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Original article

PUBLIC HEALTH RISK FROM CONTAMINATION OF DRINKING WATER WITH CARCINOGENIC CHEMICALS IN CENTRALIZED WATER SUPPLY SYSTEMS

K.Yu. Mikhaylichenko, A.I. Kurbatova, C.A. Salazar Flores, D.P. Pogorelyy, E.E. Konovalova, A.M. Savich

The paper presents the results of assessing the carcinogenic risk to public health from consuming drinking water contaminated with priority chemicals at the level of their hygienic standards. A comparative analysis of SanPiN 1.2.3685-21 "Hygienic Standards and Requirements for Ensuring the Safety and (or) Harmlessness of Environmental Factors for Humans" and repealed SanPiN 2.1.4.1074-01 "Drinking Water and Water Supply to Populated Areas. Drinking Water. Hygienic Requirements for Water Quality of Centralized Drinking Water Supply Systems. Quality Control" valid since March 01, 2021, is carried out. Maximum allowable concentrations of carcinogenic chemical substances and values of slope factors and risk potential factors have been analyzed. A comparative analysis of SanPiN 1.2.3685-21 that is currently in force and the US EPA "2018 Edition of the Drinking Water Standards and Health Advisories Tables" has been conducted. The average daily intake doses of each studied substance in drinking water at the level of maximum permissible concentrations were determined. It has been found that, despite the tightening of standards for some substances, the content of many carcinogens in water at the maximum allowable concentrations or below can lead to high values of potential carcinogenic risk, and a list of activities is needed to complement the current standards regarding the quality of water.

Keywords: *carcinogenic risk; drinking water; water quality; pollution level carcinogens*

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Научная статья

РИСК ДЛЯ ЗДОРОВЬЯ НАСЕЛЕНИЯ ОТ ЗАГРЯЗНЕНИЯ ПИТЬЕВОЙ ВОДЫ КАНЦЕРОГЕННЫМИ ХИМИЧЕСКИМИ ВЕЩЕСТВАМИ В СИСТЕМАХ ЦЕНТРАЛИЗОВАННОГО ВОДОСНАБЖЕНИЯ

К.Ю. Михайличенко, А.И. Курбатова, К.А. Саласар Флорес, Д.П. Погорелый, Э.Е. Коновалова, А.М. Савич

В работе представлены результаты оценки канцерогенного риска для здоровья населения от потребления питьевой воды, загрязненной приоритетными химическими веществами на уровне их гигиенических нормативов. Проведен сравнительный анализ СанПиН 1.2.3685-21 «Гигиенические нормативы и требования к обеспечению безопасности и (или) безвредности для человека факторов среды обитания» и СанПиН 2.1.4.1074-01 «Питьевая вода и водоснабжение населенных пунктов. Питьевая вода. Гигиенические требования к качеству воды централизованных систем питьевого водоснабжения. Контроль качества», действующего с 1 марта 2021 года. Проанализированы предельно допустимые концентрации канцерогенных химических веществ и значения коэффициентов уклона и факторов потенциального риска. Проведен сравнительный анализ действующего СанПиН 1.2.3685-21 и стандартов питьевой воды и санитарных рекомендаций Агентства по охране окружающей среды США за 2018 год. Определены среднесуточные дозы поступления каждого исследуемого вещества в питьевую воду на уровне предельно допустимых концентраций. Установлено, что, несмотря на ужесточение нормативов на некоторые вещества, содержание многих канцерогенов в воде в предельно допустимых концентрациях или ниже может приводить к *высоким значениям потенциального канцерогенного риска, и необходим перечень мероприятий, дополняющий существующий стандарты качества воды.*

Ключевые слова: *канцерогенный риск; питьевая вода; качество воды; уровень загрязнения; канцерогены*

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Introduction

Negative impact of carcinogenic chemicals on the quality of drinking water and public health. The aquatic environment is one of the leading environmental entities with the largest share of health risks. According to the World Health Organization, approximately 75% of human diseases are caused precisely by the consumption of poor-quality water [5] and the use of water that does not meet hygienic standards for domestic purposes.

Providing the population with drinking water is one of the most important factors that characterize sanitary-epidemiological well-being. Despite the fact that the discharge of technologically polluted wastewater is decreasing, the quality of centralized water supply sources does not improve [9]. That is why among the 17 sustainable development goals specified in the "Agenda for Sustainable Development" [15] and the report "On Human Development in the Russian Federation," there is the goal of "clean water and sanitation" [6]. Ensuring the safety of the drinking water supply is one of the main tasks of the Russian Federation, which is reflected in the Federal Project "Clean Water" within the National Project "Ecology," which has been implemented in Russia since 2019.

The quality of drinking water consumed by the population is a risk factor for the development of not only toxic but also carcinogenic effects. An important factor in preserving the health of the population of the country is the identification and elimination of the adverse effects of drinking water on the human body.

The question of the standards for substances with carcinogenic effects is particularly controversial since many carcinogenic substances do not have a threshold dose, and even a small number of their molecules can potentially disrupt the structure of human deoxyribonucleic acid (DNA) and subsequently cause oncological diseases.

Therefore, it is reasonable to assume that the levels of maximum permissible concentrations (MPC) for some substances in the Russian regulatory framework may be associated with high values of the potential carcinogenic risk.

Within this work, we used the Health Risk Assessment Methodology widely known abroad and used in Russia for more than ten years [1] and assessed the risk of oncological diseases in the population consuming drinking water containing some carcinogenic substances on the level of their maximum permissible concentrations for a long time.

For almost 20 years, hygienic standards for drinking water were regulated by SanPiN 2.1.4.1074-01 “Drinking Water and Water Supply to Populated Areas. Drinking Water. Hygienic Requirements for Water Quality of Centralized Drinking Water Supply Systems. Quality Control” [4]. New standards prescribed in SanPiN 1.2.3685-21 “Hygienic Standards and Requirements for Ensuring the Safety and (or) Harmlessness of Environmental Factors for Humans” [1] came into force on March 01, 2021. Despite the lower MPC values for some substances we analyzed (e.g., benzene, vinyl chloride, 1,2-dibromo-3-chloropropane, dichloromethane, arsenic, lead), standards still could not provide an acceptable maximum level of carcinogenic risk for the population consuming drinking water contaminated with these substances.

Despite the importance of the topic under consideration, there is a lack of scientific work and research on assessing the risk of dependencies between the level of drinking water contamination and the population’s health. However, in the risk analysis, the main hygienic principle is implemented: preventing threats to humans and making targeted, managerial decisions that lead to a reduction in costly financial preventive measures. These factors have determined the relevance, purpose, and objectives of the work.

This work aims to identify the compliance of the hygienic standards for drinking water approved in Russia with the acceptable level of carcinogenic risk established by the World Health Organization for some chemicals with carcinogenic effects. The following tasks were set and solved in the work to achieve this goal:

- Identify chemicals with a carcinogenic effect that are a priority for drinking water (the list of investigated carcinogenic chemicals was given in subsection 1.2 of this work);
- Determine the average daily intake of each of the investigated substances into the human body when they are in drinking water at the level of maximum permissible concentrations;
- Calculate and assess the risks to public health during the oral route of ingestion of chemicals with carcinogenic effects at the level of their maximum permissible concentrations;

- Conduct a comparative analysis of existing SanPiN 1.2.3685-21 “Hygienic Standards and Requirements for Ensuring the Safety and (or) Harmlessness of Environmental Factors for Humans” and the invalid SanPiN 2.1.4.1074-01 “Drinking Water and Water Supply to Populated Areas. Drinking Water. Hygienic Requirements for Water Quality of Centralized Drinking Water Supply Systems. Quality Control.”

Carcinogenic chemicals polluting the aquatic environment. Among the priority carcinogenic pollutants of water in centralized drinking water supply systems, there are substances whose intake is associated with a source of water supply and contamination of drinking water in the process of water treatment or its transportation.

Currently, almost all water sources are exposed to technogenic impacts of varying intensity, which increases the overall health risk and human vulnerability due to changes in the water factor.

The list of carcinogenic chemicals in drinking water studied in this work was compiled on the basis of the analysis of the following documents:

- SanPiN 2.1.4.1074-01 that have expired on March 01, 2021;
- SanPiN 1.2.3685-21 currently valid;
- document of the Environment Protection Agency (US EPA) “2018 Edition of the Drinking Water Standards and Health Advisories Tables” [11];
- list of agents (mixtures) carcinogenic, likely carcinogenic, and possibly carcinogenic to humans, which is developed by the International Agency for Research on Cancer [16].

In this work, the individual lifelong carcinogenic risk was assessed for the following carcinogenic chemicals polluting the drinking water: 1,1-dichloroethene, 1,2-dibromo-3-chloropropane, 1,2-dichloroethane, acrylamide, benz(a)pyrene, benzene, beryllium, bromodichloromethane, bromoform, vinyl chloride, hexachlorobenzene, dibromochloromethane, dichloromethane, arsenic, lead, styrene, carbon tetrachloride, tetrachlorethylene, trichloroethylene, and chloroform.

It should be noted that the health effects of carcinogenic substances in drinking water include various forms of cancer, adverse reproductive outcomes, diseases of the respiratory system, circulatory system, nervous system, and other health disorders [14].

Basis for assessing the quality of drinking water and associated health risks. When assessing the individual carcinogenic risk throughout the entire life, the *Risk* considers its generally recognized classification into four risk ranges in accordance with Guideline P 2.1.10.1920-04 [2]:

- Risk ≤ 1×10-6: includes levels of risk that are perceived by all people to be very low and which do not differ from everyday risks. These risks do not require any additional measures to reduce them, and the levels of such risks are subject to only periodic monitoring;

- 1×10-6 < Risk ≤ 1×10-4: the maximum permissible level of risk. At this level, many hygienic standards (foreign and recommended by international organizations) have been established. For drinking water, the WHO uses;
- 1×10-5 as an acceptable risk. Such levels of risk should be constantly monitored; in some situations, additional measures are required to reduce them;
- 1×10-4 < Risk < 1×10-3: an acceptable level of risk for occupational groups and an unacceptable level of risk for the general population. If such a risk appears, it is recommended to carry out special health measures;
- Risk ≥ 1×10-3: a level of risk unacceptable for the population and occupational groups. In this case, it is necessary to give recommendations to the persons who make decisions on taking emergency remedial measures to reduce the risk.

As a theoretical basis for assessing the risk of danger to the population consuming drinking water contaminated with carcinogenic chemicals, Methodological Recommendations MR 2.1.4.0032-11 "Integral Assessment of Drinking Water from Centralized Water Supply Systems in Terms of Chemical Safety Indicators" were used [1]. The method we used to assess the level of carcinogenic risk is detailed in the next section. The research results are also presented in the subsequent sections of this work.

Materials and methods

A non-threshold method was used in this work to assess the level of carcinogenic risk [2]. First of all, the *LADD* (Lifetime Average Daily Dose) indicator – the average daily lifetime dose of the substance – was calculated to assess the risk. The *LADD* indicator is based on the use of information on the values of threshold concentrations, which are determined in the course of experimental studies aimed at developing regulations for the maximum content of harmful substances in environmental objects.

The *Risk* indicator – the likelihood of a threat to human life or health or a threat to the life or health of future generations caused by the impact of environmental factors [10] – was calculated using a linear model since the calculated levels of water pollution by carcinogenic chemicals were at the MPC level:

$$Risk = SF_O \times LADD, \tag{1}$$

where: SFO (Oral Slope Factor) – slope factor, risk potential factor (a measure of additional individual risk or the degree of increase in the likelihood of an adverse effect), $(mg/(kg \times day))^{-1}$.

The *Risk* indicators were studied within this work and calculated using the MPC values of some chemicals with carcinogenic properties given in SanPiN 2.1.4.1074-01, SanPiN 1.2.3685-21, the document of the United States Environment Protection Agency (US EPA) "2018 Edition of the Drinking Water Standards and Health Advisories Tables", and the values of the indicator of the carcinogenic risk potential factor given in Guideline P 2.1.10.1920-04 (Table 1).

Table 1.

Maximum permissible concentrations of carcinogenic chemicals and values of the slope factor, the potential risk factor for SFO [1; 4; 7; 12; 13]

No.	Indicator	Chemical formula	Registration number CAS	Maximum permissible concentrations (MPC) mg/ l			SF_O, (*mg*/(*kg* × *day*))$^{-1}$
				SanPiN 2.1.4. 1074-01	SanPiN 1.2. 3685-21	US EPA	
1	1,1-dichloroethene	$C_2H_2Cl_2$	156-59-2	0.03	0.03	0.05	0.59
2	1,2-dibromo-3-chloropropane	$C_3H_5Br_2Cl$	96-12-8	0.01	0.001	0.0002	7
3	1,2-dichloroethane	$C_2H_4Cl_2$	107-06-2	0.003	0.003	0.005	0.091
4	Acrylamide	C_3H_5NO	79-06-1	0.01	0.0001	0.0005	4.5
5	Benz (a) pyrene	$C_{20}H_{12}$	50-32-8	0.000005	0.00001	0.0002	7.3
6	Benzene	C_6H_6	71-43-2	0.01	0.001	0.005	0.055
7	Beryllium	Be	7440-41-7	0.0002	0.0002	0.004	4.3
8	Bromodichloromethane	$CHBrCl_2$	75-27-4	0.03	0.03	0.08	0.062
9	Bromoform	$CHBr_3$	75-25-2	0.1	0.1	0.08	0.0079
10	Vinylchloride	C_2H_3Cl	75-01-4	0.05	0.005	0.002	1.9
11	Hexachlorobenzene	C_6Cl_6	118-74-1	0.01	0.001	0.001	1.6
12	Dibromochloromethane	Br_2CHCl	124-48-1	0.03	0.03	0.08	0.084
13	Dichloromethane	CH_2Cl_2	75-09-2	7.5	0.02	0.005	0.0075
14	Arsenic	As	7440-38-2	0.05	0.01	0.01	1.5
15	Plumbum	Pb	7439-92-1	0.03	0.01	0.015	0.047
16	Styrene	C_8H_8	100-42-5	0.1	0.02	0.1	0.03
17	Tetrachloromethane	CCl_4	56-23-5	0.006	0.002	0.005	0.13
18	Tetrachlorethylene	C_2Cl_4	127-18-4	0.005	0.005	0.005	0.052
19	Trichloroethylene	C_2HCl_3	79-01-6	0.005	0.005	0.005	0.011
20	Chloroform	$CHCl_3$	67-66-3	0.2	0.06	0.08	0.0061

It is important to note that in the Russian regulatory framework, hygienic standards for most chemical carcinogens were established without consideration of their carcinogenic effect. The existing MPC levels for some substances may be associated with high values of the potential carcinogenic risk.

We calculated the LADD indices for each investigated carcinogenic chemical using the MPC values fixed in various regulatory documents (Table 1) and the values of the lifetime carcinogenic risk to public health (Table 2).

Table 2.

Values of lifetime carcinogenic risk

No.	Indicator	Chemical formula	Carcinogenic risk value (*Risk*) calculated using the MPC value outlined in the following document		
			SanPiN 2.1.4.1074-01	SanPiN 1.2.3685-21	US EPA
1	1,1-dichloroethene	$C_2H_2Cl_2$	≈ 7.6×10^{-4}	≈ 7.6×10^{-4}	≈ 1.3×10^{-3}
2	1,2-dibromo-3-chloropropane	$C_3H_5Br_2Cl$	≈ 3×10^{-3}	≈ 3×10^{-4}	≈ 6×10^{-5}
3	1,2-dichloroethane	$C_2H_4Cl_2$	≈ 1.2×10^{-5}	≈ 1.2×10^{-5}	≈ 2×10^{-5}
4	Acrylamide	C_3H_5NO	≈ 1.9×10^{-3}	≈ 1.9×10^{-5}	≈ 9.6×10^{-5}
5	Benz (a) pyrene	$C_{20}H_{12}$	≈ 1.5×10^{-6}	≈ 3×10^{-6}	≈ 6.3×10^{-5}
6	Benzene	C_6H_6	≈ 2.4×10^{-5}	≈ 2×10^{-6}	≈ 1.2×10^{-5}
7	Beryllium	Be	≈ 3.7×10^{-5}	≈ 3.7×10^{-5}	≈ 7.4×10^{-4}
8	Bromodichloromethane	$CHBrCl_2$	≈ 8×10^{-5}	≈ 8×10^{-5}	≈ 2.1×10^{-4}
9	Bromoform	$CHBr_3$	≈ 3.4×10^{-5}	≈ 3.4×10^{-5}	≈ 2.7×10^{-5}
10	Vinylchloride	C_2H_3Cl	≈ 4.1×10^{-3}	≈ 4.1×10^{-4}	≈ 1.6×10^{-4}
11	Hexachlorobenzene	C_6Cl_6	≈ 6.9×10^{-4}	≈ 6.9×10^{-5}	≈ 6.9×10^{-5}
12	Dibromochloromethane	Br_2CHCl	≈ 1.1×10^{-4}	≈ 1.1×10^{-4}	≈ 2.9×10^{-4}
13	Dichloromethane	CH_2Cl_2	≈ 2.4×10^{-3}	≈ 6×10^{-6}	≈ 2×10^{-6}
14	Arsenic	As	≈ 3.2×10^{-3}	≈ 6.4×10^{-4}	≈ 6.4×10^{-4}
15	Plumbum	Pb	≈ 6×10^{-5}	≈ 2×10^{-5}	≈ 3×10^{-5}
16	Styrene	C_8H_8	≈ 1.3×10^{-4}	≈ 2.6×10^{-5}	≈ 1.3×10^{-4}
17	Tetrachloromethane	CCl_4	≈ 3.3×10^{-5}	≈ 1.1×10^{-5}	≈ 2.8×10^{-5}
18	Tetrachlorethylene	C_2Cl_4	≈ 1.1×10^{-5}	≈ 1.1×10^{-5}	≈ 1.1×10^{-5}
19	Trichloroethylene	C_2HCl_3	≈ 2×10^{-6}	≈ 2×10^{-6}	≈ 2×10^{-6}
20	Chloroform	$CHCl_3$	≈ 5.2×10^{-5}	≈ 1.6×10^{-5}	≈ 2.1×10^{-5}

The research results are presented in the following sections of this work, and their assessment is given.

Results

As part of the work, the MPC values of some carcinogenic chemicals were studied based on examining the existing and expired SanPiNs and a document from the US Environment Protection Agency. The average daily lifetime dose of the LADD substance and the likelihood of a threat to human life or health caused by exposure to chemicals with a carcinogenic effect, Risk, were calculated using the MPC and SFO values.

As indicated in subsection 1.3 of this work, its classification into four risk ranges is considered in assessing the carcinogenic risk [3; 8]. Table 3 shows the values of the risk range determined based on the obtained calculated Risk values.

According to the WHO recommendations regarding the quality of drinking water, the value of 1×10-5 was chosen as the value of the acceptable carcinogenic risk. After the analysis of the data obtained, it can be seen that most values go beyond the designated limit, even despite the fact that many MPC values have been tightened since March 01, 2021. In Table 3, indicators exceeding the established norm are highlighted in dark color.

Table 3.

Assessment of the level of risk to public health due to consumption of drinking water contaminated with carcinogenic chemicals

No.	Indicator	Chemical formula	Assessment of the significance of carcinogenic risk, *Risk* (risk range)		
			SanPiN 2.1.4.1074-01	SanPiN 1.2.3685-21	US EPA
1	1,1-dichloroethene	$C_2H_2Cl_2$	3	3	4
2	1,2-dibromo-3-chloropropane	$C_3H_5Br_2Cl$	4	3	2
3	1,2-dichloroethane	$C_2H_4Cl_2$	2	2	2
4	Acrylamide	C_3H_5NO	4	2	2
5	Benz (a) pyrene	$C_{20}H_{12}$	2	2	2
6	Benzene	C_6H_6	2	2	2
7	Beryllium	Be	2	2	3
8	Bromodichloromethane	$CHBrCl_2$	2	2	3
9	Bromoform	$CHBr_3$	2	2	2
10	Vinylchloride	C_2H_3Cl	4	3	3
11	Hexachlorobenzene	C_6Cl_6	3	2	2
12	Dibromochloromethane	Br_2CHCl	3	3	3
13	Dichloromethane	CH_2Cl_2	4	2	2
14	Arsenic	As	4	3	3

15	Plumbum	Pb	2	2	2
16	Styrene	C_8H_8	3	2	3
17	Tetrachloromethane	CCl_4	2	2	2
18	Tetrachlorethylene	C_2Cl_4	2	2	2
19	Trichloroethylene	C_2HCl_3	2	2	2
20	Chloroform	$CHCl_3$	2	2	2

Discussion

Based on Table 2 "Values of lifetime carcinogenic risk" and Table 3 "Assessment of the level of risk to public health due to consumption of drinking water contaminated with carcinogenic chemicals," we can note that with the introduction of SanPiN 1.2.3685-21, in which MPC standards were tightened, carcinogenic risk values have consequently decreased for the following indicators: 1,2-dibromo-3-chloropropane, acrylamide, vinyl chloride, hexachlorobenzene, dichloromethane, arsenic, and styrene.

The number of indicators exceeding the established norms has decreased: for the dichloromethane indicator, the MPC value was tightened in comparison with SanPiN 2.1.4.1074-01 [3] and SanPiN 1.2.3685-21 [1]; therefore, the carcinogenic risk for the public health for the dichloromethane indicator has decreased.

For the benzene indicator, despite MPC tightening, carcinogenic risk has not changed, and the MPC index does not exceed the established norm in comparison with SanPiN 1.2.3685-21 [1] and SanPiN 2.1.4.1074-01 [3].

On the basis of Table 3 "Assessment of the level of risk to public health due to consumption of drinking water contaminated with carcinogenic chemicals," carcinogenic risk values of other indicators have not changed when compared to SanPiN 1.2.3685-21 [1] and SanPiN 2.1.4.1074-01 [3].

After comparing currently effective SanPiN 1.2.3685-21 [1] with the US EPA regulations in force in the USA, we should note that the public health risk from the consumption of drinking water contaminated with carcinogenic chemicals is higher in accordance with the US EPA, and some indicators exceed the established norm in the US EPA system.

Conclusion

As a conclusion, it can be noted that in SanPiN 1.2.3685-21 introduced on March 01, 2021, the MPC values for some substances analyzed (e.g., benzene, vinyl chloride, 1,2-dibromo-3-chloropropane, dichloromethane, arsenic, and lead) decreased, which indicates the tightening of requirements for the quality of drinking water, but these measures are not enough. In this regard, the following activities are proposed:

- Establishing maximum permissible concentrations of carcinogenic chemicals at a level that would provide an acceptable maximum level of risk for the population when they consume drinking water;
- Conducting an in-depth assessment of aspects of existing problems and establishing the degree of their priority in relation to other hygienic, environmental, social, and economic problems;
- Preparing and implementing regulations governing the issues of drinking water quality assurance.

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AUTHOR CONTRIBUTIONS

Kseniya Yu. Mikhaylichenko: scientific consultation, design and editing of the paper.

Anna I. Kurbatova: collection and processing of the materials, preparation of the text of the paper.

Cristian A. Salazar Flores: collection and processing of the materials, preparation of the text of the paper.

Dmitriy P. Pogorelyy: collection and processing of the materials, preparation of the text of the paper.

Eleonora E. Konovalova: collection and processing of the materials, preparation of the text of the paper.

Alexandra M. Savich: collection and processing of the materials.

ВКЛАД АВТОРОВ

Михайличенко К.Ю.: научное консультирование, оформление и редакция статьи.
Курбатова А.И.: сбор и обработка материала, подготовка текста статьи.
Саласар Флорес К.А.: сбор и обработка материала, подготовка текста статьи.
Погорелый Д.П.: сбор и обработка материала, подготовка текста статьи.
Коновалова Э.Е.: сбор и обработка материала, подготовка текста статьи.
Савич А.М.: Сбор и обработка материалов.

DATA ABOUT THE AUTHORS

Kseniya Yu. Mikhaylichenko
Peoples' Friendship University of Russia
6, Miklukho-Maklaya Str., Moscow, 117198, Russian Federation
mikhaylichenko-kyu@rudn.ru
ORCID: https://orcid.org/0000-0001-8051-8528

Anna I. Kurbatova
Peoples' Friendship University of Russia
6, Miklukho-Maklaya Str., Moscow, 117198, Russian Federation
kurbatova-ai@rudn.ru
ORCID: https://orcid.org/0000-0002-8375-5323

Cristian A. Salazar Flores
Peoples' Friendship University of Russia
6, Miklukho-Maklaya Str., Moscow, 117198, Russian Federation
cristian_salazarf@hotmail.com
ORCID: https://orcid.org/0000-0002-6927-7863

Dmitriy P. Pogorelyy
Peoples' Friendship University of Russia
6, Miklukho-Maklaya Str., Moscow, 117198, Russian Federation
1132223701@pfur.ru
ORCID: https://orcid.org/0000-0002-0265-8258

Eleonora E. Konovalova
Peoples' Friendship University of Russia
6, Miklukho-Maklaya Str., Moscow, 117198, Russian Federation
konovalova_ee@pfur.ru
ORCID: https://orcid.org/0000-0002-8845-9427

Alexandra M. Savich
Peoples' Friendship University of Russia
6, Miklukho-Maklaya Str., Moscow, 117198, Russian Federation
1032196734@.rudn.ru

ДАННЫЕ ОБ АВТОРАХ

Ксения Ю. Михайличенко
Российский Университет Дружбы Народов
ул. Миклухо-Маклая, 6, г. Москва, 117198, Российская Федерация
mikhaylichenko-kyu@rudn.ru

Анна И. Курбатова
Российский Университет Дружбы Народов
ул. Миклухо-Маклая, 6, г. Москва, 117198, Российская Федерация
kurbatova-ai@rudn.ru

Кристиан А. Саласар Флорес
Российский Университет Дружбы Народов
ул. Миклухо-Маклая, 6, г. Москва, 117198, Российская Федерация
cristian_salazarf@hotmail.com

Дмитрий П. Погорелый
Российский Университет Дружбы Народов
ул. Миклухо-Маклая, 6, г. Москва, 117198, Российская Федерация
1132223701@pfur.ru

Элеонора Е. Коновалова
Российский Университет Дружбы Народов
ул. Миклухо-Маклая, 6, г. Москва, 117198, Российская Федерация
konovalova_ee@pfur.ru

Александра М. Савич
Российский Университет Дружбы Народов
ул. Миклухо-Маклая, 6, г. Москва, 117198, Российская Федерация
1032196734@.rudn.ru

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