

A Number of Modern Industries and Toxicants Release: A Review

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Abstract

Aim: The present study seeks to help the experts and specialists by investigating documents relevant to the harmful chemical compounds and toxic substances used in the production processes of a few novel industries so that, the information gap is identified by recognizing such toxicants and taking steps to fill such gap. **Methods:** By making the use of keywords related to the objective of the study (keywords such as toxicity, modern toxicity, modern industries (MIs), new toxins, modern/new chemical compounds), the indexed articles were searched from 2000 to 2022 in ProQuest, Science Direct, Pub Med, Scopus, Web of Science, and Google Scholar databases aiming at access to the toxic compounds in several MIs. In this study, out of 116 articles searched as full text and following the inclusion and exclusion criteria, 46 articles were wholly selected. **Results:** According to the results, the issues include the nanotechnology industry (silver-nanoparticles, gold-nanoparticles, titanium dioxide, zinc-oxide, cerium-dioxide, and iron-oxide nanoparticles), nuclear technology (cobalt [60 Co and 58 Co], uranium [235U], and plutonium [Pu4+]), semiconductor industries (arsenic compounds, phosphorus, dopants, acids, photoactive compounds, etc.), liquid crystal display industries (indium compounds and indium tin oxide), pharmaceutical and medical (cytotoxic and platinum-based drugs), modern dentistry (resins, silica-nanofillers, barium-glass, and beryllium compounds), as well as the MIs involved in silica, nickel, and dioxin nanoparticles, were documented and discussed. **Conclusion:** Developing MIs and equipping the traditional industries with new technologies have confronted humankind with different chemicals and toxins resulting from producing and using products that require attention, study, and research. It is hoped that the present review study will pave the way for extensive studies on occupational health and toxicology in MIs.

Keywords: Modern industries, occupational health, toxicants, toxicology

INTRODUCTION

With the advent of the industrial revolution in the 18th century, a significant change was made in the industry and production sectors. Nowadays, we are witnessing significant progress in technology and industry. Modern industries (MIs) and technologies have produced and developed many products that are critical in improving the quality of human life. MIs refer to those industries that are known as high-tech where the technical knowledge, innovation, and creativity are highly brilliant. One can see examples of MIs in electronics, semiconductor equipment, computer products, new materials industries such as composites, advanced polymers, ceramics and superconductors, biotechnology and pharmaceutical and medical products, optics and laser industries, nanotechnology and its application in various fields, military and aerospace industries, nuclear energy, and so on. Each industry uses

certain substances or chemical compounds depending on the working process, technology, and products. Hence, chemicals have become an essential part of human life. Despite many advantages in products, particularly in MIs, such chemicals can affect adversely human health and environmental integrity if misused.^[1,2]

As MIs and technologies are developed, human health and the environment are increasingly at risk. History has shown that industrial innovation rarely corresponds with the speed of community and environmental protection, as it takes

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months or even years to determine an emerging industry's health and safety risks (modern industry). Due to the economic interdependence of countries, modern technologies and industries are transferred from developed countries to developing ones.^[1] Although these modern technologies often improve the life and quality of products, they may be associated with concerns in terms of safety and healthcare since the developed countries export hazardous substances and processes to the developing countries to avoid the risks and problems with controlling the harmful factors in some industries, especially the chemical industries ignoring the fact that the required health and safety training should be offered and the skilled personnel be available.^[3] The tragedy of the Chernobyl and Bupal events in Ukraine and India, respectively, testifies to the claim mentioned above and shows that modern industrial plants are not immune to catastrophic events. Therefore, transferring the MIs to developing countries requires more attention and control, the same as the developed countries. On the other hand, industries are not static; however, they are constantly changing, including the development of new processes and products. Thus, the safety and health issues related to personnel's exposure in industries are also changing. Therefore, one can determine the emergencies and issues needed for the assessment and coping by informing the processes in factories and the physical and chemical hazards to which workers are exposed.^[1] International Labor Organization estimates that approximately 200,000 work-related deaths occur worldwide annually. Furthermore, many workers are victims of work-related accidents and illnesses. Thus, many complicated chemicals which the workers are exposed in industrial working environments, particularly in MIs, require knowledge, awareness, assessment of exposure and toxic effects, and the need to constant care, if necessary, to create a scientific basis for decisions aiming at protecting the human health from the adverse consequences of exposure to these substances in the working places.

Based on what was said above and considering the role that occupational health and toxicology play in assessing the exposures, policy-making, and participation in macro-planning, as well as achieving the health goals and reducing mortality resulting from occupational diseases due to exposure to harmful chemicals and toxicants. Hence, a review of harmful chemical compounds and toxic substances used in the production processes of MIs can help the experts identify such toxicants, find the existing information gaps, and take steps to alleviate them. Because of the expansion of MIs as well as the chemical compounds used in each industry, the present study mainly focuses on nanotechnology and its application in engineering and medical sciences, nuclear technology, and the most common radionuclide used in it (i.e. Cobalt, Uranium, and Plutonium), semiconductors and metals, dopants and toxic photoactive compounds, the electronic industry and liquid crystal display (LCD) emphasizing the with indium compounds, especially indium tin oxide (ITO), MIs involved in silica, mainly the stone and jewelry artifacts,

and jeans sandblasters, MIs involved in the production of catalysts and sensors with nickel nanoparticles, pharmaceutical industries with an emphasis on chemotherapy drugs and cytotoxic, modern dentistry focusing on the dental composites technology, and finally, the MIs which produce the dioxins and its compounds.

Therefore, this study addresses toxicants released by some MIs for the first time from a general perspective. Studies of this kind can help occupational health and toxicology specialists identify information gaps and future research subjects.

METHODS

The present study is a review that searches the databases of ProQuest, Science Direct, Web of Science, Pub Med, Scopus, and Google Scholar and extracts the articles related to the subject from 2000 to 2022. An interdisciplinary approach was used to search the studies, combining toxicology and MIs, nanotechnology, biotechnology, and nuclear energy. The search began with MIs, followed by a secondary search to complete the discussions related to each section. Similarly, once a new industry is identified, the toxicology studies conducted in that industry are reviewed, the utilized toxicants are identified, and complementary investigations are made to extract the existing toxicological findings.

The initial search was started with modern toxicity, MIs, new toxins, modern/new chemical compounds. Then, it was tracked by other keywords such as toxicology of nanoparticles, nanoparticles in medical, toxicology of radionuclides, nuclear toxicology, toxicology of the semiconductor industry, toxicology LCDs, occupational exposure to indium, silica in new/MIs, nickel nanoparticles in new/MIs, toxicology of drugs, new dentistry, and dioxin in MIs. Since a relatively limited of articles on the subject were available based on the results, we also used a list of articles' references to find the journals and articles connected to the study objective.

The original articles, reviews, systematic reviews, case studies, and editorials were investigated (inclusion criteria). Moreover, no reviews were done on books, letters to editors, letters to authors, authors' notes, newsletters, last word, and general texts (exclusion criteria). Furthermore, having at least one keyword in the title, abstract, and keywords sections was the inclusion criterion. An overview was made by reading the title, abstract, and keywords to achieve this goal and select the articles correctly. Thus, articles irrelevant to the subject were excluded from the study. Throughout the review process, an author was required to analyze the inclusion and exclusion criteria in turn, while another author was responsible for reviewing the accuracy of each assessment. Through this process, an agreement was reached on each of the articles.

At last, out of 116 articles searched as full text and following the inclusion and exclusion criteria, 46 articles were wholly selected. Figure 1 illustrates the selected studies and the search process for this review study. The articles were categorized

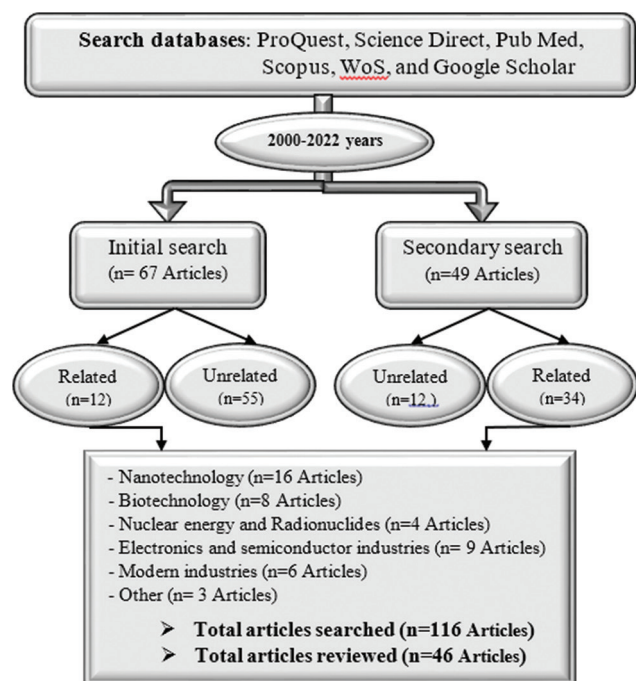


Figure 1: Flow diagram of selected articles and the search process

based on the given modern industry, various parts of the article were reviewed meticulously, and the results were extracted.

RESULTS AND DISCUSSIONS

The findings are presented within nine sections containing industries, toxins, and toxicology studies related to that industry.

Nanotechnology

In recent years, as nanotechnology and materials engineering have developed, the use of nanoparticles has also increased, particularly in MIs and technologies. Nanotechnology is the “precise and controlled manipulation of the atomic or molecular structure of materials on nano-scale to provide the ultrafine particles with emerging properties and special applications.” Nowadays, nanoparticles are applied in various areas such as engineering sciences, medicine, pharmacology, electronics, transportation, energy production, military, and defense industries, and their application is increasing more and more.^[4] In mechanical applications, the manufacturing the solid lubricants and nano-onion powders for the oils and liquid lubricants, protective nanotubes and synthetic fibers, with higher water absorption, higher melting point, more chemical permeability, higher strength and antibacterial property, carbon nanotubes to transmit the electric current, application of surface coating films to increase the strength and durability of industrial parts, fabrics made of carbine nano-fibers, nano-crystalline materials, nanostructured films used in the batteries manufacturing, solar cells, sensors and catalysts, nanocomposites structures, and many other applications are discussed.^[5] The silver nanoparticles, gold nanoparticles,

titanium dioxide, zinc oxide, cerium dioxide, silicon dioxide, nanotubes, and carbon nano-fibers (CNFs) are the nanoparticles used in MIs. Because of the unique characteristics of bioconjugation, gold nanoparticles are increasingly used in medicine and nano-therapeutic. Nanoparticles of titanium dioxide and zinc oxide are often used in sunscreen products which are widely used today.^[6] Numerous studies have reported zinc oxide nanoparticles’ antibacterial, anticancer, antioxidant, and immune system protective effects. Furthermore, zinc oxide nanoparticles can be used as an auxiliary therapy to reduce the toxic effects of chemotherapy drugs. However, zinc oxide nanoparticles have toxic impacts on various body organs. According to the studies, the affected organs are the liver, spleen, kidneys, stomach, pancreas, heart, and lungs.^[7,8] In addition, zinc oxide nanoparticles negatively affect the nervous system, lymphatic system, hematological characteristics, sex hormone levels, and fetal growth.^[7] Due to their antibiotic property, silver nanoparticles are also widely used in the medical and pharmaceutical industries, especially in the present era.^[9] Iron oxide nanoparticles with high magnetic properties are used in many biomedical applications, such as contrast in MRI imaging. There is evidence for the toxicity of iron oxide nanoparticles on neurological effects, mutations, DNA damage, and sensitization. There is contradictory information on the toxicity mechanism of the serum dioxide nanoparticles. Such nanoparticles are used in catalysts, gas sensors, solar cells, ultraviolet (UV) absorbers, glass polishing materials, and medicine to treat some cancers.^[10] Due to their unique physicochemical and mechanical properties such as thermal and chemical stability, high tensile strength, low weight, and electrical conductivity, carbon nanotubes, especially single-wall carbon nanotubes and multi-wall carbon nanotubes as one of the nanotechnology products, are applied in various sciences such as pharmacology, optics, renewable energy technologies, sensors, filters, electronics, and aerospace and recently in occupational toxicology studies and air pollutant analysis to absorb polycyclic aromatic hydrocarbons (Phenanthroline).^[11,12]

Because of the widespread application of nanotubes, it is possible to encounter carbon nanotube particles in production and research centers and during their transportation and movement. Single-walled carbon nanotubes and multi-walled carbon nanotubes were tested for cytotoxicity on human lung epithelial cells using toxicological indicators (NOAEC, IC50, and TLC). The results showed significant cytotoxicity of carbon nanotubes on human lung epithelial cells.^[13,14] As a new class of synthesized carbon material, CNFs have an excellent potential for absorbing pollutants and are used in composite absorbers and cartridges of respirators.^[15,16] Based on the studies, there are impacts of cytotoxicity and genotoxicity responses comparable to asbestos and even more robust than carbon nanotubes resulting from the CNFs.^[17,18] Therefore, future studies need to consider the toxicity potential of these nano-fibers and their release from the respirator cartridges, and also the dissemination of composite coatings containing

CNFs. Furthermore, there is a need for more studies on metallic nanoparticles to overcome their toxicity limitations. In this regard, methods based on the simultaneous use of NPs with antitoxic strategies and green noncytotoxic nanomaterials seem more promising.^[19]

Based on what was mentioned above, nanoparticles are widely used in many scientific, medical, and industrial sections without any manifestation of their toxic effects. Therefore, it is necessary to investigate the toxicity of these nanoparticles to employ them.

Nuclear technology and radionuclide

As one of the modern technologies, nuclear technology is widely used around the world, such that the engineering and medical sciences and laboratory research involved in the nuclear industry are associated with the generation of various radionuclides in various physical and chemical forms. Internal contamination by acute or chronic radionuclides exposure may cause both radiological and chemical toxicities. Once entering the body, radionuclides join the biomolecules leading to their absorption and transfer to the cells, tissues, and body organs. Similarly, they interact with intracellular components such as amino acids, peptides, proteins, and nucleic acids to make their side effects. Furthermore, radionuclides may compete for the biological location of essential metallic ions and cause structural confusion and malfunctioning biochemical macromolecules. Nowadays, the molecular basis of transmission, toxicity, accumulation, or detoxification mechanisms in which the intracellular radionuclides are involved is not far-understanding, and it is well-established that these processes, as well as the bioavailability of radionuclides, are highly dependent on their speciation and interactions with biological molecules.^[20,21] Speciation is linked to metallomics and emphasizes the identification of biological molecules attached to the metal ions in connection to biological functions and metabolism. Although metallic and nonmetallic chemical elements involved in the nuclear industry have received attention within the past decades, the information on the speciation of radionuclides has been biologically limited.^[20]

In case of infection, understanding the functional modes of radionuclides in living organisms is among the critical goals of nuclear toxicology studies. The toxicity mechanisms of radionuclides at the molecular level are highly dependent on speciation. The nature of each radionuclide should be taken into account based on its specific activity and decline mode (e.g., alpha, beta, gamma, or X) because different isotopes of a particular element (such as ^{238}Pu and ^{239}Pu) can exhibit different biological behaviors.^[20] Basis of Hard and Soft Acids and Bases classification, elements in nuclear toxicology are divided into three groups: Hard (Th^{4+} , Pu^{4+} , UO_2^{2+} , and Co^{3+}), borderline (Co^{2+}), and soft acids (Cs^+) or soft bases (I^-).^[20] As one of the MIs in today's world, the nuclear industry always deals with three common compounds, i.e. Cobalt, Uranium, and

Plutonium, in the various nuclear processes. The radioactive forms of Cobalt in the nuclear industry are ^{60}Co and ^{58}Co , found as the activation product of cobalt and stable nickel in alloys. Skin absorption and inhalation of radio cobalt pose a potential risk for workers in nuclear facilities or nuclear waste disposal sites.^[20,22] Uranium creates radiological and chemical toxicity in various proportions based on its ^{235}U richness. Therefore, considering the given isotope, the chemical or radiological impacts can be investigated.^[20,21] Plutonium is an industrial actinide of which the primary source is the use and reprocessing of nuclear fuel. Plutonium toxicity is essentially radiological and known as an alpha emitter.^[20,23]

Semiconductor industries

The semiconductor industry represents one of the newest high-tech industries in the industrialized world, in which the globalization process has taken place. Many harmful chemical compounds are used in this industry. Therefore, paying particular attention to health issues, toxicology, and exposure control is necessary. The semiconductor industry, despite its relatively long history, is changing, and exposure to toxins such as Arsine (AsH_3), Arsenic pentafluoride (AsF_5), Diborane (B_2H_6), Boron trifluoride (BF_3), Phosphine (PH_3), and Silane (SiH_4) can be seen in its development. These compounds come with impacts such as acute hemolysis, secondary renal failure, hypoxia with a toxicity of the cardiovascular, nervous, and pulmonary systems, pulmonary edema, suffocation, depression, and many other problems and complications. On the other hand, strong base acids such as hydrochloric acid (HCL), ammonia (NH_3), and hydrofluoric acid (HF) are used in semiconductors.^[3]

Dopants are the substances added to the silicon substrate of semiconductor chips to change the electrical properties. Dopants contain countless chemicals, some known to be toxic; e.g., some phosphorus-containing compounds (POCl_3 , PCl_3 , and PO_5) are converted to HCl and phosphoric acid. Arsenic compounds are also common in dopants, especially in gallium-based chips. The main risk of exposure to the gases and dopant compounds used in the semiconductor industry is accidental exposure to high concentrations. Many photoactive chemicals are used in the semiconductor industry, indicating the sensitivity in the skin or respiratory effects. Photoresist compounds are complex mixtures composed of plastic monomers or polymers, sensitizers, stabilizers, and solvents. These factors are used in photolithographic processes, which build the pattern in semiconductor chips. Photoinitiators are used to begin the polymerization of silicon chips coated by resistance. However, there are many advanced formulations for photosynthetic about which there is no toxicological information. The formulation of photoresist compounds includes several well-known sensors line urethane, phthalates, isocyanates, epoxy esters, and several metal halides. Other photoinitiators include highly reactive chemicals such as anthrone, Kinnon, thiazoline, and nitro aniline. The healthcare impacts of using these factors

are not appropriately known in the semiconductor industry, and E-mails further study.^[31]

Due to the long history of semiconductor processes in developed countries, more toxicological studies have been conducted. While, despite the penetration of these industries into most developing countries, including Iran, more toxicological studies should be conducted aiming at identifying the effects and complications of the chemical compounds on humans and the environment.

Liquid crystal display displays industries

Manufacturing LCDs is a novel technology in which we observe the increasing progress and expansion. Since the fast expansion of LCD screens, the use of indium and its compounds have increased.^[24,25] The pulmonary toxicity of various indium compounds, including indium trichloride, indium phosphide, and indium arsenide, as well as the ITO, both inhaled and injected, have been reported in animal experiments.^[26,27] However, the number of human studies or studies separating the effects of different indium compounds on humans is limited. The ITO is a synthesized material composed of indium (In_2O_3) and tin oxide (SnO_2) with an ordinary weighing ratio of 90–10. Because of its unique properties of high electrical conductivity, transparency, and mechanical resistance, the ITO is mainly used for manufacturing thin-film LCD screens.^[27] Before 2003, there was no attention to the adverse effects of indium compounds such as ITO, InAs, and InP. Due to the limitation of occupational exposure, there was no measurement of indium concentration in the working places. Until then, no data were found to indicate an indium health risk to electronics plants' respiratory, gastrointestinal, or nervous systems workers. The study by Homma *et al.* was the first report on the possible health impacts of ITO particles containing a high percentage of indium among the workers.^[25]

Because of the increasing industrial use of ITO in manufacturing flat-screen monitors, there is not enough information on the potential health hazards of indium compounds among the exposed workers. ITO is used in these monitors as transparent conductive films. In connection to other contaminants of the industry of LCD manufacturing, the information on occupational toxicology is limited such that in the study on recycling the wastes, the focus is mainly on recycling the indium compounds as the most critical contaminant in these industries.^[28,29]

Concerning the recent market growth due to the increasing use of LCD screens in PCs and plasma display panels in wall-mounted televisions, the demand for ITO has risen rapidly around the world.^[30] Hence, concerning the growing trend of the technologies related to electronics and LCDs, as well as the demand in global markets for such novel technology, it is necessary to study widely the impacts of toxicity of the compounds used in this industry, particularly the indium compounds. Healthcare actions should also be prioritized to minimize the exposure to the ITO particles in the working environments involved in such contaminants.

Modern industries involved with silica

Artificial stone fabricators, jewellery polishers, and denim jean sandblasters

Silica (silicon dioxide [SiO_2]) is a natural mineral that constitutes 59% of the Earth's crust mass. Even though we mostly assume that exposure to the silica and pulmonary diseases connected to it is related to the traditional occupations such as mining, tunneling, casting and melting industries, glass and cement industries, and construction works,^[31] most MIs make the workers to be exposed to silica, mainly crystalline silica.^[32]

In general, the MIs at risk of exposure to silicosis include the gemstone industry, dental equipment, metal grinder, agate mill, slate pencil, denim jean sandblasting, electronics industry, power cables, stone artifacts, crushing process, and jewellery polishing industries. Barnes *et al.* compared the prevalence and mortality rate of silicosis between the traditional and MIs and showed that in MIs, the prevalence rate is 50%–60%, and the mortality rate is 10%–100% which is much more than the mortality rate in traditional industries (6 deaths per 1000 workers).^[32]

The stone chips industry is one of the MIs that expose workers to crystalline silica. The artificial stone contains 85%–93% crystalline silica, much more than any other material. On the other hand, those who work in this industry use high-powered hand tools such as trolleys to form and cut this stone to make the sinks, washbasin, and faucets, and also polish the final product. These processes generate high levels of exposure to crystalline silica dust.^[28] According to a study in Spain, the number of silicosis has increased from 95 in 2003 to 295 in 2011, all of which were associated with the exposure to artificial stone in the fabrication of countertops.^[33] The second modern industry which exposes the workers to silica is denim jean sandblasting. Jean's sandblasting process uses the silica-containing sand as the abrasive on the jean surface to produce a 'worn-out' look. In a study (2007) in Turkey, 50 silicosis cases with silicosis were found.^[34] Despite the significant development of denim jean industries and mass production, few studies have assessed workers' exposure to silica. The jewellery industry is the third modern industry putting the workers at the exposure to silica. The cutting and polishing gemstones and using the plaster molds containing the silica in jewelry casting lead to a high concentration of silica dust (98%–99% silica combined with aluminum and iron oxide). In a screening in India on 20 workers, it became clear that eight persons are afflicted with silicosis based on the chest radiography.^[35] Screening of 32 males working at agate mill workshops in China showed that 15 persons are suffering the accelerated silicosis (prevalence of 47%).^[36]

Modern industries involved in nickel nanoparticles (catalysts and sensors)

Nickel nanoparticles (Ni NPs) are widely used in MIs such as catalysts, sensors, and electronic applications. Due to its widespread industrial applications, occupational exposure is the

primary source of inhalation and contact with the Ni NPs.^[37-40] Ni NPs are characteristics such as high surface energy levels, high magnetism, low melting point, high surface area, and low combustion point.^[38-40] Numerous studies are evaluating the toxic potential of nickel nanoparticles. Based on the animal studies, different cases such as cellular toxicity cytotoxicity and apoptosis in epidermal cells of rats,^[41] cellular toxicity in the leukemia cancer cells, and toxicity and developmental defects resulting from the nickel nanoparticles in zebrafish^[42] have been reported. Furthermore, another study reported the cytotoxic effects of nickel nanoparticles in leukemia cancer cells.^[43] There is a story of a healthy 38-year-old man who was exposed acutely to the Ni NP while spraying them on the wind turbine bearings using the metal arch process and died after 13 days; based on the autopsy result, his death was due to the adult's respiratory distress syndrome, and the results of studies showed that nickel nanoparticles with <25 nm in diameter were evident in the lung macrophages and high values of nickel were measured in his urine. There was evidence of acute tubular necrosis in the kidneys. This case study confirms that nickel nanoparticles can be toxic for human and leads to acute or even fatal diseases for the workers.^[44] Oxidative stress has been signified as a description of the toxicity of the nanoparticles. According to recent studies, oxidative stress resulting from the nanoparticles is determined by increasing the membrane reactive oxygen species, decreasing the intracellular glutathione, and lipid peroxidation. The lack of toxicity data for the nickel nanoparticles in human lungs led Ahamed (2019) to design a study to investigate the oxidative stress and apoptosis resulting from the nickel nanoparticles in epithelial cells of human lung A549.^[38] Finally, results indicated substantial toxicity of nickel nanoparticles in human lung epithelial A549 cells, and it was concluded that such toxicity is likely to be mediated through oxidative stress.^[38] Accordingly, studies like this indicate the necessity of a more careful assessment of nickel nanoparticles for industrial applications.

Pharmaceutical and medical industries

Although the most toxicological assessments in the pharmaceutical industry are limited to the patients who are using the new medicines, there are two other groups of people who are less taken into account despite their potential to expose the pharmaceutical compounds: The first group is the health-care providers (physicians, nurses, and pharmacists) and the second group is the practitioners who are involved in the production of these compounds; these two groups are categorized in the occupational toxicology area. New medicines and treatment processes must be further explored to determine their possible impacts on the employees.

Nowadays, the spread of cancer and chemotherapy medicines have raised concerns for those working in the pharmaceutical industry and hospitals. Based on studies, the genotoxicity effects of these medicines have been investigated in biological samples of the employees. Among these, the most significant impact is oncology nurses involved in the preparation and prescription of medicines. Oncology nurses

are usually exposed to chemotherapeutic medicines such as doxorubicin, bleomycin, Vinblastine dark basin 6-Methotrexate 5-Fluorouracil Basin Irinotecan 6-Mercaptopurine Is Platinum Etoposide and 6-Thioguanine cyclophosphamide and medicines with platinum compounds. These medicines can have toxic effects on the workers' body cells and lead to mutation activities. In the last decade, Hyperthermic Intra-Peritoneal Chemotherapy (HIPEC) has been introduced to treat peritoneal carcinomatosis. In HIPEC, the cytotoxic medicines are directly administered into the abdominal cavity. More recently, Pressurized Intra-Peritoneal Aerosol Chemotherapy (PIPAC) has been proposed to the patients as a new approach, where the chemotherapeutic medicine is injected into the peritoneal cavity as an aerosol under pressure. The amount of medicine used in the PIPAC approach is ten times lower than in the HIPEC approach; however, exposure to cytotoxic medicines and other chemotherapy medicines poses an occupational risk for those working in the operating room personnel.^[45,46] Pathologists in the medical centers also encounter various chemical compounds such as xylene due to the nature of their work on biological tissues and samples, and it is worthwhile to follow up and investigate the toxic effects of the chemical compounds on the pathological and histological laboratories staff.^[47]

Modern dentistry

Concerning the dentistry sciences, novel scientific methods have also replaced the old ones. Advances include bonding and laminating techniques, composites, and dental prostheses, used to correct appearance defects, repair, and healing. In recent decades, dental composites made of resins have become the preferred restorative material for many dentists due to their sufficient strength, beauty, low cost, and the ability to attach to the teeth compared to ceramics. Composite resins comprise four main parts: Organic polymer matrix, inorganic filler particles, coupling agents, and accelerator initiation system. Various types of composites are made up of different compounds such as silica nanofiller, barium glass, types of resins such as Bis-GMA, TEGDMA, Bis-EMA, Three fillers—Prepolymerized filler, etc., which are often known by commercial titles.^[48]

Today, a wide range of materials are used in dentistry. Although amalgam containing mercury is no longer used as in the past, most dentists face this substance in their working phases, posing a risk. In addition to mercury, amalgam or "silver filler" contains a mixture of silver, copper, and tin, which chemically bind these components to a rigid, stable, and relatively harmless material. The highest levels of mercury exposure are related to the use of amalgam in dental restorations, although storing and disposing of amalgam capsules is an important source of exposure.^[49] Other toxic compounds that dentists, especially dental prosthesis technicians, may be exposed to are methyl methacrylate and cyanoacrylate, shown to cause dermatitis and respiratory problems in dental personnel.^[50-52] Sensitivity to latex and chloramine T (sodium-n-chlorine-p-toluene sulfonamide) is highly prevalent among dentists.^[53] Toxic

Table 1: Toxic compounds and their application in modern industries

Modern industry	Toxic compounds	Application	Ref
Nanotechnology	Silver nanoparticles	Medicine (antibiotic properties)	(4-19)
	Gold nanoparticles	Medicine and Nanotherapy	
	Titanium dioxide	Treatment and sunscreen products	
	zinc oxide	Antioxidants, Antibacterials and Anti-cancer	
	Serum dioxide	Catalysts, gas sensors, solar cells, UV absorbers, medicine and cancer treatment	
Nuclear technology and radionuclide	Carbon nanotubes and nanofibers	Different application in engineering sciences	(20-23)
	Iron oxide nanoparticles	Biomedical and MRI imaging	
	Cobalt (58Co and 60Co)	Nuclear facilities, nuclear waste disposal sites	
	Uranium (235U)	Nuclear reactors	
Semiconductor Industries	Plutonium (Pu4+)	Re-processing of nuclear fuel	(3)
	Arsenic compounds (Arsine, Arsenic Pentafluoride, Gallium Arsenide)	Manufacturing of semiconductor products and electronics	
	Borane compounds (Diborane, Boron trifluoride)	Production of semiconductors and integrated circuits (silicon chips)	
	Phosphorus compounds (PO ₅ , POCl ₃ , PCl ₃ , PH ₃)	Production of semiconductors	
	Acids (HCl, NH ₃ , HF)	Changing the electrical properties of silicon chips	
	Dopantes	Photoactive and Photoresist (urethane, phthalates, isocyanates, epoxy esters)	
	Photoactive and Photoresist (urethane, phthalates, isocyanates, epoxy esters)	Photolithographic and creating of pattern in semiconductor silicon chips	
LCD displays industry	Photoinitiators (Anthrone, Kinnon, Thiazoline, NitroAniline)	Polymerization of semiconductor silicon chips	(24-30)
	Indium compounds (Indium Trichloride, Indium Phosphide, Indium Arsenide, Indium-Tin-Oxide)	Production of liquid crystal displays (LCD)	
	Tin oxide		
Artificial stone fabricators	Silica (Crystalline silicon)	Forming and cutting of artificial stones	(31-36)
Jewellery polishers		Cutting and polishing process of agate and other gemstones	
Denim jean sandblasters		Sandblasting of denim jean	
manufacturing of catalysts and sensors	Nickel nanoparticles	Manufacturing of catalysts and sensors in the electronics industry	(37-44)
Pharmaceutical and medical industries	Cytotoxic and Platinum-based Drugs	Chemotherapy and cancer treatment	(45-47)
Modern dentistry Beryllium Compounds,	Resins, Silica nanofillers and Barium glass	Manufacture of dental composites	(48-53)
Methyl Methacrylate and Cyanocariate	Application in dental technologies		(54-58)
Waste recycling Industries	Dioxin	Recycling of electronic, domestic, industrial and hospital waste	

metals such as beryllium may also be produced from dental materials containing beryllium alloys and expose the staff to the dental technology. On the other hand, using radiographic equipment in dental clinics is common now, and this issue provides the ground for exposure to ionizing and nonionizing radiation in this profession. The use of blue and UV lights for treatment or polymerization of dental materials, especially composite resins, bonding agents, and sealants, and their combination with chemicals is one of the major concerns in modern dentistry.^[49]

Modern industries involved in dioxin (incinerators)

In their study, Lynch and Stretesky refer to dioxins as the nightmare of modern industry.^[54] Dioxin is a challenging substance with many critics.^[54-56] Humans have turned to incinerators for decades to dispose of waste, especially hazardous waste such as hospital waste and e-waste. Despite the numerous advantages of using incinerators compared to

other waste disposal methods, it has challenged humanity to address the issue of dioxins. Occupational exposure to dioxins often results from the industrial chlorination processes, incineration of municipal waste, particular herbicide industries, paper bleaching processes in paper mills, smelters, cement furnaces, and many chemical plants.^[57] Ma *et al.* conducted a study to assess the concentrations and profiles in China. Their study estimated human exposures to dioxin and its related compounds from the electronic waste recycling facilities and a chemical industrial complex. This study analyzed the samples from e-waste recycling sites and soil samples from nearby facilities and the agricultural soils in the various parts of China. Results of this study showed that the concentration of dioxin in all samples was high and in the soil around recycling facilities was higher than in other samples. Therefore, it has put the workers to the skin and inhalation exposures.^[58]

CONCLUSION

Developing MIs and equipping the traditional industries with new technologies have confronted humankind with different chemicals and toxins resulting from producing and using products that require attention, study, and research. The results of this review provided some harmful chemicals (toxicants) used in a few MIs to raise the awareness of occupational toxicologists and occupational health experts, as summarized in Table 1. The present study hoped to provide the basis for extensive studies in occupational toxicology and occupational health in MIs to identify and evaluate the harmful chemical compounds and their toxic impacts on humans.

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Conflicts of interest

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REFERENCES

- Swaminathan V. Occupational health and safety in chemical industries in transitional economies. *Indian J Occup Environ Med* 2011;15:85-6.
- Wishart D, Arndt D, Pon A, Sajed T, Guo AC, Djoumbou Y, *et al*. T3DB: The toxic exposome database. *Nucleic Acids Res* 2015;43:D928-34.
- Schenker M. Occupational lung diseases in the industrializing and industrialized world due to modern industries and modern pollutants. *Tuber Lung Dis* 1992;73:27-32.
- Khin MM, Nair AS, Babu VJ, Murugan R, Ramakrishna S. A review on nanomaterials for environmental remediation. *Energy Environ Sci* 2012;5:8075-109.
- Dwivedi A, Dwivedi A. Emerging trends in nano technology for modern industries. *Int J Eng Innov Technol (IJEIT)* 2012;2:1-13.
- Elsaesser A, Howard CV. Toxicology of nanoparticles. *Adv Drug Deliv Rev* 2012;64:129-37.
- Elshama SS, Abdallah ME, Abdel Karim RI. Zinc oxide nanoparticles: Therapeutic benefits and toxicological hazards. *Open Nanomed J* 2018;5:16-22. DOI: 10.2174/1875933501805010016.
- Sharma V, Singh P, Pandey AK, Dhawan A. Induction of oxidative stress, DNA damage and apoptosis in mouse liver after sub-acute oral exposure to zinc oxide nanoparticles. *Mutat Res* 2012;745:84-91.
- Sthijns MM, Thongkam W, Albrecht C, Hellack B, Bast A, Haenen GR, *et al*. Silver nanoparticles induce hormesis in A549 human epithelial cells. *Toxicol In Vitro* 2017;40:223-33.
- Girigoswami K. Toxicity of Metal Oxide Nanoparticles. In: Saquib Q, Faisal M, Al-Khedhairi A, Alatar A. (eds) *Cellular and Molecular Toxicology of Nanoparticles*. Advances in Experimental Medicine and Biology, vol 1048. Springer, Cham. 2018. Available from: https://doi.org/10.1007/978-3-319-72041-8_7.
- Mauter MS, Elimelech M. Environmental applications of carbon-based nanomaterials. *Environ Sci Technol* 2008;42:5843-59.
- Abedinloo R, Shahtaheri SJ, Moradi R, Divani R, Azam K. Optimization of adsorption phenanthrene on the multi-walled carbon nanotubes. *Health Saf Work* 2015;5:29-38.
- Mohammadian Y, Shahtaheri SJ, Kakooei H, Hajaghazadeh M. Determination of toxicological indexes of carbon nanotubes and Chrysotile according to invitro cytotoxicity on human lung epithelium cells. *J Sch Public Health Inst Public Health Res* 2013;10:33-44.
- Mohammadian Y, Shahtaheri SJ, Yaraghi AA, Kakooei H, Hajaghazadeh M. Cytotoxicity of single-walled carbon nanotubes, multi-walled carbon nanotubes, and chrysotile to human lung epithelial cells. *Toxicol Environ Chem* 2013;95:1037-47.
- Jahangiri M, Shahtaheri SJ, Adl J, Rashidi A, Clark K, Sauvain JJ, *et al*. Emission of carbon nanofiber (CNF) from CNF-containing composite adsorbents. *J Occup Environ Hyg* 2012;9:D130-5.
- Jahangiri M, Adl J, Shahtaheri SJ, Rashidi A, Ghorbanali A, Kakooei H, *et al*. Preparation of a new adsorbent from activated carbon and carbon nanofiber (AC/CNF) for manufacturing organic-vacubour respirator cartridge. *Iranian J Environ Health Sci Eng* 2013;10:15.
- Genaidy A, Sequeira R, Rinder M, A-Rehim A. Risk analysis and protection measures in a carbon nanofiber manufacturing enterprise: An exploratory investigation. *Sci Total Environ* 2009;407:5825-38.
- Kisin ER, Murray AR, Sargent L, Lowry D, Chirila M, Siegrist KJ, *et al*. Genotoxicity of carbon nanofibers: Are they potentially more or less dangerous than carbon nanotubes or asbestos? *Toxicol Appl Pharmacol* 2011;252:1-10.
- Attarilar S, Yang J, Ebrahimi M, Wang Q, Liu J, Tang Y, *et al*. The toxicity phenomenon and the related occurrence in metal and metal oxide nanoparticles: A brief review from the biomedical perspective. *Front Bioeng Biotechnol* 2020;8:822.
- Bresson C, Ansoborlo E, Vidaud C. Radionuclide speciation: A key point in the field of nuclear toxicology studies. *J Anal At Spectrom* 2011;26:593-601.
- Templeton DM, Ariese F, Cornelis R, Danielsson LG, Muntau H, van Leeuwen HP, Lobinski R. Guidelines for terms related to chemical speciation and fractionation of elements. Definitions, structural aspects, and methodological approaches (IUPAC Recommendations 2000). *Pure and applied chemistry*. 2000;72:1453-70.
- Kim JH, Gibb HJ, Howe P. Cobalt and inorganic cobalt compounds. World health organization; 2006.
- Ansoborlo E, Prat O, Moisy P, Den Auwer C, Guilbaud P, Carriere M, *et al*. Actinide speciation in relation to biological processes. *Biochimie* 2006;88:1605-18.
- Hamaguchi T, Omae K, Takebayashi T, Kikuchi Y, Yoshioka N, Nishiwaki Y, *et al*. Exposure to hardly soluble indium compounds in ITO production and recycling plants is a new risk for interstitial lung damage. *Occup Environ Med* 2008;65:51-5.
- Homma T, Ueno T, Sekizawa K, Tanaka A, Hirata M. Interstitial pneumonia developed in a worker dealing with particles containing indium-tin oxide. *J Occup Health* 2003;45:137-9.
- Chonan T, Taguchi O, Omae K. Interstitial pulmonary disorders in indium-processing workers. *Eur Respir J* 2007;29:317-24.
- Lison D, Laloy J, Corazzari I, Muller J, Rabolli V, Panin N, *et al*. Sintered indium-tin-oxide (ITO) particles: A new pneumotoxic entity. *Toxicol Sci* 2009;108:472-81.
- Amato A, Becci A, Mariani P, Carducci F, Ruello ML, Monosi S, *et al*. End-of-life liquid crystal display recovery: toward a zero-waste approach. *Applied Sciences*. 2019;9:2985.
- Zhuang X, He W, Li G, Huang J, Ye Y. Materials separation from waste liquid crystal displays using combined physical methods. *Pol J Environ Stud* 2012;21:1921-7.
- Homma S, Miyamoto A, Sakamoto S, Kishi K, Motoi N, Yoshimura K. Pulmonary fibrosis in an individual occupationally exposed to inhaled indium-tin oxide. *Eur Respir J* 2005;25:200-4.
- Omidianidost A, Ghasemkhani M, Kakooei H, Shahtaheri SJ, Ghanbari M. Risk assessment of occupational exposure to crystalline silica in small foundries in Pakdasht, Iran. *Iran J Public Health* 2016;45:70-5.
- Barnes H, Goh NS, Leong TL, Hoy R. Silica-associated lung disease: An old-world exposure in modern industries. *Respirology* 2019;24:1165-75.
- Pérez-Alonso A, Córdoba-Doña JA, Millares-Lorenzo JL, Figueroa-Murillo E, García-Vadillo C, Romero-Morillos J. Outbreak of silicosis in Spanish quartz conglomerate workers. *Int J Occup Environ Health* 2014;20:26-32.
- Alper F, Akgun M, Onbas O, Araz O. CT findings in silicosis due to denim sandblasting. *Eur Radiol* 2008;18:2739-44.
- Panchadhayee P, Saha K, Saha I, Ta RK, Ghosh S, Saha A, *et al*. Rapidly fatal silicosis among jewellery workers attending a district medical college of West Bengal, India. *Indian J Chest Dis Allied Sci* 2015;57:165-71.
- Jiang CQ, Xiao LW, Lam TH, Xie NW, Zhu CQ. Accelerated silicosis in workers exposed to agate dust in Guangzhou, China. *Am J Ind Med* 2001;40:87-91.
- Cempel M, Nikel G. Nickel: A review of its sources and environmental toxicology. *Pol J Environ Stud* 2006;15:375-82.

38. Ahamed M. Toxic response of nickel nanoparticles in human lung epithelial A549 cells. *Toxicol In Vitro* 2011;25:930-6.
39. Zhang Q, Kusaka Y, Zhu X, Sato K, Mo Y, Kluz T, *et al.* Comparative toxicity of standard nickel and ultrafine nickel in lung after intratracheal instillation. *J Occup Health* 2003;45:23-30.
40. Sivulka DJ. Assessment of respiratory carcinogenicity associated with exposure to metallic nickel: A review. *Regul Toxicol Pharmacol* 2005;43:117-33.
41. Zhao J, Bowman L, Zhang X, Shi X, Jiang B, Castranova V, *et al.* Metallic nickel nano- and fine particles induce JB6 cell apoptosis through a caspase-8/AIF mediated cytochrome c-independent pathway. *J Nanobiotechnology* 2009;7:2.
42. Ispas C, Andreescu D, Patel A, Goia DV, Andreescu S, Wallace KN. Toxicity and developmental defects of different sizes and shape nickel nanoparticles in zebrafish. *Environ Sci Technol* 2009;43:6349-56.
43. Guo D, Wu C, Li X, Jiang H, Wang X, Chen B. *In vitro* cellular uptake and cytotoxic effect of functionalized nickel nanoparticles on leukemia cancer cells. *J Nanosci Nanotechnol* 2008;8:2301-7.
44. Phillips JI, Green FY, Davies JC, Murray J. Pulmonary and systemic toxicity following exposure to nickel nanoparticles. *Am J Ind Med* 2010;53:763-7.
45. Ndaw S, Hanser O, Kenepkian V, Vidal M, Melczer M, Remy A, *et al.* Occupational exposure to platinum drugs during intraperitoneal chemotherapy. Biomonitoring and surface contamination. *Toxicol Lett* 2018;298:171-6.
46. Gajski G, Ladeira C, Gerić M, Garaj-Vrhovac V, Viegas S. Genotoxicity assessment of a selected cytostatic drug mixture in human lymphocytes: A study based on concentrations relevant for occupational exposure. *Environ Res* 2018;161:26-34.
47. Shah Taheri S, Afshar M, Majedi Far M, Nasl Saraji J. Occupational exposure to xylene in workers, employing at pathology wards of hospitals belonging to the Qazvin university of medical sciences. *Tehran Univ Med J* 2005;63:32-9.
48. Mazaheri R, Malekipour MR, Seddighi H, Sekhavati H. Effect of common drinks in children on the color stability of microhybrid and nanohybrid composites. *J Mashhad Dent Sch* 2013;37:163-76.
49. Leggat PA, Kedjarune U, Smith DR. Occupational health problems in modern dentistry: A review. *Ind Health* 2007;45:611-21.
50. Leggat PA, Kedjarune U, Smith DR. Toxicity of cyanoacrylate adhesives and their occupational impacts for dental staff. *Ind Health* 2004;42:207-11.
51. Golbabaie F, Mamdouh M, Jelyani KN, Shahtaheri SJ. Exposure to methyl methacrylate and its subjective symptoms among dental technicians, Tehran, Iran. *Int J Occup Saf Ergon* 2005;11:283-9.
52. Golbabaie F, Mamdouh M, Nouri Jelyani K, Shahtaheri S. Exposure to methyl methacrylate and its subjective symptoms among dental technicians, Tehran-Iran. *Iran Occup Health J* 2006;3:6.
53. Rankin KV, Jones DL, Rees TD. Latex glove reactions found in a dental school. *J Am Dent Assoc* 1993;124:67-71.
54. Lynch MJ, Stretesky P. Toxic crimes: Examining corporate victimization of the general public employing medical and epidemiological evidence. *Crit Criminol* 2001;10:153-72.
55. WHO (World Health Organization). Exposure to Dioxins and Dioxin-Like Substances: A Major Public Health Concern. Preventing Disease through Healthy Environments; 2010.
56. Colborn T, Dumanoski D, Myers J. Our Stolen Future: Are we Threatening Our Fertility, Intelligence, and Survival? A Scientific Detective Story. USA, New York: Plume, Penguin Books; 1997.
57. Rathoure AK. Dioxins source origin and toxicity assessment. *Biodivers Int J* 2018;2:310-4.
58. Ma J, Kannan K, Cheng J, Horii Y, Wu Q, Wang W. Concentrations, profiles, and estimated human exposures for polychlorinated dibenzo-p-dioxins and dibenzofurans from electronic waste recycling facilities and a chemical industrial complex in Eastern China. *Environ Sci Technol* 2008;42:8252-9.