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MULTI-ENVIRONMENTAL CARCINOGENIC RISK AND VALIDATION OF APPROACHES TO ITS MINIMIZATION IN CHELYABINSK

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Abstract. To determine the reasons for high cancer level in Chelyabinsk, a multi-environmental assessment of carcinogenic risks associated with exposure to chemicals in drinking water, food products, soil, atmospheric air (stationary pollution sources) was carried out. Individual life-long levels of carcinogenic risks were determined and classified as unacceptable to public health at large (>1E-04). It was discovered the food products and drinking water present the biggest cumulative risk of cancer. The top risk factors include 8 carcinogens revealed in milk and dairy products, vegetables and vegetable products, grains and baked goods, and in drinking water. Risk minimization approaches were developed along with areas of future studies of the environmental quality and public health in the city.

Key words: carcinogenic risk, chemical carcinogens, atmospheric air, drinking water, soil, food products.

Introduction. A high level of malignant growth incidence has been a pressing issue for Chelyabinsk in the last several decades. In 2008-2012, about 4.7 cases of malignant growths were reported per year, and over 2 thousand fatalities [2]. The number of malignant growths in Chelyabinsk among the total number of malignant growths in the region in 2009-2011 totaled 32.0-34.0%. As compared to 2006, the number of cancer cases in 2010 went up by 14.3%, in 2011 by 11.9%, in 2012 – by 6.7%. The incidence of cancer in the city exceeds the average regional level by 5.5-1.0%, average national level – by 14-8.7% [1]. In a group of children under 14, the disease rate went up in 2010 by 7.8%, in 2011 – by 13.3%, in 2012 – by 14.4%. Premature morbidity and loss of working capacity lead to demographic losses and economic damages due to disease and care for sick family members [8]. For this reason, it is reasonable to determine the causes of ill-being and, using health risk assessment techniques and the results of socio-hygienic monitoring [1, 2, 10] and validate health prevention activities.

Purpose and objectives of the research. The main objective of this research is to assess

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the level of carcinogenic risk under chronic public exposure to carcinogens in the atmospheric air, drinking water, soil, and food products, and identify the guidelines for sanitary-hygienic and environmental activities. For the purpose of this research, we carried out a number of relevant activities involving hazard identification, laboratory studies of the environmental quality, data processing, exposure assessment, calculation of the carcinogenic risk level and contribution of individual factors.

Materials and methods. Under this research, we used the materials provided by the local office of the Federal State Statistics Service (Chelyabinsk), Chelyabinsk Regional Clinical Oncologic Dispensary, Chelyabinsk Regional Medical Information Analysis Center, and Chelyabinsk Regional Center of Hygiene and Epidemiology.

Risk assessment was conducted in accordance with the Guidelines [8] and following the following stages: hazard identification, 'dose-response' relationship assessment, exposure assessment, and risk characterization. The level of exposure to food contaminants was assessed using the methodological guidelines [7]. Risk classification under the Guidelines includes the following [8]: 1st ICR range (individual carcinogenic risk)≤10-6, negligible risk; 2nd range ≤10-4, acceptable risk; 3rd range 10-4-10-3, 4th range ≥10-3, unacceptable risk.

The average concentrations of carcinogens in atmospheric air in Chelyabinsk were measured in the emissions of 16 industrial enterprises (about 95% share in the overall city emissions), calculation of dispersion at 34 086 receptor points, with the grid spacing of 500 meters in the x and y directions. In the process of the research, the following software was used: a) "Ecolog" unified program of air pollution estimation (version 2.0, Standard version); b) "Srednie", implementing guidance documents [5, 6.

To assess the level of pollution of drinking water, soil, and food products, we used the results of 2006-2011 laboratory studies by Chelyabinsk Regional Center of Hygiene and Epidemiology. We analyzed the following research materials: 2117 samples of drinking water were tested for 13 substances; 1271 samples of soil were tested for 5 substances; 1776 samples of 7 groups of food products were tested for 7 carcinogens. In the course of the study, substances were selected and excluded for calculations.

To calculate the risks associated with atmospheric air, we used the average calculated concentrations, for peroral consumption of food products, water, and soil – 5% trimmed mean concentrations which minimize the impact of dispersion on the evaluation of central tendency while cutting off uncharacteristic values [4]. It is important to note that the obtained values of 5% trimmed mean concentrations are somewhat lower as compared to the values of mean concentrations calculated using the standard methodology.

To determine the factors of carcinogenic potential and other data, we used national and international databases as well as available scientific literature [8-11].

Results and discussion. We used the 1, 2A, and 2B group substances by IARC classification as potential chemical carcinogens. Peroral chemical exposure to carcinogens in atmospheric air, drinking water, soil and food products is caused by substances from the sources located in the area under study in Chelyabinsk and beyond. The main sources of pollution in Chelyabinsk affecting the population are industrial emissions and soil in residential neighborhoods.

The sources of chemical substances imported in Chelyabinsk and, subsequently, affecting the population of the area under study include the following: most food products; water from the Miass River with artificial water storage basins Argazinsky and Shershnevsky; soil; places and areas located to the north of Chelyabinsk around the Miass watershed and water basins. For instance, service water in Miass and Karabash as well as industrial waste from the enterprises located in those cities are both fed to the Miass River and then to the Argazinsky and Shershnevsky water basins. Other fugitive sources of chemical waste fed to the Miass River and water basins include dumps of dredges and overburden rocks (in Miass and Karabash), dumps from a local steel plant (Karabash), fields and animal-breeding farms (Argayashsky and Sosnovsky districts), waste from residential areas (Miass, Karabash, Argayashsky and Sosnovsky districts, and Chelyabinsk).

Chemical substances contained in the above sources of environmental pollution may impact the population both directly and indirectly due to cross-media pollution and secondary pollution, e.g. in chain order: air – soil – farm products; water – soil – farm products, etc. Using this data, we developed an impact scenario and a concept of chemical transition from a source to a human as well as calculated the levels of carcinogenic risks.

The levels of carcinogenic risks associated with inhalation intake were conducted with the account for mean concentrations of 18 carcinogens (cadmium, nickel, chrome 6+, lead, arsenic, carbon soot, benzene, benzo(a)pyrene, formaldehyde, acetaldehyde, etc.) contained in the emissions and waste from 16 local enterprises exclusive of the background values in the 7 Chelyabinsk districts (see Table 1). The average weighed risk coming from inhalation intake of combined carcinogens totals 4.7 E-05, which is classified as a 2nd range risk. In all the districts, carcinogenic risks are classified as 2nd range risks which are acceptable in terms of public health effects.

The levels of carcinogenic risks associated with drinking water were calculated with the account for mean concentrations of 8 carcinogens (arsenic, chrome +6, bromodichloromethane,

lead, cadmium, chloroform, etc.) (see Table 2). The average risk coming from combined carcinogens in the city totals 1.9E-04 which is classified as a 3rd range risk. The top contaminants bearing carcinogenic risks when consumed with drinking water are arsenic, chrome 6+, and bromodichloromethane (contributions to the total risk are 37.9%, 24.3% and 16.7% respectively). Carcinogenic risks presented by each of the 8 substances are classified as 2nd and 3rd range risks. However the total risk created by exposure to the 8 carcinogens combined is classified as a 3rd range risk. The biggest carcinogenic risk – a 34d range risk - is registered in Metallurgichesky district (total ICR = 2.1E-04). Total carcinogenic risks in all the districts are also 3rd range.

Table 1

Calculations of carcinogenic risks associated with inhalation intake of chemical substances

Substance District	Cd	Ni	NiOx	Pb	Cr (6+)	As	C	Ben zene	Benzo (a) pyrene	Ethylb enzene	Tetrac hloreth ylene	Methyl Chlo ride Oxi rane	Acetal dehyde	Formal dehyde	Epoxye thane	Acrylo nitrile	Asbest os contain ing dust	Styrene	Total risk
Metallurgi chesky	5,78 E-07	1,44 E-10	1,71 E-06	1,63 E-08	4,27 E-05	3,81 E-07	2,26 E-06	1,47 E-05	3,98 E-07	4,51 E-11	4,47 E-11	2,06 E-10	5,78 E-12	6,05 E-09	1,31 E-10	4,39 E-06	1,01 E-06	0,00 E+00	6,83 E-05
Kurchatovsky	1,36 E-06	9,66 E-11	4,38 E-07	2,77 E-08	2,03 E-05	3,66 E-07	7,69 E-07	1,34 E-06	7,74 E-08	1,94 E-11	5,83 E-12	1,45 E-10	3,89 E-12	1,22 E-09	8,85 E-11	7,95 E-07	5,45 E-07	0,00 E+00	2,61 E-05
Kalininsky	1,35 E-06	2,00 E-10	6,29 E-07	3,36 E-08	4,44 E-05	5,75 E-07	1,54 E-06	2,40 E-06	1,88 E-07	4,15 E-11	8,57 E-12	2,80 E-10	7,25 E-12	3,13 E-09	1,65 E-10	2,22 E-06	7,53 E-06	0,00 E+00	6,11 E-05
Traktoroza vodsky	4,74 E-07	6,33 E-10	7,16 E-07	1,34 E-08	5,64 E-05	3,14 E-07	1,55 E-06	3,09 E-06	2,02 E-07	1,02 E-10	8,32 E-12	6,36 E-10	1,74 E-11	5,47 E-09	3,95 E-10	3,68 E-06	2,39 E-06	0,00 E+00	6,91 E-05
Central	3,45 E-07	1,36 E-10	3,39 E-07	9,25 E-09	2,17 E-05	2,09 E-07	5,98 E-07	8,67 E-07	6,44 E-08	2,48 E-11	3,28 E-12	1,85 E-10	4,76 E-12	1,10 E-09	1,08 E-10	6,52 E-07	5,70 E-07	0,00 E+00	2,54 E-05
Sovetsky	1,68 E-07	2,18 E-10	2,72 E-07	4,84 E-09	1,98 E-05	1,22 E-07	4,82 E-07	6,81 E-07	5,13 E-08	3,71 E-11	2,22 E-12	2,66 E-10	6,68 E-12	1,09 E-09	1,52 E-10	5,29 E-07	3,28 E-07	0,00 E+00	2,24 E-05
Leninsky	2,12 E-07	6,75 E-09	3,76 E-07	7,42 E-09	5,12 E-05	1,54 E-07	7,95 E-07	2,15 E-06	8,09 E-08	6,62 E-10	3,22 E-12	1,78 E-09	4,53 E-11	4,90 E-09	1,03 E-09	9,38 E-07	6,12 E-07	0,00 E+00	5,67 E-05
City average	6,41 E-07	1,17 E-09	6,40 E-07	1,61 E-08	3,66 E-05	3,03 E-07	1,14 E-06	3,61 E-06	1,52 E-07	1,33 E-10	1,09 E-11	5,00 E-10	1,30 E-11	3,28 E-09	2,95 E-10	1,89 E-06	1,85 E-06	0,00 E+00	4,70 E-05

Table 2

Calculations of carcinogenic risk associated with intake of substances from drinking water

Substance District	Cadmium	Lead	Chrome 6+	Arsenic	Chloroform	Berylliu m	Bromodichloromethane	Tetrachloromethane	Total risk
Metallurgichesky	2,84E-07	1,43E-06	4,71E-05	9,34E-05	2,53E-05	1,38E-06	3,24E-05	1,46E-05	2,16E-04
Kurchatovsky	4,34E-07	2,18E-06	4,71E-05	8,73E-05	2,15E-05	1,38E-06	3,24E-05	1,46E-05	2,07E-04
Kalininsky	2,50E-07	2,00E-06	4,71E-05	6,90E-05	2,04E-05	1,38E-06	3,24E-05	1,46E-05	1,87E-04
Traktoroza vodsky	4,08E-07	1,17E-05	4,71E-05	5,32E-05	1,96E-05	1,38E-06	3,24E-05	1,46E-05	1,80E-04
Central	6,63E-07	3,26E-06	4,71E-05	6,23E-05	1,83E-05	1,38E-06	3,24E-05	1,46E-05	1,80E-04
Sovetsky	1,10E-06	2,12E-06	4,71E-05	6,16E-05	1,99E-05	1,38E-06	3,24E-05	1,46E-05	1,80E-04
Leninsky	3,08E-07	1,99E-06	4,71E-05	8,71E-05	2,11E-05	1,38E-06	3,24E-05	1,46E-05	2,06E-04
City average	4,93E-07	3,53E-06	4,71E-05	7,34E-05	2,09E-05	1,38E-06	3,24E-05	1,46E-05	1,94E-04

The carcinogenic risk resulting from accidental consumption of soil is calculated with the account for the mean concentrations of the following carcinogens: arsenic, chrome 6+, lead, and cadmium (see Table 3). The risk coming from accidental consumption of soil and subsequent exposure to combined carcinogens equals 1.75 E-05, which is classified of a 2nd range risk. The top component contributing to carcinogenic risk from accidental consumption of soil is arsenic. The average ICR of arsenic in the districts totals 1.68E-05 (a 2nd range risk); its share in the total is 97.1%. In all the districts, the total carcinogenic ICR is reported at E-06 and E-07 (a 2nd and 1st range risk); the maximum carcinogenic risk is registered in Sovetsky district, with a total ICR at 1.0E-04.

Table 3

Calculation of carcinogenic risk associated with chemicals in soil

Substance District	Cadmium	Lead	Chrome 6+	Arsenic	Total risk
Metallurgichesky	1,22E-07	6,77E-07	4,31E-09	4,31E-06	5,12E-06
Kurchatovsky	8,83E-08	3,40E-07	4,18E-09	2,79E-06	3,22E-06
Kalininsky	9,62E-08	3,86E-07	1,08E-07	1,56E-06	2,15E-06
Traktorozavodsky	6,14E-08	3,65E-07	4,70E-09	1,25E-06	1,68E-06
Central	7,30E-08	4,95E-07	1,23E-08	2,26E-06	2,84E-06
Sovetsky	8,66E-08	2,70E-07	7,95E-09	1,05E-04	1,05E-04
Leninsky	2,36E-08	3,16E-07	4,29E-09	5,25E-07	8,69E-07
City average	7,88E-08	4,07E-07	2,08E-08	1,68E-05	1,73E-05

The carcinogenic risk from food product consumption was calculated with the account for mean concentrations of 5 carcinogens (hexachlorocyclohexane, DDT, cadmium, arsenic, and lead) contained in 7 groups of food products (See table 4). The average weighted risk from food products and subsequent exposure to combined carcinogens totals 7E-04, which is classified as a

3rd range risk. The biggest contributors to the total carcinogenic risk are milk and dairy products – 30.3%, vegetables and vegetable produce – 25%, grains and baked goods – 17.5%. The leading component in the development of carcinogenic risk from food products is arsenic. The average ICR of arsenic in the district under study equals 6.9E-04 (a 3rd range risk); its share in the total risk is 98.4%. The analysis of carcinogenic risks showed that in all the city districts, the carcinogenic risk level is registered at E-04 (a 3rd level risk). The biggest carcinogenic risk from food products is registered in Leninsky district, the total ICR equals 9.0E-04.

Table 4

Calculation of carcinogenic risk from exposure to chemicals in food products

Substance District	Cadmium	Lead	Chrome 6+	Arsenic	DDT	Hexachlor hexane	Total risk
Metallurgichesky	3,05E-06	3,07E-07	0,00E+00	5,69E-04	1,81E-07	0,00E+00	5,73E-04
Kurchatovsky	4,26E-06	8,86E-08	0,00E+00	8,75E-04	1,81E-07	7,11E-07	8,80E-04
Kalininsky	7,82E-06	7,15E-07	0,00E+00	7,18E-04	0,00E+00	7,39E-07	7,28E-04
Traktorozavodsky	6,67E-06	1,02E-06	0,00E+00	8,19E-04	1,16E-06	7,75E-06	8,36E-04
Central	8,64E-06	4,83E-06	0,00E+00	4,29E-04	2,48E-06	1,66E-07	4,45E-04
Sovetsky	3,34E-06	3,82E-07	0,00E+00	5,52E-04	3,62E-07	2,78E-06	5,58E-04
Leninsky	6,75E-06	1,23E-05	0,00E+00	8,81E-04	7,34E-07	9,89E-08	9,01E-04
City average	5,79E-06	2,81E-06	0,00E+00	6,92E-04	7,29E-07	1,75E-06	7,03E-04

Based on the above data, we calculated and assessed the level of carcinogenic risk under combined (inhalation and peroral) exposure to chemical substances.

The results of the calculations showed that individual carcinogenic risk (city average, combined exposure) totals 9.6E-04, which is classified as a 3rd range risk (see Table 5). This risk comes, mainly, from peroral exposure. TCR under peroral exposure equals 9,14E-04 (95.1%) and is classified as a 3rd range risk. Under inhalation exposure ICR equals 4.7E-05 (4.9%) and is classified as a 2nd range risk.

Table 5

Average individual life-long carcinogenic risk under chemical exposure in Chelyabinsk

№	Intake route and media	Individual carcinogenic risk	Contribution (%)	Risk characteristics
1	Total risk for all routes and media (O+I)	0,00096	100	Unacceptable for public health
1.1	Total risk from arsenic, all routes and media (O+I)	0.00078	81,3	Unacceptable for public health
2	Peroral intake (O)	0,00091	95,1	Unacceptable for public health
2.1	Food products	0,0007	73,2	Unacceptable for public health
2.1.1	Including milk and dairy products	0,00021	22,2	Unacceptable for public health
	Whole milk	0,000052	5,4	Acceptable risk
2.1.2	Grains and baked goods	0,00012	12,8	Unacceptable for public health
	Wheat bread	0,000088	9,2	Приемлемый риск
2.1.3	Vegetables and vegetable produce	0,00017	18,3	Unacceptable for public health

№	Intake route and media	Individual carcinogenic risk	Contribution (%)	Risk characteristics
	Potatoes	0,00016	16,7	Unacceptable for public health
2.1.4	Arsenic in food products	0,00069	71,9	Unacceptable for public health
2.2	Drinking water	0,00019	19,8	Unacceptable for public health
2.2.1	Arsenic in drinking water	0,000073	7,6	Acceptable risk
2.2.2	Chrome 6+ in drinking water	0,000047	4,9	Acceptable risk
2.2.3	bromodichloromethane in water	0,000032	3,3	Acceptable risk
2.2.4	Tetrachloromethane in water	0,0000146	1,5	Acceptable risk
2.2.5	Chloroform in water	0,0000209	2,2	Acceptable risk
2.3	Soil, accidental consumption	0,0000173	1,8	Acceptable risk
3	Inhalation intake (I)	0,000047	4,9	Acceptable risk
3.1	Chrome 6+ in air	0,000037	3,9	Acceptable risk

Food products are the top media in peroral exposure to chemical substances; their contribution to the cross-media risk is 73.2% (drinking water – 20.1%, soil -1.8%).

The following substances are major contributors to cross-media carcinogenic risk: arsenic – 81.4%, chrome 6+ - 8.7%, bromodichloromethane – 3.4%, chloroform - 2,2%, tetrachloromethane – 3.4% (Figure 2). Other substances are insignificant contributors; their share is less than 1%.

Arsenic is a top contributor in peroral intake; its carcinogenic risk totals 7.8E-04 (a 3rd range risk). The main media for arsenic is food products (its TCR, on average for the districts under study, equals 6.9E-04 - 88%). Arsenic is contained in the following food products: 1) vegetables and vegetable produce (potatoes ICRav =1.64E-04), 2) grains and baked goods (wheat bread ICRav =8.82 E-05), 3) milk and dairy products (whole milk ICRav =5.22E-05).

Chrome 6+ with a total carcinogenic risk of 8.37E-05, comes mainly with peroral intake (56.2%) from drinking water as well as with inhalation intake (43.7%) from air.

Bromodichloromethane, chloroform, tetrachloromethane, with carcinogenic risks at 3.2E-05, 2.1E-05, and 1.5E-05 respectively, come mainly with peroral intake from drinking water (1005).

The highest individual carcinogenic risk is registered in Leninsky district; here, total TCR equals 1.03E-03, and is classified as a 4th range carcinogenic risk; in other districts, TCR is at E-04 (a 3rd range risk).

For Chelyabinsk population at large (1 131 200 inhabitants), the total carcinogenic population life-long risk for the period of 70 years involves 1125.2 additional cases of cancer, or 994.7 additional cases per 1 million inhabitants.

The obtained data leads to the following conclusions and recommendations:

- Based on the analyzed factors, routes and media, carcinogenic risk in Chelyabinsk requires regular corrective measures;

- Peroral intake is the biggest contributor to the total carcinogenic risk. The main media in peroral intake are food products and drinking water.

- Major contributors to the risk include carcinogens in milk and dairy products (ICR=2.1E-04), vegetables and vegetable produce (1CR=1.7E-04), grains and baked goods(ICR=1.8E-04), and drinking water (ICR=1.9E-04);

- The role of arsenic in the total carcinogenic risk requires additional analysis and scientific validation of its genesis;

- Based on the fact that a number of local food products and drinking water contain carcinogens, it is recommended to strengthen laboratory control over their content in dairy products and vegetable produce, baked goods and water. It is necessary to identify acceptable and carcinogen-safe concentrations of substances in the local food products and water;

- Based on the fact that drinking water contains chloroform and other carcinogens (formed from chlorine treatment), it is necessary to introduce water cleaning and sterilizing procedures at water treatment plants now and plan for other sterilizing activities in the future. Also it is very important to repair and renew the water-supply system on a regular basis (particularly, in Metallurgichesky district).

- Since arsenic, chrome 6+ and bromodichloromethane are the leading contributors to carcinogenic risk from drinking water, it is recommended to implement strict controlling activities over economic entities in Miass and Karabash towns.

- The carcinogenic risk from industrial emissions (air) of the leading enterprises in Chelyabinsk is permissible in terms of public health but subject to regular monitoring. The main enterprises subject to monitoring in terms of their contribution to individual carcinogenic risk include Chelyabinsk Electrometallurgical Integrated Plant (62.2%), Chelyabinsk Pipe-Rolling Plant (16.9%), a group of enterprises at Chelyabinsk Metallurgical Integrated Plant (44.4% inhalation carcinogenic risk).

To further regulate and decrease the level of atmospheric emissions, it is recommended to implement the following cancer hazard mitigating activities at industrial enterprises:

• Replace carcinogens used in (or available from) technological processes with non-carcinogens;

• Significantly reduce the volume of atmospheric emissions containing carcinogens (ideally, lower than 0.1 MCL in atmospheric air of a residential area);

• Equip the emission sources with monitoring and control systems to control the quality of atmospheric emissions;

Considering increased number of vehicles in the city, their significant contribution to atmospheric emissions (more than 60%), it is reasonable to assess the level of risks associated with motor vehicles in Chelyabinsk.

Carcinogenic risk from accidental consumption of soil is acceptable for the population however is subject to regular monitoring. The areas subject to monitoring include beaches, schools, and playgrounds.

To identify the persons (groups) exposed to risk, it is necessary to analyze the levels of carcinogenic substances (lead, arsenic, cadmium, etc.) in the biological mediums (hair, blood, and urine) of children and adults.

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