doi: 10.2478/ACEE-2024-0024

ASSESSMENT OF ENVIRONMENTAL RISKS FROM POLLUTION BY TOXIC EMISSIONS IN HEAT TREATMENT PROCESS OF ELECTRODE PRODUCTION

Olena IVANENKO [a], Andrii VAHIN [b], Tetyana SHABLIY [c], Oksana TERESHCHENKO [d], Denis SHVACHKO [e], Sergii PLASHYKHIN [f], Nonna PAVLIUK [g]*

[a] Dr. Hab., Eng.; Department of Ecology and Technology of Plant Polymers National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37, Prospect Beresteiskyi, Kyiv, 03056, Ukraine, 0000-0001-6838-5400 – ORCID

[b] PhD; Environmental Management Private Joint Stock Company "Ukrainian Graphite", 20, Pivnichne shose str., Zaporizhzhia, 69600, Ukraine, 0000-0002-1234-0753 – ORCID

[c] Dr. Hab., Eng.; Department of Ecology and Technology of Plant Polymers National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37 Prospect Beresteiskyi, Kyiv, 03056, Ukraine, 0000-0002-6710-9874 – ORCID

[d] PhD; Department of Ecology and Technology of Plant Polymers National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37 Prospect Beresteiskyi, Kyiv, 03056, Ukraine, 0000-0003-1216-9201 – ORCID

[e] PhD; Department of Chemical, Polymer, and Silicate Mechanical Engineering National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37 Prospect Beresteiskyi, Kyiv, 03056, Ukraine, 0000-0001-6031-1490 – ORCID

[f] Dr., Eng.; Automation Hardware and Software Department National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37 Prospect Beresteiskyi, Kyiv, 03056, Ukraine
Department of Heat-Physical Problems of Heat Supply Systems, Institute of Engineering Thermophysics of National Academy of Sciences, 2a, Marii Kapnist (Zhelyabova) Str., Kyiv, 03057, Ukraine, 0000-0003-0039-3302 – ORCID

[g] Dr. Eng.; Department of Heat-Physical Problems of Heat Supply Systems Institute of Engineering Thermophysics of National Academy of Sciences, 2a, Marii Kapnist (Zhelyabova) Str., Kyiv, 03057, Ukraine; 0000-0001-5415-2454 – ORCID
*Corresponding author. E-mail address: *nonna.ittf@gmail.com*

Received: 3.06.2024; Revised: 12.08.2024; Accepted: 19.08.2024

Abstract
The purpose of this work is to assess the risks to the health of the population living in the zone of influence of emissions of pollutants into the atmospheric air from the operating enterprise for the production of carbon electrodes and to generalize the experience of applying the procedure for assessing risks and damage to the health of the population in the system of new monitoring and management mechanisms air quality. The risk assessment of the impact of planned activities on the health of the population from atmospheric air pollution was carried out based on the risk calculations of the devel-opment of non-carcinogenic and carcinogenic effects. During the assessment of the risk to public health from the emissions of the enterprise for the production of carbon electrodes, carbon monoxide was identified as one of the priority pollutants, to reduce the emissions of which it is proposed to use catalytic methods in the furnaces for firing and graphitizing carbon electrodes. Based on the results of the conducted research, it is proposed to introduce technologies that will allow to achieve the maximum permissible emissions of pollutants into the atmosphere during heat treatment.

Keywords: **Toxic emissions; Combustion furnaces; Graphitization furnaces; Heat treatment; Environmental risks; Risk assessment; Carcinogenic risks.**

1. INTRODUCTION

Metallurgy is one of the main branches of the Ukrainian economy, because it creates about 30% of the GDP and provides 40% of foreign currency income to the economy. The importance of the metallurgical industry in the country's economy is due to the fact that this industry produces raw materials for the engineering, transport and construction industries. One of the main metallurgical centers of Ukraine is the city of Zaporizhzhia. It is a large metallurgical center of Ukraine and is part of the Dnipro region, on its relatively small area (631.9 thousand m^2 or 5.3% of the area of Ukraine) 40% of the ferrous and non-ferrous metallurgical industry, 20.5% of the chemical and machine-building industry are located industry, 41% energy. Therefore, for the city of Zaporizhzhia, as well as for many other industrial cities of Ukraine, which have a significant number of sources of atmospheric air pollution, the substantiation of safe for health volumes of emissions of pollutants into the atmospheric air is more relevant [1, 2]. Atmospheric air pollution significantly affects people's health because breathing is the basis of vital activity of any organism. As a result of constant and repeated effects on a person through the air, they can change the quality of life and the state of health of the population, even to an increase in the mortality rate, the appearance of genetic disorders, and the growth of oncological diseases.

Since enterprises of the metallurgical industry are significant suppliers of toxic emissions of carbon monoxide, during the production of graphite electrodes in the city of Zaporizhzhia, gaseous waste contains carbon monoxide in the amount of 47% [3]. In Ukraine, the total amount of carbon monoxide emissions is 704,344.218 t/year, or 31% of the total emissions of pollutants and greenhouse gases other than carbon dioxide [4]. Therefore, the prevention of environmental pollution with toxic gases directly in the process of industrial production is undoubtedly relevant and necessary as a way to improve people's quality of life.

2. ANALYSIS OF PREVIOUS STUDIES

The polluted atmospheric air of large cities worldwide has always been and remains an important risk factor for the health of the population, as evidenced by numerous studies [5, 6]. There is a growing understanding that atmospheric pollution affects medical and demographic indicators – mortality, morbidity, and life expectancy of the population [7, 8], and in some cases, it is the cause of increased social tension and a decrease in the attractiveness of the city as a place of permanent residence. Pollution of the city's atmospheric air with chemical substances causes adverse changes in people's health [9], which in certain cases can provoke the further development of pathological conditions and complications of chronic diseases [10, 11]. In connection with the harmonization with international standards, the technology of risk assessment and management in the field of environmental protection and improvement of public health is being implemented in our country according to the methodology of risk analysis approved by the World Health Organization in the document "Health Risk Assessment from Air Pollution. General Principles" and is used in several countries. The tool undoubtedly provides greater targeting of actions and optimization of financial costs to achieve the main management goals [12].

Every year, about seven million people worldwide die from diseases caused by dirty air. Inhalation of harmful substances causes deterioration of the health of all age categories of the population; decrease in life expectancy, worsening conditions for the development of the health care system [13]. Damage to health is considered as a source of direct losses from environmental pollution, which are supplemented by indirect losses (increased costs and loss of income as a result of pollution, expenses for restoring the health of accident victims, etc.) [14].

Due to the global deterioration of the air in 2021, the WHO revised the air quality standards for the first time since 2005 [15]. Thus, the organization lowered the permissible content of solid particles (PM), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO). Exceeding these standards can lead to extremely negative health consequences, while compliance with the new standards can save millions of lives. Therefore, today in Ukraine more and more attention is paid to the timely detection of risk and its analysis [16].

The purpose of the work is to assess the risks to the health of the population living in the zone of influence of emissions of pollutants into the atmospheric air from the operating enterprise "Ukrgrafit", the city of Zaporizhzhia after the introduction of catalytic methods of carbon monoxide purification in calcination and graphitization furnaces, to generalize the experience of applying the assessment procedure risks and damage to public health in the system of new mechanisms for air quality monitoring and management.

3. MATERIALS AND METHODS

The assessment of the risk of impact on the environment from stationary sources of emissions of pollutants into the atmospheric air of the operating enterprise PJSC "Ukrgrafit" was carried out in accordance with the raw and energy resources existing at the time of the calculation, improved by eco-modernization of technological processes of production, assortment, and volume of products; qualitative and quantitative composition of pollutant emissions into atmospheric air; the potential influence of other influencing factors on the environment and public health; taking into account the existing planning infrastructure of industrial and settlement areas [17] using the report on the inventory of sources of emissions of pollutants into the atmosphere from stationary sources of PJSC "Ukrgrafit" [18]. The basis for determining the risk assessment of the impact of the planned activity on the environment is the methodological recommendations "Assessment of the risk to public health from atmospheric air pollution" [9], requirements for the composition and content of the environmental impact assessment section in the design documentation for new construction, reconstruction, and overhaul of buildings and structures of any purpose and their complexes [19], the procedure for determining the values of background concentrations of pollutants in atmospheric air [20].

PJSC "Ukrgrafit" is located on four production sites, the distance between which is less than 500 m, therefore the enterprise was considered as one production site. 159 stationary emission sources were included in the study. Expected harmful components: substances in the form of suspended particles undifferentiated by composition, emissions after the afterburning of pungent gases (nitrogen oxides, sulfur oxides, carbon oxides), benzene, styrene, benzapyrene, naphthalene, dibutyl phthalate, phenol and some others.

Graphitization furnaces are resistance furnaces (Acheson furnaces), where the heater is the heat-insulation charge located between the workpieces. The operating mode of the ovens is cyclic. Acheson's furnaces emit a large amount of pollutants. Therefore, it was proposed to implement the Kastner method, which consists in heating the workpieces with a current that is passed directly through the workpiece. This will make it possible to reduce emissions of dust, carbon oxides, and sulfur into the atmosphere and to reach the standards of maximum permissible emissions of pollutants into the atmosphere during graphitization.

The materials do not consider the influence of industrial emissions of other enterprises. The results of establishing the level of average concentrations of priority pollutants in the surface layer of the atmosphere are generated by the program of dispersion of pollutants in the surface layer of the atmosphere "EOL 2000" in DBF format. This system made it possible to calculate pollution fields for a point model of a source of emission of harmful substances with a round or rectangular mouth of the pipe. When assessing the impact of enterprises undergoing reconstruction on atmospheric pollution, the calculation was made taking into account background concentrations.

The risk assessment of the impact of the planned activity on the health of the population from atmospheric air pollution was carried out based on the calculations of the risk of the development of non-carcinogenic and carcinogenic effects [9, 10].

Characterization of the risk of development of non-carcinogenic effects in the case of combined and complex action of chemical compounds is carried out based on the calculation of the hazard index (HI). The danger index for conditions of simultaneous intake of several substances by the same route (for example, inhalation or oral) is calculated according to the following formula:

$$HI = HQ_i, \quad (1)$$

where HQ_i – hazard coefficients for individual substances, which are determined in accordance:

$$HQ_i = C_i/RfC_i, \quad (2)$$

where C_i – estimated annual average concentration of the *i*-th substance, mg/m^3; RfC_i – reference (safe) concentration of the *i*-th substance, mg/m^3 (in the absence of reference doses/concentrations (according to the list), the maximum permissible concentration (MPC) can be used as an equivalent; $HQ_i = 1$ – the limit value of the accepted risk.

The calculation of hazard indices is carried out considering critical organs and systems that are negatively affected by the investigated substances. As evidenced by the results of scientific research, when the components of the mixture affect the same organs or systems of the body, the most likely type of combined effect is summation [9, 10].

With HQ equal to or less than 1, the risk of harmful effects was considered to be quite low. With an increase in HQ, the probability of the development of harmful effects should increase, however, it is impossible to accurately indicate the value of this probability (Table 1).

Table 1.
Non-carcinogenic risk criteria

Risk characteristics	Hazard ratio
The risk of harmful effects is considered insignificantly small	< 1
The limit value that does not require urgent measures, however, cannot be considered as quite acceptable	1
The likelihood of developing harmful effects increases in proportion to the increase in HQ	> 1

The risk of developing individual carcinogenic effects (ICR) from substances with carcinogenic effects is calculated according to:

$$ICR = C_i \cdot UR_i, \tag{3}$$

where C_i – estimated annual average concentration of the i-th substance, mg/m^3; UR – the unit carcinogenic risk of the i-th substance, mg/m^3.

The unit risk is calculated using the value of SF (mg/kg·day), the standard value of human body weight of 70 kg, and daily air consumption of 20 m^3 [9, 10]:

$$UR = SF_i /(70 \cdot 20). \tag{4}$$

Hazard ratios were calculated separately for each substance at each calculation point and differentiated for different conditions (acute and chronic exposure). The danger factor is a multiple of the reference concentration for acute or chronic exposure to the maximum or average annual calculated concentration of a toxic substance in the surface layer of the air. The hazard index is the sum of these hazard coefficients from individual pollutants.

In connection with the fact that multicomponent chemical pollution of environmental objects was analyzed in the studied territories, the total risks caused by the simultaneous action of several chemical compounds were evaluated.

The characterization of the carcinogenic risk was carried out in the following stages: summarization and analysis of all available information about harmful factors, features of their effects on the human body, exposure levels; calculation of the carcinogenic risk for each substance entering the human body; calculation of the carcinogenic risk for each carcinogenic component of the investigated mixture of chemicals, as well as the total carcinogenic risk for the entire mixture; calculation of total carcinogenic risks for each of the analyzed routes of entry, as well as the total summarized carcinogenic risk for all substances and all routes of their entry into the body; summarizing and presenting the results of risk characterization.

The calculation of the carcinogenic risk was carried out only for the range of doses of the chemical substance that corresponds to the linear portion of the "dose-response" dependence. The characteristics of the "dose-response" dependence, which are most often used to assess carcinogenic risk, have been sufficiently studied in epidemiological studies. Among them is the factor of carcinogenic potential (ICS), which reflects the probability of the development of a harmful reaction when the dose (concentration) increases by 1 mg/kg or 1 mg/m^3 per exposure level, associated with a certain probability of effect (the indicators of this group are used for the establishment of reference, i.e., reference doses and concentrations) [9, 10].

The carcinogenic risk due to the combined effect of several chemical compounds is considered additive, and the combined effect of several carcinogenic substances polluting the atmosphere (CR_a) is determined according to:

$$CR_a = \sum ICR_i, \tag{5}$$

where ICR_i – the carcinogenic risk of the i-th substance.

The calculation of hazard indices was carried out taking into account critical organs and systems that are negatively affected by the investigated substances. Individual carcinogenic risk characterizes the limit of carcinogenic risk during the period corresponding to the average life expectancy of a person (within 70 years) (Table 2).

Table 2.
Classification of carcinogenic risk levels

Risk level	Risk during CRa lifetime
Unacceptable for professional contingents and the population	Greater than 10^{-3}
Acceptable for professional contingents and unacceptable for the population	$10^{-3} - 10^{-4}$
Conditionally acceptable	$10^{-4} - 10^{-6}$
Acceptable	Less than 10^{-6}

The calculation of climatological, meteorological coefficients and indicators of the dispersion of pollutants in the atmosphere were carried out taking into account the maximum and average annual concentrations using the unified program for calculating atmospheric pollution "EOL 2000", which allows you to calculate surface concentrations of pollutants in the atmosphere following [20], given in Table 3.

Table 3.
Meteorological characteristics and coefficients determining the conditions of dispersion of pollutants in the atmosphere of the city of Zaporizhzhia

The name of the characteristic	Value
Coefficient A, which depends on the temperature stratification of the atmosphere	200
The average maximum outdoor air temperature of the coldest month of the year, °C	- 4.2
The average maximum outdoor air temperature of the hottest month of the year, °C	+ 33.2
Mid-year wind rose, %	
North	17.2
North-East	14.0
East	11.7
The South-East	12.5
South	12.0
South-West	10.4
Western	11.2
North-West	11.0
Wind speed (w), the repeatability of which is exceeded by 5%, m/s	10-11

To calculate and assess non-carcinogenic risks based on hazard ratios (HQ), individual carcinogenic risks for the health of the exposed population exposed to atmospheric air pollution by emissions from stationary sources of the operating enterprise PJSC «Ukrgrafit», according to the provided materials, stationary sources were included in the study emissions of PJSC "Ukrgrafit".

Taking into account the criteria for the selection of pollutants emitted into the atmospheric air by stationary sources of the operating enterprise of PJSC "Ukrgrafit", namely: analysis of volumes (g/s) of pollutants entering the atmospheric air; assessment of the toxicity of polluting chemical substances capable of affecting the health of the population; data analysis regarding hazard parameters and "dose-response" dependencies (reference concentrations; factors of carcinogenic potential; current domestic regulations (limit-permissible maximum single and average daily concentrations); estimates of the directionality of the impact on the organs and systems of the human body; the number of the population exposed from the company's emissions, a list of pollutants necessary for researching the assessment of the risk to public health from air pollution by emissions from stationary sources of PJSC "Ukrgrafit" was formed.

4. RESULTS AND DISCUSSION

PJSC "Ukrgrafit" is a Ukrainian enterprise in the field of graphite processing and production of electrical equipment from it, today it produces electrodes for electrometallurgical enterprises, graphite anodes for the magnesium industry, as well as graphite blocks for the aluminum and metallurgical industries. On the territory of the production site, there are firing shops and graphitization shops, where innovative technologies of catalytic neutralization of toxic carbon monoxide using metal oxide catalysts on zeolite (Fig. 1) and fibrous carriers (Fig. 2) were introduced [21, 22].

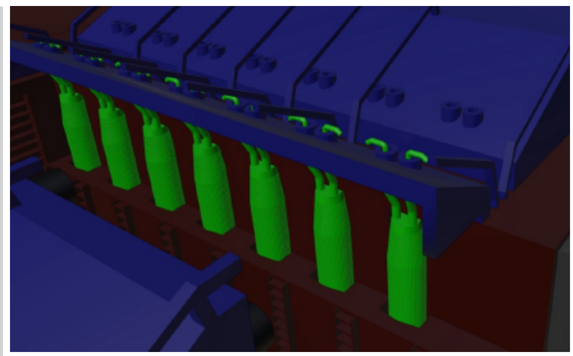

Figure 1.
Design features of catalytic reactors arrangement with modified zeolite in the fire channels of the firing furnace

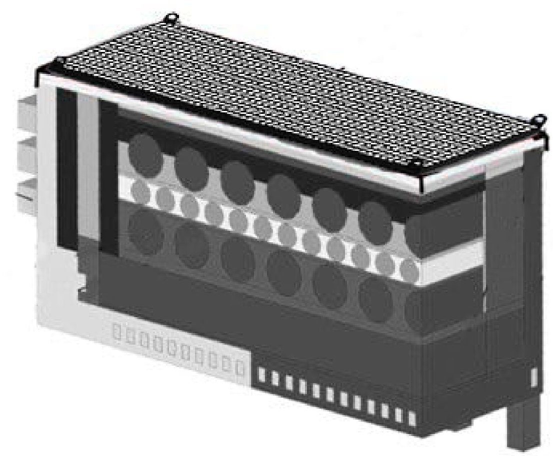

Figure 2.
Scheme of laying modified ceramic fiber in a metal frame on top of thermal insulation of the graphitization furnace

The main task in hazard identification was to identify specific chemical substances that could negatively affect the health of the local population. Considering the criteria for the selection of pollutants emitted into the atmosphere by stationary sources of the operating enterprise PJSC "Ukrgrafit" after the introduction of catalytic systems on furnaces, a list of 25 pollutants necessary for further research on the assessment of the risk to public health from air pollution was formed by emissions from stationary sources of the operating enterprise PJSC "Ukrgrafit" (Table 4).

Table 4.
General list of emissions of polluting substances at the enterprise after reconstruction

NO	Substance Name	Code	MPCm.v. Tentative Safe Level of Impact, mg/m³	Hazard Class	Emission Power of Pollutants	
					g/s	tons/year
1	Iron and its compounds calculated as iron	123	0.04 (s.d.)	3	3.062	
2	Manganese and its compounds calculated as manganese dioxide	143	0.01	2	0.0290	2
3	Mercury and its compounds calculated as mercury	183	0.00003 (s.d.)	1	0.000004	3
4	Lead and its compounds calculated as lead	184	0.001	1	0.000002	4
5	Chromium and its compounds calculated as chromium trioxide	203	0.002	1	0.000003	5
6	Nitrogen oxides (nitric oxide and nitrogen dioxide) are calculated as nitrogen dioxide	301	0.02	3	7.646110	6
7	Ammonia	303	0.02	4	0.0000004	7
8	Sulfur dioxide (dioxide and trioxide) is calculated as sulfur dioxide	330	0.05	3	16.7639	8
9	Hydrogen sulfide	333	0.0082	2	1.40820	9
10	Carbon monoxide	337	50	4	1.991226	10
11	Fluorine and its vapor and gas compounds calculated as hydrogen fluoride	342	0.02	2	0.0000600	11
12	Methane	410	50 Tentative Safe Level of Impact	-	0.0058500	12
13	Benzene	602	1.5	2	0.146932	13
14	Styrene	620	0.004	2	0.199898	14
15	Benzo(a)pyrene	703	0.01 μg per 100 m³ (s.d.)	1	0.001383	15
16	Naphthalene	708	0.003	4	2.35334	16
17	Acenaphthene	714	0.007	-	2.802001	17
18	Phenol	1071	0.001	2	2.74862	18
19	Dibutyl phthalate	1215	0,1	-	0.170112	4.84293
20	Dimethyl sulfide	1707	0,08	4	0.633460	19.20096
21	Mineral petroleum oil	2735	0.05 Tentative Safe Level of Impact	-	0.00001	0.00018
22	Hydrocarbon homologues C12-C19	2754	1.0	4	0.00524	0.05394
23	Substances in the form of suspended solid particles undifferentiated by composition	2902	0.5	3	8.44289	111.11265
24	Nitrogen (I) oxide [N_2O]		No MPC	-	0.02871	0.38667
25	Carbon dioxide	11811	No MPC	-	5,107.231	98,942.758
	In total				5,164.727	100,793.00
	Excluding greenhouse gases				57.46784	1,849.8609

According to [23], the main production relates to chemical enterprises (enterprises for the processing of coal) with a sanitary protection zone of 1000 m. Calculation of the dispersion of pollutants in the atmosphere for methane and hydrocarbons of the C12-C19 range was not carried out, as the sum of the maximum ground-level concentrations in fractions of MAC (Maximum Allowable Concentration) is less than 0.1. The list of priority chemical substances emitted by stationary sources of PJSC "Ukrgrafit" after reconstruction is presented in Table 5, where the direction of impact on the organs of vision (OV), immune system (IS), skeletal system (SS), nervous system (NS), respiratory organs (RO), reproductive system (RS), parenchymal organs (PO), cardiovascular system (CVS), central nervous system (CNS), carcinogenic effects (CE), congenital malformations (CM), liver (L), kidneys (K), nasal cavity (NC), blood (B), demographic indicators (DI) – increase in mortality rate – is justified.

Based on the calculated exposure levels, the characteristics of the risk of atmospheric air pollution caused by the emissions of the operating enterprise PJSC «Ukrgrafit» were established, which included the calculations of the hazard indices for individual HQ substances (non-carcinogenic risks) and for the combined effect of HI (Table 6) and calculations of carcinogenic individual of ICR risks and by the combined effect of CRa (Table 7). The assessment of non-carcinogenic risks was carried out based on the calculation of the HQ hazard indices, which are the ratio between the exposure values and the safe (reference) action level.

Table 5.
List of priority chemical substances emitted by stationary sources of PJSC "Ukrgrafit"

	CAS	Code	Substance Name	RfC, mg/m^3	SFi, (mg/kg-day)$^{-1}$	MPCm.v., mg/m^3	MPCs.p., mg/m^3	Impact on Organs and Systems
1	TSP	2902	Substances in the form of suspended solid particles	0.1	-	0.5	0.15	RO
2	10102-44-0	301	Nitrogen oxides (nitric oxide and nitrogen dioxide)	0.04	-	0.2	-	RO
3	630-08-0	337	Carbon monoxide	5.0	-	5.0	3.0	CNS, CVS
4	7446-09-5	330	Sulfur dioxide (sulfur dioxide and trioxide)	0.08	-	0.5	0.05	RO
5	7439-96-5	143	Manganese and its compounds in terms of manganese dioxide	0.00005	-	0.01	-	CNS
6	7439-92-1	184	Lead and its compounds in terms of lead	0.00015	0.042	0.001	-	CNS, CVS, K, CM
7	18540-29-9	203	Chromium and its compounds in terms of chromium trioxide	0.0001	42	0.002	-	RO
8	50-32-8	703	Benzo(a)pyrene	-	3.1	-	0.00001	-
9	7439-97-6	183	Mercury and its compounds in terms of mercury	0.003	-	-	0.0003	CNS
10	7664-41-7	303	Ammonia	0.1	-	0.2	-	RO
11	7664-39-3	342	Fluorine and its gaseous and vaporous compounds in terms of hydrogen fluoride	0.03	-	0.02	-	SS, RO
12	71-43-2	602	Benzene	0.06	0.027	1.5	-	CM, K, CNS
13	100-42-5	620	Styrene	1.0	-	0.04	-	CNS
14	108-95-2	1071	Phenol	0.006	-	0.01	-	CVS, K, CNS, L
15		333	Hydrogen sulfide	-	-	0.008	-	-
16		410	Methane	-	-	50 Tentative Safe Level of Impact	-	-
17		708	Naphthalene	-	-	0.003	-	-
18		714	Acenaphthene	-	-	0.07	-	-
19		1215	Dibutyl phthalate	-	-	0.1	-	-
20		1707	Dimethyl sulfide	-	-	0.08	-	-
21		2735	Mineral oil	-	-	0.05 Tentative Safe Level of Impact	-	-
22		2754	Hydrocarbon homologues C12-C19	-	-	1.0	-	-
23		123	Iron and its compounds in terms of iron	-	-	-	0.04	-

The assessment of long-term effects at the level of the average annual concentration on human health of the studied substances, which will allow assessment of the chronic inhalation effect of the occurrence of negative effects on the health of the exposed population during life for the assessment and characterization of multistage risk, showed that the HQ hazard indices do not exceed the norm.

Calculations of acute and chronic inhalation hazard indices resulting from emissions from the operating enterprise PJSC "Ukrgrafit" after the implementation of catalytic purification showed that the hazard indices HQ for the impact of substances in the form of suspended solid particles, mercury, and its compounds in terms of mercury, ammonia, fluorine, and its gaseous and vaporous compounds in terms of hydrogen fluoride, styrene, phenol, nitrogen oxides (nitric oxide and nitrogen dioxide) in terms of nitrogen dioxide, carbon monoxide, sulfur dioxide (sulfur dioxide and trioxide) in terms of sulfur dioxide, manganese, and its compounds in terms of manganese dioxide, hydrogen sulfide, naphthalene, acenaphthene, dibutyl phthalate, dimethyl sulfide, iron, and its compounds in terms of iron, hydrocarbon homologues C12-C19, and mineral oil in the atmospheric air can be considered permissible, with an extremely low risk of adverse effects occurrence.

During the analysis of air pollution levels by chemical carcinogens emitted into the atmosphere by the sources of PJSC "Ukrgrafit" after reconstruction, namely: benzo(a)pyrene, benzene, lead and its compounds in terms of lead, chromium and its

Table 6.
Risks of developing non-carcinogenic effects

Boundary of Residential Area	Reference (Safe) Concentration (RfC_i), mg/m^3	Average Annual Concentration (Ci), mg/m^3	Critical Organs/ Systems	Hazard Quotient (HQ)	Criteria for Non-carcinogenic Risk	
Suspended substances						
TSP	0.1	0.05859362	RO	0.5859362	<1	Risk of adverse effects is extremely low
Mercury and its compounds in terms of mercury						
7439-97-6	0.003	3.712 -10	CNS	1.24E-7	<1	Risk of adverse effects is extremely low
Ammonia						
7664-41-7	0.1	0.00000003	RO	3.00E-7	<1	Risk of adverse effects is extremely low
Fluorine and its gaseous and vaporous compounds in terms of hydrogen fluoride						
7664-39-3	0.03	0.00001477	SS, RO	0.00049233	<1	Risk of adverse effects is extremely low
Styrene						
100-42-5	1.0	0.00017315	CNS	0.00017315	<1	Risk of adverse effects is extremely low
Phenol						
108-95-2	0.006	0,00046636	CVS, L, K, CNS	0.07772667	<1	Risk of adverse effects is extremely low
Nitrogen oxides (nitric oxide and nitrogen dioxide)						
10102-44-0	0.04	0.00330166	RO	0.0825415	<1	Risk of adverse effects is extremely low
Carbon monoxide						
630-08-0	3.0	0.01295109	CNS, CVS, B	0.00431703	<1	Risk of adverse effects is extremely low
Sulfur dioxide (sulfur dioxide and trioxide)						
7446-09-5	0.08	0.07545244	RO	0.9431555	<1	Risk of adverse effects is extremely low
Manganese and its compounds in terms of manganese dioxide						
7439-96-5	0.00005	0.00003778	CNS	0.7556	<1	Risk of adverse effects is extremely low
Hydrogen sulfide						
-	0.008	0.00120000	-	0.15	<1	Risk of adverse effects is extremely low
Naphthalene						
-	0.003	0.00171000	-	0.57	<1	Risk of adverse effects is extremely low
Acenaphthene						
-	0.07	0.01330000	-	0.19	<1	Risk of adverse effects is extremely low
Dibutyl phthalate						
-	0.1	0.00100000	-	0.01	<1	Risk of adverse effects is extremely low
Dimethyl sulfide						
-	0.08	0.00320000	-	0.04	<1	Risk of adverse effects is extremely low
Iron and its compounds in terms of iron						
-	0.04	0.00000100	-	0.000025	<1	Risk of adverse effects is extremely low

Table 7.
Risks of developing carcinogenic effects

Residential Area Boundary	Carcinogenic Risk SF, mg/(kg·day)	Single carcino-genic risk UR, mg/m^3	Average Annual Concentration C_i, mg/m^3	Critical Organs/Systems	Individual Effect Development Risk ICR	Risk Level
Benzo(a)pyrene						
50-32-8	3.1	0.002214	0.00000257	-	5.69 -9	Acceptable
Benzene						
71-43-2	0.027	1.93 -5	0.00025415	CM, K, CNS	4.91 -9	Acceptable
Lead and its compounds in terms of lead						
7439-92-1	0.042	3.0 -5	0.00000015	CM, K, CNS	4.50 -12	Acceptable
Chromium and its compounds in terms of chromium trioxide						
18540-29-9	42	0.03	0.00000101	RO	3.03 -8	Acceptable

compounds in terms of chromium trioxide, it was established that the values of individual carcinogenic risk ICR during the entire stay of a person in the area of the nearest residential development are as follows:

– benzo(a)pyrene ICR = 5.69×10^{-9};
– benzene ICR = 4.91×10^{-9};
– lead and its compounds in terms of lead ICR = 4.50×10^{-12};
– chromium and its compounds in terms of chromium trioxide ICR = 3.03×10^{-8}.

Such risks do not require additional measures to reduce them.

5. CONCLUSIONS

In assessing the health risks to the population of Zaporizhzhia from emissions of PJSC "Ukrgrafit", priority pollutants were identified: carbon oxide, nitrogen oxides, sulfur oxides, and substances in the form of undifferentiated suspended solid particles. Hazard indices were determined for individual substances HQ (non-carcinogenic risks) and for combined action HI, calculated carcinogenic individual risks (ICR), and for combined action (CRa).

Evaluation of the long-term effects (at the level of average annual concentration) on human health of the investigated substances, allowing assessment of the chronic inhalation impact and the occurrence of negative health effects in the exposed population over a lifetime for assessing and characterizing the multi-stage risk, showed that hazard indices (HQ) do not exceed the norms.

Analyzing the above, it is necessary to note that the assessment of emissions from PJSC "Ukrgrafit", taking into account their toxicity, which is used in the methodology for assessing the health risk to the population, allows determining the environmental situation, provides a sufficiently reasoned, objective assessment of the harmfulness of emissions into the atmosphere, developing a rational, scientifically based approach to mitigating the impact of emissions on public health regarding the urgency and priority of implementing environmental tasks facing the enterprise and the local authorities of the city.

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