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Research article

ASSESSMENT OF THE HEALTH RISK FOR PEOPLE RESIDING ON THE TERRITORY INFLUENCED BY THE VOSTOCHNY COSMODROME UNDER MULTI-FACTOR AND MULTI-ENVIRONMENT EXPOSURE TO CHEMICALS

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Rocket and space activities are an important source of hazardous impact on the environment. Its results can manifest themselves in an area where a cosmodrome is located, adjacent territories, in areas where separated parts of a launch vehicle fall. This impact has certain specific features that create population health risks.

Health risks for population of Tsiolkovsky settlement were assessed upon exposure to chemicals that pollute the environment in accordance with the methodical approaches stipulated in the valid Guide (R 2.1.10.3968-23). Initial data were represented by results of environmental surveillance accomplished within social-hygienic monitoring and in field conditions as well as by data collected for a project aimed at substantiating a sanitary protection zone for the Vostochny Cosmodrome launch sites.

Average annual concentrations and their 95 % confidence intervals, which were established based on average daily concentrations, were used to calculate chronic chemical exposures. The 95 % percentile of maximum single concentrations was employed to calculate acute exposures.

Ambient air was established to make the greatest contribution (88.99 %) into non-carcinogenic health risks for people residing in Tsiolkovsky settlement. Particulate matter made the greatest contribution (42.4 %) to the risk of chronic non-carcinogenic effects.

Alerting chronic non-carcinogenic risks of respiratory diseases (up to 5.9 HI) and the blood system (up to 4.1 HI) were established under combined inhalation chemical exposures. Major contributions to non-carcinogenic risks are made by particulate matter (up to 42.4 %), lead (up to 25.9 %), nitrogen oxide (up to 20.2 %), nitrogen dioxide and carbon oxide (23.1 % each).

Keywords: *rocket and space activities, Vostochny cosmodrome, Tsiolkovsky settlement, rocket fuel, risk assessment, environmental factors, chemical pollutants, health problems, carcinogenic and non-carcinogenic risk.*

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Rocket and space activities occupy an important place among modern sources of impact on the environment. This activity sphere has certain specific features; its results can manifest themselves in an area where a cosmodrome is located, adjacent territories, in areas where separated parts of a launch vehicle (hereinafter LV) fall [1, 2].

Cosmodrome operations belong to activities of extremely high risk as per potential population health risks[1]. Launch technology does not exclude possible pollution of ecosystems at all stages of LV preparation, launch and flight. Given that, pollution sources might include rocket fuel and products created by its combustion and decay; products of a reaction between fuel and ambient air components; fuel leak; as well as accidents during transportation and filling of rockets and storage of toxicants [3–6]. However, objects of a cosmodrome surface infrastructure[2] are the most hazardous potential sources that can emit highly toxic chemicals. These objects are employed for preparing a LV launch and include launch and technical complexes, storages of highly toxic components of rocket fuel, systems for filling and sewage pumping, stations where vapors and sewage is neutralized [7, 8].

All environmental objects in a zone influenced by a cosmodrome are under technogenic impacts. Upon entering them, rocket fuel goes through certain physical and chemical transformations. For example, it can evaporate off the water surface; be absorbed by soils, plants, or sediments; dissolve in subterranean and surface waters, soil water and precipitations, etc. [9–15].

Observation results confirm significant negative influence exerted by pollutants associated with cosmodrome operations on human health and the environment. A person may suffer damage done by aggressive and highly toxic fuel components when a technological process is violated; there has been an industrial accident; when maintaining rockets or entering a contact with broken constructions of LV stages in fall areas; as well as upon long-term occupational contacts with the analyzed components even in low doses. This means both acute and chronic diseases are possible due to exposure to chemical components in rocket fuel [16–21].

For example, unsymmetrical dimethylhydrazine (UDMH, heptyl) and its derivatives are extremely hazardous components of rocket fuel per intensity of their adverse effects on live organisms upon introduction through the gastrointestinal tract, respiratory organs, skin and mucosa[3]. They affect many organs and systems including the cardiovascular and nervous system, liver, respiratory organs, digestive organs, blood-making organs, urine excretion system; they disrupt protein, lipid, and carbohydrate metabolism, redox reactions, oxygen transport and blood coagulation. Remote UDMH effects, including carcinogenic, mutagenic, teratogenic, and embryotrophic ones, have been evidenced in animal experiments[3] [16, 18, 20–22].

Tsiolkovsky closed administrative-territorial formation includes Tsiolkovsky settlement and the Vostochny Cosmodrome, a city-forming enterprise, which is chemical, explosion and fire-hazardous. It is necessary to analyze and assess possible outcomes of the technogenic impacts exerted by the cosmodrome on human health and the environment. This analysis and assessment should be

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[1] O federal'nom gosudarstvennom sanitarno-epidemiologicheskom kontrole (nadzore): Postanovlenie Pravitel'stva Rossiiskoi Federatsii ot 30.06.2021 № 1100 [On the Federal State Sanitary-Epidemiological Control (Surveillance): the Order by the RF Government issued on June 30, 2021 No. 1100]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/607148291 (March 12, 2024) (in Russian).

[2] Proekt obosnovaniya sanitarno-zashchitnoi zony ploshchadok №№ 1, 2, 3 kosmodroma «Vostochnyi» [The project for substantiating a sanitary protection zone for the Vostochny Cosmodrome launch sites No. 1, 2, 3]: project documentation, 2013, vol. 1 (in Russian).

[3] Spravochnik po toksikologii i gigienicheskim normativam (PDK) potentsial'no opasnykh khimicheskikh veshchestv [Reference book on toxicology and hygienic standards (MPL) of potentially hazardous chemicals]. In: V.S. Kushneva, R.B. Gorshkova eds. Moscow, IzdAT Publ., 1999, 272 p. (in Russian).

regular and expand together with the development of the cosmodrome [23–25].

The methodology for health risk assessment is one of the most effective analytical instruments for assessing health risks caused by environmental exposures. Given that, **the aim of this study** was to assess health risks for people living in Tsiolkovsky settlement under multifactorial exposure to chemicals in ambient air, drinking water and soils and to develop hygienic activities aimed at minimizing technogenic impacts of the cosmodrome on human health.

Materials and methods. The study was accomplished within the Federal Target Program 'Development of Cosmodromes for the Period 2017–2025 to Support Space Activities in the Russian Federation'.

Vostochny Cosmodrome was chosen as the research object since it is a potential source of adverse impacts on the environment and health of people living in Tsiolkovsky settlement.

Some analytical methods employed in this study cannot be considered highly sensitive in comparison with reference concentrations under inhalation exposure to potentially hazardous chemicals. Bearing this in mind, we combined monitoring results with data obtained by modeling emission dispersion for several pollutants (UDMH, kerosene, dimethylamine, ethylbenzene) in exposure assessment.

Average annual concentrations and their upper 95 % confidence limits established as per average daily concentrations over the analyzed period were used to calculate levels of chronic chemical exposure. Acute exposures were assessed using 95 % percentile of single maximum levels.

Results of laboratory tests performed on environmental objects (ambient air, drinking water, and soil) were obtained within social and hygienic monitoring and the expanded monitoring program upon LV launches. All tests were conducted at the Center for Hygiene and Epidemiology No. 51 of the Federal Medical-Biological Agency (FMBA) of Russia and Scientific Research Institute for Hygiene, Occupational Pathology and Human Ecology of the FMBA over 2017–2023. We also used our own data obtained by field instrumental research.

Overall, levels of 22–27 pollutants emitted into ambient air were controlled in 2017–2023; between 39 to 42 indicators were controlled in drinking water including organoleptic, microbiological, and parasitological ones. Soil pollution in residential areas of Tsiolkovsky settlement was assessed as per 19 chemicals identified in it. Soil samples were tested to identify specific chemicals in them, such as UDMH and products created by its destruction, including nitrosodimethylamine (NDMA), dimethylamine (DMA), tetramethyltetracene (TMT), and formaldehyde. They were also tested to identify generally toxic chemicals in them including sulfur and nitrogen dioxides, nitrogen and carbon oxides, hydrogen sulphide, phenol, and particulate matter. We quantified lead, mercury, nickel, cadmium, cobalt, zinc, copper, and chromium; we also identified levels of benzo(a)-pyrene, arsenic, petroleum products, etc.

A chemical was removed from the list if its levels below limits of detection were identified in more than 95 % of tested samples.

The Unified Program for Calculating Ambient Air Pollution (UPRZA) 'Ekolog', version 4.6, the 'Mediums' software module, was used for modeling dispersion of pollutants emitted from stationary sources of the cosmodrome into ambient air and for calculating average annual concentrations. Meteorological characteristics of the analyzed territory were provided as a meteofile following a specific inquiry by the Voeikov Main Geophysical Observatory (MGO). Dispersion was calculated for UDMH, kerosene, dimethylamine, and ethylbenzene.

Main technogenic sources of chemical environmental pollution located on the Vostochny Cosmodrome Area were examined using data from the project for substantiating a sanitary protection zone for the launch and technical complexes and the complex for production and storage of rocket fuel components.

Health risks were assessed using the methodology described in the Guide on Assessing Health Risks under Exposure to Chemical Pollutants in the Environment (R 2.1.10.3968-23)[4] by subsequent implementation of all relevant stages. Risks were calculated separately for carcinogenic and non-carcinogenic effects together with describing priority exposure media and ways of introduction of chemical pollutants into the human body.

When selecting chemicals in ambient air, drinking water and soils as priority ones to be covered by subsequent health risk assessment, we analyzed their toxicity and hazards including reference levels and relevant critical organs and systems as well as factors of carcinogenic potential.

Health risk assessment covered chemicals that met the following criteria: a chemical was listed as priority and extremely hazardous[5]; a chemical made a considerable (not less than 95 %) contribution to the index of relative non-carcinogenic hazard and to a level of mass emissions; the hazard quotient (HQ) value was not below 0.1 for a chemical; a chemical could produce carcinogenic effects.

Since carcinogenic effects pose serious threats for health, risk assessment covered all chemicals with carcinogenic properties according to the IARC and U.S. EPA and in conformity with the Guide R 2.1.10.3968-23, for which factors of carcinogenic potential were established.

The exposure assessment stage involved calculating dose burdens for people living in Tsiolkovsky settlement under different ways of chemical introduction into the body (by inhalation, orally, or through skin) from ambient air, drinking water, and soil. It is impossible to identify exact sources of possible pollution when assessing exposure routes for a chemical penetrating the body with drinking water and soil. Given that, these exposure routes were not fully investigated. The ultimate exposure scenario for the analyzed chemicals is provided in Table 1.

Table 1

Scenario of exposure to chemicals in the analyzed environmental objects

Environmental object	Introduction		
	inhalation	oral	subcutaneous
Ambient air	+	–	–
Drinking water	–	+	+
Soil	–	+	+

Occupational exposures were not considered in the present study.

Introduction of chemicals with drinking water and soil was calculated by analyzing available monitoring data.

Hazard quotients (HQ) and hazard indexes (HI) were calculated to assess health risks, including total hazard index (THI) upon multi-media and multifactorial exposure. Individual carcinogenic risk (CR) was calculated using data on exposure levels and values of carcinogenic potential factors for an analyzed way of introduction upon multifactorial and multi-media exposure (TCR) in accordance with relevant formulas provided in the Appendix 14 to the Guide R 2.1.10.3968-23.

Acceptability and gradations of carcinogenic and non-carcinogenic risks were taken in conformity with the Guide R 2.1.10.3968-23.

[4] R 2.1.10.3968-23. Rukovodstvo po otsenke riska zdorov'yu naseleniya pri vozdeistvii khimicheskikh veshchestv, zagryaznyayushchikh sredu obitaniya, utv. Federal'noi sluzhboi po nadzoru v sfere zdravookhraneniya ot 5 sentyabrya 2023 g. [The Guide on Assessing Health Risks under Exposure to Chemical Pollutants in the Environment, approved by the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing on September 05, 2023]. *GARANT: information and legal support*. Available at: https://base.garant.ru/408644981/ (January 15, 2024) (in Russian).

[5] O spiske prioritetnykh veshchestv, soderzhashchikhsya v okruzhayushchei srede, i ikh vliyanie na zdorov'e naseleniya: informatsionnoe pis'mo Departamenta Gossanepidnadzora Minzdrava RF ot 7 avgusta 1997 goda № 11/109-111 [In the list of priority chemicals in the environment and their impact on human health: information letter by the Department for State Sanitary and Epidemiological Surveillance of the RF Ministry of Health dated August 07, 1997 No. 11/109-111]. *GARANT: information and legal support*. Available at: https://base.garant.ru/4177814/ (November 30, 2023) (in Russian).

The boundary of permissibility (acceptability) of carcinogenic risk is between $1.0\cdot10^{-6}$ and $1.0\cdot10^{-4}$. For non-carcinogenic risk, a value of the hazard quotient should not be above 1.0; a value of the hazard index, above 3.0.

Results and discussion. Twelve priority chemicals were identified at the hazard identification stage by ranking chemicals in ambient air per a threat they pose. All these chemicals have potential ability to produce chronic non-carcinogenic effects on exposed population; six can produce acute non-carcinogenic effects (nitrogen dioxide, benzene, sulfur dioxide, carbon oxide, formaldehyde, and phenol); seven chemicals can produce carcinogenic effects (UDMH, benzo(a)pyrene, formaldehyde, benzene, ethylbenzene, soot (carbon), and lead).

Combined introduction of the analyzed chemicals under chronic inhalation exposure can cause diseases of the respiratory system (nitrogen dioxide, nitrogen oxide, formaldehyde, soot, sulfur dioxide, and particulate matter); hematopoietic system (benzene, nitrogen dioxide, nitrogen oxide, carbon oxide, and lead); affect developmental processes (benzo(a)pyrene, ethylbenzene, carbon oxide, and lead); cause diseases of the central nervous system (carbon oxide and lead), cardiovascular system (carbon oxide and phenol), liver (UDMH, phenol), and kidneys (lead and phenol).

Acute inhalation exposure may lead to non-carcinogenic adverse effects on the respiratory system (nitrogen dioxide, sulfur dioxide, and phenol) and eyes (formaldehyde and phenol).

Thirteen priority chemicals were identified in drinking water from the centralized water supply system; 12 of them can affect the central nervous system (manganese, arsenic, and mercury), developmental processes (arsenic, mercury, and boron), hematopoietic system (nitrites, nitrates, and zinc), kidneys (molybdenum, cadmium, and mercury), and gastrointestinal tract (copper, fluoride, and iron). According to IARC and U.S. EPA, cadmium, arsenic, and lead can produce carcinogenic effects upon oral introduction with drinking water.

Ten priority chemicals were identified in soils; 4 of them have carcinogenic properties (UDMH, arsenic, cadmium, and lead) and other 8, upon combined introduction, can cause diseases of the central nervous system (manganese, arsenic, and mercury), hematopoietic system (zinc and nitrates), kidneys (cadmium and mercury), and gastrointestinal tract (formaldehyde and copper); they can also affect developmental processes (arsenic and mercury).

Carcinogenic risk assessment established that the greatest contributions to the total individual carcinogenic risk were made by arsenic (introduced with drinking water, both for children and adults 97.92 %; with soil, 25.44 and 20.5 % accordingly), formaldehyde (introduced form ambient air, 80.85 % for children and 80.88 % for adults), and UDMH (introduced from soil, 65.29 % for children and 65.58 % for adults) (Table 2).

Drinking water makes the major contribution of 58.94 % to the total carcinogenic health risks for adults among all analyzed ways of chemical introduction into the body. For children, the greatest contributions are made by drinking water and ambient air, 36.09 % and 35.44 % accordingly (Table 3).

Table 2

Total individual carcinogenic risk upon multi-route and multi-media chemical exposure

Chemical	Ambient air		Drinking water		Soil	
	CR	Contribution, %	CR	Contribution, %	CR	Contribution, %
1	2	3	4	5	6	7
Adults						
Benzo(a)pyrene	6.6E-10	0.01	–	–	–	–
UDMH	6.4E-08	0.67	–	–	2.6E-06	**65.58**
Benzene	1.5E-06	15.76	–	–	–	–

End of the Table 2

1	2	3	4	5	6	7
Soot	4.5E-09	0.05	–	–	–	–
Formaldehyde	7.7E-06	**80.88**	–	–	–	–
Ethylbenzene	8.7E-10	0.01	–	–	–	–
Lead	2.5E-07	2.63	1.1E-08	0.05	8.4E-09	0.21
Cadmium	–	–	3.9E-07	2.02	3.5E-07	8.71
Arsenic	–	–	1.9E-05	**97.92**	1.0E-06	**25.50**
Total individual carcinogenic risk (∑CR)	9.5E-06	100	1.9E-05	100	4.0E-06	100
Children						
Benzo(a)pyrene	6.2E-10	0.01	–	–	–	–
UDMH	6.0E-08	0.67	–	–	4.7E-06	**65.29**
Benzene	1.4E-06	15.72	–	–	–	–
Soot	4.2E-09	0.05	–	–	–	–
Formaldehyde	7.2E-06	**80.85**	–	–	–	–
Ethylbenzene	8.1E-10	0.01	–	–	–	–
Lead	2.4E-07	2.69	5.0E-09	0.05	1.5E-08	0.21
Cadmium	–	–	1.8E-07	2.02	6.5E-07	9.06
Arsenic	–	–	8.9E-06	**97.92**	1.8E-06	**25.44**
Total individual carcinogenic risk (∑CR)	8.9E-06	100	9.1E-06	100	7.2E-05	100

Table 3

Individual carcinogenic risk and contributions made by environmental objects to the total individual carcinogenic risk under multi-route and multi-medium chemical exposure

Introduction	Ambient air	Drinking water	Soil	Total individual carcinogenic risk for an analyzed way of introduction	Contribution, %
Adults					
Inhalation	9.5E-06	–	–	9.5E-06	28.61
Oral	–	1.9E-05	3.6E-07	2.0E-05	**60.24**
Subcutaneous	–	1.0E-07	3.6E-06	3.7E-06	11.14
Total individual carcinogenic risk (∑CR)	9.5E-06	2.0E-05	4.0E-06	3.3E-05	100
A contribution in percent made by environmental objects to the total individual carcinogenic risk for an analyzed way of introduction, %	28.92	**58.94**	12.14	100	–
Children					
Inhalation	8.9E-06	-	-	8.9E-06	35.46
Oral	–	9.0E-06	3.6E-07	9.4E-06	**37.45**
Subcutaneous	–	5.9E-08	6.8E-06	6.8E-06	27.09
Total individual carcinogenic risk (∑CR)	8.9E-06	9.1E-06	7.2E-06	2.5E-05	100
A contribution in percent made by environmental objects to the total individual carcinogenic risk for an analyzed way of introduction, %	**35.44**	**36.09**	28.47	100	–

However, in spite of all foregoing, total individual carcinogenic risks turned out to be permissible (acceptable) for people living in Tsiolkovsky settlement even under multi-media and multifactorial introduction of the analyzed chemical carcinogens. They equaled $2.5\cdot10^{-5}$ for children and $3.3\cdot10^{-5}$ for adults.

Calculations of acute non-carcinogenic health risks did not establish any values of hazard quotients or indexes for non-carcinogenic effects above their permissible levels. Levels of acute non-carcinogenic risk of respiratory diseases were up to 0.26 HIac for adults and 1.19 HIac for children; diseases of the eye and adnexa, 0.27 HIac and 1.22 HIac accordingly.

We established an alerting non-carcinogenic health risk for children under chronic inhalation exposure to particulate matter (up to 2.5 HQch).

Alerting non-carcinogenic risk levels were established under combined inhalation exposure (between 3.5 and 5.9 HI) as regards diseases of the respiratory system (up to 5.9 HI) and the hematopoietic system (up to 4.1 HI). A major contribution to non-carcinogenic risk of respiratory diseases was made by particulate matter (up to 42.4 %); diseases of the blood and blood-forming organs, by lead (up to 25.9 %), nitrogen dioxide and carbon oxide (23.1 % each), and nitrogen oxide (up to 20.2%) (Table 4).

Ambient air makes the greatest contribution of 88.99 % to non-carcinogenic health issues under chronic exposure (Table 6).

Table 4

Non-carcinogenic health risks (hazard indexes) per critical organs / systems and per environmental objects under multi-media and multifactorial chemical exposure

Critical organ / system	Ambient air		Drinking water		Soil		Total hazard index (∑THI)	
	adults	children	adults	children	adults	children	adults	children
Respiratory organs	1.50	**5.90**	–	–	–	–	1.50	**5.90**
Cardiovascular system	0.40	1.76	–	–	–	–	0.40	1.76
Central nervous system	0.40	1.70	0.19	0.44	0.0007	0.004	0.59	2.14
Hematopoietic system	0.86	**3.47**	0.25	0.58	0.00001	0.0001	1.11	**4.05**
Development processes	0.40	1.70	0.19	0.45	0.0006	0.003	0.59	2.15
Liver	0.20	0.96	-	-	-	-	0.20	0.96
Kidneys	0.40	1.86	0.09	0.21	0.002	0.001	0.49	2.07
Gastrointestinal tract	–	–	0.07	0.16	0.00001	0.0001	0.07	0.16

Table 6

Contributions made by environmental objects to the total hazard index under multi-media and multifactorial chemical exposure

Critical organ / system	Contribution, %		
	Ambient air	Drinking water	Soil
Respiratory organs	100.0	–	–
Cardiovascular system	100.0	–	–
Central nervous system	76.7	23.1	0.2
Hematopoietic system	83.8	16.2	below 0.01
Development processes	76.3	23.6	0.1
Liver	100.0	–	–
Kidneys	88.2	11.8	below 0.01
Gastrointestinal tract	–	100.0	below 0.01
Contributions made by environmental objects to the total hazard index, %	**88.99**	10.93	0.08

Conclusions. Assessment of multi-media health risks established ambient air to be the leading medium as regards non-carcinogenic health risks for people living in Tsiolkovsky settlement (88.99 %). A major contribution to the risk of non-carcinogenic effects was made by particulate matter (42.4 %); its levels in ambient air created unacceptable health risks at the level of 2.5 HQch.

Alerting levels of unacceptable non-carcinogenic risks were established under combined inhalation exposure (between 3.5 and 5.9 HI) as regards diseases of the respiratory system (up to 5.9 HI) and the hematopoietic system (up to 4.1 HI). A major contribution to non-carcinogenic risk of respiratory diseases was made by particulate matter (up to 42.4 %); diseases of the blood and blood-forming organs, by lead (up to 25.9 %), nitrogen dioxide and carbon oxide (23.1 % each), and nitrogen oxide (up to 20.2%).

These established risk levels are unacceptable for population in general and require development and implementation of health promotion activities.

Our study findings indicate the necessity to make relevant management decisions aimed at creating a safe and comfortable living environment for people who live and work in Tsiolkovsky settlement.

Economic activities are going to intensify drastically due to completion of construction and putting the new launch complex for Angara LV into operation. Implementation of new technologies and rocket models determines the necessity to conduct monitoring over levels of exposure to adverse chemical factors. Primarily, it is necessary to control levels of rocket fuel, dynamics and peculiarities of its accumulation in environmental objects due to the cosmodrome operations for further hygienic assessment of effects produced by rocket and space activities on human health and the environment.

To minimize health risks for Tsiolkovsky settlement population, it is necessary to:

– identify priorities of environmental protection programs implemented at the Vostochny Cosmodrome;

– optimize programs for monitoring over quality of the environment considering priority sources of environmental pollution and chemicals making the greatest contributions to risks of negative health outcomes;

– employ information and analytical capabilities of the system for social and hygienic to make health risk management more targeted.

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References

1. Ladygina L.F., Galutskaya T.V., Ragozina M.A. Environmental problems of space exploration: impact of the missile and space equipment on surrounding environment. *Reshetnevskie chteniya*, 2013, vol. 2, pp. 355–356 (in Russian).

2. Baranov M.E., Dubynin P.A. The socio-ecological consequences of space-rocket activity. *Aktual'nye problemy aviatsii i kosmonavtiki*, 2018, no. 2, pp. 470–472 (in Russian).

3. Kondratyev A., Koroleva T. Liquid Propellants: Monitoring and Evaluation of Environmental Hazards. *Ekologiya i promyshlennost' Rossii*, 2017, vol. 21, no. 2, pp. 45–51. DOI: 10.18412/1816-0395-2017-2-45-51 (in Russian).

4. Koroleva T., Krechetov P., Sharapova A., Kondratyev A. Technogenic Transformation of Terrestrial Ecosystems in the Operation of Rocket and Space Technology. *Ekologiya i promyshlennost' Rossii*, 2017, vol. 21, no. 8, pp. 26–32. DOI: 10.18412/1816-0395-2017-8-26-32 (in Russian).

5. Piankov E.A., Shevkunova O.I., Ufimtseva L.V. Environmental pollution by the components of propellant of "Fregat" booster block in case of emergency during the preparation phase and launch from the Vostochny cosmodrome. *Nauchno-tekhnicheskoe i ekonomicheskoe sotrudnichestvo stran ATR v XXI veke*, 2014, vol. 1, pp. 244–249 (in Russian).

6. Semenova O.N., Voronin N.F., Ivanov S.E., Chistyakov S.V. Scientific and methodical support of environmental and health physics safety of the sites of in-silo launchers after their decommissioning and remediation of lands. *Meditsina ekstremal'nykh situatsii*, 2020, vol. 22, no. 2, pp. 186–192 (in Russian).

7. Semyonova O.N., Alekhnovich A.V., Kruglov A.A., Chushnyakov S.P., Livanov A.S. Organizational, toxicological and sanitary-hygienic aspects of chenimal security of the territories in the zone of possible influence of the industrial enterprise. *ZNiSO*, 2015, no. 11 (272), pp. 27–30 (in Russian).

8. Semenova O.N., Ivanov S.E., Shashkova O.B., Khudyakova O.M., Smirnova S.V. The contents of heavy metals in the soil of the residential area of the CTF Tsiolkovsky at the initial stage of operation of the Vostochny cosmodrome. *Meditsina ekstremal'nykh situatsii*, 2020, vol. 22, no. 1, pp. 75–83 (in Russian).

9. Semenova O.N., Ivanov S.E., Chistyakov S.V., Ryabova T.V. Monitoring results of hazardous chemical factors of the environment around the "Vostochny"cosmodrome at the initial stage of its operation. *Amurskii meditsinskii zhurnal*, 2018, no. 3 (23), pp. 14–19. DOI: 10.22448/AMJ. 2018.3.14-19 (in Russian).

10. Zyablitskaya A.N., Shchuchinov L.V., Alekseev V.B., Nurislamova T.V. Ekologicheskoe soprovozhdenie na territorii Respubliki Altai puskov raket-nositelei «Proton» s kosmodroma Baikonur [Environmental support in the Altai Republic of launches of the Proton launch vehicle from the Baikonur cosmodrome]. *Analiz riska zdorov'yu – 2020 sovmestno s mezhdunarodnoi vstrechei po okruzhayushchei srede i zdorov'yu RISE-2020 i kruglym stolom po bezopasnosti pitaniya: materialy X Vserossiiskoi nauchno-prakticheskoi konferentsii s mezhdunarodnym uchastiem*: in 2 volumes. In: A.Yu. Popova, N.V. Zaitseva eds. Perm, Perm National Research Polytechnic University Publ., 2020, vol. 1, pp. 243–249 (in Russian).

11. Shchuchinov L.V., Zyablitskaya A.N., Alekseev V.B., Nurislamova T.V. Osobennosti monitoringa vliyaniya raketno-kosmicheskoi deyatel'nosti na zdorov'e naseleniya i okruzhayushchuyu sredu Respubliki Altai [Features of monitoring the impact of rocket and space activities on the population health and the environment of the Altai Republic]. *Aktual'nye voprosy analiza riska pri obespechenii sanitarno-epidemiologicheskogo blagopoluchiya naseleniya i zashchity prav potrebitelei: materialy VIII Vserossiiskoi nauchno-prakticheskoi konferentsii s mezhdunarodnym uchastiem*. In: A.Yu. Popova, N.V. Zaitseva eds. Perm, 2018, pp. 257–261 (in Russian).

12. Polyakov A.D., Kombarova M.Yu. Obespechenie bezopasnosti okruzhayushchei sredy kak kompleksnaya gigienicheskaya problema pri ekspluatatsii raketno-kosmicheskoi tekhniki [Ensuring environmental safety as a complex hygienic problem of rocket and space technology]. *Razvivaya vekovye traditsii, obespechivaya "sanitarnyi shchit" strany: materialy XIII Vserossiiskogo s"ezda gigienistov, toksikologov i sanitarnykh vrachei s mezhdunarodnym uchastiem, posvyashchennogo 100-letiyu osnovaniya Gosudarstvennoi sanitarno-epidemiologicheskoi sluzhby Rossii*. In: A.Yu. Popova, S.V. Kuzmin eds. Mytishchi, Federal Scientific Center for Hygiene named after F.F. Erisman Publ., 2022, vol. 2, pp. 168–172 (in Russian).

13. Puzanov A.V., Kirillov V.V., Bezmaternykh D.M., Alekseev I.A., Vdovina O.N., Ermolaeva N.I., Zarubina E.Yu., Vinokurova G.V. [et al.]. Ecological status of streams in the area of the Vostochnyi cosmodrome. *Geografiya i prirodnye resursy*, 2017, no. 2, pp. 66–72. DOI: 10.21782/GIPR0206-1619-2017-2(66-72) (in Russian).

14. Koroleva T.V., Sharapova A.V., Krechetov P.P. A chemical composition of snow on areas exposed to space-rocket activities pollution (Altai Republic). *Gigiena i sanitariya*, 2017, vol. 96, no. 5, pp. 432–437. DOI: 10.1882/0016-9900-2017-96-5-432-437 (in Russian).

15. Puzanov A.V., Sambros V.V., Alekseev I.A., Bezmaternykh D.M. Landshafty territorii kosmodroma «Vostochnyi» i ikh antropogennaya transformatsiya [Landscapes of the territory of the Vostochny cosmodrome and their anthropogenic transformation]. Barnaul, OOO «Pyat' plyus» Publ., 2018, 227 p. (in Russian).

16. Yaguzhinskii L.S., Manukhov I.V., Vagapova E.R., Kassenikh A.G., Konopleva M.N., Zavil'gel'skii G.B., Kotova V.Yu., Bruskov V.I. [et al.]. Eksperimental'nye issledovaniya vliyaniya nizkikh kontsentratsii geptila i produktov ego gidroliza na vodu i biologicheskie ob"ekty [Experimental studies of the influence of low concentrations of heptyl and its hydrolysis products on water and biological objects]. In: Doctor of Chemical Sciences, Prof. L.S. Yaguzhinskii ed. Moscow, Interdisciplinary Center for Fundamental Research MIPT Publ., 2015, 230 p. (in Russian).

17. Shpigun O.A., Kondratev A.D. Estimation peculiarities low concentration of unsymmetrical dimethylhydrazine influence on environment during exploration of rocket equipment. *Ekologicheskii vestnik nauchnykh tsentrov Chernomorskogo ekonomicheskogo sotrudnichestva*, 2004, no. 4, pp. 59–63 (in Russian).

18. Kolyado I.B., Plugin S.V., Tribunsky S.I., Karpenko A.A. The dynamics of the prevalence of diseases of the circulatory system among the population of the Altai territory, living in the zone of infl uence of rocket and space activities. *Meditsina truda i promyshlennaya ekologiya*, 2019, no. 6, pp. 353–358. DOI: 10.31089/1026-9428-2019-59-6-353-358 (in Russian).

19. Meshkov N.A., Valtseva E.A., Kharlamova E.N., Kulikova A.Z. Real and unreal backlashes of aerospace activity for the health of population residing near areas of fall of being separated parts of carrier rockets. *Gigiena i sanitariya*, 2015, vol. 94, no. 7, pp. 117–122 (in Russian).

20. Kolyado I.B., Plugin S.V., Shoikhet Ya.N. Population health in the Altai krai territories adjacent to the areas of falling of separable parts of rocket engines. A comparative study of heath indexes. *Byulleten' nauki i praktiki*, 2016, no. 6, pp. 115–125 (in Russian).

21. Skrebtsova N.V., Sovershaeva S.L., Pavlova E.A. Kharakteristika i analiz dinamiki smertnosti naseleniya, prozhivayushchego vblizi raionov padeniya otdelyayushchikhsya chastei raketnositelei [Characteristics and analysis of the dynamics of mortality among population living near the fall areas of the separated parts of launch vehicles]. *ZNiSO*, 2005, no. 5 (146), pp. 30–32 (in Russian).

22. Sidorov P.I., Skrebtsova N.V., Sovershaeva S.L. Human health in the space rocket-making areas: medical and environmental aspects. *Gigiena i sanitariya*, 2006, no. 3, pp. 11–15.

23. Alekseev I.A., Alekhnovich A.V., Meredelina T.A., Karatsuba L.P., Shchiptsova E.A., Kruglov A.A. The content of heavy metals in soil and groung of natural-anthropogenic complexe and launching area of the cosmodrome "Vostochny". *Meditsina ekstremal'nykh situatsii*, 2016, no. 3 (57), pp. 70–76 (in Russian).

24. Polyakov A.D., Kombarova M.Yu., Salnikov A.A. Hygienic aspects of water use of the population of the territory in the zone of influence of the Vostochny cosmodrome. *Sanitarnyi vrach*, 2023, no. 1, pp. 26–35. DOI: 10.33920/med-08-2301-03 (in Russian).

25. Kombarova M.Yu., Polyakov A.D. Gigienicheskaya otsenka zagryaznennosti pochvy v zone vliyaniya kosmodroma «Vostochnyi» [Hygienic assessment of soil contamination in the zone influenced by the Vostochny cosmodrome]. *Profilakticheskaya meditsina – 2020: sbornik nauchnykh trudov Vserossiiskoi nauchno-prakticheskoi konferentsii s mezhdunarodnym uchastiem*. Saint Petersburg, North-Western State Medical University named after I.I. Mechnikov Publ., 2020, pt 1, pp. 209–212 (in Russian).

Polyakov A.D., Kombarova M.Yu., Radilov A.S., Alikbaeva L.A., Iakubova I.S., Suvorova A.V., Khurtsilava O.G. Assessment of the health risk for people residing on the territory influenced by the Vostochny Cosmodrome under multi-factor and multi-environment exposure to chemicals. Health Risk Analysis, 2024, no. 2, pp. 63–73. DOI: 10.21668/health.risk/2024.2.06.eng

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