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NANOPARTICLES IN THE AIR OF THE WORKING ZONE AS A RISK FACTOR FOR THE HEALTH OF WORKERS OF VARIOUS INDUSTRIES

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Ключевые слова: *наночастицы, мелкодисперсные фракции пыли, воздух рабочей зоны, профессиональный риск*

Abstract. Nanoparticles in the air of the working zone as a risk factor for the health of workers of various industries. Sevalnev A.I., Sharavara L.P., Kutsak A.V., Nefodov O.O., Zemliynyi O.A., Pisarevskyi K.I., Shevchenko O.S. *Purpose: analysis of scientific literature, summarizing data on domestic and foreign experience of assessing the determination of nanoparticles in the air of the working zone as a risk factor for the health of workers of various industries. The article analyzes the literature data on the study of the content of fine dust and nanoparticles in the atmospheric air and air of the working zone of different industries. Numerous studies indicate that fine dust is contained in the emissions of many industrial enterprises. According to the World Health Organization by level of impact on human health, suspended particles in the air and especially in the air of the working zone belong to the priority pollutants. Evaluation of the dust content in the air of large industrial cities is particularly relevant, because of a large number of sources of dust emissions of various origins in urban areas. Various technological processes contribute to the formation of fine dust and nanoparticles which pollute the ambient air and the air of the working zone. Data on the negative impact of fine dust and nanoparticles on health of workers are presented. Attention is paid to the problem of hygienic assessment of nanoscale dust content in the working zone air. The obtained results indicate that today the issues of studying the physicochemical properties of nanoparticles, their toxicity to the body, analysis of potential risks to humans, the development of an effective and reliable system for monitoring ultrafine particles in the environment and the production environment are still relevant as for informing employees about the risks involved, reducing and preventing harmful effects on humans. The potential negative effects on workers' health determine the need and opportunity for further research in this area.*

Реферат. Наночастинки в повітрі робочої зони як фактор ризику для здоров'я працюючих у різних галузях виробництва. Севальнєв А.І., Шаравара Л.П., Куцак А.В., Нефьодов О.О., Земляний О.А., Писаревський К.І., Шевченко О.С. *Мета роботи: аналіз наукової літератури для узагальнення даних про вітчизняний і зарубіжний досвід оцінки визначення наночастинок у повітрі робочої зони як фактора ризику для здоров'я працівників різних галузей виробництва. У статті проведено аналіз літературних даних щодо дослідження* *вмісту дрібнодисперсного пилу та наночастинок в атмосферному повітрі та повітрі робочої зони різних галузей виробництва. Численні дослідження свідчать про те, що дрібнодисперсний пил міститься у викидах багатьох промислових підприємств. За рівнем впливу на здоров'я людини зважені частинки в атмосферному повітрі й особливо в повітрі робочої зони Всесвітньою організацією охорони здоров'я відносяться до пріоритетних забруднювачів. Особливо актуальна оцінка вмісту пилу в повітрі великих промислових міст, оскільки на урбанізованих територіях знаходитися велика кількість джерел пилових викидів різного походження. Різноманітні технологічні процеси сприяють утворенню дрібнодисперсного пилу і наночастинок, які забруднюють атмосферне повітря та повітря робочої зони. Приводяться дані щодо негативного впливу дрібнодисперсного пилу та наночастинок на здоров'я людини та працюючих. Приділено увагу проблемі гігієнічної оцінки вмісту пилу нанорозмірного діапазону в повітрі робочої зони. Одержані результати свідчать про те, що на сьогодні все ж таки залишаються актуальними питання вивчення фізико-хімічних властивостей наночастинок, їх токсичності для організму, аналізу потенційних ризиків для людини, розробки ефективної та достовірної системи моніторингу ультродисперсних частинок у навколишньому та виробничому середовищі, обов'язкового інформування працюючих про наявні ризики, зменшення та профілактику шкідливого впливу на людину. Можливі негативні наслідки для здоров'я працюючих зумовлюють необхідність і доцільність подальших досліджень у цій галузі.*

Today, one of the leading directions in the development of world technological progress is work on the use of nanotechnology in industry and the creation of promising nanomaterials. In this regard, a large number of materials appear in different industries, which in their composition have particles of the nanoscale range (less than 100 nm). Nanotechnology has not only obvious advantages, but also carries a potential danger to human health and the environment. The use of nanotechnology and the emergence of new nanomaterials in industry require a detailed assessment of the potential risks associated with their use. The study of occupational risks in contact with humans and biological objects of the environment with nanoparticles is an urgent and important task of occupational medicine today.

Purpose: to analyze the scientific literature, to summarize data on domestic and foreign experience in assessing the determination of nanoparticles in the air of the working zone as a risk factor for the health of workers in various industries.

According to the World Health Organization by the level of impact on human health, suspended particles in the air and especially in the air of the working zone belong to the priority pollutants. The undoubted danger to human health is represented by particles of the PM_{10} and $PM_{2,5}$ fraction, which have the ability to penetrate the thoracic section of the respiratory system and cause a negative effect on human health. The presence of nanoparticles in the atmospheric air of populated areas and in the air of the working zone of various industries is proved by the data of domestic and foreign studies [4, 5, 15, 21, 25, 27, 40]. Numerous studies have proved the negative effect of dust on human health [7, 34, 37, 39, 44], especially on the cardiovascular system [13, 29, 30, 38, 43], respiratory system [2, 21, 33, 42, 43], contributing to the increase in mortality from cardiovascular and respiratory diseases, lung cancer [1, 8, 13].

According to research of scientists from different countries, suspended particles formed as a result of motor vehicles emission, cause an increase in mortality by 6% among different population groups and increase the total amount of cases of chronic bronchitis and asthma attacks in adults and children as well.

Evaluation of the dust content in the air of large industrial cities is particularly relevant, because of a large number of sources of dust emissions of various origins in urban areas: the operation of automobile engines, the movement of cars along the roads, the burning of solid fuels, and various industrial enterprises.

Numerous studies indicate that dust is contained in the emissions of many industrial enterprises: of ferrous and non-ferrous metallurgy, construction, mechanical engineering, electrical engineering. Technological processes at these industrial enterprises result in the formation of fine dust [3, 18, 16, 19, 21, 22, 27, 41] and, accordingly, the formation of particles of the nanoscale range is possible.

The technological processes of crushing, grinding, mixing, storage and transportation of bulk materials, melting contribute to the formation of fine dust and dust with an aerodynamic size of less than 10 microns, which are not captured by dust cleaning plants and contribute to the pollution of atmospheric air and air of the working area with solid particles of different sizes, including ultrafine [14, 18, 17, 23, 35].

The concentrations of suspended particles in the air of the working zone are much higher than the concentrations of these particles in the atmospheric air due to the close proximity to the source of formation and the use of processes of solid materials processing. Depending on the mechanisms of formation, aerosols of disintegration, formed as a result of processing of solid materials (cutting, crushing, grinding, grinding, etc.), and condensation aerosols, formed as a result of cooling of vapors (melting, welding of metal) are distinguished.

Numerous studies indicate that nanoparticles cause a negative effect on the worker's health and can cause changes in the human body, in particular, changes in the immune system [36], development of cancer [40], they affect the respiratory system [31], cause diseases of the cardiovascular system and increase the risk of mortality from coronary heart disease [28, 32], increase the incidence of the urogenital and digestive system diseases, affect the central nervous system, cause diseases of locomotor apparatus [16, 38].

Unfortunately, nowadays, the hygienic assessment of dust content in the air of the working zone does not reflect such characteristics of dust as the particle size, their shape, surface area, the number of particles; this does not allow to fully determine the amount of potential risk to human health

Today, in Ukraine and worldwide, there are no values of maximum permissible concentrations (MPC) for nanoscale particles of different chemical composition, which is a serious problem in the assessment of the level of occupational risk [12, 33]. In the case of hygienic assessment of the level of exposure of nanoparticles in the air, foreign scientists propose to use "test levels", namely for metals and biologically stable dispersed nanoparticles with a density of >6000 kg/m^3, the quantitative concentration of particles in the range 1−100 nm should not contain more than 20 000 particles/cm^3, for biologically stable dispersed nanoparticles with a density of <6000 kg/m^3 − more than 40 000 particles/cm^3. However, for some nanomaterials, there are maximum allowable concentrations determined by leading experts of the US Institute of Occupational Health and Safety (TiO2 – 0,3 mg/m^3, carbon nanotubes and nanofibers – 0,007 mg/m^3), and for other substances it is recommended to use safety factors recommended by British Institute for Standards for Risk Assessment [11, 12].

Today different scientists worldwide actively conduct research of influence of nanoparticles on the state of health of humans [34] and determination of their presence in the air of the working zone. So, by the group of scientists content of nanoparticles in the air of the working zone of workers, at a receipt and production of nanoparticles of different chemical composition for industry was investigated. As a result of the study, it was found that the available concentrations of nanoparticles in the air of the working zone can exceed the calculated MPC according to safety factors for nanomaterials, even if there is no excess of the existing MPC for these substances in the usual form. Also, the results of the study indicate the presence of a background concentration of nanoparticles before work and the presence of other chemical elements not related to the process; this may be a consequence of internal and external factors, that also increases the level of risk for workers [9, 10, 16, 20, 24, 26].

According to the research, of Varivonchik D.V. and others a hygienic assessment of the working conditions of dentists and dental technicians was carried out as a result of which it was established that they are exposed to dust of the nanoscale range of about 14 metals that make up the materials they work with. The recommended standards for nanodispersed dust of II-III hazard classes were exceeded by 4,8 times according to the Hygienic classification of working conditions [5, 6].

According to the results of studies of Movchan N.A. et al.at the Institute of Occupational Medicine of the Academy of Medical Sciences, it was found that lead has a high level of emissions of the nanoparticles of this element into the air of the working zone. Almost 90 % of all sizes have sizes from 1 to 100 nm, and their values in fractions of 5-10 nm, 10-15 nm and 15-20 nm, the development and implementation of preventive measures are required to improve the working conditions of workers. area [15].

A large number of studies, which confirm the presence of nanoparticles in the air of the working zone of various industries and possible negative consequences for the health of workers, necessitates the expediency of their research, namely, the physicochemical and toxicological properties of nanoparticles of various chemical composition, their effect on the human body and the development of scientific justification of the hygienic standard of these substances in the air of the working area.

CONCLUSIONS

1. Numerous studies of scientists indicate that fine dust is contained in the emissions of many industrial enterprises. Various technological processes contribute to the formation of fine dust and nanoparticles, which pollute the ambient air and the air of the working zone.
2. According to the World Health Organization by the level of impact on human health, suspended particles in the air and especially in the air of the working zone belong to the priority pollutants. Numerous studies indicate that nanoparticles cause a negative effect on the worker's health and can cause changes in the human body, in particular, changes in the immune system, development of cancer, they affect the respiratory system, cause diseases of the cardiovascular system and increase the risk of mortality from coronary heart disease, increase the incidence of the urogenital and digestive system diseases, affect the central nervous system, cause diseases of locomotors apparatus.

3. Analysis of literary sources suggests that today the priority scientific, research in the field of nanoparticles including medical, should be considered:

- the study of the physicochemical properties of nanoparticles, their toxicity to the body;
- analysis of potential risks for humans, the development of an effective and reliable system for controlling ultrafine particles in the surrounding and production environment;
- development of a system for mandatory informing employees about existing risks in order to reduce and prevent harmful effects on humans.

Conflict of interests. The authors declare no conflict of interest.

REFERENCES

1. Aidinov HT, Marchenko BI. [Multivariate analysis of the structure and share contribution of potential risk factors for malignant neoplasms of the trachea, bronchi and lung]. Analiz riska zdorovia. 2017;1:45-55. Russian. doi: https://doi.org/10.21668/health.risk/2017.1.06
2. Gasainieva AG, Gasainieva MG. [On atmospheric pollution with fine dust and its effect on human health]. Engineering Bulletin of the Don. 2017;4. Russian. Available from: ivdon.ru/ru/magazine/archive/n4y2017/4664.
3. Kopytenkova OI, Tursunov ZSh, Levanchuk AV, Mironenko OV, et al. [Hygienic assessment of working conditions in certain professions of construction organizations]. Hygiene and sanitation. 2018;97(12):1203-9. Russian. doi: https://doi.org/10.18821/0016-9900-2018-97-12-1203-1209
4. Merinov AV, Shaiakhmetov SF, Lisetskaia LG, Meshchakova NM. [Hygienic characteristics of gas-aerosol suspensions in modern aluminum production]. Siberian Medical Review. 2019;3:78-83. Russian. doi: https://doi.org/10.20333/2500136-2019-3-78-83
5. Kundijev JuI, Varyvonchyk DV, Kopach KD, et al. [Hygienic working conditions of dental workers in the application of modern medical technologies]. Ukrainian Journal of Occupational Medicine. 2017;4(53):3-11. Ukrainian. doi: https://doi.org/10.33573/ujoh2017.04.003
6. Demetska OV, Andrusishina IM, Kopach KD. [Estimation of nanoparticles emission into the air of the working area using modern dental materials]. Medical forum: scientific periodical. 2016;8:64-67. Ukrainian. Available from: https://ua.ujoh.org/DEVELOPMENT-OF-A-COMBINATION-OF-HYGIENIC-MEASURES-FOR-PREVENTION-OF-HARMFUL-EFFECT-OF-NANO--AND-LOW-DISPERSED-AEROSOLS-ON-WORKERS--OF-THE-DENTAL-SERVICE--UA.html
7. Shatorna VF, Chekman IS, Harets VI, Nefodova OO, et al. [Experimental study of the influence of nanometals on embryogenesis and cardiac development]. 2017;1(92):59-63. Ukrainian. Available from: http://files.odmu.edu.ua/anthropology/2017/01/a171_59.pdf
8. Zhilinskii EV. [Nanotechnology in healthcare: risk assessment and security strategy]. Power. 2017;25(3):79-86. Russian. Available from: https://cyberleninka.ru/article/n/nanotehnologii-v-zdravo-ohranenii-otsenka-riskov-i-strategiya-bezopasnosti.
9. Zaitseva NV, Ulanova TS, Zlobina AV. [Studies of nanosized particles in industrial aerosols and suspended solids in the air of the working area]. Toxicological Bulletin. 2017;1(142):20-26. Russian. doi: https://doi.org/10.36946/0869-7922-2017-1-20-26
10. Zemlianova MA, Ignatova AM, Stepankov MS. [Identification of ultrafine particles of aluminum oxide for assessing the professional risk of welders]. Materials of the 16th International Scientific and Practical Conference on Ecology and security. 2018;193-5. Russian. Available from: https://elibrary.ru/item.asp?id=37631783
11. Leonenko NS, Demetskaia AV, Leonenko OB. [Dynamics of the concentration of nanosized particles in the air of a working zone under industrial conditions]. 2019;1:53-61. Ukrainian. doi: https://doi.org/10.33273/2663-4570-2019-85-1-53-61
12. Lutsenko LA, Gvozdeva LL, Tatianiuk TK. [Information content of differentiated accounting of the size of solid particles in the air to protect the health of workers in dust occupations and the public (literature review)]. Hygiene and sanitation. 2018;97:514-9. Russian. doi: http://dx.doi.org/10.18821/0016-9900-2018-97-6-514-519
13. Maremukha TP, Petrosian AA. [Air pollution by fine dust fractions (PM10 and PM2.5) in the area of operation of a coal-fired power plant]. Zdorove i okruzhaiushchaia sreda. 2016;26:39-42. Russian. Available from: https://elibrary.ru/item.asp?id=29746732.
14. Azarov VN, Horshkov EV, Marinin NA, Azarov AV. [Fine dust as a factor in air pollution]. Sociology of the city. 2018;2:5-14. Russian. Available from: https://elibrary.ru/item.asp?id=36654926
15. Melnyk NA, Movchan VO. [Investigation of the emission of nanoparticles into the air on an experimental model of the technological process of recovery of lead]. Collection of scientific papers «Actual problems of preventive medicine». Edition 12. 2015;153-8. Russian. Available from: http://appm.meduniv.lviv.ua/images/pdf/-Zbirka_2015_3c.pdf#page=153
16. Yavorovskyi OP, Tkachishin VS, Arustamian OM, et al. [Nanoparticles and nanomaterials: structure, physicochemical and toxicological properties, influence on the organism of workers]. Environment&Health. 2016;3:29-35. Ukrainian. Available from: https://cyberleninka.ru/article/n/nanochastki-i-nanomateriali-budova-fiziko-himichni-i-toksikologichni-vlastivosti-vpliv-na-organizm-pratsivnikiv
17. Nasimi MKh, Soloveva TV. [About pollution of fine air PM10 with fine dust by the city of Kabul]. Don Engineering Journal. 2017;2(45). Available from: http://ivdon.ru/ru/magazine/archive/n4y2017/4664

18. Azarov VN, Barikaeva NS, Nikolenko DA, Soloveva TV. [On the study of air pollution with fine dust using a random function apparatus]. Engineering Herald of Don. 2015;4. Russian. Available from: ivdon.ru/ru/magazine/archive/n4y2015/3350. Russian.

19. Ulanova TS, Antipeva MV, Zabirova MI, Volkova MV. [Determination of nanoscale particles in the air of a working zone of metallurgical production]. Health risk analysis. 2015;1:77-80. Russian.
doi: https://doi.org/10.21668/health.risk/2015.1.10

20. Vlasova EM, Ustinova OYu, Nosov AE, et al. [Features of respiratory diseases in smelters of titanium alloys under the combined effects of fine dust and chlorine compounds]. Hygiene and sanitation. 2019;98(2):153-8. Russian.
doi: https://doi.org/10.18821/0016-9900-2019-98-2-153-158

21. Prosviryakova IA, Shevchuk LM. [Hygienic assessment of PM10 i PM2,5 particulate contain in the air and the risk to the health of residents in the zone of influence of emissions of stationary sources of industrial enterprises]. Health risk analysis. 2018;2:14-22. Russian.
doi: https://doi.org/10.21668/health.risk/2018.2.02

22. Radchenko DN, Hadzhieva LAS, Gavrilenko V.V. [Monitoring the content of ultrafine aerosols in the air of the mining region]. Bulletin of the Peoples' Friendship University of Russia. Series: Ecology and Life Safety. 2017;25(4):520-8. Russian. Available from: http://journals.rudn.ru/ecology.

23. Sevalnev AI, Sharavara LP. [Harmful working conditions as a risk factor for development of morbidity due to workers in auxiliary professions]. Zaporozhye medical journal. 2019;2(113):246-52. Ukrainian.
doi: https://doi.org/10.14739/2310-1210.2019.2.161505

24. Solokha NV. [Physiological and hygienic characteristics of operators upon receipt of nanosized silicides and metal nitrides and the state of their digestive system]. Ukrainian Journal of Occupational Medicine. 2015;2(43):18-25. Ukrainian.
doi: https://doi.org/10.33573/ujoh2015.02.018

25. Ulanova TS, Gileva OV, Volkova MV. [Determination of micro- and nanoscale particles in the air of a working zone at mining enterprises]. Health risk analysis. 2015;4:44-48. Russian.
doi: https://doi.org/10.21668/health.risk/2015.4.06

26. Yavorovskii AP, Solokha NV, Demetskaia AV, Andrusishina IN. [Physiological and hygienic assessment of the working conditions of the operator in the synthesis of nanocrystalline chromium disilicide powder by high-energy mechanical activation]. Health problems and ecology. 2017;2(52):86-95. Belorussian. Available from: https://cyberleninka.ru/article/n/fiziologo-gigieniches-kaya-otsenka-usloviy-truda-operatora-pri-sinteze-nanokri-stallicheskogo-poroshka-disilitsida-hroma-metodom

27. Binoy K Saikia, Jyotilima Saikia, Shahadev Rabha. Ambient nanoparticles/nanominerals and hazardous elements from coal combustion activity: Implications on energy challenges and health hazards. Geoscience Frontiers. 2018;9:863-75.
doi: https://doi.org/10.1016/j.gsf.2017.11.013

28. Dayana M Agudelo-Castanedaa, Elba C Teixeirab. Cluster analysis of urban ultrafine particles size distributions. Atmospheric Pollution Research. 2018;29:1-7.

29. Ramirez-Lee MA, Aguirre-Banuelos P, Martinez-Cuevas PP, Gonzalez C, et al. Evaluation of cardiovascular responses to silver nanoparticles (AgNPs) in spontaneously hypertensive rats. Nanomedicine: Nanotechnology, Biology and Medicine. 2018;14(2):385-95.
doi: https://doi.org/10.1016/j.nano.2017.11.013

30. Newby DE, Mannucci PM, Tell GS. Expert position paper on air pollution and cardiovascular disease. Eur Heart J. 2015;36:83-93.
doi: https://doi.org/10.1093/eurheartj/ehu458

31. Juan C Rojasa, Nazly E Sanchezb, Ismael Schneiderc, Marcos LS Oliveirac. Exposure to nanometric pollutants in primary schools: Environmental implications. Silvac Urban Climate. 2019;27:412-9.
doi: https://doi.org/10.1016/j.uclim.2018.12.011

32. George D Thurston, Richard T Burnett, Michelle C Turner. Ischemic Heart Disease Mortality and Long-Term Exposure to Source-Related Components of U.S. Fine Particle Air Pollution. Environmental Health Perspectives. 2016;124(6):785-94.
doi: https://doi.org/10.1289/ehp.1509777

33. Peixe TS, de Souza Nascimento E, Schofi eld KL, Arcurid ASA, Bulcao RP. Nanotoxicology and Exposure in the Occupational Setting. Occupational Diseases and Environmental Medicine. 2015;3:35-48.
doi: https://doi.org/10.4236/odem.2015.33005

34. Ray JL, Holian A. Sex differences in the inflammatory immune response to multi walled carbon nanotubes and crystalline silica. Inhalation Toxicology. 2019;31(7):285-97.
doi: https://doi.org/10.1080/08958378.2019.1669743

35. Saliou Mbengue, Laurent Y Alleman, Pascal Flament. Erratum to «Metal-bearing fine particle sources in a coastal industrialized environment». Atmospheric Research. 2017;183:202-11.
doi: https://doi.org/10.1016/j.atmosres.2016.08.014

36. Kurjane N, Zvagule T, Martinsone J et al. The effect of different workplace nanoparticles on the immune systems of employees. Journal of Nanoparticle Research. 2017;19(9):320.
doi: https://doi.org/10.1007/s11051-017-4004-6

37. Zhou F, Liao F, Liu Y, et al. The size-dependent genotoxicity and oxidative stress of silica nanoparticles on endothelial cells. Environmental Science and Pollution Research. 2019;26(2):1911-20.
doi: https://doi.org/10.1007/s11356-018-3695-2

38. Thomson EM. Air pollution, stress, and allostatic load: linking systemic and central nervous system impacts. Journal of Alzheimer's Disease. 2019;69(3):597-614. doi: https://doi.org/10.3233/JAD-190015

39. Teresa Moreno, Pedro Trechera, Xavier Querol, et al. Trace element fractionation between PM10 and PM2.5 in coal mine dust: Implications for occupational respiratory health. International Journal of Coal Geology. 2019;203:52-59.
doi: https://doi.org/10.1016/j.coal.2019.01.006

40. Lin Huang, Yun-He Bai, Rui-Yue Ma, Ze-Ming Zhuo, Ling Chen. Winter chemical partitioning of metals bound to atmospheric fine particles in Dongguan, China, and its health risk assessment. Environmental Science and Pollution Research. 2019;26:664-75. doi: https://doi.org/10.1007/s11356-019-05001-8

41. Atin Adhikari, Aniruddha Mitra, Abbas Rashidi, Imaobong Ekpo, Jefferson Doehling et al. Wood Dust and Nanoparticle Exposure among Workers during a New Building Construction. International Journal of Medical and Health Sciences. 2018;12(3). Available from: https://digitalcommons.georgiasouthern.edu/bee-facpres/6

42. Yang Gao, Hongbing Ji. Microscopic morphology and seasonal variation of health effect arising from heavy metals in PM2.5 and PM10: One-year measurement in a densely populated area of urban Beijing. Atmospheric Research. 2018;212:213-26. doi: https://doi.org/10.1016/j.atmosres.2018.04.027

43. Zapor L. Effects of silver nanoparticles of different sizes on cytotoxicity and oxygen metabolism disorders in both reproductive and respiratory system cells. Archives of Environmental Protection. 2016;42(4):32-47. doi: https://doi.org/10.1515/aep-2016-0038

44. Li X, Ji X, Wang R, et al. Zebrafish behavioral phenomics employed for characterizing behavioral neurotoxicity caused by silica nanoparticles. Chemosphere. 2020;240:124937.
doi: https://doi.org/10.1016/j.chemosphere.2019.124937

СПИСОК ЛІТЕРАТУРИ

1. Айдинов Г. Т. Марченко Б. И. Многомерный анализ структуры и долевого вклада потенциальных факторов риска при злокачественных новообразованиях трахеи, бронхов и легкого. *Анализ риска здоровью.* 2017. № 1. С. 45-55. DOI: https://doi.org/10.21668/health.risk/2017.1.06

2. Гасайниева А. Г., Гасайниева М. Г. О загрязнении атмосферы мелкодисперсной пылью и о ее влиянии на здоровье человека. *Инженерный вестник Дона.* 2017. № 4.
URL: ivdon.ru/ru/magazine/archive/n4y2017/4664.

3. Гигиеническая оценка условий труда в отдельных профессиях строительных организаций / О. И. Копытенкова и др. *Гигиена и санитария*. 2018. Т. 97, № 12. С. 1203-1209.
DOI: https://doi.org/10.18821/0016-9900-2018-97-12-1203-1209

4. Гигиеническая характеристика газоаэрозольных взвесей в современном производстве алюминия / А. В. Меринов и др. *Сибирское медицинское обозрение.* 2019. № 3. С. 78-83.
DOI: https://doi.org/10.20333/2500136-2019-3-78-83

5. Гігієнічні умови праці працівників стоматологічної служби в умовах застосування сучасних медичних технологій / Ю. І. Кундієв та ін. *Український журнал з проблем медицини праці*. 2017. Т. 53, № 4. С. 3-11.
DOI: https://doi.org/10.33573/ujoh2017.04.003

6. Демецька О. В., Андрусишина І. М., Копач К. Д. Оцінка емісії наночастинок у повітря робочої зони при використанні сучасних стоматологічних матеріалів. Медичний форум: наук. період. видання. 2016. № 8. С. 64-67. URL: https://ua.ujoh.org/DEVELOPMENT-OF-A-COMBINATION-OF-HYGIENIC-MEASURES-FOR-PREVENTION-OF-HARMFUL-EFFECT-OF-NANO--AND-LOW-DISPERSED-AEROSOLS-ON-WORKERS--OF-THE-DENTAL-SERVICE--UA.html.

7. Експериментальне вивчення впливу нанометалів на ембріонгенез і розвиток серця / В. Ф. Шаторна та ін. *Інтегративна антропологія*. 2017. Т. 29, № 1. С. 59-63. URL:
http://files.odmu.edu.ua/anthropology/2017/01/a171_59.pdf.

8. Жилинский Е. В. Нанотехнологии в здравоохранении: оценка рисков и стратегия безопасности. *Власть*. 2017. Т. 25, № 3. С. 79-86. URL: https://cyberleninka.ru/article/n/nanotehnologii-v-zdravoohranenii-otsenka-riskov-i-strategiya-bezopasnosti

9. Зайцева Н. В., Уланова Т. С., Злобина А. В. Исследования наноразмерных частиц в составе промышленных аэрозолей и взвешенных веществ в воздухе рабочей зоны. *Токсиколог. вестник*. 2017. Т. 142, № 1. С. 20-26.
DOI: https://doi.org/10.36946/0869-7922-2017-1-20-26

10. Землянова М. А., Игнатова А. М., Степанков М. С. Идентификация ультрадисперсных частиц оксида алюминия для оценки профессионального риска сварщиков. Дальневосточная весна − 2018: материалы 16-й Междунар. науч.-практ. конф. по проблемам экологии и безопасности (г. Комсомольск-на-Амуре, 27 апреля 2018 г.). Комсомольск-на-Амуре, 2018. С. 193-195.
URL: https://elibrary.ru/item.asp?id=37631783

11. Леоненко Н. С., Демецкая А. В., Леоненко О. Б. Динамика концентраций наноразмерных частиц в воздухе рабочей зоны в производственных условиях. *Укр. журнал сучасних проблем токсикології.* 2019. № 1. С. 53-61.
DOI: https://doi.org/10.33273/2663-4570-2019-85-1-53-61

12. Луценко Л. А., Гвоздева Л. Л., Татянюк Т. К. Информативность дифференцированного учёта размеров твёрдых частиц в воздушной среде для защиты здоровья работников пылевых профессий и населения: обзор литературы. Гигиена и санитария. 2018. № 97. С. 514-519. DOI: http://dx.doi.org/10.18821/0016-9900-2018-97-6-514-519

13. Маремуха Т. П., Петросян А. А. Загрязнение атмосферного воздуха фракциями мелкодисперсной пыли (PM10 и PM2,5) в районе функционирования угольной ТЭЦ. *Здоровье и окружающая среда*. 2016. № 26. С. 39-42.
URL: https://elibrary.ru/item.asp?id=29746732

14. Мелкодисперсная пыль как фактор загрязнения атмосферного воздуха / В. Н. Азаров и др. *Социология города*. 2018. № 4. С. 5-14. URL: https://elibrary.ru/item.asp?id=36654926

15. Мельник Н. А., Мовчан В. О. Дослідження емісії наночастинок у повітря на експериментальній моделі технологічного процесу рекуперації свинцю.

Актуальні проблеми проф. медицини: зб. наук. праць. Львів, 2015. Вип. 12. С. 153-158. URL: http://appm.meduniv.lviv.ua/images/pdf/Zbirka_2015_3c.pdf#page=153.

16. Наночастинки і наноматеріали: будова, фізико-хімічні і токсикологічні властивості, вплив на організм працівників / О. П. Яворовський та ін. *Environment&Health*. 2016. № 3. С. 29-35. URL: https://cyberleninka.ru/article/n/nanochastki-i-nanomateriali-budova-fiziko-himichni-i-toksikologichni-vlastivosti-vpliv-na-organizm-pratsivnikiv

17. Насими М. Х., Соловьева Т. В. О загрязнении мелкодисперсной пылью РМ10 атмосферного воздуха города Кабул. Инженер. вестник Дона. 2017. N. 45, № 2. С. 43. URL: ivdon.ru/ru/magazine/archive/n4y2017/4664

18. Об исследовании загрязнения воздушной среды мелкодисперсной пылью с использованием аппарата случайных функций / В. Н. Азаров и др. *Инженер. вестник Дона*. 2015. № 4. URL: ivdon.ru/ru/magazine/archive/n4y2015/3350

19. Определение частиц нанодиапазона в воздухе рабочей зоны металлургического производства / Т. С. Уланова и др. *Анализ риска здоровью*. 2015. № 1. С. 77-80. DOI: https://doi.org/10.21668/health.risk/2015.1.10

20. Особенности заболеваний органов дыхания у плавильщиков титановых сплавов в условиях сочетанного воздействия мелкодисперсной пыли и соединений хлора / Е. М. Власова и др. *Гигиена и санитария.* 2019. Т. 98, № 2. С. 153-158. DOI: https://doi.org/10.18821/0016-9900-2019-98-2-153-158

21. Просвирякова И. А., Шевчук Л. М. Гигиеническая оценка содержания твердых частиц РМ10 и РМ2,5 в атмосферном воздухе и риска для здоровья жителей в зоне влияния выбросов стационарных источников промышленных предприятий. *Анализ риска здоровью.* 2018. № 2. С. 14-22. DOI: https://doi.org/10.21668/health.risk/2018.2.02

22. Радченко Д. Н., Гаджиева Л. А. С., Гавриленко В. В. Мониторинг содержания ультрадисперсных аэрозолей в воздухе горнопромышленного региона. *Вестник Рос. университета дружбы народов*. (Серия: Экология и безопасность жизнедеятельности). 2017. Т. 25, № 4. С. 520-528. URL: http://journals.rudn.ru/ecology.

23. Севальнєв А. І., Шаравара Л. П. Шкідливі умови праці як фактор ризику розвитку виробничо зумовленої захворюваності у працівників допоміжних професій. *Запорізький медичний журнал*. 2019. Т. 21, № 2 (113). С. 246-252. DOI: https://doi.org/10.14739/2310-1210.2019.2.161505.

24. Солоха Н. В. Фізіолого-гігієнічні особливості операторів при одержанні нанопорошків силіцидів і нітридів металів та стан їхньої гепатобіліарної системи. *Укр. журнал з проблем медицини праці*. 2015. Т. 43, № 2. С. 18-25. DOI: https://doi.org/10.33573/ujoh2015.02.018

25. Уланова Т. С., Гилева О. В., Волкова М. В. Определение частиц микро- и нанодиапазона в воздухе рабочей зоны на предприятиях горнодобывающей промышленности. *Анализ риска здоровью*. 2015. № 4. С. 44-48. DOI: https://doi.org/10.21668/health.risk/2015.4.06

26. Физиолого-гигиеническая оценка условий труда оператора при синтезе нанокристаллического порошка дисилицида хрома методом высокоэнергетической механоактивации / А. П. Яворовский и др. *Проблемы здоровья и экологии*. 2017. Т. 52, № 2. С. 89-95. URL: https://cyberleninka.ru/article/n/fiziologo-gigienicheskaya-otsenka-usloviy-truda-operatora-pri-sinteze-nanokristallicheskogo-poroshka-disilitsida-hroma-metodom

27. Ambient nanoparticles/nanominerals and hazardous elements from coal combustion activity: Implications on energy challenges and health hazards / Binoy K. Saikia et al. *Geoscience Frontiers*. 2018. Vol. 9. P. 863-875. DOI: https://doi.org/10.1016/j.gsf.2017.11.013

28. Dayana M. Agudelo-Castanedaa, Elba C. Teixeirab. Cluster analysis of urban ultrafine particles size distributions. *Atmospheric Pollution Research*. 2018. Vol. 29. P. 1-7.

29. Evaluation of cardiovascular responses to silver nanoparticles (AgNPs) in spontaneously hypertensive rats / M. A. Ramirez-Lee et al. *Nanomedicine: Nanotechnology, Biology and Medicine*. 2018. Vol. 14. No. 2. P. 385-395. DOI: https://doi.org/10.1016/j.nano.2017.11.013

30. Expert position paper on air pollution and cardiovascular disease / David E. Newby et al. *European Heart Journal.* 2015. No. 36. P. 83-93. DOI: https://doi.org/10.1093/eurheartj/ehu458

31. Exposure to nanometric pollutants in primary schools: Environmental implications / Juan C. Rojasa et al. *Silvac Urban Climate*. 2019. Vol. 27. P. 412-419. DOI: https://doi.org/10.1016/j.uclim.2018.12.011

32. George D. Thurston, Richard T. Burnett, Michelle C. Turner. Ischemic Heart Disease Mortality and Long-Term Exposure to Source-Related Components of U.S. *Fine Particle Air Pollution. Environmental Health Perspectives*. 2016. Vol. 124, No. 6. P. 785-794. DOI: https://doi.org/10.1289/ehp.1509777

33. Nanotoxicology and Exposure in the Occupational Setting / Peixe T. S. et al. *Occupational Diseases and Environmental Medicine*. 2015. Vol. 3. P. 35-48. DOI: https://doi.org/10.4236/odem.2015.33005

34. Ray J. L., Holian A. Sex differences in the inflammatory immune response to multi walled carbon nanotubes and crystalline silica. *InhalationToxicology*. 2019. Vol. 31, No. 7. P. 285-297. DOI: https://doi.org/10.1080/08958378.2019.1669743

35. Saliou Mbengue, Laurent Y. Alleman, Pascal Flament. Erratum to «Metal-bearing fine particle sources in a coastal industrialized environment». *Atmospheric Research.* 2017. Vol. 183. P. 202-211. DOI: https://doi.org/10.1016/j.atmosres.2016.08.014

36. The effect of different workplace nanoparticles on the immune systems of employees / N. Kurjane et al. *Journal of Nanoparticle Research*. 2017. Vol. 19. P. 320. DOI: https://doi.org/10.1007/s11051-017-4004-6

37. The size-dependent genotoxicity and oxidative stress of silica nanoparticles on endothelial cells / F. Zhou et al. *Environmental Science and Pollution Research.* 2019. Vol. 26, No. 2. P. 1911-1920. DOI: https://doi.org/10.1007/s11356-018-3695-2

38. Thomson E. M. Air pollution, stress, and allostatic load: linking systemic and central nervous system impacts. *Journal of Alzheimer's Disease*. 2019. Vol. 69, No. 3. P. 597-614. DOI: https://doi.org/10.3233/JAD-190015

39. Trace element fractionation between PM10 and PM2.5 in coal mine dust: Implications for occupational respiratory health / Teresa Moreno et al. *Inter. Journal of Coal Geology*. 2019. Vol. 203. P. 52-59. DOI: https://doi.org/10.1016/j.coal.2019.01.006

40. Winter chemical partitioning of metals bound to atmospheric fine particles in Dongguan, China, and its health risk assessment / Lin Huang et al. *Environmental Science and Pollution Research.* 2019. Vol. 26. P. 664-675. DOI: https://doi.org/10.1007/s11356-019-05001-8

41. Wood Dust and Nanoparticle Exposure among Workers during a New Building Construction / Atin Adhikari et al. *Inter. Journal of Medical and Health Sciences.* 2018. Vol. 12, No. 3. URL: //digitalcommons.georgiasouthern.edu/bee-facpres/6

42. Yang Gao, Hongbing Ji. Microscopic morphology and seasonal variation of health effect arising from heavy metals in PM2.5 and PM10: One-year measurement in a densely populated area of urban Beijing. *Atmospheric Research.* 2018. Vol. 212. P. 213-226. DOI: https://doi.org/10.1016/j.atmosres.2018.04.027

43. Zapor L. Effects of silver nanoparticles of different sizes on cytotoxicity and oxygen metabolism disorders in both reproductive and respiratory system cells. *Archives of Environmental Protection*. 2016. Vol. 42, No. 4. P. 32-47. DOI: https://doi.org/10.1515/aep-2016-0038

44. Zebrafish behavioral phenomics employed for characterizing behavioral neurotoxicity caused by silica nanoparticles/Li X. et al. *Chemosphere*. 2020.Vol. 240. P. 124937. DOI: https://doi.org/10.1016/j.chemosphere.2019.124937

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