Antonio Kruljac*, Anka Ozana Čavlović[1]

Risks of Carcinogenic Pollution in Wood Industry within European Regulations

Rizici kancerogenog onečišćenja u drvnoj industriji prema europskim propisima

REVIEW PAPER
Pregledni rad
Received – prispjelo: 18. 6. 2024.
Accepted – prihvaćeno: 11. 2. 2025.
UDK: 614.71; 674.82
https://doi.org/10.5552/drvind.2025.0221

ABSTRACT • *Many materials used in wood industry are considered to have carcinogenic or mutagenic effects, which is a health risk for workers in production. Carcinogenic chemical compounds, apart from causing cancer, also pose a great risk for human health in other terms like respiratory issues, skin irritation, allergic reactions, congenital abnormalities in women, visual impairments, immune system and neurological disorders, hormonal imbalances, etc. Carcinogenic pollution in the wood industry is associated with activities related to the emission of wood dust, production of panel materials, drying and steaming of wood, sharpening tools, the activities of handling glues, paints, varnishes, coatings, wood preservatives, exposure to fossil and biofuel exhaust gases, and many others. The purpose of this paper was to present the carcinogenic substances to which workers in the wood industry are professionally exposed, to present previous research and currently valid regulations and protection measures in the EU. By reviewing the sources, it can be concluded that, although legislation often requires clearly defined etiological factors, scientists agree that the understanding of the relationship between occupational exposures and cancer is not yet complete and that occupational carcinogenic factors are considered occupational exposures if a significant number of workers were exposed to significant levels.*

KEYWORDS: *occupational health; carcinogens; wood dust; formaldehyde; nanoparticles*

SAŽETAK • *Smatra se da mnogi materijali koji se upotrebljavaju u drvnoj industriji imaju kancerogene ili mutagene učinke koji su zdravstveni rizik za radnike u proizvodnji. Osim što uzrokuju rak, kancerogeni kemijski spojevi ujedno su veliki rizik za ljudsko zdravlje u smislu drugih tegoba kao što su respiratorni problemi, iritacija kože, alergijske reakcije, kongenitalne abnormalnosti u žena, oštećenje vida, bolesti imunološkog sustava i neurološki poremećaji, hormonska neravnoteža itd. Kancerogeno onečišćenje u drvnoj industriji povezano je s procesima vezanima za mehaničku obradu drva i emisiju drvne prašine, proizvodnju pločastih materijala, sušenje i parenje drva, oštrenje alata, rukovanje ljepilima, premazima i sredstvima za zaštitu drva, izloženošću ispušnim plinovima od fosilnih goriva i biogoriva te s mnogim drugim procesima. Cilj ovog rada bio je prezentirati kancerogene tvari kojima su profesionalno izloženi radnici u drvnoj industriji, prikazati rezultate dosadašnjih istraživanja te dati uvid u trenutačno važeće propise i mjere zaštite u Europskoj uniji. Iako zakonodavstvo često zahtijeva jasno definirane etiološke čimbenike, pregledom literaturnih izvora može se zaključiti da se znanstvenici slažu kako*

* Corresponding author
[1] Authors are PhD student and professor at University of Zagreb, Faculty of Forestry and Wood Technology, Department of Wood Technology, Zagreb, Croatia. https://orcid.org/0009-0008-3088-4173; https://orcid.org/0000-0003-3882-2889

odnos između profesionalne izloženosti i karcinoma još nije potpuno razjašnjen te da se izloženost profesionalnim kancerogenim čimbenicima smatra profesionalnom izloženošću kada je znatan broj radnika bio izložen povišenim razinama onečišćenja.

KLJUČNE RIJEČI: *zdravlje na radu; kancerogene tvari; drvna prašina; formaldehid; nanočestice*

1 INTRODUCTION
1. UVOD

The activity of wood processing emits numerous pollutants into the working environment, including those classified as mutagens and carcinogens, posing a serious risk to the worker's health. According to the Proposal for a Directive of the European Parliament and of the Council amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work, at the end of 2016 the European Commission launched a proposal to reduce the limit values for 13 carcinogenic substances, considering the fact that annually 53 % of work-related deaths are attributed to cancer. In 1981 the International Agency for Research on Cancer (IARC) listed occupational risks associated with the wood industry, including nasal cancer, nasopharyngeal cancer, laryngeal cancer, lung cancer, stomach cancer, hematopoietic and lymphoreticular cancer (IARC, 1981). In addition to emitted wood dust, some chemical compounds related to wood products and wood processing also pose a carcinogenic risk to human health. Formaldehyde is released during the drying and steaming of wood and production of wood-based panels (chipboards, medium-density fiberboard and plywood, etc.). Also, carcinogenic formaldehyde is slowly being released in the occupational area during the lifetime of wood-based panels (for example particleboards and MDF) formaldehyde (IARC, 1995; IARC, 2012a; Beane Freeman *et al*., 2009). Combustion of fossil fuels to drive vehicles and devices, obtain energy or drive a chainsaw, releases toxic gases not only into the surrounding air but also into the working environment. There is also metal dust from wear and sharpening of hard metal tool blades that contain carcinogenic substances such as tungsten carbides and cobalt (Wild *et al*., 2009; IARC, 2022). Numerous nanomaterials are used to improve the properties of wood and wood surfaces, the most common being nanoTiO_2, nanoSiO_2 and nanoAg (IARC 2010; Aschberger *et al*., 2011). Carcinogenic heavy metal compounds (lead, cadmium, chromium, nickel) are not completely banned but restricted in wood preservatives, paints, coatings or varnishes, and can be used in products under certain conditions (restorations,

Table 1 Sources of carcinogenic and/or mutagenic substances in wood industry
Tablica 1. Izvori kancerogenih i/ili mutagenih tvari u drvnoj industriji

Source / *Izvor*	**Carcinogenic substances** / *Kancerogene tvari*
Mechanical wood processing / *strojna obrada drva*	Wood dust / *drvna prašina*
Wood-based panels, wood drying and streaming *ploče od drvnog materijala, sušenje i parenje drva*	Formaldehyde / *formaldehid*
Fossil fuel exhaust gases, biofuel combustion *ispušni plinovi od fosilnih goriva*	Benzene / *benzen* Benzo[α]pyrene / *benzo[α]piren* Xylene / *ksilen;* Toluene / *toluen*
Biofuel combustion *izgaranje biogoriva*	Dioxins and furans / *dioksini i furani* Benzo[α]pyrene / *benzo[α]piren*
Tool sharpening *oštrenje alata*	Tungsten carbides and cobalt dust *prašina volframovih karbida i kobalta*
Wood preservatives, paints and varnishes *sredstava za zaštitu drva, boje i lakovi*	Heavy metals (Lead, Cadmium, Chromium, Nickel) *teški metali (olovo, kadmij, krom, nikal)*
Paints and varnishes *boje i lakovi*	Hexamethylene diisocyanate / *heksametilen diizocijanat* Polychlorinated Biphenyls (PCBs) / *poliklorirani bifenili (PCB)* Xylene / *ksilen;* Toluene / *toluen* Nanoparticles / *nanočestice*
Resins *smole*	Acrylonitrile / *akrilonitril* Epoxy resins hardeners – epichlorohydrin *učvršćivači epoksidnih smola – epiklorohidrin*
Fungicides and insecticides *fungicidi i insekticidi*	CCA salts (copper, chromium and arsenic oxides) *CCA soli (bakar, krom i arsenovi oksidi)* Arsenic and arsenical compounds / *arsen i njegovi spojevi* Creosote oil / *kreozotno ulje* Coal-tar oil / *ugljenokatransko ulje* Pentachlorophenol / *pentaklorofenol*

works of art). Among epoxy resin hardeners, epichlorohydrin is classified as a carcinogen, while there is insufficient evidence for diaminodiphenyl sulfone and glycidyl ethers. Acrylic resins (acrylonitrile) probably carcinogenic in humans, as well as Polychlorinated Biphenyls (PCBs), Toluene and Xylene, are used in paints and varnishes (IARC, 1981; EU-OSHA, 2014, Regulations NN148/2023). Carcinogenic fungicides and insecticides, CCA salts (copper, chromium and arsenic oxides), arsenic and arsenical compounds, creosote oil and coal-tar oil and pentachlorophenol have limited use in industrial plant and professional use. Asbestos tremolite was banned for production and market in 2006. It was previously used in paper production, in talc production as coating pigment, in furniture production as filler in melamine-formaldehyde glues and in carpentry as insulator, flame retardant. Mineral oil, which is used as a solvent for chlorophenols in sawmills, is also carcinogenic in humans (IARC, 1981; EU-OSHA, 2014, Regulatins NN148/2023). Table 1 shows the most common carcinogenic substances, from the above sources, whose carcinogenic and/or mutagenic influence on human health has been investigated and scientifically proven, as well as their sources in the wood industry.

The aim of the work is to present the previous research on the most significant carcinogenic substances that are produced in the wood industry and their characteristics related to certain health risks as well as norms and regulations providing protective measures.

2 RISKS OF OCCUPATIONAL EXPOSURE TO WOOD DUST
2. RIZICI OD PROFESIONALNE IZOŽENOSTI DRVNOJ PRAŠINI

In 1995, the IARC stated that wood dust, especially dust from hard wood species, generally causes significant health problems. Separated wood particles are classified as carcinogenic substances and can cause many types of cancer especially those related to the respiratory system, sinonasal adenocarcinomas (Siew *et al*., 2017; Soćko, 2021), nasopharyngeal cancer (Beigzadeh *et al*., 2019; Meng *et al*., 2020) and lung cancer (Scarabelli *et al*., 2021; Matrat *et al*., 2019). European Directive 2017/2398 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work prescribes an Occupational Exposure Limit (OEL) of 2 mg/m^3 for 8-hours exposure to inhalable hardwood dusts. European wood processing facilities use beech wood and oak wood as their raw material in large quantities and according to Hausen (1981), respiratory cancers are prevailing among workers who deal with these wood species. In the wood processing industry, separation of wood particles is inevitable during mechanical processing. According to Kauppinen *et al.* (2006) about 3.6 million workers in the EU are exposed to inhalable wood dust, about 16 % of workers are exposed to mass concentrations of inhalable wood particles of up to 5 mg/m^3 and 25 % of workers to mass concentrations of up to 2 mg/m^3. According to the Health Council of the Netherlands (2000), 1 of 250 workers would be a victim of nasal cancer while being exposed to a wood dust concentration of 5.8 mg/m^3 during their working life of 40 years. Scheeper *et al.* (1995) also explain higher wood dust exposure caused by a poor solution or lack of an exhaust ventilation system connected to the machines. Similarly, Čavlović *et al.* (2022) noticed that the wood dust exposure was lower than the level of increased risk (2 mg/m^3) at workplace near the CNC machine connected to a quality central suction machine. While researching the effect of wood moisture content and average chip thickness during routing operation on rubberwood, Ratnasingam *et al*. (2009) concluded that higher wood moisture content and lower average chip thickness, which can be achieved by manipulating the rotational speed of the cutting tool, results in a significant reduction of airborne wood dust emission. Studying different materials like medium density fibreboard (MDF) and plywood, Welling *et al.* (2009) concluded that sanding MDF produces much higher dust emissions than sanding pine and birch plywood. Wood sanding produces the smallest wood dust particles that remain airborne for longer periods of time and pose greater health risks (Beljo-Lučić *et al.*, 2011). According to Thorpe and Brown (1995), mean aerodynamic diameter of a wood dust particle is inversely proportional to the mentioned density and hardness of wood. They concluded that overall wood dust produced by the coarsest sandpaper was negligibly higher than that of a finer grade sandpaper.

There are two hypotheses that explain why wood dust could cause sinonasal adenocarcinoma. The first possible explanation for the cause of the sinonasal cancer are inhalable potentially carcinogenic substances like tannins, aldehydes and other chemicals that are being used in the wood industry. The second explanation might be the inhalation of wood dust particles that are smaller than 5 μm and intervene with normal mucosa function, which leads to a higher risk of cancer (Elwood, 1981). Nylander *et al.* (1993) concluded in their paper that workers in the furniture industry have the highest risk of developing nasal cancer induced by wood dust among all other workers in the wood processing industry. Furthermore, wood dust could be the cause of other tumors in the lungs, stomach and the above-mentioned types of cancer because wood dust can easily come into contact with these organs.

3 RISKS OF EXPOSURE TO OTHER CANCIROGENS
3. RIZICI OD IZLOŽENOSTI OSTALIM KANCEROGENIM TVARIMA

3.1 Formaldehyde
3.1. Formaldehid

In 1995, IARC classified formaldehyde as a Group 1 carcinogen for humans. Apart from exposure through inhalation, formaldehyde can be absorbed through the skin or ingested (Protano *et al*., 2022). Formaldehyde is a chemical compound that is naturally found in wood composition. Cellulose, hemicelluloses and lignin are the main components of wood and according to Schäfer and Roffael (2000) formaldehyde can be formed out of the mentioned components, just as from wood extractives. The amount of formaldehyde is very small but still occurs and is traceable in solid wood. The emission of formaldehyde from solid wood is dependent on its pH value and temperature. With increased temperature and heating wood for a longer period, the amount of formaldehyde emission is increased. This process is usually conducted when wood is being dried, where apart from formaldehyde other volatile organic compounds are released (Cronn *et al*., 1983). European Directive 2019/983 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work prescribes an OEL of 0.37 mg/m^3 for 8-hours exposure to formaldehyde. In the wood industry, synthetic resins are mostly used in the production of wood-based panels. It is important to mention that 95 % of all wood adhesives used in wood-based panel production are based on formaldehyde. Adhesives that are being used in industry today are phenol-formaldehyde (PF), melamine-formaldehyde (MF), melamine-urea-formaldehyde (MUF) and lastly urea-formaldehyde (UF), which is the most used synthetic resin (Pizzi *et al*., 2020). Particleboard, medium-density fiberboard and plywood are widely used in furniture production, flooring industry, i.e., multi-layered parquetry, construction industry, etc. Airborne formaldehyde is released in living spaces and the level of exposure to formaldehyde depends on various factors like temperature, humidity and ventilation rate (Liu *et al*., 2015). In 2012, IARC stated that there was enough epidemiological and toxicological evidence that formaldehyde could be a cause of nasopharynx tumors and limited evidence for nasal sinus tumors. Newer reports indicate possible leukaemia induction by formaldehyde (Beane Freeman *et al*., 2009).

3.2 Benzene and benzo[α]pyrene
3.2. Benzen i benzo[α]piren

Among the many polycyclic aromatic hydrocarbons (PAHs), benzene and benzo[α]piren stand out as carcinogens and mutagens. Exposure to benzene and benzo[α]piren at work in the wood processing and forestry sectors is associated with fossil combustion sources, i.e. biofuels. Chainsaw workers are exposed to risks not only in a forest, but also in the industrial facilities, in closed environments, when cutting down logs to preferred lengths. Apart from chainsaw use, transporting devices, like forklifts, loaders or trucks with grapple loaders, running on internal combustion engines and fossil fuels are also often used in the wood industry. In wood processing companies and power plants, the consumption of wood fuel (solid biomass) for energy production is increasing, and thus the emission of pollutants from industrial furnaces from the combustion of wood fuel, among which is benzo[α]piren. Moreover, due to the incomplete combustion of fuel, there is the formation of floating particles smaller than 2.5 µm (PM 2.5) that adsorb toxic chemical compounds such as PAH shorter aromatic chains (Simoneit, 2002). Also, residential use of coal and wood as a source of thermal energy increases the emission of benzo[α]piren (Guerreiro *et al*., 2014).

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds made of multiple aromatic rings known to be the cause of mutations in DNA. Santesson (1897) noticed benzene toxicity to blood forming organs. Infante *et al.* (1977) described five times increased risk of leukaemia caused by occupational benzene exposure. In 2012, IARC stated that there was sufficient evidence for benzene to cause acute myeloid leukaemia and limited evidence for acute lymphocytic leukaemia, chronic lymphocytic leukaemia, etc. Apart from leukaemia which is the most common type of cancer caused by benzene, lung cancer, kidney cancer, nasal cavity and oesophagus cancer and other less common types of cancer were reported. European Directive 2022/431 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work prescribes an OEL of 0.66 mg/m^3 for 8-hours exposure to benzene (OEL of 1.65 mg/m^3 is valid from 5 April 2024 until 5 April 2026). Benzo[α]piren is lipophilic, which makes it able to penetrate the cell membrane without any difficulty (Petrulis and Perdew, 2002). The chemical process in a cell and its nucleus is carried out causing DNA to mutate and eventually start a cancer (Kucab *et al*., 2015). Damage to the human DNA can lead to specific mutations that lead to cancer (Cooper, 2000). An example of prolonged exposure to benzo[α]piren and its bad influences on the human body is the mutation of the TP53 tumor suppressor genes (Krais *et al*., 2016).

3.3 Dioxins and furans
3.3. Dioksini i furani

Dioxins are a group of chemical compounds out of which 17 isomers are considered to be toxic and mutagenic. Dixons belong to a group of 75 polychlorinated dibenzo-p-dioxins and 135 polychlorinated dibenzofurans. Combustion of wood and wood processing generates emission of dioxins, which represents a great danger to human health because dioxin can accumulate in fat tissues (Lavric *et al*., 2004). Schatowitz *et al*. (1994) concluded that dioxin annual emissions during the combustion of natural wood were not significantly increased, while the combustion of waste wood, such as wood chips coming from the demolition of buildings, greatly increased dioxin emissions. A wide range of different inorganic compounds are used for wood treatment like salts that improve fire-resistant properties (Richards and Zheng, 1991). Chromated copper arsenate, copper boron azole, etc. improve wood resistance to microbial and fungal degradation (Humprey, 2002). The addition of inorganic compounds affects the emissions of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans. According to the research conducted in 2007 by Tame *et al*., combustion of wood with improved properties by preservatives produces higher levels of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, and hence they strongly advise not to use impregnated wood as a source of thermal energy in households. It is possible to reduce the production of dioxins in wood combustion by adding sulphur or nitrogen-containing agents. Furthermore, it is important to prevent particles of burned biomass from reaching the atmosphere using filters and particle removers. Before filtering the particles, good conditions for effective combustion contribute to lower dioxin emissions (Lavric *et al*., 2004).

3.4 Hard metal dust
3.4. Prašina tvrdih metala

Hard metals are widely used in wood industry; they represent a material that is bound together with cobalt or nickel (Santhanam, 1992). Apart from hard metals, metallic carbides are also commonly used. Tungsten carbide is the most widespread metallic carbide in wood industry. Such hard metals and metallic carbides are used for the production of wood cutting tools. Common exposure to metal dust in wood industry occurs while doing the maintenance and resharpening of hard-metal tools. The IARC (2006) states that the levels of exposure to metal dust are much lower during their use than during their manufacture. However, grinding of the tools and blades while sharpening and doing maintenance release cobalt in the air at a concentration of several hundred micrograms per cubic meter (Mosconi *et al.*, 1994). Metal dust, especially cobalt metal, is classified as "probably carcinogenic to humans" following the testing on animals (IARC, 2022). Furthermore, the study of tungsten conducted by Wild *et al.* (2009) in hard-metal factories shows increased risk of lung cancer among workers.

3.5 Nanoparticles
3.5. Nanočestice

Natural wood is an effective structural material, but it is not durable and stable. To ensure its stability and durability, wood is treated with coatings and chemical treatments (Unger *et al.*, 2001). Nanoparticles are used as treatments to improve wood properties. De Filpo *et al*. (2013) described the prevention of fungal growth by submerging wood samples in a solution of titanium dioxide (TiO_2). NanoTiO_2 helped to prevent the decay through its photo-catalytic activity. Using nano zinc oxide (ZnO) treatments, Clausen *et al*. (2010) managed to contribute to a significant decrease in wood greying. ZnO is a strong ultraviolet absorbent, meaning that it reduces the UV radiation effect and lignin decay, which gives wood its natural colour. Chemical reagents like nano copper oxide (nanoCuO), which was confirmed to be effective against fungi by Aguayo *et al.* (2021), are also commonly used. Nano silica dioxide (nanoSiO_2) is used to improve the properties of paints used in wood surface treatments. Paints with the addition of SiO_2 showed improved water repellence, scratch resistance, antimicrobial properties and durability (Kaiser, 2013). Nano silver is commonly used in furniture production because of its antimicrobial properties (van Broekhuizen, 2012). According to van Broekhuizen (2012), nanomaterials do not have a common effect on health, moreover every nanomaterial has its own unique influence on human health. Van Broekhuizens summary suggests that nanoTiO_2 is the most common nanomaterial used in furniture production. According to IARC (2010), nanoTiO_2 is possibly carcinogenic to humans and could pose a slightly increased risk of lung cancer. NanoSiO_2 and nanoAg are the second most used nanomaterials in furniture production, but lack of evidence and research leads to a bad understanding of their health effects. Inflammation is the most frequently studied health effect of nanomaterials, which leads to cell death or scar-tissue forming dominantly in lungs that could result in a cancer (Aschberger *et al*., 2011).

4 CONCLUSIONS
4. ZAKLJUČAK

Researching the literature, it can be observed that there is a lack of studies that explain why wood dust is considered directly carcinogenic. Further studies should emphasize their investigation of the effects of the chemical composition of wood dust on human health, and the correlation of the effect with the size of the wood dust particles. Scientific knowledge is applied in the development of the best available techniques for reducing the emission of carcinogenic substances in the working environment of the wood industry and its general environment. Apart from wood dust being a carcinogen, wood industry workers are faced with chemical compounds that represent a great health concern as well. Protection should be provided to workers and citizens who might be affected by the harmful carcinogenic sources generated by wood industry activities. European legislative bodies are trying to prevent workers from getting cancer at work through legislative action, not just guidelines, by finalizing the Carcinogens and Mutagens Directive (CMD). In order to ensure a safer working and ambient environment around industrial plants and residential areas, regulations and safety protocols need to be applied to reduce the source of air pollution, especially carcinogens and mutagens.

5 REFERENCES
5. LITERATURA

1. Aguayo, M. G.; Oviedo, C.; Reyes, L.; Navarrete, J.; Gomez, L.; Torres, H.; Gavino, G.; Trollund, E., 2021: Radiata pine wood treated with copper nanoparticles: Leaching analysis and fungal degradation. Forests, 12: 1606. https://doi.org/10.3390/f12111606
2. Aschberger, K.; Micheletti, C.; Sokull-Klüttgen, B.; Christensen, F. M., 2011: Analysis of currently available data for characterizing the risk of engineered nanomaterials to the environment and human health – Lessons learned from four case studies. Environment International, 37 (6): 1143-1156. https://doi.org/10.1016/j.envint.2011.02.005
3. Beane Freeman, L. E.; Blair, A.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Hoover, R. N.; Hauptmann, M., 2009: Mortality from lymphohematopoietic malignancies among workers in formaldehyde industries: the National Cancer Institute Cohort. Journal of the National Cancer Institute, 101 (10): 751-761. https://doi.org/10.1093/jnci/djp096
4. Beigzadeh, Z.; Pourhassan, B.; Kalantary, S.; Golbabaei, F., 2019: Occupational exposure to wood dust and risk of nasopharyngeal cancer: A systematic review and meta-analysis. Environmental Research, 171: 170-176. https://doi.org/10.1016/j.envres.2018.12.022
5. Beljo-Lučić, R.; Čavlović, A. O.; Jug, M., 2011: Definitions and relation of airborne wood dust fractions. In: Proceedings of the 4th International Scientific Conference–Woodworking Techniques, Prague, Czech Republic, 7 September, pp. 25-32.
6. Van Broekhuizen, F., 2012: Nano in Furniture – State of the art 2012 – Executive summary, Netherlands.
7. Clausen, C. A.; Green, F.; Kartal, S. N., 2010: Weatherability and leach resistance of wood impregnated with nano-zinc oxide. Nanoscale Research Letters, 5 (9): 1464-1467. https://doi.org/10.1007/s11671-010-9662-6
8. Cooper, G., 2000: The Cell. A molecular Approach, 2nd ed., Sinauer Associates.
9. Cronn, D. R.; Truitt, S. G.; Campbell, M. J., 1983: Chemical characterization of plywood veneer dryer emissions. Atmospheric Environment, 17 (2): 201-211. https://doi.org/10.1016/0004-6981(83)90034-3
10. Čavlović, A. O.; Bešlić, I.; Pervan, S.; Barlović, N.; Mikšik, M.; Klarić, M.; Prekrat, S., 2022: Occupational exposure to inhalable and respirable wood dust of pedunculate oak (*Quercus robur* L.) in a Furniture Factory. BioResources, 17 (4): 5831-5847. https://doi.org/10.15376/biores.17.4.5831-5847
11. De Filpo, G.; Palermo, A. M.; Rachiele, F.; Nicoletta, F. P., 2013: Preventing fungal growth in wood by titanium dioxide nanoparticles. International Biodeterioration & Biodegradation, 85: 217-222. https://doi.org/10.1016/j.ibiod.2013.07.007
12. Elwood, J. M., 1981: Wood exposure and smoking: Association with cancer of the nasal cavity and paranasal sinuses in British Columbia. Canadian Medical Association Journal 124: 1573-1577.
13. Guerreiro, C. B. B.; Foltescu, V.; De Leeuw, F., 2014: Air quality status and trends in Europe. Atmospheric Environment, 98: 376-384. https://doi.org/10.1016/j.atmosenv.2014.09.017
14. Hausen, B. M., 1981: Wood Injurious to Human Health: a Manual. Walter de Gruyter and Co., Berlin, New York, pp. 1-189.
15. Humphrey, D. G., 2002: The chemistry of chromated copper arsenate wood preservatives. Reviews in Inorganic Chemistry, 22: 1-40. https://doi.org/10.1515/REVIC.2002.22.1.1
16. Infante, P. F.; Rinsky, R. A.; Wagoner, J. K.; Young R. J., 1977: Leukaemia in benzene workers. Lancet, 2: 76-78. https://doi.org/10.1016/S0140-6736(77)90074-5
17. Kaiser, J.; Zuin, S.; Wick, P., 2013: Is nanotechnology revolutionizing the paint and lacquer industry? A critical opinion. Science of The Total Environment, 442: 282-289. https://doi.org/10.1016/j.scitotenv.2012.10.009
18. Kauppinen, T.; Vincent, R.; Liukkonen, T.; Grzebyk, M.; Kauppinen, A.; Welling, I.; Arezes, P.; Blacks, N.; Bochmann, F.; Campelo, F. *et al.,* 2006: Occupational exposure to inhalable wood dust in the member states of the European Union. The Annals of Occupational Hygiene, 50 (6): 549-561. https://doi.org/10.1093/annhyg/mel013
19. Krais, A. M.; Speksnijder, E. N.; Melis, J. P.; Indra, R.; Moserova, M.; Godschalk, R. W.; van Schooten, F. J.; Seidel, A.; Kopka, K.; Schmeiser, H. H.; Stiborova, M.; Phillips, D. H.; Luijten, M.; Arlt, V. M., 2016: The impact of p53 on DNA damage and metabolic activation of the environmental carcinogen benzo-α-pyrene: effects in TRP53(+/+), Trp53(+/-) mice. Archives of Toxicology, 90: 839-851. https://doi.org/10.1007/s00204-015-1531-8
20. Kucab, J. E.; van Steeg, H.; Luijten, M.; Schmeiser, H. H.; White, P. A.; Phillips, D. H.; Arlt, V. M., 2015: TP 53 mutations induced by BPDE in Xpa-WT and Xpa-Null human TP53 knock-in (Hupki) mouse embryo fibroblasts. Mutation Research, 773: 48-62. https://doi.org/10.1016/j.mrfmmm.2015.01.013
21. Lavric, E. D.; Konnov, A. A.; De Ruyck, J., 2004: Dioxin levels in wood combustion – a review. Biomass and Bioenergy, 26: 115-145. https://doi.org/10.1016/S0961-9534(03)00104-1
22. Liu, X.; Mason, M. A.; Guo, Z.; Krebs, K. A.; Roache, N. F., 2015: Source emission and model evaluation of formaldehyde from composite and solid wood furniture in a full-scale chamber. Atmospheric Environment, 122: 561-568. https://doi.org/10.1016/j.atmosenv.2015.09.062
23. Matrat, M.; Radoi, L.; Fevotte, J.; Guida, F.; Cenee, S.; Cyr, D.; Sanchez, M.; Menvielle, G.; Schmaus, A.; Marrer, E., 2019: Occupational exposure to wood dust and risk of lung cancer: the ICARE study. Occupational and Environmental Medicine, 76 (12): 901-907. https://doi.org/10.1136/oemed-2019-105802

24. Meng, E.; Yin, J. Z.; Jin, W.; Mao, Y. Y.; Wu, Q. H.; Qiu, J., 2020: Wood dust exposure and risks of nasopharyngeal carcinoma: A meta-analysis. European Journal of Public Health, 30 (4): 817-822. https://doi.org/10.1093/eurpub/ckz239
25. Mosconi, G.; Bacis, M.; Leghissa, P.; Maccarana, G.; Arsuffi, E.; Imbrogno, P.; Airoldi, L.; Caironi, M.; Ravasio, G.; Parigi, P. C.; Polini, S; Luzzana, G., 1994: Occupational exposure to metallic cobalt in the Province of Bergamo. Results of a 1991 survey. Science of The Total Environment, 150:121-128. https://doi.org/10.1016/0048-9697(94)90138-4
26. Nylander, L. A.; Dement, J. M., 1993: Carcinogenic effects of wood dust: Review and discussion. American Journal of Industrial Medicine, 24: 619-647. https://doi.org/10.1002/ajim.4700240511
27. Petrulis, J. R.; Perdew, G. H., 2002: The role of chaperone proteins in the aryl hydrocarbon receptor core complex. Chemico-Biological Interactions, 141: 25-40. https://doi.org/10.1016/s0009-2797(02)00064-9
28. Pizzi, A.; Papadopoulos, A.; Policardi, F., 2020: Wood composites and their polymer binders. Polymers, 12 (5): 1115. https://doi.org/10.3390/polym12051115
29. Protano, C.; Buomprisco, G.; Cammalleri, V.; Pocino, R. N.; Marotta, D.; Simonazzi, S.; Cardoni, F.; Petyx, M.; Iavicoli, S.; Vitali, M., 2022: The carcinogenic effects of formaldehyde occupational exposure: A systematic review. Cancers*,* 14: 165. https://doi.org/10.3390/cancers14010165
30. Ratnasingam, J.; Scholz, F.; Natthondan, V., 2009: Minimizing dust emission during routing operation of rubberwood. European Journal of Wood and Wood Products, 67: 363-364. https://doi.org/10.1007/S00107-009-0328-y
31. Richards, G. N.; Zheng, G., 1991: Influence of metal ions and of salts on products from pyrolysis of wood: applications to thermochemical processing of newsprint and biomass. Journal of Analytical and Applied Pyrolysis, 21: 133-146. https://doi.org/10.1016/0165-2370(91)80021-Y
32. Santesson, G. G., 1897: Uber chronische Vergiftungen mit steinkohlen Benzin. Vier todes falle. Archiv für Hygiene 31: 336-376.
33. Santhanam, A. T., 1992: Cemented carbides. In: Kroschwitz, J. I. & Howe-Grant, M., eds., Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 4, 4th ed. New York: John Wiley & Sons, pp. 848-860.
34. Scarabelli, T. M.; Corsetti, G.; Chen-Scarabelli, C.; Saravolatz, L. D., 2021: Follicular B-cell lymphoma and particulate matter associated with environmental exposure to wood dust. American Journal of Case Reports, 22: e929396. https://doi.org/10.12659/AJCR.929396
35. Schäfer, M.; Roffael, E., 2000: On the formaldehyde release of wood. Holz als Roh- und Werkstoff, 58: 259-264. https://doi.org/10.1007/s001070050422
36. Schatowitz, B.; Brandt, G.; Gafner, F.; Schlumpf, E.; Bühler, R.; Hasler, P.; Nussbaumer, T., 1994: Dioxin Emissions from wood combustion. Chemosphere, 29 (9-11): 2005-2013. https://doi.org/10.1016/0045-6535(94)90367-0
37. Scheeper, B.; Kromhout, H.; Boleij, J. S. M., 1995: Wood-dust exposure during wood-working processes. The Annals of Occupational Hygiene, 39 (2): 141-154. https://doi.org/10.1016/0003-4878(94)00105-A
38. Siew, S. S.; Martinsen, J. I.; Kjaerheim, K.; Sparen, P.; Tryggvadottir, L.; Weiderpass, E.; Pukkala, E., 2017: Occupational exposure to wood dust and risk of nasal and nasopharyngeal cancer: A case-control study among men in four Nordic countries-With an emphasis on nasal adenocarcinoma. International Journal of Cancer, 141 (12): 2430-2436. https://doi.org/10.1002/ijc.31015
39. Simoneit, B. R. T., 2002: Biomass burning – a review of organic tracers for smoke from incomplete combustion. Applied Geochemistry, 17: 129-162. https://doi.org/10.1016/S0883-2927(01)00061-0
40. Soćko, R., 2021: A Quantitative risk assessment of sinonasal cancer as a function of time in workers occupationally exposed to wood dust. International Journal of Occupational Medicine and Environmental Health, 34 (4): 541-549. https://doi.org/10.13075/ijomeh.1896.01673
41. Tame, N. W.; Dlugogorski, Z.; Kennedy, E. M., 2007: Formation of dioxins and furans during combustion of treated wood. Progress in Energy and Combustion Science, 33 (4): 384-408. https://doi.org/10.1016/j.pecs.2007.01.001
42. Thorpe, A.; Brown, R. C., 1995: Factors influencing the production of dust during the hand sanding of wood. American Industrial Hygiene Association Journal, 56: 236-242. https://doi.org/10.1080/15428119591017060
43. Unger, A.; Schniewind, A. P.; Unger, W., 2001: Conservation of wood artefacts: a handbook. Berlin.
44. Welling, I.; Lehtimäki, M.; Rautio, S.; Lähde, T.; Enbom, S.; Hynynen, P.; Hämeri, K., 2009: Wood Dust Particle and Mass Concentrations and Filtration Efficiency in Sanding of Wood Materials. Journal of Occupational and Environmental Hygiene, 6 (2): 90-98. https://doi.org/10.1080/15459620802623073
45. Wild, P.; Bourgkard, E.; Paris, C., 2009: Lung Cancer and Exposure to Metals: The Epidemiological Evidence. In: Cancer Epidemiology. Methods in Molecular Biology, 472. https://doi.org/10.1007/978-1-60327-492-0_6
46. ***European Agency for Safety and Health at Work (EU-OSHA), 2014: Exposure to carcinogens and work-related cancer: A review of assessment methods European Risk Observatory Report, Luxembourg: Publications Office of the European Union. ISBN: 978-92-9240-500-7. doi: 10.2802/33336
47. ***European Directive (EU) 2017/2398, 2017: European Directive (EU) No 2017/2398 of 12 December 2017 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work of the European Parliament and of the Council, European Union, Brussels, Belgium.
48. ***European Directive (EU) 2019/983, 2019: European Directive (EU) No 2019/983 of 5 June 2019 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work of the European Parliament and of the Council, European Union, Brussels, Belgium.
49. ***European Directive (EU) 2022/431, 2022: European Directive (EU) No 2022/431 of 9 March 2022 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work of the European Parliament and of the Council, European Union, Brussels, Belgium.
50. ***Health Council of the Netherlands, 2000: Health Council of the Netherlands: Hardwood and softwood dust; evaluation of the carcinogenicity and genotoxicity. The Hague: Health Council of the Netherlands. Publication no. 2000/08OSH.
51. ***International Agency for Research on Cancer (IARC), 1981: IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans. Wood, leather and some associated industries, Volume 25, WHO.

52. ***International Agency for Research on Cancer (IARC), 1995: IARC monographs on the evaluation of carcinogenic risks to humans: Wood dust and formaldehyde. Lyon, France: IARC Press.
53. ***International Agency for Research on Cancer (IARC), 2006: IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Cobalt in Hard Metals and Cobalt Sulfate, Gallium Arsenide, Indium Phosphide and Vanadium Pentoxide, Vol 86; WHO, International Agency for Research on Cancer: Lyon, France.
54. ***International Agency for Research on Cancer (IARC), 2010: Carbon Black, Titanium Dioxide and Talc, IARC Monographs on the Evaluation of Carcinogic Risks to Humans, Vol 93.
55. ***International Agency for Research on Cancer (IARC), 2012: IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Chemical Agents and Related Occupations, Vol 100 F, A Review of Human Carcinogen; WHO, International Agency for Research on Cancer: Lyon, France.
56. ***International Agency for Research on Cancer (IARC), 2012: Personal habits and indoor combustions. IARC Monographs on the Evaluation of Carcinogic Risks to Humans, 100E:1-575.
57. ***International Agency for Research on Cancer (IARC), 2022: IARC Monographs evaluate the carcinogenicity of cobalt, antimony compounds, and weapons-grade tungsten alloy, Vol 131; WHO, International Agency for Research on Cancer: Lyon, France.
58. ***Pravilnik o izmjenama i dopunama Pravilnika o zaštiti radnika od izloženosti opasnim kemikalijama na radu, graničnim vrijednostima izloženosti i biološkim graničnim vrijednostima [Regulations on amendments to the Regulations on the protection of workers from exposure to hazardous chemicals at work, exposure limit values and biological limit values, in Croatian]. Narodne novine 148/2023.

Corresponding address:

ANTONIO KRULJAC, mag. ing. techn. lign.
Antonio, obrt za proizvodnju i usluge, Pod rub 2, Ravna Gora, CROATIA, University of Zagreb Faculty of Forestry and Wood Technology, Svetosimunska 23, 10000 Zagreb CROATIA, e-mail: antonio.kruljac98@hotmail.com