New Approaches to Express Parameter Assessment of Heavy Metal Compounds in Terms of Their Toxicity to Humans

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Abstract: For an express assessment of the toxicometrics parameters of heavy metal compounds and their effect on human health as a result of being inhaled, we proposed a new approach facilitating the prediction of toxicometrics parameters of heavy metal compounds in relation to people via determining the concentration of a substance in the air and individual physiological parameters of a person.

Keywords: toxicity, heavy metals, atmospheric air, inhalants, mathematical modeling

Introduction

The toxicity of many heavy metals, their participation in biogeochemical processes and a significant technogenic release into the atmosphere have led to their leading place among pollutants subject to monitoring and control. Heavy metals are included in the list of priority pollutants adopted by the European Union (EU) in 1982 and United States Environmental Protection Agency (USEPA) [1, 2]. Observation of pollutants included in the list of priority substances is mandatory in all media of the environment. First of all, of interest are those metals that are used in industry most widely and in significant quantities, and, as a result of their accumulation in natural environment, pose a serious threat in terms of their biological activity and toxic properties. These include lead, mercury, cadmium, zinc, bismuth, cobalt, nickel, copper, tin, antimony, vanadium, manganese, chromium, molybdenum, and arsenic [3]. At present, the importance of improving the methodology for assessing the effects of risks for the population health in conditions of unfavorable influence of environmental factors through the implementation of targeted measures is increasing. The criterion assessment of the effects, and proof of causal relationships of negative responses of the body to the impact of environmental factors, are important for the tasks of increasing the effectiveness of the measures aimed to ensure the sanitary and epidemiological well-being of the population.

Our study goal was to substantiate a new approach to express parameter assessment of heavy metals in terms of their toxicity to humans, in order to monitor the population health near industrial and technical complexes for heavy metal waste disposal.

Intensity of involvement in the biological cycle	Accumulation in soil profile	Redox regimes						
		Oxidative				Redox		Reductive
		Alkaline and acidic conditions						
		Strongly acidic and acidic	Slightly acidic	Neutral and slightly alkaline	Alkaline	Acidic	Slightly acidic and neutral	Strongly acidic and acidic
High	Accumulation in the upper layer of the profile	1	2	3		4	5	6
Moderate	Accumulation with two maximums: at the top and in the middle of the profile	7	8		9		10	
	Removal from the top and accumulation in the middle of the profile	11	12		13	14		
Weak	Removal from the top and cryogenic conservation	15		16		17	18	19
	Removal outside the profile	20	21			22		

Scale 1:30,000,000
Migration conditions in alluvial soils:
23 Predominantly oxidative
24 Predominantly permafrost conditions, with variable redox regime
25 Sharply contrasting geochemical conditions at river mouths

Potential danger of arable land contamination when applying mineral fertilizers

High
Increased
Average
Low

Urban soil contamination with heavy metals sensu integrated indicator Zc

Extremely dangerous (>128)
Dangerous (32–128)
Moderate (16–32)
Permissible (8–16)

Figure. **Heavy metals in Russian Federation soils (borrowed from [8])**

TABLE.
Critical Organs and Systems and Expected Types of Diseases in Chronic Environmental Exposure to Heavy Metals

Metals	Inhalation intake route			Oral intake route	
	RfC, mg/m^3	Critical organs and systems	Mean annual concentration (mg/m^3) in atmospheric air	RfD, mg/kg	Critical organs and systems
Manganese	5×10^{-5}	Central nervous system Peripheral nervous system Respiratory organs Skeletomuscular system	0.0009 ± 0.0001	0.14	Central nervous system Circulatory system Hematopoietic organs
Nickel	5×10^{-5}	Respiratory organs Circulatory system Hematopoietic organs Immune system Central nervous system	$0.0005 \pm 7 \times 10^{-5}$	0.02	Liver Cardiovascular system Gastrointestinal tract Thyroid
Hexavalent chromium	0.0001	Respiratory organs Liver Kidneys Immune system Gastrointestinal tract Cardiovascular system	Chromium oxide $0.0007 \pm 9 \times 10^{-5}$	0.003	Liver Kidneys Gastrointestinal tract Mucous membranes Thyroid
Lead	0.0005	Central nervous system Circulatory system Hematopoietic organs Cardiovascular system Reproductive system Endocrine system Kidneys	0.0003 ± 10^{-5}	0.0035	Central nervous system Circulatory system Hematopoietic organs Ontogenetic processes Reproductive system Endocrine system

Note: **RfC – inhalation reference concentration; RfD – inhalation reference dose.**

Proposed Method

The main sources of heavy metals in the environment are enterprises of metallurgical, metallochemical, chemical and aviation industries, along with instrumentation industry, radio engineering, electronic engineering and mechanical engineering, and also the branches of production involving the processes of welding, brazing and galvanization. A powerful factor of contaminating the environment with metals is the combustion of all fuel types and of industrial waste. The direct causes of soil and groundwater pollution include the disposal of industrial solid waste. Use of metal compounds as pesticides and fertilizers also leads to their accumulation in objects of the environment [4–7]. An important place of heavy metal accumulation in the environment is the soil cover (Figure).

An assessment of atmospheric air quality in the Russian Federation cities over the period of 2005–2009, based on the data of the Federal Information Foundation for Social and Hygienic Monitoring, indicated that lead and its compounds, along with hexavalent chromium, were included in the list of leading pollutants, exceeding the maximum permissible daily average concentration ($MPC_{d.a.}$) limit by 5 times or more [8]. The population numbers exposed to high levels of air pollution in 2005–2007 amounted to 3,587.8 thousand people. In conditions of an average annual concentration of lead in the range of 0.1–0.2 µg/m^3 (i.e., 0.3–0.7 $MPC_{d.a.}$), about 10 million people live [9, 10]. The average annual concentrations of manganese in the atmospheric air of large cities without metallurgical enterprises are 0.03–0.07 µg/m^3 (i.e., 0.1–0.2 $MPC_{d.a.}$).

The presence of metals in the environment leads to their entry into the human body with water, food, or inhaled air. At the same time, the target organ for any metal is the digestive system, which is associated with two factors. First, the gastrointestinal tract can be directly exposed to metals at the stage of their entry into the body [11], and not only with water and food, but also with inhaled air due to swallowing some of it with saliva [12, 13]. Secondly, the possibility of the toxic effect of metals on the digestive function is associated with the process of eliminating these substances from the body, since one of the ways of their evacuation is the gastrointestinal tract [12], the importance of which in this process significantly increases with toxic kidney damage [14]. Besides, metal compounds may affect the digestive organs (gastric and intestinal mucosae, pancreas, liver).

There is a prototype method for evaluating the hazard of metal compounds, for calculating the risks, and for revealing their effect on the digestive function in the minimum effective doses with intraperitoneal administration and conversion into the threshold concentrations in atmospheric air.

The calculation for metals was carried out according to the formula:

$$MEC = \frac{MED \times 100}{(40 \times 0.6W) \times V}, \qquad (1)$$

where *MEC* is the minimum effective concentration (mg/m³);

MED is the minimum effective dose for intraperitoneal administration (mg/kg);

W is the volume of metal absorption from gastrointestinal tract into the blood (%);

V is the volume of inhaled air per day (m³).

The calculation was based on the following provisions:

- The volume of metal absorption into the blood, occurring directly in the respiratory organs, was assumed at 40 % [23];

- The volume of metal absorption into the blood, occurring in the gastrointestinal tract due to the ingestion of dust particles with saliva, taking into account published data, was assumed for zinc at 50 % [15–17], for lead at 10% [15, 18], for chromium at 10 % [16], and for molybdenum and tungsten at 70 % [15, 19, 20];

- The volume of inhaled air per day for a person weighing 70 kg was determined at 35 L/min · 60 min · 24 hrs. = 16,800 L = 16.8 m³ [3].

By analogy, a new method has been developed for predicting toxicometrics parameters of heavy metal compounds for humans:

$$D_{inh} = Z \times EC, \qquad (2)$$

Where D_{inh} is the dose received by a person via the inhalation route of intake, mg/kg;

Z is a number of characteristics reflecting a number of physiological indicators;

EC is the effective concentration in the surface layer of the atmosphere (working zone), mg/m³.

Conclusion

We conducted the analysis of toxicological characteristics of heavy metals commonly used in the course of various industrial activities. It has been shown that the inhalation route of pollutant intake is the most difficult for the assessment of toxicometrics parameters of heavy metal compounds due to the difficulty of determining the dose received by the body, expressed in mg per kg of a body weight.

The features of the action of heavy metals on the human body during the inhalation route of intake are shown, which is also associated with their negative effect on digestive organs (the mucous membrane of the stomach and intestines, pancreas, liver) due to the fact that one of the ways of evacuation of these compounds is the gastrointestinal tract.

Based on the data obtained in our study, we have filed an application for the invention.

References

1. Directive 2000/60/EC of the European Parliament and of the Council Of Europe establishing a framework for community action on water policy. Luxembourg, 2000. Available at: https://eur-lex.europa.eu/eli/dir/2000/60/oj

2. Petncom E., Liotta L. Clinical applications of proteomics. *J. Nutr*; 2003; 133: 2476–2484. DOI: 10.1093/jn/133.7.2476S

3. Skalny A.V., Bykov A.T. Ecological and Physiological Aspects of Using Macro- and Microelements in Restorative Medicine. Orenburg: *OSU Publishing House*, 2003. 199 p. (In Russ.).

4. Mudry I.V. Heavy metals in the soil - plant - human system (Review). *Hygiene and Sanitation*.1997.1:14–17. (In Russ.).

5. Rusakov N.V., et al. Assessment of the hazard of industrial waste containing heavy metals. *Hygiene and Sanitation.* 1998;4:27–29. (In Russ.).

6. Roshchin A.V. Environmental pollution with metals. In: *Metals. Hygienic Aspects of Assessing and Improving the Environment*: Collection of articles. Ed. A.A. Kasparova, Yu.G. Shirokova. Moscow, 1983. 7–15. (In Russ.).

7. Trakhtenberg I.M. Kolesnikov V.S., Lukovenko V.P. Heavy Metals in the Environment: Modern Hygienic and Toxicological Aspects. Minsk: *Science and Technolog*y, 1994. 285 p. (In Russ.).

8. Revich B.A. Hot Spots of Chemical Pollution of the environment and the Health of the Population of Russia. Ed. V.M. Zakharova. Moscow: *Acropolis*, Public Chamber of the Russian Federation, 2007. 192 p. Available at: https://allbeton.ru/upload/iblock/3dd/goryachie-tochki-himicheskogo-zagryazneniya-okrujayuschey-sredi-i-zdorove-naseleniya-rossii-yrevichi.pdf (In Russ.).

9. Kolpakova A.F. Pollution of the environment in Taimyr Autonomous Okrug with heavy metals and their content in blood samples of the population. *Labor Medicine and Industrial Ecology*.1999;11:5–8. Available at: https://cyberleninka.ru/article/n/o-roli-zagryazneniya-okruzhayuschey-sredy-tyazhelymi-metallami-v-patogeneze-hronicheskih-zabolevaniy-organov-dyhaniya (In Russ.).

10. Chernyaeva T.K., Kuzmichev T.G., Bozhatkov D.K. Polluting the environment of an industrial city with heavy metals and the state of health in children. *Proceeding of the 8th Russian National Congress of Hygienists and Sanitary Physicians.* Ed. A.I. Potapov. Moscow, 1996;1: 202–204. Available at: https://cyberleninka.ru/article/n/aktualnye-problemy-vliyaniya-othodov-proizvodstva-i-potrebleniya-na-obekty-okruzhayuschey-sredy-i-sostoyanie-zdorovya-naseleniya-obzor (In Russ.).

11. Lyubchenko P.N. Intoxication Diseases of the Digestive System. Voronezh, 1990. 182 p. (In Russ.).

12. Donaldson R.M., Barreras R.E. Intestinal absorption of trace quantities of Chromium. *J. Lab. Clin. Med.* 1966; 68:484–493.

13. Sorensen I.A. Andersen O., Nielsen I.B. An in vivo study of the gastrointestinal absorption site for zinc chloride in mice. *J.Trace Elem. Med. Biol*; 1998; 12(1): 16–22. DOI: 10.1016/S0946-672X(98)80016-3

14. Impact of hazardous and harmful environmental factors on the human body. Metrological aspects. OK. Isaeva, editor. Moscow: *PAIMS*. Vol. 2. 495 p. Available at: https://rusneb.ru/catalog/002178_000020_BGUNB-RU%7C%7C%7CBGU%7C%7C%7Cliber%7C%7C%7C0009773/ (In Russ.).

15. Grin N.V. Biological Action and Hygienic Value of Atmospheric Emissions from the Production of Fireproof Products. DSc. Dissertation Abstract. Donetsk, 1971.32 p. Available at: https://rusneb.ru/catalog/000199_000009_007258647/ (In Russ.).

16. Davydova V.I., Blokhin V.A., Neizvestnova E.M. An issue of the toxic effect of condensation of chromium anhydride aerosol. In: *Issues of Hygiene and Professional Pathology in Nonferrous and Ferrous Metallurgy*. Moscow, 1981. 90–96. Available at: https://rusneb.ru/catalog/000199_000009_002108619/ (In Russ.).

17. Ershov Yu.A., Pleteneva T.V. Mechanisms of Toxic Action of Inorganic Compounds. Moscow: *Medicine*, 1989. 272 p. (In Russ.).

18. Hygienic Criteria for the State of the Environment. Chromium. Geneva: WHO, 1990. 167 p. Available at: https://apps.who.int/iris/bitstream/handle/10665/139700/5225032850.PDF (In Russ.).

19. Izraelson Z.I., Mogilevskaya O.Ya., Suvorov S.V. Occupational Hygiene an. Available at: http://www.bookre.org/reader?file=577646d Occupational Pathology When Working with Rare Metals. Moscow: *Medicine*, 1973. 303 p. (In Russ.).

20. Kuzubova L.I., Shuvaeva O.V., Anoshin G.N. Environmental Toxicants in Food. Hygienic Characteristics, Concentration Standards in Food Products, Methods of Determination: An Analytical Review. Novosibirsk, *Ecology Series*, 2000; 58. 67 p. (In Russ.).