactive and chemical substances using the integration of various data sources and a combination of ground-based measurements, remote sensing and modeling of processes in atmospheric air. The proposed approach corresponds to international practice in ensuring increased spatial and temporal representativeness of monitoring results. The proposed approach corresponds to international practice in ensuring increased spatial and temporal representativeness of monitoring results.

The key methodological element is data assimilation, which allows combining measurement results with different spatial and temporal resolutions into a single, consistent assessment system. For this purpose, methods of statistical processing, spatial interpolation and model adjustment are used, which ensure a reduction in uncertainties and an increase in the reliability of assessments.

The assessment of the state of atmospheric air is proposed to be carried out on the basis of:

- actual measurements of pollutant concentrations;
- remote indicators (aerosol optical thickness, gas impurity content, meteorological fields);

- results of numerical modeling of the transport and transformation of impurities in the atmosphere.

Forecasting of atmospheric air quality is based on the use of meteorological forecasts, emission scenarios and modeling and assessment of the transfer of radionuclides, which allows forming short- and medium-term forecasts of pollution levels and assessing possible risks for the population and the environment.

The conceptual model of the radiation component of remote monitoring of atmospheric air is considered as a superstructure over existing state monitoring systems, which does not replace, but at the same time complements ground-based observations, ensuring their spatial and information expansion. This model involves the formation of a single information and analytical circuit, which includes:

- data collection and initial validation;
- information integration and assimilation;
- analytical processing and forecasting;
- formation of information products for users of various levels.

CAMS methodological approaches [2] were used as a reference model for building the system architecture, taking into account the features, structure of observation networks and regulatory requirements of Ukraine.

It should be noted that the radiation component of remote monitoring of atmospheric air is based on a comprehensive analysis of data from ground-based measurements of radionuclides and the results of evaluation using models of their transport in the atmosphere. The main attention is paid to critical radionuclides, such as ^{137}Cs , ^{131}I , ^{222}Rn and others, specified in [1, 9], which characterize the radiation state of atmospheric air.

The approach proposed by the authors involves:

- use of data from automated radiation monitoring stations;
- involvement of remote indicators of atmospheric processes (aerosol load, circulation parameters);
- application of atmospheric transport models to predict the distribution of radionuclides.

This approach provides the ability to assess the radiation situation even under conditions of limited access to ground observation points and allows for a prompt response to potential radiation threats. An important element of this approach is ensuring the compatibility of the radiation component of remote monitoring with existing information systems at the national level. Integration is envisaged with the Integrated Automated Radiation Monitoring System (IASRM) and the State Air Monitoring System.

Data exchange should be carried out on the basis of unified protocols and formats, which will provide the possibility of further integration with the international networks EURDEP [21], ECURIE [22] and IRMIS [23] and will create the prerequisites for prompt international information and fulfillment of Ukraine's obligations in the field of radiation and environmental safety.

The proposed approach and algorithm are being further developed to form a scientifically sound basis for creating a remote component of monitoring atmospheric air pollution by radioactive and chemical substances. Their implementation will ensure a systematic transition

from fragmented observations to integrated assessment and forecasting of the state of atmospheric air, which is a necessary condition for the effective implementation of the Draft Recovery Plan of Ukraine [3].

CONCLUSIONS AND SUGGESTIONS

The radiation monitoring system of atmospheric air in Ukraine is based mainly on ground-based measurements of dose rate and laboratory determination of radionuclides, which is a spatially limited approach. Remote sensing methods and satellite data are not used systematically to assess and predict the transport of radionuclides in the atmosphere, despite their active use in international practice. The regulatory and legal framework in the field of radiation safety of Ukraine does not provide for the integration of radiation monitoring data with remote atmospheric observations and model calculations.

Compliance with the requirements for standardized formats, unified validation algorithms and speed of information transmission for providing data to international data exchange networks (EURDEP, ECURIE, IRMIS), which creates additional requirements for national monitoring systems.

In conditions of emergency situations and military risks, exclusively ground-based radiation monitoring does not provide sufficient speed and completeness of information for predicting the development of the radiation situation.

The authors of the study proposed further development and implementation of a remote component of atmospheric radiation monitoring, which is focused on integrating the measurement of critical radionuclides in combination with modeling of processes in atmospheric air.

In addition, an important component of the system is the further provision of international standards for measurements, validation and data transmission, compatible with the requirements of the EURDEP, ECURIE and IRMIS networks.

At the same time, the use of EU Copernicus CAMS approaches and modeling of atmospheric processes will contribute to supporting the interpretation of radiation measurements and forecasting the spread of radionuclides.

Integration of the remote component of radiation monitoring into the IASRM as a functional module, and adoption of the developed approach as a scientific and methodological basis for the modernization of atmospheric radiation monitoring within the framework of the Draft Ukraine Recovery Plan.

REFERENCES

1. Report on scientific and research work on the topic "Development of a Project for the remote component of monitoring atmospheric air pollution by radiation and chemical substances for the Draft Ukraine Recovery Plan" (interim), 2025. USRIEP. 100 p. (UA0125U001198).
2. Copernicus Atmosphere Monitoring Service (CAMS). URL: <https://www.copernicus.eu/en/copernicus-services/atmosphere>.

3. Draft Ukraine Recovery Plan dated August 9, 2022 URL: <https://www.kmu.gov.ua/storage/app/sites/1/recoveryrad/ua/environmental-safety-assembly.pdf>
4. S.V. Barbashev, V.I. Vitko, Kovalenko G.D. Radiation monitoring in Ukraine: status, problems and ways to solve them: monograph. Odesa, 2011, 80 p.
5. S.V. Barbashev, V.I. Vitko, G.D. Kovalenko. Automated radiation control systems in the surrounding environment: monograph. Odesa, 2015, 132 p.
6. Barbashev S.V. Approaches to building a network of automated radiation monitoring posts in the territory of Ukraine // *Problems of Atomic Science and Technology*. 2024, №3 (151), p. 142-147; DOI: <https://doi.org/10.46813/2024-151-142>
7. H. Khabarova, G. Kovalenko, S. Barbashev. State and prospects of using remote air monitoring methods in Ukraine // *Ecological Sciences*. 2025, № 4(61), p. 92-97; <https://doi.org/10.32846/2306-9716/205.eco.4-61.15>
8. H.V. Khabarova, G.D. Kovalenko, S.V. Barbashev. Application of satellite technologies for monitoring the radiation state of the atmospheric air during the war and post-war reconstruction of Ukraine // *Problems of Atomic Science and Technology*. 2025, № 3(157), p. 194-199; DOI: <https://doi.org/10.46813/2025-157-194>.
9. G.V. Khabarova, G.D. Kovalenko, S.V. Barbashev. Remote monitoring of forest fires in wartime in the Kharkiv region // *Ecological safety: problems and solutions: collection of scientific articles of the XXI International Scientific and Practical Conference*, 25–26 September 2025, Kharkiv, p. 388-395; <http://doi.org/10.63341/ep/11.2025>
10. H. Khabarova, V. Vitko, G. Kovalenko, S. Barbashev. The role of modern remote sensing technologies in atmospheric air monitoring under martial law in Ukraine // *Proceedings of the XXIII conference on High Energy and Nuclear Physics*, 8–10 April 2025, Kharkiv, Ukraine, p. 176-179; DOI: <https://doi.org/10.46813/pc-hepnp/2025-176>
11. The European Environment Information and Observation Network (Eionet). URL: <https://www.eionet.europa.eu/>
12. H.V. Khabarova, V.I. Vitko, G.D. Kovalenko, S.V. Barbashev. Mutual transboundary radiation impact of NPPs in Ukraine and neighboring countries: analysis, forecast and control // *Problems of Atomic Science and Technology*. 2025, №6(160), p. 124-130; DOI: 10.46813/2025-160-124
13. Law of Ukraine "On Air Protection". URL: <https://zakon.rada.gov.ua/laws/show/2707-12#Text>.
14. Law of Ukraine "On the use of nuclear energy and radiation safety". URL: <https://zakon.rada.gov.ua/go/39/95-%D0%B2%D1%80>
15. Law of Ukraine "On Environmental Protection" URL: <https://zakon.rada.gov.ua/go/1264-12>
16. Resolution of the Cabinet of Ministers of August 14, 2019 No. 827 "Some issues of state monitoring in the field of atmospheric air protection" as amended by Resolution of the Cabinet of Ministers of May 7, 2023, No. 513. URL: <https://zakon.rada.gov.ua/laws/show/827-2019-%D0%BF#Text>

17. Resolution of the Cabinet of Ministers of Ukraine dated April 29, 2022 No. 323-r. "On approval of the Strategy of the Integrated Automated Radiation Monitoring System for the period until 2024". URL: <https://zakon.rada.gov.ua/go/323-2022-%D1%80>
18. Resolution of the Cabinet of Ministers of Ukraine dated July 7, 2023 № 610-r. "On approval of the Concept of the State Targeted Environmental Monitoring Program". URL: <https://zakon.rada.gov.ua/laws/show/610-2023-%D1%80#Text>
19. International Atomic Energy Agency (IAEA). URL: <https://www.iaea.org/>
20. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. URL: <https://eur-lex.europa.eu/eli/dir/2013/59/oj>
21. The European Radiological Data Exchange Platform (EURDEP). URL: <https://remon.jrc.ec.europa.eu/About/Rad-Data-Exchange>
22. The European Community Urgent Radiological Information Exchange (ECURIE). URL: https://energy.ec.europa.eu/topics/nuclear-energy/emergency-preparedness-and-response_en
23. International Radiation Monitoring Information System (IRMIS). URL: <https://www.iaea.org/ru/node/281678>
24. IAEA Environmental and Source Monitoring for Purposes of Radiation Protection. URL: <https://www.iaea.org/publications/7176/environmental-and-source-monitoring-for-purposes-of-radiation-protection>

НАУКОВО-МЕТОДИЧНИЙ ПІДХІД ДО СТВОРЕННЯ В УКРАЇНІ ДИСТАНЦІЙНОГО РАДІАЦІЙНОГО МОНІТОРИНГУ АТМОСФЕРНОГО ПОВІТРЯ

Г.В. Хабарова, Г.Д. Коваленко, С.В. Барбашев

Представлено наукове обґрунтування створення дистанційної складової радіаційного моніторингу атмосферного повітря України на основі інтеграції супутникових даних, наземних радіометричних і гамма-спектрометричних вимірювань та моделювання процесів перенесення радіонуклідів. Вказано на необхідність впровадження дистанційних технологій радіаційного контролю у державну систему моніторингу в умовах воєнних ризиків, потенційних аварій на ядерно- та радіаційно-небезпечних об'єктах, а також транскордонного перенесення радіонуклідів. Розроблено підхід та концептуальний алгоритм оцінювання та прогнозування просторово-часового розподілу радіонуклідів в атмосферному повітрі із застосуванням теорії адвекційно-дифузійного перенесення, асиміляції даних та інтеграції з Європейською системою обміну радіологічними даними (EURDEP). Запропоновано архітектуру системи, що забезпечує отримання, попередню обробку, гармонізацію, модельну інтерпретацію та оперативну передачу інформації відповідно до міжнародних стандартів щодо радіаційної безпеки.