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The formation of carcinogenic risk for the population of a megalopolis (using the example of benz(a)pyrene)

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ABSTRACT. ***Introduction.*** A rapid growth of the number of industrial facilities in large cities undoubtedly affects the quality of their atmosphere air. Every year, as a result of the activities of enterprises, tons of chemical compounds containing both carcinogenic and non-carcinogenic substances are released into the environment. Substances of carcinogenic nature that are subject to constant monitoring and subsequent calculation of the carcinogenic risk to public health require special attention. ***The purpose of the study:*** to analyze the pollution of the atmospheric air of the megalopolis with benz(a)pyrene, a substance belonging to the 1st hazard class. ***Materials and methods.*** The assessment of the level of atmospheric air pollution in the megalopolis was carried out using data on monitoring the quality of atmospheric air. The calculation of the individual carcinogenic risk to the population was also carried out with the inhalation intake of benz(a)pyrene according to the methodology presented in R 2.1.10.3968-23 "Guidelines for assessing the risk to public health when exposed to chemicals that pollute the environment". ***Results and discussion.*** The results of the study showed that the level of atmospheric air pollution of the megalopolis with benz(a) pyrene ranged from 1.2 to 2.0 of the average daily maximum permissible concentration. At the same time, the most frequent exceedances of the maximum permissible concentrations were recorded in areas with the largest number of industrial facilities. Nevertheless, the calculation of indicators of individual carcinogenic risk for benz(a) pyrene for the population showed that its values are within the first range, which corresponds to an acceptable risk that does not require additional preventive measures. ***Conclusion.*** Therefore, the results of the study showed that the level of atmospheric air pollution with benz(a)pyrene in the megapolis is at a fairly low level, despite the large number of functioning industrial facilities.

KEYWORDS: benz(a)pyrene, individual carcinogenic risk, public health, industrial ecology

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Формирование канцерогенного риска для населения мегаполиса (на примере бенз(а)пирена)

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РЕЗЮМЕ. ***Введение.*** Стремительный рост числа промышленных объектов в крупных городах, несомненно, отражается на качестве атмосферного воздуха в них. Ежегодно в результате деятельности предприятий в окружающую среду выбрасываются тонны химических соединений, имеющих в своем составе как канцерогенные, так и неканцерогенные вещества. Особого внимания требуют вещества канцерогенной природы, подлежащие постоянному мониторингу с последующим расчетом канцерогенного риска для здоровья населения. ***Цель исследования:*** провести анализ загрязненности атмосферного воздуха мегаполиса бенз(а)пиреном — веществом, относящимся к 1-му классу опасности. ***Материалы и методы.*** Оценка уровня загрязнения атмосферного воздуха мегаполиса проводилась с применением данных по мониторингу качества атмосферного воздуха. Был проведен также расчет индивидуального канцерогенного риска для населения при ингаляционном поступлении бенз(а)пирена согласно методике, представленной в Р 2.1.10.3968-23 «Руководство по оценке риска здоровью населения при воздействии химических веществ, загрязняющих среду обитания». ***Результаты и обсуждение.*** Результаты проведенного исследования показали, что уровень загрязнения атмосферного воздуха мегаполиса бенз(а)пиреном составлял от 1,2 $ПДК_{с.с.}$ до 2,0 $ПДК_{с.с.}$ При этом наиболее часто превышения предельно допустимых концентраций регистрировались в районах с наибольшим количеством промышленных объектов. Тем не менее расчет показателей индивидуального канцерогенного риска по бенз(а)пирену для населения показал, что его значения находятся в пределах первого диапазона, который соответствует допустимому риску, не требующему дополнительных профилактических мероприятий. ***Заключение.*** Таким образом, результаты исследования показали, что уровень загрязнения атмосферного воздуха бенз(а)пиреном в мегаполисе находится на достаточно низком уровне, несмотря на большое количество функционирующих промышленных объектов.

КЛЮЧЕВЫЕ СЛОВА: бенз(а)пирен, индивидуальный канцерогенный риск, здоровье населения, промышленная экология

INTRODUCTION

Currently, air pollution is a key problem in our country. Solving of this problem is provided at the national level thanks to the development and implementation of the national project "Ecology" by the Ministry of Natural Resources and Environment of the Russian Federation. One of the main reasons for the increase in the number of environmental pollutants is rapid growth in the number of urbanized areas. This problem is especially relevant in megacities, where a large number of industrial facilities are concentrated and operate, the functioning of which leads to the release of chemical compounds into the atmosphere [1, 2]. Anthropogenic pollutants formed during the technological process can negatively influence humans living in megacities in the form of carcinogenic and non-carcinogenic effects [3, 4]. Specificity of this impact will be due to the profile of leading industry for a given territory, as well as a list of priority pollutants generated as a result of the activities of industrial enterprises [5].

Of considerable interest are large cities, where the large proportion of emissions into the atmosphere are chemical compounds that have a carcinogenic effect [6, 7]. One of such industrially developed cities can be considered St. Petersburg, where the leading industries are mechanical engineering and chemical industry [8, 9].

According to data on the environmental situation in St. Petersburg, the list of priority air pollutants, the content of which is a subject to constant monitoring, includes chemical substances such as nitrogen oxide, nitrogen dioxide, sulfur dioxide, carbon monoxide, suspended matter, as well as a class I carcinogenic substance, benzo(a)pyrene [10, 11]. The presence of this carcinogenic chemical substance in the air of megacity is a risk factor for the development of neoplasms in humans [12, 13]. Thus, concentrations of benzo(a)pyrene as a class 1 hazard substance in the air must be regularly monitored and remain within the permissible values established by the requirements of SanPiN 1.2.3685-21 [14]. An increase of maximum permissible concentrations (MPC) of benzo(a)pyrene, despite carcinogenic effect (the development of malignant neoplasms in the population), can also have mutagenic, embryotoxic and hematotoxic effects [15, 16]. Thus, this chemical substance is dangerous both for the population living in the megacity, and for subsequent generations.

An analysis of population morbidity in St. Petersburg showed that diseases related to the class of neoplasms are among the most common and occupy tenth place in the overall structure [17].

Thus, high rates of industrial enterprises development have an adverse effect on the quality of atmospheric air in large cities, leading to the release of chemicals into the environment that have a carcinogenic effect [18]. Chronic inhalation of high concentrations of such substances can increase the risk of developing malignant neoplasms, and also affect the health of the younger generation [19–23]. This fact indicates that the concentrations of chemicals, especially carcinogenic ones, should be subject to constant monitoring with subsequent calculation and prediction of the health risk to the population living in megacities [24, 25].

AIM

To assess the quality of atmospheric air in terms of benz(a)pyrene pollution with subsequent calculation of the carcinogenic risk for the population.

TASKS

To assess the quality of atmospheric air in St. Petersburg in terms of benzo(a)pyrene content, the following tasks were set during the study.

1. To assess the technogenic potential of St. Petersburg.
2. To analyze the quality of atmospheric air in St. Petersburg in terms of benzo(a)pyrene content.
3. To calculate individual carcinogenic risks for the urban population exposed to benzo(a) pyrene through inhalation.

MATERIALS AND METHODS

The study object is atmospheric air of the industrially developed metropolis, polluted by emissions from stationary sources. To assess the technogenic potential of St. Petersburg, an analysis was conducted based on data provided by the Ministry of Industry and Trade of the Russian Federation. According to the industri-

al atlas, there are approximately 400 industrial facilities of various types located and operating within the city. Our database included 392 industrial facilities divided according to the location, industrial sectors and economic activities.

Air quality was assessed according to the data obtained during the air quality monitoring at 25 automatic stations in St. Petersburg. Results of the monitoring were published by the Government of St. Petersburg in reports on the environmental status. The total amount of pollutant emissions from stationary sources, as well as the share of individual ingredients in them, were taken into account. In particular, the level of content of solids, volatile organic compounds (VOCs), hydrocarbons (non-VOCs), nitrogen oxide (NO_2), carbon monoxide and sulfur dioxide in atmospheric air. Also, exceedances of MPC of chemical substances in atmospheric air were recorded for the entire study period in accordance with the regulatory document SanPiN 1.2.3685-21 [14]. During the formation of databases of primary material, 3100 information units were analyzed.

The calculation of the individual carcinogenic risk for benzo(a)pyrene, taking into account the data on the exposure level and the values of carcinogenic potential factors, was carried out according to the methodology presented in R 2.1.10.3968-23 “Guidelines for assessing the risk to public health from exposure to chemicals polluting the environment” [26]. In assessing carcinogenic risks, the lifetime average daily doses (LADD) of benzo(a)pyrene present in emissions were used, averaged over a human lifetime. During the calculation, the following parameters were also taken into account: the concentration of benzo(a)pyrene in atmospheric air (C), its intake rate (CR), exposure duration (ED), exposure frequency (EF), human body weight (BW), and the averaging time (AT) — set at 70 years for carcinogens, with 365 days per year. The average daily dose was calculated using Formula 1:

$$LADD = (C \cdot CR \cdot ED \cdot EF) / (BW \cdot AT \cdot 365).$$

The LADD calculation subsequently allowed to determine the individual carcinogenic risk (CR) taking into account such indicators as the slope factor for inhalation exposure (SFI) and the coefficient of severity of malignant neoplasms. The individual carcinogenic risk for the population of a metropolis was calculated using Formula 2:

$$CR = LADD \cdot SFI \cdot g.$$

RESULTS AND DISCUSSION

The results of the analysed data of the Ministry of Industry and Trade of the Russian Federation made it possible to create a database of industrial facilities operating in the territory of St. Petersburg, taking into account the area of their location. It was established that more than 300 industrial facilities operate in the city. The leading profiles are mechanical engineering, chemical industry, light industry and pharmaceutical industry. At the first stage of the study, the districts of St. Petersburg were categorized into groups based on the number of industrial facilities in each. The 18 districts of St. Petersburg formed four groups. The results of this distribution are shown in Table 1.

Ranking of city districts depending on the number of industrial facilities in them allowed us to put forward a hypothesis about which districts will be more exposed to man-made loads and characterized by the highest values of carcinogenic risk for benzo(a)pyrene for the health.

At the second stage of the research, an analysis of state reports of the Government of St. Petersburg on the level of air pollution by benz(a) pyrene, the concentrations of which in the city were determined using an automated monitoring system. During data processing, it was established that over a ten-year period, concentrations of ben(a)pyrene exceeding the maximum permissible values established by the hygienic standard SanPiN 1.2.3685-21 varied within the range from 1.2 MPCs.s. to 2.0 MPCs.s. It is noteworthy that the most frequent exceedances were recorded in the Kalininsky and Moskovsky districts of St. Petersburg, which belong to the III and IV ranked groups, respectively. It should be noted that the ten-year dynamics of measurements of benzo(a)pyrene concentrations is characterized by the absence of exceedance of average annual concentrations of this compound in the atmospheric air of St. Petersburg from 2012 to 2018. However, the excess of MPCc.c. was registered from 2019 to 2021. Thus, the MPC c.c. in 2019 was exceeded by 2 times compared to the hygienic standard, and in 2020–2021 this value was 1.2 MPC c.c. In addition, in most cases, the change in benz(a)pyrene concentration

Table 1

The distribution of Saint Petersburg districts into groups depending on the number of industrial facilities

Таблица 1

Распределение районов Санкт-Петербурга на группы в зависимости от количества промышленных объектов

Группа, № / Group, No.	**Количество промышленных объектов / Number of industrial facilities**	**Район Санкт-Петербурга / District of Saint Petersburg**
I	до 10 / up to 10	Красносельский / Krasnoselsky Кронштадский / Kronshtadtsky Курортный / Kurortny Пушкинский / Pushkin
II	до 20 / up to 20	Колпинский / Kolpinsky Петродворцовый / Petrodvorets Фрунзенский / Frunzensky Центральный / Central
III	до 30 / up to 30	Василеостровский / Vasileostrovsky Калининский / Kalininsky Красногвардейский / Krasnogvardeysky Приморский / Primorsky
IV	30 и более / 30 or more	Адмиралтейский / Admiralteysky Выборгский / Vyborgsky Кировский / Kirovsky Московский / Moskovsky Невский / Nevsky Петроградский / Petrogradsky

Table 2

Indicators of individual carcinogenic risk for benz(a)pyrene for the population of Saint Petersburg

Таблица 2

Показатели индивидуального канцерогенного риска по бенз(а)пирену для населения Санкт-Петербурга

Район Санкт-Петербурга / District of Saint Petersburg	**LADD**	**SFI**	**CR (Carcinogenic Risk)**	**Диапазон / Range**
Адмиралтейский / Admiralteysky	$6{,}0\times10^{-8}$	3,9	$2{,}3\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Василеостровский / Vasileostrovsky	$6{,}28\times10^{-8}$	3,9	$2{,}4\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Выборгский / Vyborgsky	$7{,}43\times10^{-8}$	3,9	$2{,}9\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Калининский / Kalininsky	$4{,}86\times10^{-8}$	3,9	$1{,}9\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Кировский район / Kirovsky district	$8{,}57\times10^{-8}$	3,9	$3{,}3\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Колпинский / Kolpinsky	$6{,}57\times10^{-8}$	3,9	$2{,}6\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Красногвардейский / Krasnogvardeysky	$8{,}28\times10^{-8}$	3,9	$3{,}2\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Красносельский / Krasnoselsky	$6{,}86\times10^{-8}$	3,9	$2{,}7\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Кронштадский / Kronshtadtsky	$6{,}0\times10^{-8}$	3,9	$2{,}3\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Курортный / Kurortny	$2{,}28\times10^{-8}$	3,9	$8{,}9\times10^{-8}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$
Московский / Moskovsky	$7{,}43\times10^{-8}$	3,9	$2{,}9\times10^{-7}$	1-й диапазон / 1st range $CR \leq 1\times10^{-6}$

Ending of the Table 2 / Окончание табл. 2

Район Санкт-Петербурга / District of Saint Petersburg	LADD	SFI	CR (Carcinogenic Risk)	Диапазон / Range
Невский / Nevsky	$1{,}11\times10^{-7}$	3,9	$4{,}3\times10^{-7}$	1-й диапазон / 1st range CR $\leq1\times10^{-6}$
Петроградский / Petrogradsky	$2{,}85\times10^{-8}$	3,9	$1{,}1\times10^{-7}$	1-й диапазон / 1st range CR $\leq1\times10^{-6}$
Петродворцовый / Petrodvorets	$6{,}0\times10^{-8}$	3,9	$2{,}3\times10^{-7}$	1-й диапазон / 1st range CR $\leq1\times10^{-6}$
Приморский / Primorsky	$6{,}57\times10^{-8}$	3,9	$2{,}6\times10^{-7}$	1-й диапазон / 1st range CR $\leq1\times10^{-6}$
Пушкинский / Pushkin	$6{,}0\times10^{-8}$	3,9	$2{,}3\times10^{-7}$	1-й диапазон / 1st range CR $\leq1\times10^{-6}$
Фрунзенский / Frunzensky	$6{,}0\times10^{-8}$	3,9	$2{,}3\times10^{-7}$	1-й диапазон / 1st range CR $\leq1\times10^{-6}$
Центральный / Central	$9{,}43\times10^{-8}$	3,9	$3{,}7\times10^{-7}$	1-й диапазон / 1st range CR $\leq1\times10^{-6}$

Примечание / Note: LADD — lifetime average daily dose / среднесуточная пожизненная доза; SFI — slope factor inhalation / фактор канцерогенного потенциала при ингаляции; CR — carcinogenic risk / величина индивидуального канцерогенного риска.

is characterized by seasonality (annual variation). Thus, an increase in concentrations during the year is most often observed in the cold season during the heating period: from November to February.

The next stage of the study was to calculate the LADD and CR for residents of the districts of St. Petersburg. The results of the calculations are presented in Table 2.

As the results of statistical processing of the obtained data using Pearson's correlation coefficient, it was established that between the two indicators (the number of industrial facilities in the region and the obtained value of individual carcinogenic risk) an average positive linear correlation was observed (r=0.3736).

According to the Office of the Federal State Statistics Service for the city of St. Petersburg and the Leningrad Region, the incidence of neoplasms in the population has a tendency to increase over the period from 2016 to 2019. Moreover, the maximum level of this indicator was reached in 2019 and amounted to 6875.5 per 100,000 people in St. Petersburg. In 2020, the decrease in morbidity was due to low rates of appeal of the population associated with the epidemiological situation. Since 2021, we again note a trend towards an increase in the number of neoplasms.

An analysis of the obtained data allows to conclude that the indicators of individual carcinogenic risk for the level of benzo(a)pyrene in the atmospheric air for the population of St. Petersburg are within the first range, which refers to the acceptable level of risk.

CONCLUSION

Thus, the research allowed to establish that there are over 300 large and medium-sized industrial facilities operating in St. Petersburg, which form the technogenic potential of the metropolis.

Every year, during the technological process, stationary sources emit tons of chemicals into the atmosphere, including carcinogenic ones. In this article, the level of benzo(a)pyrene air pollution in St. Petersburg was discussed. The results showed that the level of this pollution in megacity is within the low levels, despite the large number of industrial facilities operating in St. Petersburg.

This fact is confirmed by the results obtained during the calculation of individual carcinogenic risk for residents of each of the metropolitan districts. The values of individual carcinogenic risk are within the first range and correspond to the acceptable risk level.

ADDITIONAL INFORMATION

Author contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be

published and agree to be accountable for all aspects of the study.

Competing interests. The authors declare that they have no competing interests.

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